HYDROLOGY AND WATER QUALITY OF THE COPPER-NICKEL STUDY REGION, NORTHEASTERN MINNESOTA

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CONVERSION FACTORS

Multiply inch-pound unit	By	To obtain SI unit
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
foot per day (ft/d)	0.3048	meter per day (m/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per minute per foot [(gal/min)/ft]	0.207	liter per second per meter [(L/s)/m]
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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 "mean sea level". The datum was derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts.

HYDROLOGY AND WATER QUALITY OF THE COPPER-NICKEL STUDY REGION, NORTHEASTERN MINNESOTA

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ABSTRACT

Data were collected on the hydrology of the Copper-Nickel study region, to identify the location and nature of ground-water resources, determine the flow characteristics and general quality of the major streams, and determine the potential effects of mining copper and nickel on the hydrologic system. Ground-water investigations indicate that water generally occurs in local flow systems within surficial deposits and in fractures in the upper few hundred feet of bedrock. Availability of ground water is highly variable. Yields commonly range from only 1 to 5 gallons per minute from wells in surficial materials and bedrock, but can be as much as 1,000 gallons per minute from wells in the sand and gravel aquifer underlying the Embarrass River valley. Except over the mineralized zone, ground water in the surficial deposits is a mixed calcium magnesium bicarbonate type. Ground water over the mineralized zone generally has both a greater percentage of sulfate, compared to bicarbonate, and concentrations of copper and nickel greater than 5 micrograms per liter.

Surface-water investigations indicate that the average annual runoff from streams is about 10 inches. Flow characteristics of streams unregulated by industry are similar, with about 60 percent of the annual runoff occurring during snowmelt in April, May, and June. Flood peaks are reduced in the Kawishiwi River and other streams that have surface storage available in on-channel lakes and wetlands. These lakes and wetlands also trap part of the suspended-sediment load. Specific conductance in streams can exceed 250 micromhos per centimeter at 25° Celsius where mine dewatering supplements natural discharge.

Between 85 and 95 percent of the surface water used is for hydroelectric power generation at Winton and thermo-electric power generation at Colby Lakes. Mine dewatering accounts for about 95 percent of the ground-water used. Estimated ground-water discharge to projected copper-nickel mines ranges from less than 25 to about 2,000 gallons per minute, depending on the location and type of mining activity. The introduction of trace metals from future mining to the ground-water system can be reduced if tailings basins and stockpiles are located on material of low permeability, such as till, peat, or bedrock.

INTRODUCTION

Mining of low-grade copper-nickel ore in the Duluth Complex of northeastern Minnesota has been proposed by mining companies at several sites near the Boundary Waters Canoe Area (BWCA), a Federally designated wilderness area. A regional environmental impact study of the effect of proposed underground and open-pit mines on the associated physical, cultural, and economical aspects of the area is required by the State of Minnesota. As part of the environmental assessment, this report and a companion report on the physiography and surficial geology of the Copper-Nickel study region (Olcott and Siegel, 1978) document the U.S. Geological Survey study during 1975-78 in cooperation with the Minnesota Environmental Quality Board (MEQB), Regional Copper-Nickel Study Staff, and the Minnesota Department of Natural Resources (MDNR).

The Copper-Nickel study region is approximately bisected by the Laurentian Divide between Ely and Hoyt Lakes (fig. 1). It includes 1,400 mi in parts of St. Louis and Lake Counties.

The objectives of this study were to determine the (1) location and extent of aquifers, (2) occurrence and movement of ground water, including the sources of recharge and areas of discharge, (3) chemical quality of the ground water, (4) amount of water available from wells in the various aquifers, (5) surface-water resources and flow characteristics of streams, (6) chemical quality of the surface water, and (7) possible impacts of mining on the hydrologic system.

Together with the companion report describing the surficial geology and physiography (Olcott and Siegel, 1978), this report should provide baseline data necessary for evaluation of hydrologic changes in the event of mining.

METHODS

The geohydrologic information presented was developed from logs of wells and core holes, U.S. Geological Survey topographic maps, field observations, test augering, and the literature. Water samples were collected from Geological Survey and U.S. Forest Service wells and analyzed in the Survey's Central Laboratory for common inorganic constituents, nutrients, selected trace metals, and organic constituents. Other data were obtained from files of the Minnesota Department of Health, the Geological Survey, the Forest Service, and private sources.

In the description of ground-water quality, the significance of differences between mean values of chemical constituents or parameters was evaluated through the use of the T-test at 0.05 level of significance. Hydrologic data collected by the Geological Survey for this study on stream discharge, surface-water quality, and ground-water quality are published in Water Resources Data for Minnesota (U.S. Geological Survey, 1976; 1977; 1978). In addition to the streamflow data network, continuous records of water temperature and specific conductance were collected at Stony River near Babbitt, Dunka River near Babbitt, and Partridge River above Colby Lake at Hoyt Lakes.

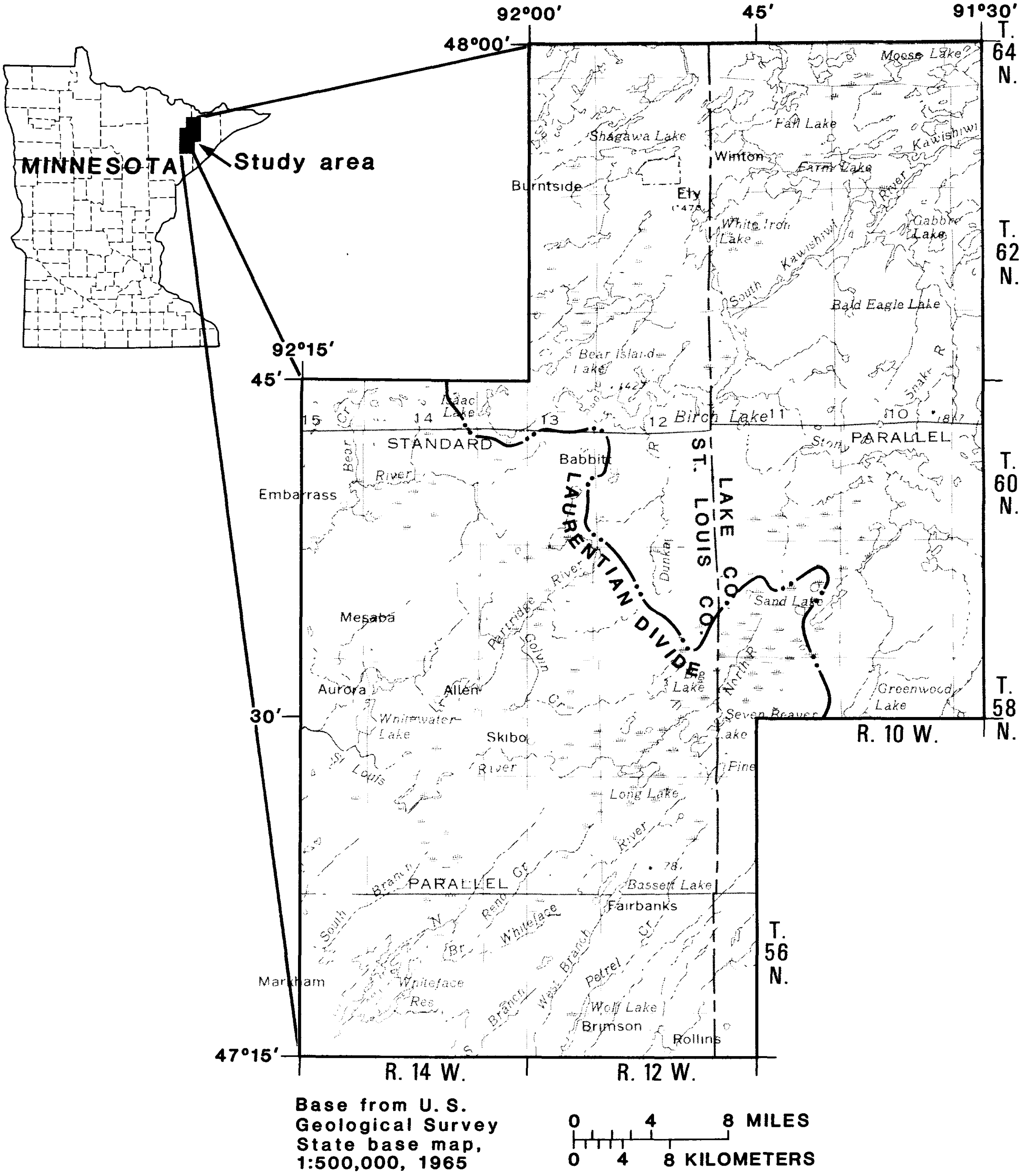

Figure 1.--Location of Copper-Nickel study region

A continuous record of water temperature was obtained at Kawishiwi River near Ely and periodic suspended-sediment samples were collected at Stony River near Babbitt, Dunka River near Babbitt, and Bear Island River near Ely.

Drainage areas for all gaging stations and miscellaneous water-data sites were determined from Geological Survey $7^1/2$- and 15-minute maps. Topographic divides for sites were delineated on maps, and areas were determined by planimetering.

GROUND WATER

Occurrence and Movement

Ground water in unconsolidated surficial deposits generally occurs under unconfined conditions. Artesian to partly confined conditions occur in the southwestern part of the region where clay-rich till of the Des Moines lobe confines the water in the underlying sand and gravel deposits (Maclay, 1966).

Ground water moves slowly from areas of recharge to areas of discharge. The rate of movement is determined by the hydraulic conductivity of material through which it moves and the hydraulic gradient of the water table or potentiometric surface.

Variations in hydraulic conductivities for surficial materials depend on particle-size distribution and degree of stratification. From laboratory experiments, Stark (1977) estimated that hydraulic conductivities ranged from 0.4 to 362 ft/d for 12 samples of sand and gravel and from 0.04 to 6.7 ft/d for 12 samples of Rainy lobe till. For this study, hydraulic conductivities were calculated from particle-size distributions (Krumbein and Monk, 1943) of eight samples of sand and gravel and ranged from 0.004 to 15.5 ft/d. Hydraulic conductivities calculated for four samples of Rainy lobe till ranged from 2.1×10^{-5} to 0.13 ft/d.

Results from seven aquifer tests in the sandy drift of the Dunka River basin had hydraulic conductivity values that ranged from 0.6 to 16 ft/d (Erskine, 1975). From these data and other data in Minnesota for comparable sediment types, hydraulic conductivities were estimated for the study area. They range from about 10 to 3,500 ft/d for sand and gravel deposits, 0.01 to about 30 ft/d for till deposited by the Rainy lobe, and 10^{-5} to 10^{-1} ft/d for peat and till deposited by the Des Moines lobe.

The water table in sand, gravel, and till is generally deeper under high areas than under low areas underlain by similar material. Generally, the water table is near or at land surface in topographic lows and wetland areas.

A map of the water table was prepared (plate 1) by use of the assumptions that (1) the water table is a subdued replica of the land surface, (2) lake elevations reflect the water-table elevation, (3) the water table is at the surface in swamps and other wetlands, and at perennial streams, and (4) water levels in the 17 piezometers installed in surficial material generally reflect water levels in similar materials elsewhere in the study area. It should be noted that this generalized map shows the approximate elevation of the water table in surficial materials and the upper part of the underlying decomposed or fractured bedrock. Contours of the water table will be the least accurate where unfractured bedrock is near land surface.

The approximate hydraulic gradient for surficial aquifers can be determined from the contour map of the water table. Ground-water divides underlie and approximately coincide with topographic highs, and generally delineate local ground-water-flow systems in the drift.

The hydraulic gradients within the physiographic areas (fig. 2), which are defined by Olcott and Siegel (1978), can vary considerably. The largest range of hydraulic gradient is in the Embarrass Mountain-Taconite mining physiographic area, which has both steep topography and a large flat wetland area along the southern margin of the Embarrass Mountains. Gradients may range from 640 ft/mi for short distances at the northeast end of the Embarrass Mountains to less than 5 ft/mi in wetlands.

Gradients in the Drumlin-bog, Shallow bedrock-moraine, and Outwash-moraine complex physiographic areas generally range from 10 to 80 ft/mi, but along the flanks of larger drumlins and topographic ridges gradients can exceed 350 ft/mi for short distances. Gradients in the Seven Beaver-Sand Lake wetland and Aurora-Markham till plain physiographic areas are generally less than 40 ft/mi.

Ground water flows perpendicular to the water-table contours within local flow systems. The lengths of flow paths are generally 1 to 2 miles, from subbasin divides to streams, lakes, and wetlands. The local flow systems are interconnected so that regional ground-water movement is northward from the Laurentian Divide to the Kawishiwi River system and westward and southwestward from the Divide to the St. Louis River.

In the Shallow bedrock-moraine and Outwash-moraine complex physiographic areas, water movement is toward the Stony and Kawishiwi River systems. Movement is generally slow because the till and peat are relatively impermeable and because the flow system in the surficial materials is disrupted by outcrops of relatively impermeable bedrock. Water velocity through sand and gravel beds is greater, but the volume of flow is not great because the saturated thickness is generally less then 10 feet and gradients are low. In the Drumlin-bog and Seven Beaver-Sand Lake physiographic areas, ground-water movement is towards the larger streams and lakes.

Ground water within the Toimi Drumlin field generally moves perpendicular to the NE-SW trend of the drumlins. Movement within wetlands that are interspersed between the drumlins and associated with the Seven Beaver-Sand Lake wetland area follows the southward trends of surface-water drainage.

The aquifers within the sand and gravel deposits that underlie the Embarrass-Dunka Rivers sand plain area have boundaries well delineated by till end-moraines and the Embarrass Mountains. Ground water moves toward the Embarrass and Dunka Rivers.

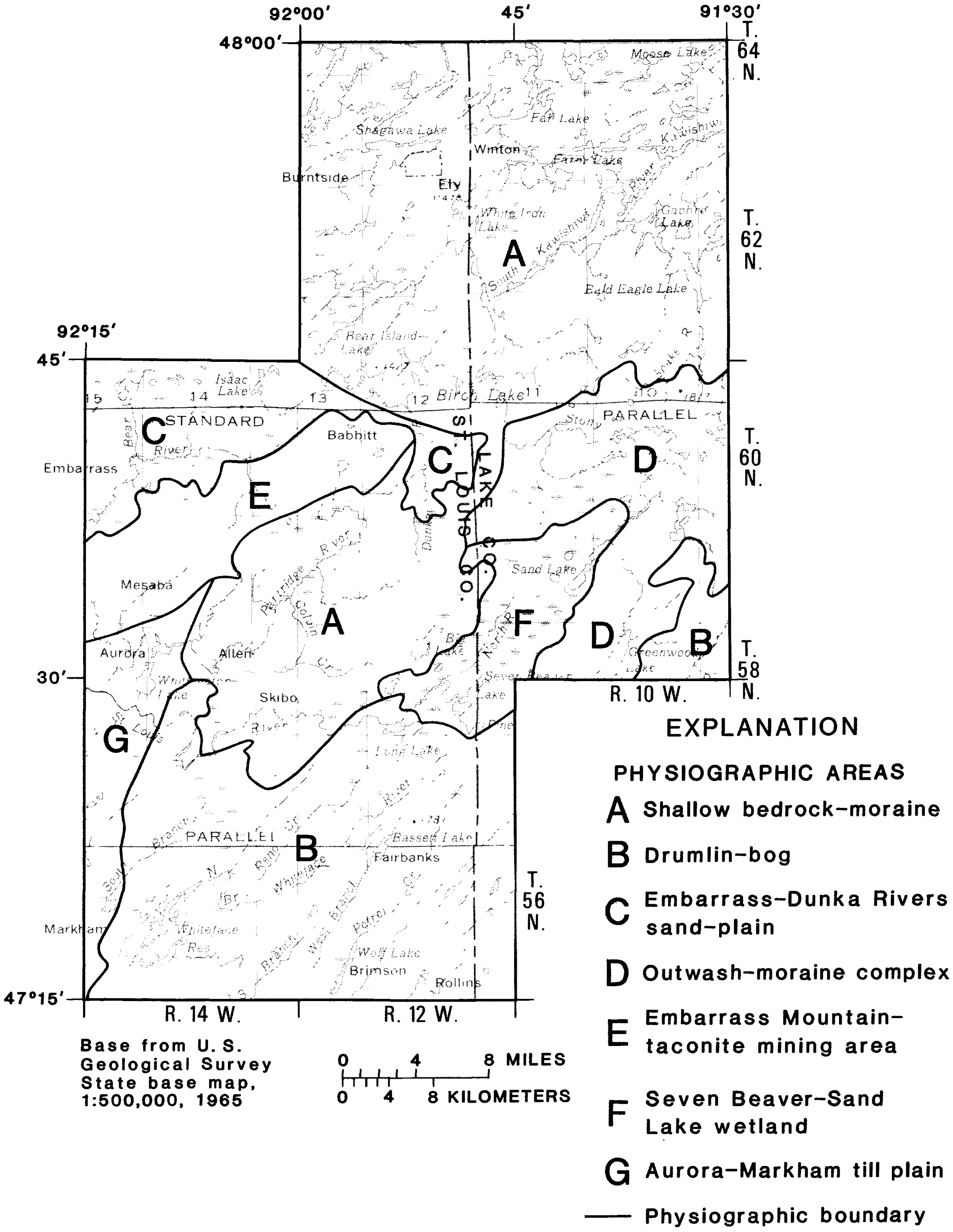

Figure 2.--Physiographic areas of the Copper-Nickel study region

Ground water in the surficial deposits is mostly recharged by precipitation. Infiltration rates are greatest in the Embarrass and Dunka River basins, which are underlain by permeable sand and gravel deposits, and least in the perennially saturated wetland areas.

Recharge to surficial aquifers from underlying bedrock aquifers is insignificant because the major bedrock units are relatively impermeable. In the southern part of the study region near Aurora, however, semiconfined sand and gravel aquifers may locally discharge water to overlying aquifers where confining beds are discontinuous. Seepage from the Whitewater Reservoir at high stage also recharges adjacent sand and gravel aquifers.

Water levels in till and sand and gravel aquifers respond to long-term precipitation trends. Water-table hydrographs (figs. 3 and 4) for observation wells monitored from 1975 through spring 1978 show that the water table fluctuated similarly to but as much as 6 months behind major trends in the cumulative departure from mean monthly precipitation (fig. 5), as recorded at Babbitt between 1956 through 1974. The lag time is roughly dependent upon the depth of the well. The water-table decline during the drought from spring 1976 to summer 1977 averaged about 4 feet for sand and gravel aquifers to about 6 feet for till aquifers.

Water in near-surface bedrock aquifers is under unconfined conditions except where the bedrock is overlain by drift of low permeability. Water in the bedrock occurs in secondary openings such as joints, fractures, and leached zones. The bedrock generally has extremely low primary hydraulic conductivity and yields little or no water unless secondary openings exist. Fractures and joints in the Duluth Complex may extend to considerable depths but are more extensive in the upper 200 to 300 feet of the bedrock. Water occurs in the Biwabik Iron-formation in its area of subcrop, where leaching of oxidized and hydrated taconite minerals has produced extensive secondary porosity up to 50 percent (Cotter and others, 1965).

Near the surface, water in bedrock fractures and joints is hydraulically connected with overlying surficial aquifers, and water movement is coincident with local gradients on the water table. Regionally, ground water probably moves very slowly through deep fractures toward the main drainages. Highly mineralized water in a fracture at a depth of of about 1,400 feet in the Duluth Complex (J. B. Malcolm, written commun., 1976) indicates that water locally may be trapped in small deep-seated fracture systems.

Recharge to the bedrock aquifers is by leakage from overlying surficial aquifers and infiltration of precipitation in outcrop areas.

The extent of ground-water discharge from bedrock aquifers is unknown, but probably is minimal due to the low permeability. Discharge from the Biwabik Iron-formation and surficial aquifers creates small lakes in abandoned open-pit mines in the taconite mining area from Babbitt to south of the study region.

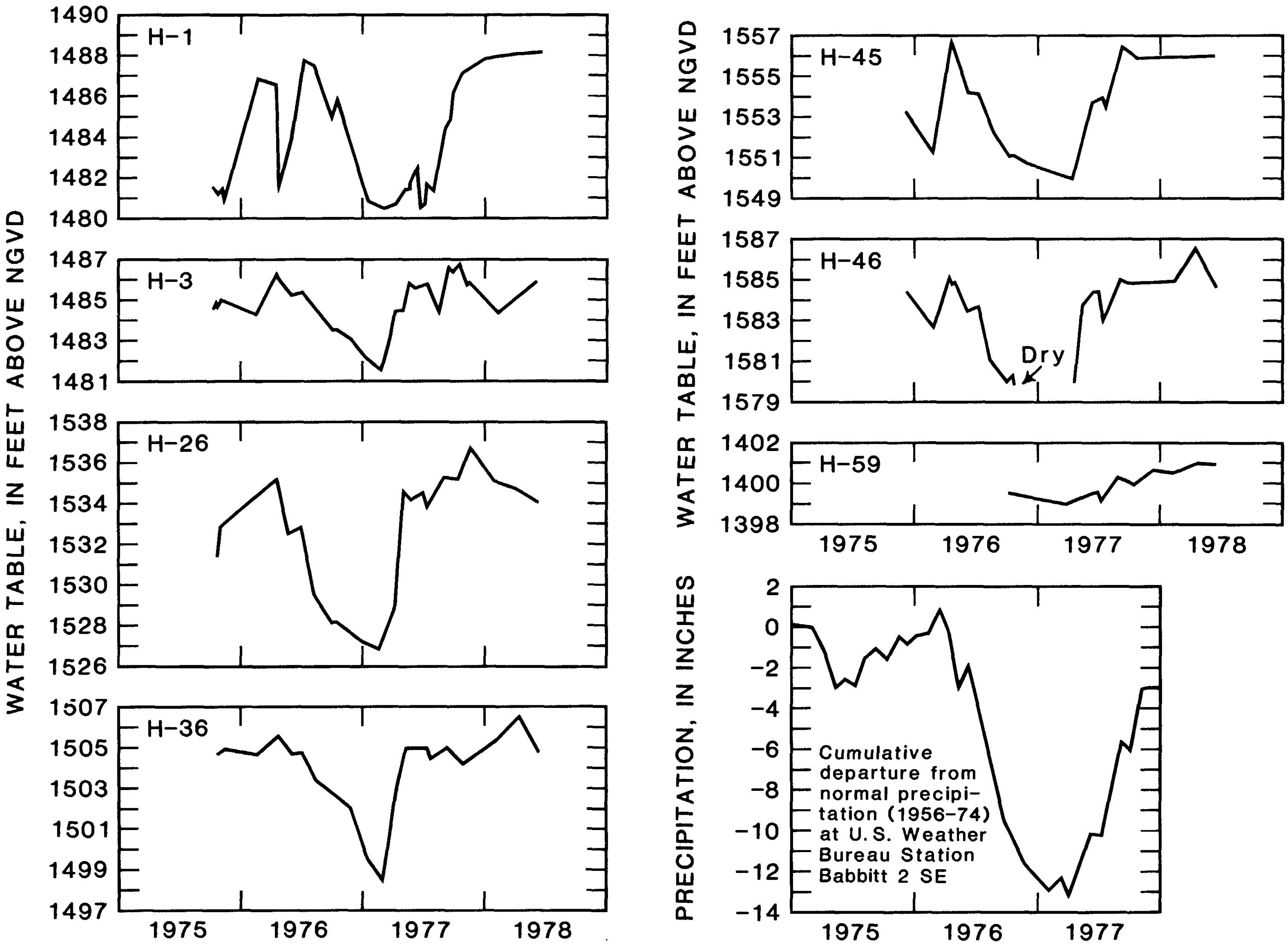

Figure 3.--Water table in the till and the cumulative departure curve from mean monthly precipitation recorded at Babbitt, Minnesota

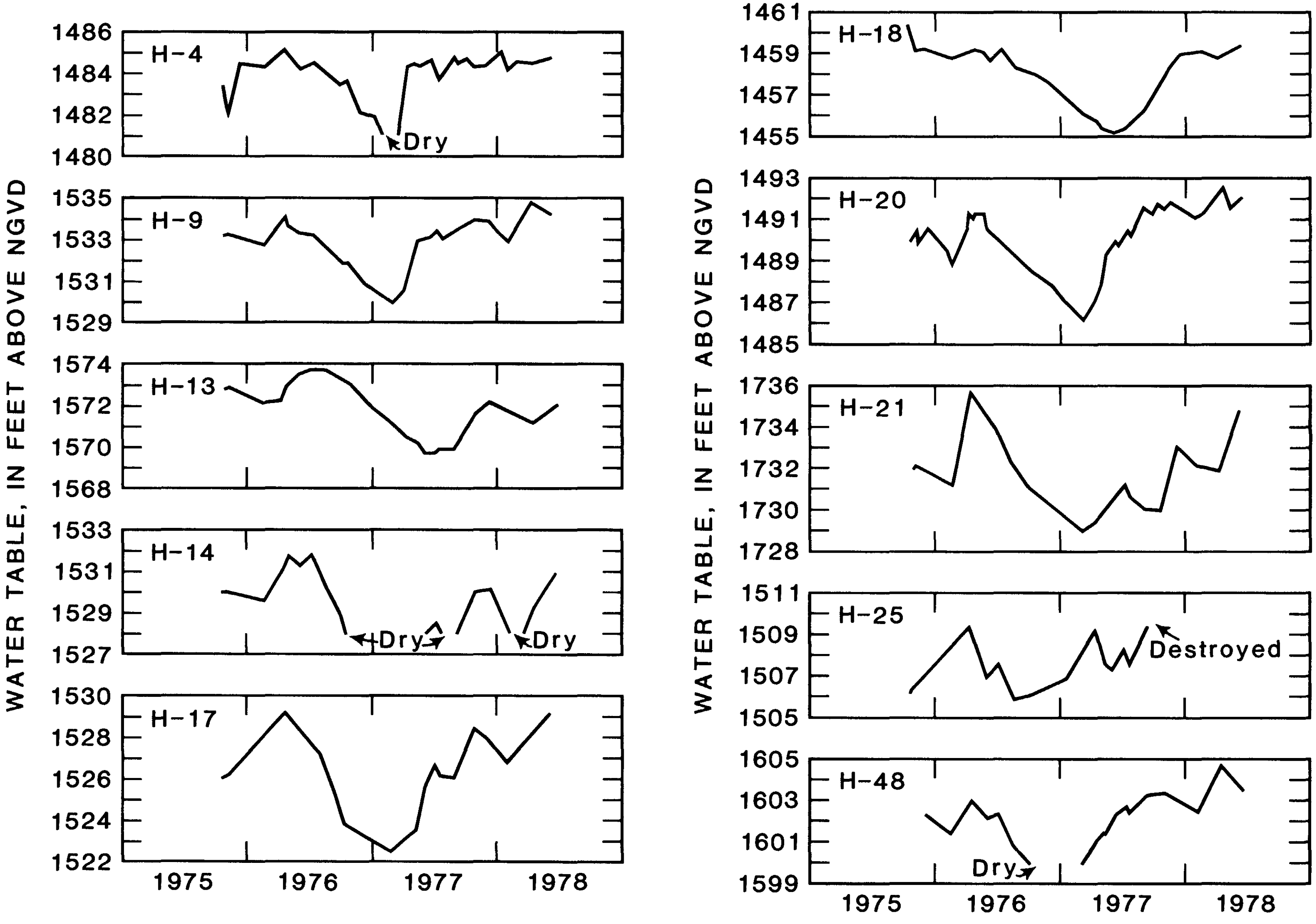

Figure 4.--Water table in sand and gravel

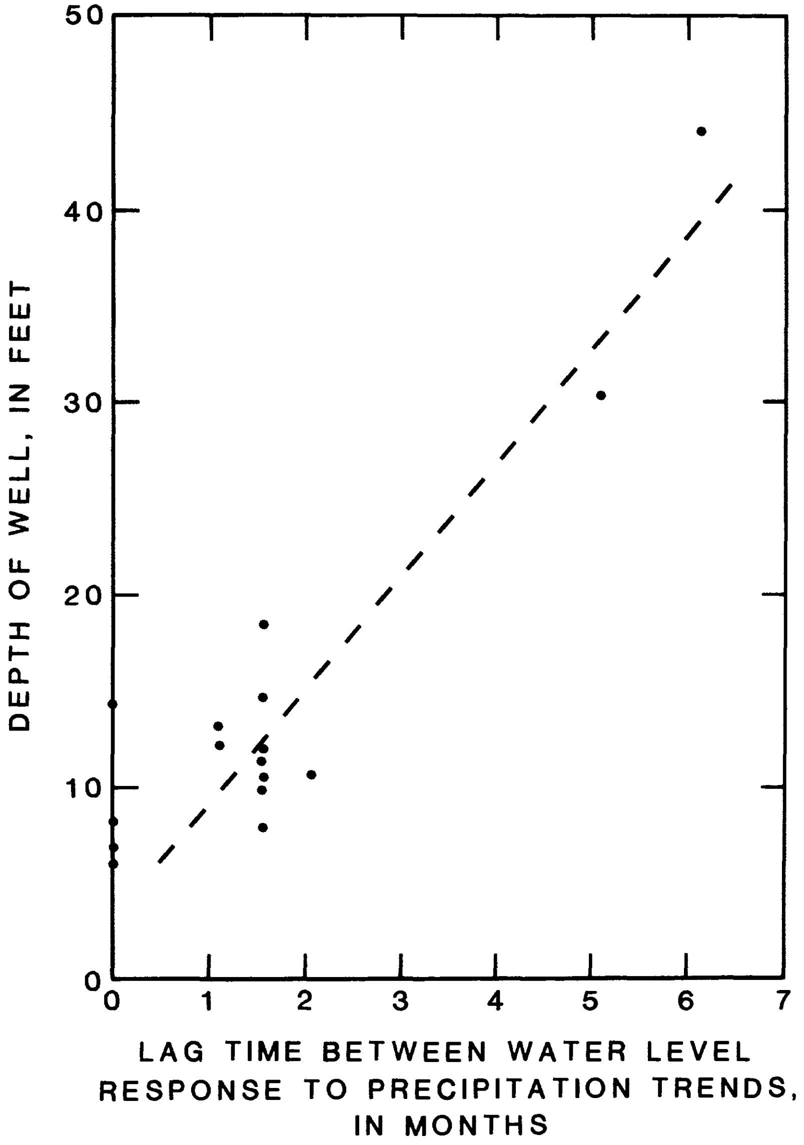

Figure 5.--Relationship between depth of observation well and lag time in water-level response to major trends in cumulative departure from normal precipitation at Babbitt, Minnesota

Information on water-level fluctuations in bedrock wells is scant. Water levels in the bedrock respond similarily to water-table fluctuations where the connection between bedrock and surficial aquifers is good.

Availability

Availability of ground water is highly variable (fig. 6). Yields of 1 to 5 gal/min are obtained over most of the area from shallow dug wells in drift that obtain water from a thin saturated zone at the bedrock surface. Although susceptible to depletion by drought, these supplies are adequate for domestic use most of the time. Similar small supplies are obtained from wells drilled into crystalline bedrock. Sand and gravel deposits, depending on extent and saturated thickness, yield from less than 5 to about 1,000 gal/min. The Biwabik Iron-formation in its area of outcrop also yields as much as 1,000 gal/min to wells. The lithologic and water-bearing characteristics of the geologic units are summarized in table 1.

Ground-water availability by physiographic area is given in table 2.

Specific capacity (well yield per foot of drawdown in water level) of wells is given in tables 3 and 4. The values are an indication of the maximum potential yields of wells. For ideal conditions, doubling the yield of a well will double the drawdown. Specific capacities for wells in sand and gravel deposits range from 0.03 to 38 (gal/min)/ft and in bedrock from 0.02 to 0.11 (gal/min)/ft. Wells in the Biwabik Iron-formation, where fractured and leached, have specific capacities of 0.24 to 6.44 (gal/min)/ft.

Water Quality

Water samples were collected for chemical analysis quarterly during 1976-77 from 12 observation wells finished in glaciofluvial sand and gravel, 11 wells in the Rainy lobe till, and 2 wells in peaty material. In addition, 11 U.S. Forest Service campground wells were sampled during October 1976 when ground-water levels were extremely low. This sampling included 3 wells finished in sand and gravel, 5 wells in Rainy lobe till, and 3 wells in the Duluth Complex. Three other wells in the Duluth Complex were sampled during 1976. Locations of sampled wells and wells which had previously been sampled for water-quality data are given in figure 7.

Water collected from wells in sand and gravel and in peat is a calcium magnesium bicarbonate type, based on predominant ions (fig. 8). This type of water is typical of ground waters which have either a short residence time or have been collected in a recharge zone. Analyses plotted are of samples collected during summer 1976, when ground-water levels were declining in response to drought.

Water collected from the till is classified as either calcium magnesium bicarbonate or calcium magnesium sulfate types. The calcium magnesium sulfate water was collected from wells near the mineralized zone between the Duluth Complex and the Giants Range Granite in the northern part of the study region. Oxidation of sulfide minerals in the till probably causes the increase in the proportion of sulfate relative to other anions.

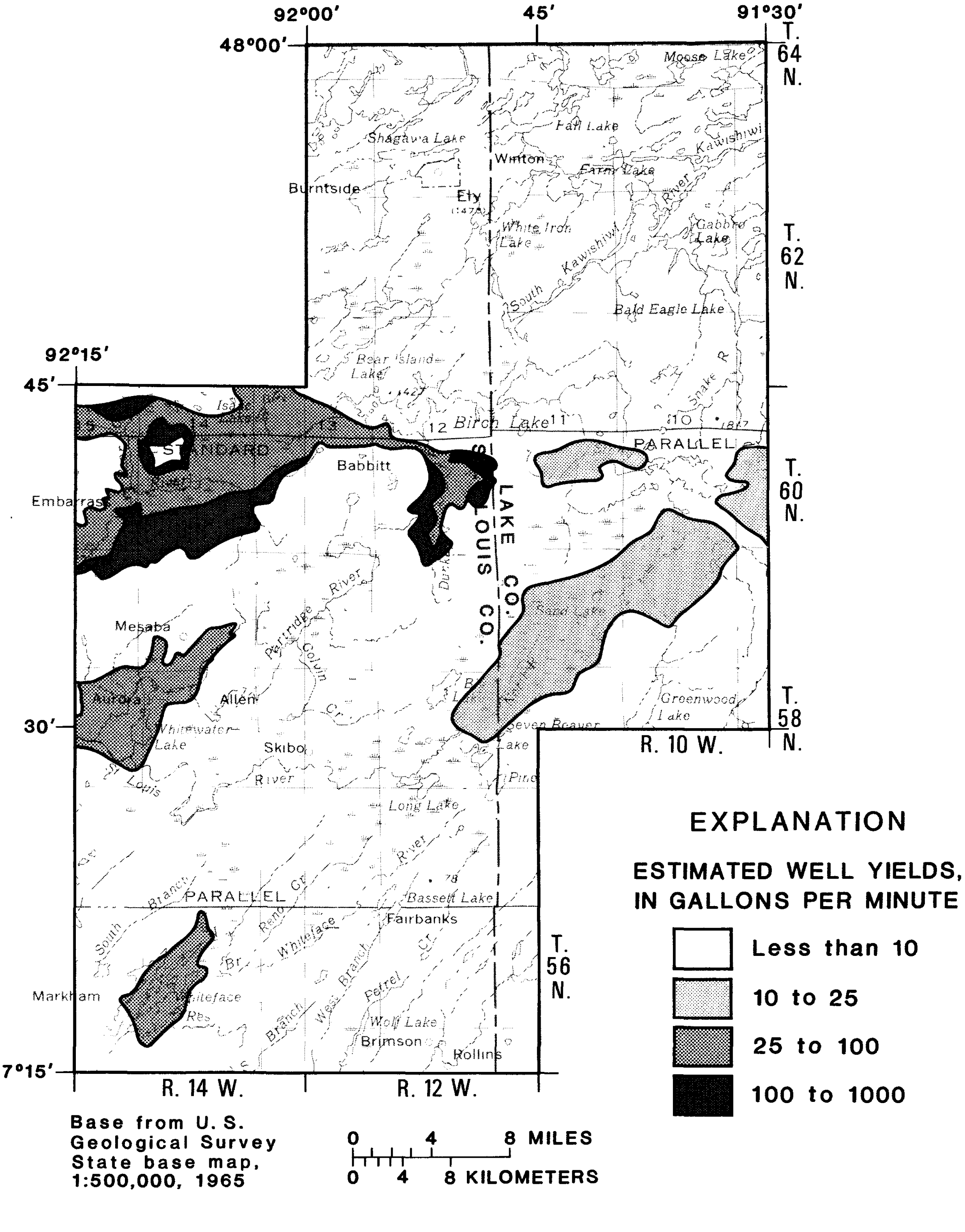

Figure 6.--Estimated average yield of wells in surficial materials

Table 1.--Geologic units and their lithologic and water-bearing characterisitics

System	Series	Units	Estimated maximum thickness (ft)	Description	Estimated range of hydraulic conductivities (ft/d)	Water supply and water-bearing characterisitics
Quaternary	Holocene	Peat deposits	40±	Peat, locally contains clay, silt, and fine sand	10^{-3} to 10^{-1}	Not a significant source of water
		Alluvial deposits	20±	Fine to medium sand, some silt and gravel. Unit lies in flood plains of the Embarrass and Dunka Rivers.	10^{1} to $10^{3.5}$	Not a significant source of water
	Pleistocene (Wisconsin)	Red Clay till of Des Moines lobe	50±	Till, red to brown, clayey; generally contains small basaltic pebbles; locally bouldery; leached to lighter tone in upper 1 foot. Unit caps much of the uplands of the Aurora area.	10^{-2} to 10^{-5}	Not a significant source of water
		Glaciofluvial deposits	300±	Sand, gravel, and silt. Unit thinly capped in some places by red clay till but locally exposed along channels. Terrace deposits are largely sand but include some kame deposits composed predominantly of fine to medium sand. Esker deposits composed largely of poorly sorted sand, gravel, and boulders. Channel deposits of sand, fine to coarse gravel, clay, and silt.	10^{1} to $10^{3.5}$	Sand and gravel deposits are major sources of water. Channel and kame deposits are probably the most productive aquifers. Yields to wells range from less than 5 gal/min from silty sand to as much as 1,000 gal/min from coarse gravel.
		Bouldery till of Rainy lobe	100±	Till, sandy, bouldery, gray. Gravel and boulders are largely composed of gabbro, granite, and other associated igneous rocks.	10^{-1} to $10^{1.5}$	Not a major source of water; however, locally yields 5-10 gal/min to domestic wells.
Proterozoic		Duluth Complex	(?)	Largely troctolite.	—	May yield 5-15 gal/min from fractured zones near its upper surface.
		Virginia Argillite	2000±	Thinly bedded, gray to black argillite.	—	May yield up to 30 gal/min from fractured zones near upper surface. Utilized for many domestic supplies.
		Biwabik Iron-formation	800±	Taconite--dark colored hard dense iron-bearing silicate rock. Ore--black, yellow, or red, soft iron-bearing porous rock.	—	May yield up to 1,000 gal/min to wells in highly fractured taconite and ore. Utilized for many municipal and industrial supplies.
		Pokegama Quartzite	350±	Varicolored vitreous quartzite.	—	May yield 5-15 gal/min from fractures zones near its upper surface.
Archean		Giants Range Granite	(?)	Largely granodiorite.	—	May yield 5-15 gal/min from fractured zones near its upper surface.

Table 2.--Ground-water availability by physiographic area

Physiographic area	Water-bearing units	General aquifer thickness, in feet	Estimated potential yields to wells, in gallons per minute
Shallow bedrock-moraine area	Till on fractured bedrock	Less than 10 feet of till; up to 100 feet of bedrock	Less than 10
Drumlin-bog area	Till, discontinuous lenses of sand and gravel within till	Less than 50	Less than 10
Embarrass-Dunka Rivers sand plain area	Sand and gravel	Less than 50 to 1,000±	Less than 10 to 1,000
Outwash-moraine complex area	Till, sand and gravel lenses	Less than 25	Less than 25
Seven Beaver-Sand Lake wetland area	Till, sand and gravel lenses	Less than 25	Less than 25
Aurora-Markham till plain area	Sand and gravel	Less than 50 to 100	Less than 10 to 300
Embarrass Mountains taconite mining area	Biwabik-Iron-formation	800±	100 to 1,000

Table 3.--Specific capacities of selected wells in sand and gravel aquifers

Well locations	Well depth (feet)	diameter (inches)	Pumping period (hours)	Specific capacity [(gal/min)/ft]
56-14-17cda	90	6	8	0.19
56-14-17cdc	80	6	8	.03
56-14-20bab	35	6	8	1.88
57-12-31baa	70	6	8	.05
57-14-8ba	37	6	8	.32
57-15-22cdb	80	4	24	.57
58-15-3bcc	70	6	3	25
58-15-3bcc	70	6	10	23
58-15-4dba	35	6	0.5	7.1
59-10-18adb	48	6	6	.14
59-15-31dac	64	18	1 week	18
60-9-18aab	23	7	8	11
60-9-27bac	78	6	8	.25
60-9-27cac	30	6	8	10
60-10-21bbb	49	6	8	7.5
60-10-36dab	28	6	8	18
60-12-5baa2	13	12	4	4.0
60-13-1bab1	138	26	8	38
60-13-1bab3	128	12	8	13
60-13-1bab4	157	16	11.5	5.9
60-13-1bba	67	24	10	19
61-14-2db	40	20	4	30
61-14-4cca	98	20	4	13
63-11-31aac	16	24	1	10
63-13-27acc	70	6	12	1.0

Table 4.--Specific capacities of selected wells in bedrock aquifers

Water-bearing unit	Well location	Pumping period, in hours	Depth, in feet	Specific capacity, in (gal/min)/ft
Biwabik Iron-formation	58-15-3cca2	6	455	3.0
	59-15-26dbc	24	299	0.24
	59-15-26dbc	45	398	.25
	60-12-17aad	20	110	6.55
Giants Range Granite	59-14-2adc	8	197	.03
Duluth Complex	61-11-19bdc	4	125	.11
	61-11-34bbc	4	225	.02

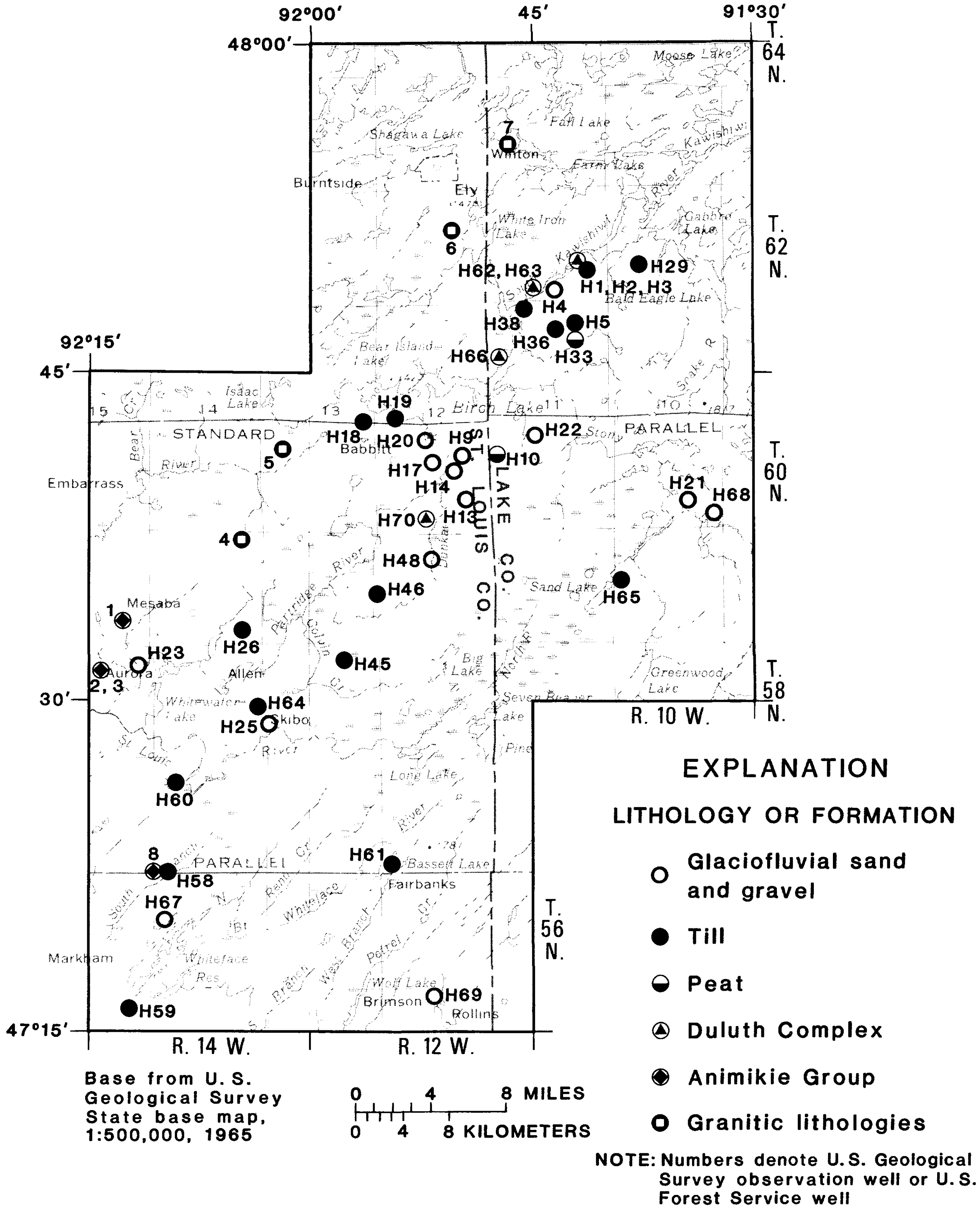

Figure 7.--Wells sampled for chemical analysis

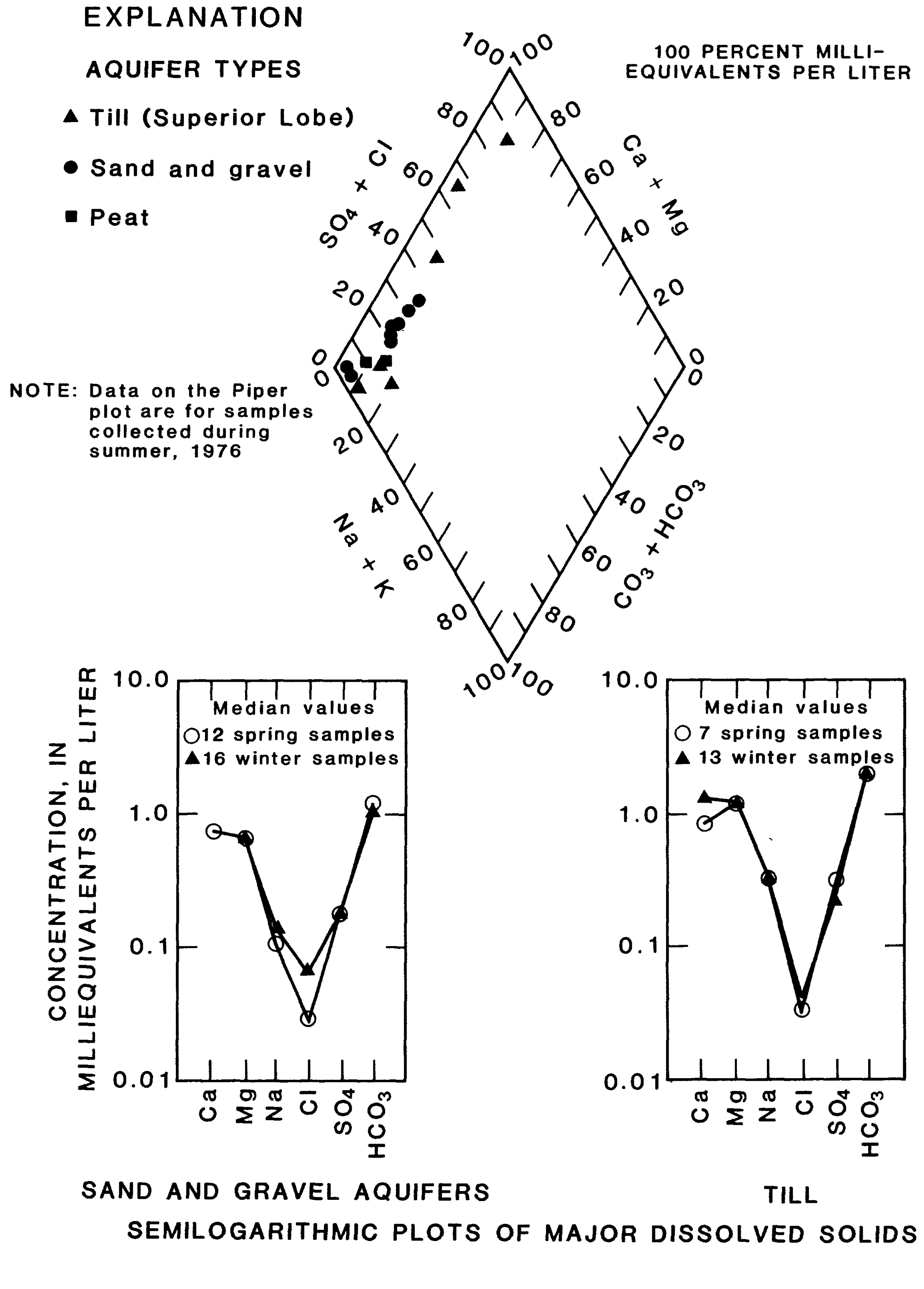

Figure 8.--Piper plot and semilogarithmic graphs of ground-water quality in surficial materials

Semilogarithmic plots of water quality (fig. 8) show the chemical similarity between water in sand and gravel and till, and between samples collected during both spring and winter. Median concentrations were chosen so that the plots would not be biased with extreme values. The similarity off the semilogarithmic curves indicates that water-quality differences in the surficial aquifers are more a matter of relative concentrations than of differences in the proportions of specific ions. Dilution by spring recharge, most apparent in water sampled from sand and gravel, is reflected by the shift of the curves toward the axes of the graphs.

The concentration differences in major constituents can be related to differences in the sedimentologic and hydrologic characteristics between the till and sand and gravel. Silt and finer-sized particles in the till have large surface area to volume ratios, which places large areas of minerals in contact with the water and enhances chemical reactions. In addition, the time available for chemical reactions is greater in the till, where water movement is slow because of low hydraulic conductivity.

Water in sand and gravel is classified (Hem, 1975) as moderately hard to hard. Water in the till is moderately hard to very hard.

Summary statistics for major dissolved constituents and other properties in ground water from surficial materials are presented in table 5. Order of magnitude ranges in the data reflect the diversity of local hydrochemical conditions.

With the exception of chloride, mean values of major dissolved constituents are significantly higher for water from till than from sand and gravel. Mean and median concentrations of the major ions, specific conductivity, and hardness in water from till are about twice that found in sand and gravel. Mean concentrations of dissolved nitrite and nitrate, dissolved phosphorous, total organic carbon, silica, and chemical oxygen demand in water from sand and gravel and till are not significantly different.

Summary statistics for selected minor and trace metals in ground water from surficial materials are given in table 6.

Concentrations of copper, cobalt, and nickel generally are less than 30 ug/L but can exceed 100 ug/L in surficial material directly over the mineralized zone. The occurrence of these metals is probably related to the oxidation of sulfide ores at the contact zone and in the nearby glacial deposits.

The areal distribution of copper and nickel concentrations in water from surficial aquifers reflects proximity to the mineralized contact zone between the Duluth Complex and older rocks (figs. 9 and 10). Consistently higher concentrations of both copper and nickel occur in zones 5 to 10 miles wide centered on the contact.

Concentrations of chromium, cadmium, and lead range from 0 to 15 mg/L.

Table 5.--Quality of ground water from surficial materials, 1976

[Concentrations in milligrams per liter except where designated otherwise]

Constituent or property	Samples from till					Samples from sand and gravel				
	Number of samples	Maximum	Minimum	Mean	Median	Number of samples	Maximum	Minimum	Mean	Median
Specific conductance (micromhos)............	32	1250	120	368	251	40	577	5.5	193	166
pH......................	25	8.0	5.7	6.81	6.70	28	7.1	5.7	6.33	6.35
Chemical oxygen demand...	10	870	22	198	51	18	500	0	93	18
Hardness (Ca,Mg).........	30	637	37	173	104	40	284	26	93	71
Dissolved calcium........	31	150	6.5	39	22	40	76	6.0	20	16
Dissolved magnesium......	31	64	5.1	18	14	41	31	1.1	10	7.3
Dissolved sodium.........	31	18	2.1	7.7	6.9	41	7.3	1.4	3.1	2.9
Dissolved potassium......	31	9.3	0.1	2.7	2.1	41	3.0	0.2	1.3	1.1
Bicarbonate..............	30	423	45	145	120	38	392	15	95	69
Dissolved sulfide........	11	12	0	1.5	0.4	17	4	0	0.9	0.6
Sulfate..................	31	450	1.8	61	11	40	35	0.7	11	6
Chloride.................	31	35	0.4	4	1.4	40	18	0.1	4	2.2
Silica...................	13	37	13	20	18	21	28	10	19	18
Solids (residue at 180°F).................	13	938	97	293	187	14	284	55	148	130
Nitrate plus nitrite.....	11	12	0	1.5	0.4	37	10	0.01	2.2	0.62
Total phosphorus.........	13	0.07	0	0.006	0.001	21	0.04	0	0.003	0.001
Dissolved organic carbon.................	22	46	2.1	18	13	33	52	0.7	11	6.4

Table 6.--Summary statistics of selected dissolved trace and minor metals in water from surficial materials

[Concentrations in micrograms per liter]

Constituent	Till aquifers					Sand and gravel aquifers				
	Number of samples	Maxi-mum	Mini-mum	Mean	Median	Number of samples	Maxi-mum	Mini-mum	Mean	Median
Cadmium..........	29	8.4	0	0.8	0.3	30	1.2	0	0.3	0.3
Cobalt...........	30	28	0.3	3.5	1.4	30	46	0.1	6.3	0.7
Chromium.........	30	5.5	0	0.9	0.6	31	3.2	0	0.6	0.5
Copper...........	30	190[a]	0.6	12	3.8	30	45	0.2	7.2	4.2
Lead.............	30	6.4	0.1	1.8	1.3	31	18	0	1.9	1.1
Nickel...........	27	120	1.0	15	9.0	29	40	0.7	7.5	5.0
Aluminum.........	24	200	0	20	20	30	280	0	32	29
Zinc.............	30	170	3.9	28	8.9	30	620	0.7	56	14
Iron.............	30	3100	0	221	25	38	67,000	0	5152	45
Manganese........	31	7190	10	1268	330	38	26,000	0	2140	45

[a]May reflect contamination.

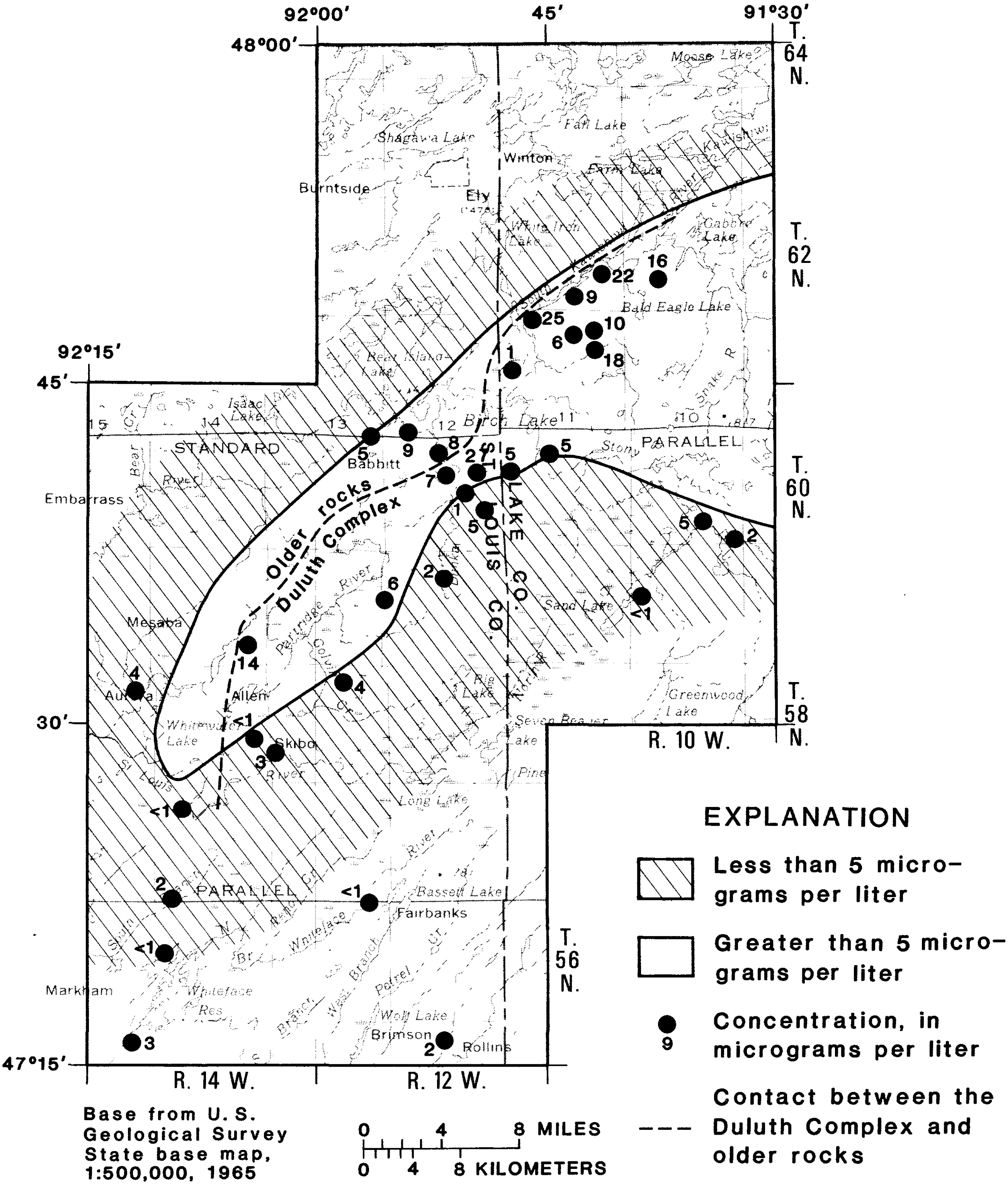

Figure 9.--Generalized copper distribution in ground water from surficial materials (data from October or April, 1976)

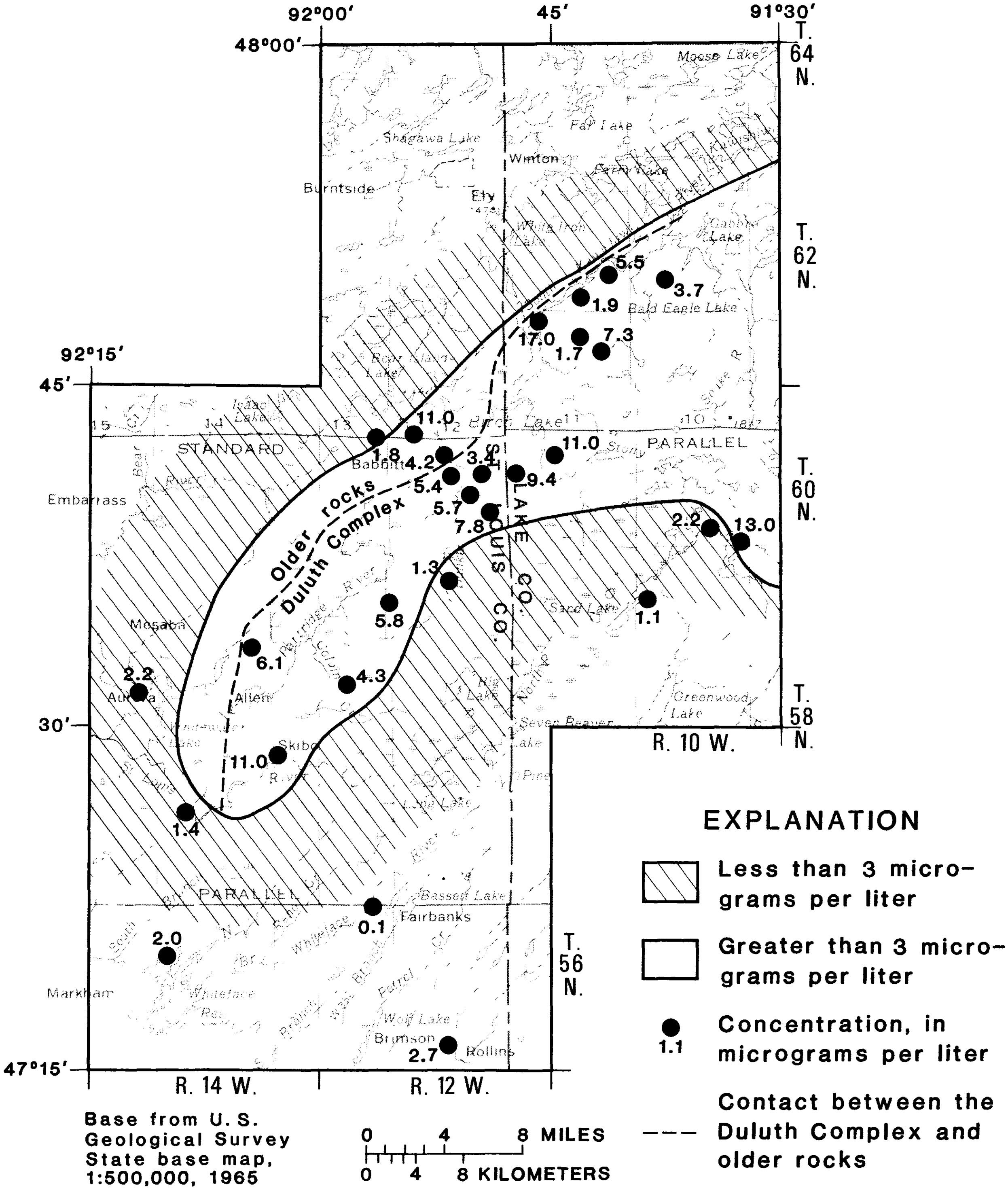

Figure 10.--Generalized nickel distribution in ground water from surficial materials (data from October or April, 1976)

Iron is occasionally found in anomalously high concentrations--up to 67 mg/L. These concentrations of iron are difficult to explain with the scant data base, but probably are related to reducing conditions in the system.

Representative analyses of water samples collected from wells in the major bedrock units are given in table 7.

Concentrations of major constituents in water from the Duluth Complex are highly variable. Specific conductance ranges from 220 to 4,620 umho/cm at 25°C, while chloride concentration ranges from 1.3 to 1,500 mg/L. Field pH in water from the Duluth Complex ranges from 7.0 to 8.5, which is generally one pH unit more basic than water from the surficial deposits. Because water in the Duluth Complex occurs in isolated fractures and joints, water quality is probably a function of local hydrogeochemical conditions. However, data from six wells suggests that concentrations increase with depth.

Water from the Duluth Complex can be classified as a sodium chloride or sodium bicarbonate type (fig. 11).

Water in granite, Biwabik Iron-formation, and Virginia Argillite (figs. 11 and 12) is a calcium magnesium bicarbonate type, similar to water from surficial materials.

Except for iron and manganese, few analyses have been made for trace and minor metals in water from the bedrock aquifers. The few analyses available suggest that dissolved copper, nickel, cadmium, silver, mercury, and lead concentrations are low, generally less than a few micrograms per liter, in water from most bedrock.

Iron and manganese concentrations in water from wells in the Duluth Complex range from 0 to 150 and 0 to 60 ug/L, respectively. Concentrations of these metals are higher in water from wells in the Biwabik Iron-formation, ranging from 50 to about 5,000 ug/L for iron and from 0 to 1,800 ug/L for manganese. Data from four wells indicate that concentrations of iron and manganese in water from the Giants Range Granite are as high as 500 ug/L.

Specific conductance is correlated with dissolved calcium, hardness (Ca + Mg), and dissolved solids, as shown in figure 13. From these correlations, specific conductance can be used to estimate the concentrations of these constituents in ground water.

SURFACE WATER

General Description

The 1,400 mi^2 study area is within the drainage basins of the Kawishiwi and St. Louis Rivers (fig. 14), which are separated by the Laurentian Divide. North of the divide, water in the Kawishiwi and Shagawa Rivers flows through Rainy Lake and Lake of the Woods to Hudson Bay. South of the divide, water in the St. Louis River flows to Lake Superior and eventually to the Atlantic Ocean.

Table 7.--Representative ground-water analyses from major bedrock types in the Copper-Nickel study region

[BBKF = Biwabik Iron-formation, DCPX = Duluth Complex, GRNT = Giants Range Granite or other granite, VRGN Virginia Argillite; concentrations in milligrams per liter except where designated otherwise]

Well number	Source of Analysis	Aquifer	Depth of well (ft)	Date of sample	Specific conductance (micromhos)	pH	Total hardness (Ca, Mg)	Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Dissolved sodium (Na)	Dissolved potassium (K)	Bicarbonate (MCO$_3$)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved silica (SIO_2)	Dissolved solids (sum of constituents)
62.11.33da	USGS	DCPX	225	10-20-76	320	8.5	7	2.7	0.1	73	0.9	167	3.8	5.3	—	—
62.11.33ac	USGS	DCPX	1000	10-29-76	1300	7.4	150	44	9.1	220	3.3	155	45	310	—	—
61.11.19bd	USGS	DCPX	125	10-10-76	220	7.7	9	3.1	0.3	48	0.3	115	9.6	4.3	—	—
60.12.32aa	AMAX	DCPX	1046	12-15-77	4620	8.1	1100	420	2.0	470	2.0	94	3.6	1500	—	—
59.15.26dcb	USGS	BBKF	398	12- 4-74	380	7.4	200	43	22	5	2.3	189	41	9	18	—
62.12.14dbd	USGS	BBKF	147	0- 8-72	298	7.1	110	19	6	4.6	0.6	71	17	12	17	—
58.15.3bcc2	MSBOH	BBKF	180	10- -65	—	—	130	58	—	—	—	99	47	1.4	—	—
58.15.3caa	MSBOH	BBKF	—	10- -70	—	8.9	94	42	—	20	7	32	88	7.8	—	180
59.14.2ad	MDH	GRNT	197	8- 8-75	240	8.2	—	93	52	7.3	0.8	207	17	1.0	—	—
60.13.7abc	USGS	GRNT	425	12- 5-74	143	8.3	63	31	9.1	13.0	1.9	140	7.3	1.3	14	—
62.12.14dbd	USGS	GRNT	147	9- 8-72	572	7.5	193	19	6.0	4.6	0.9	71	65	7.5	13	323
63.11.17ccc	USGS	GRNT	121	9-12-72	237	—	—	110	10	26	2.6	204	13.8	1.5	—	—
56.14.6bba	USGS	VRGN	90	12- 3-74	745	7.8	390	46	66	19	4.2	523	22	1.3	19	436

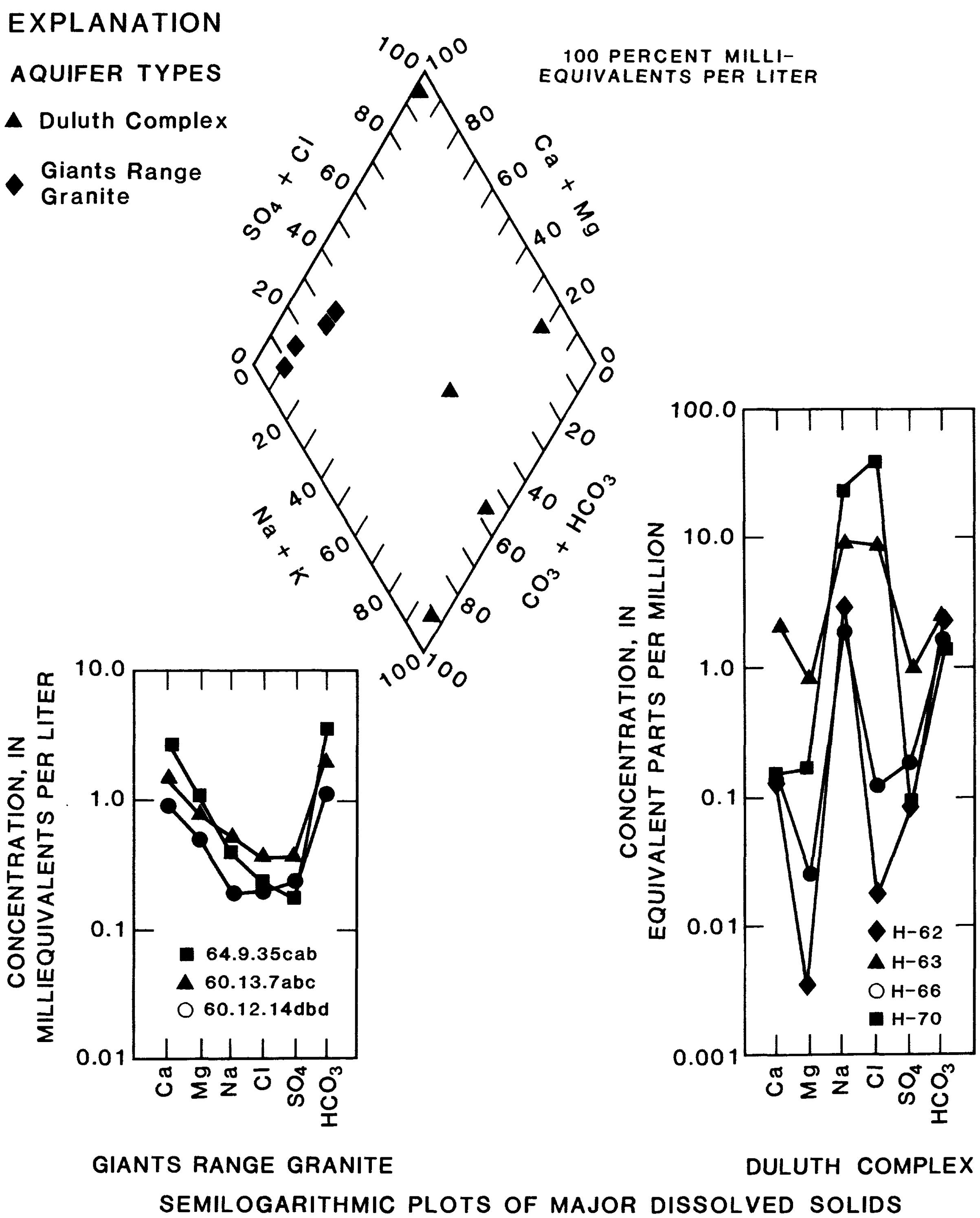

Figure 11.--Piper plot and semilogarithmic graphs of ground-water quality in the Duluth Complex and Giants Range Granite

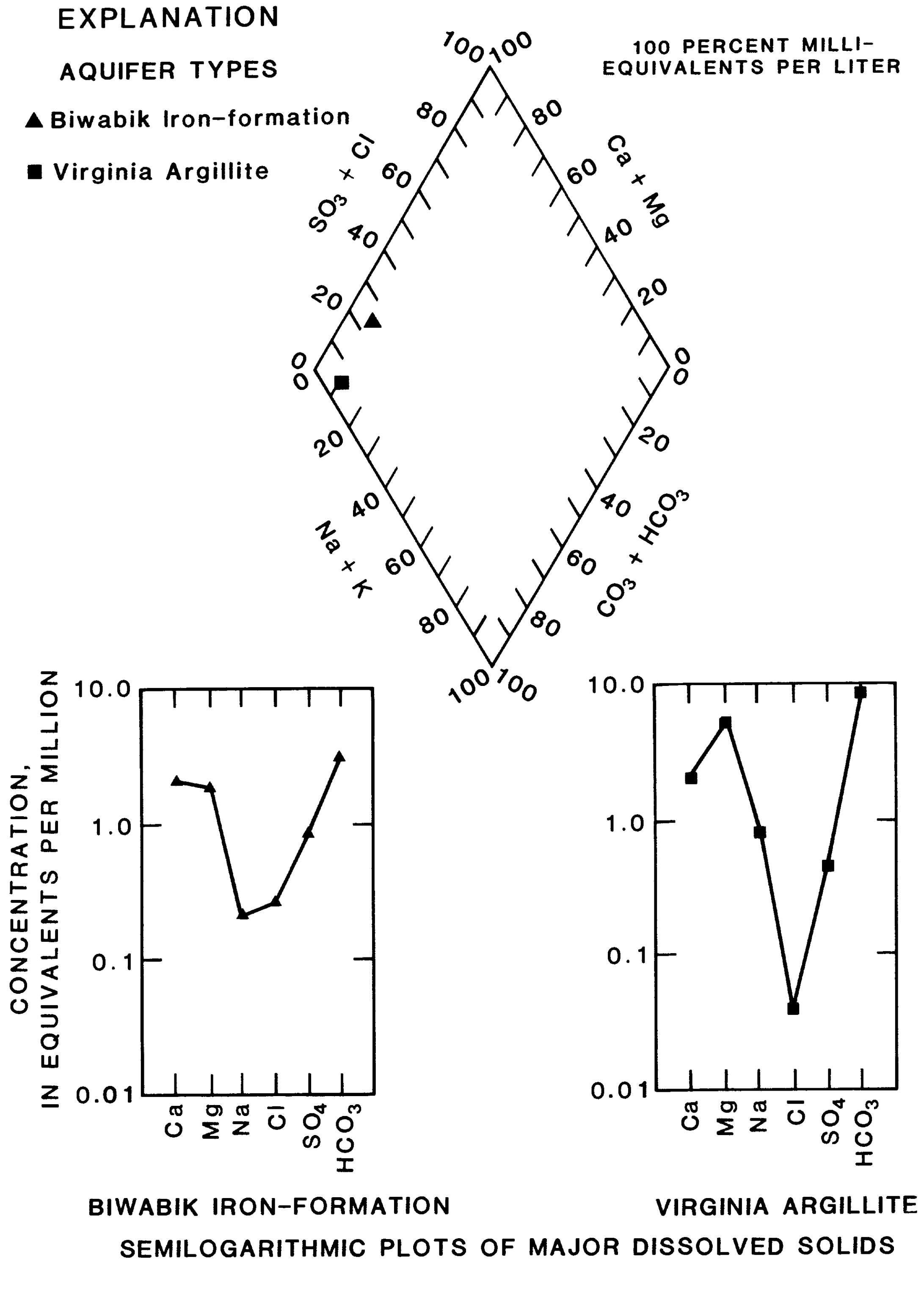

Figure 12.--Piper plot and semilogarithmic graphs of ground-water quality in the Biwabik Iron-formation and the Virginia Argillite

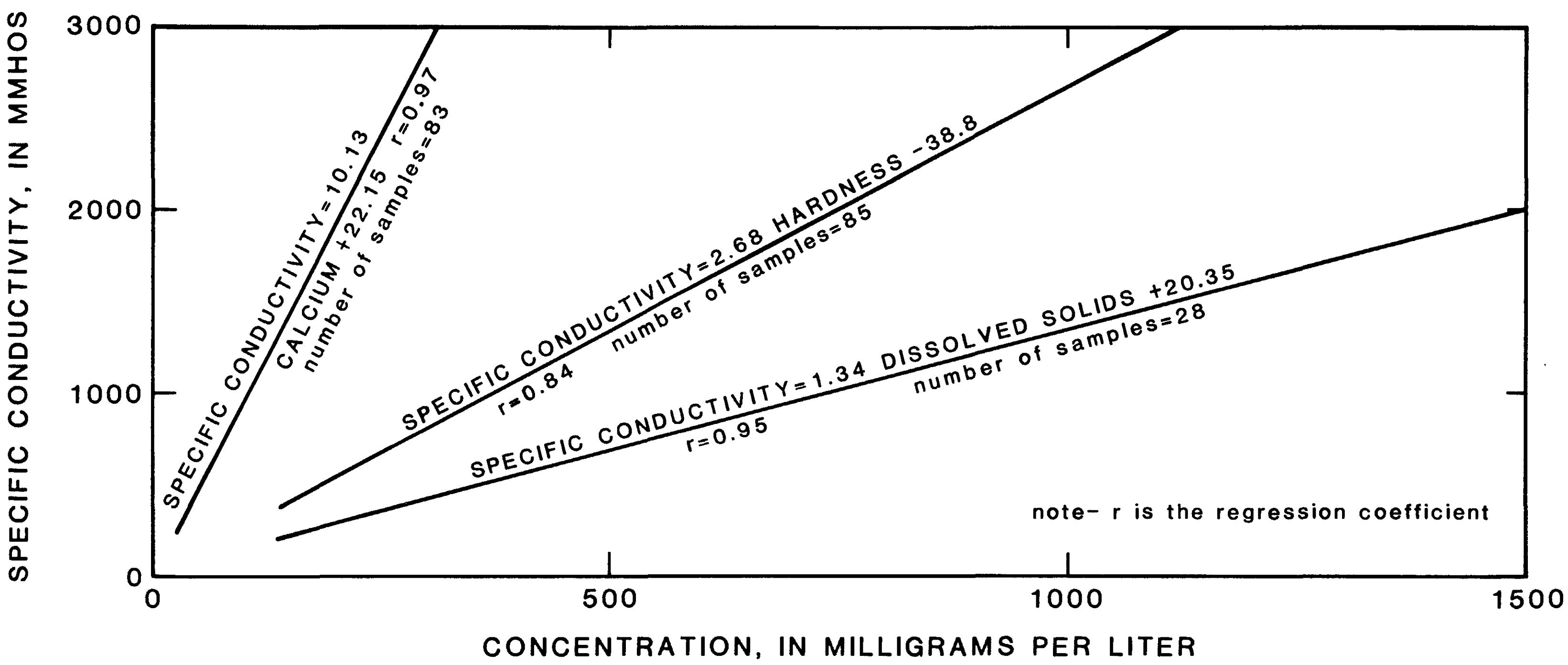

Figure 13.--Relationship between specific conductance and selected constituents in ground water collected from the Copper-Nickel study area

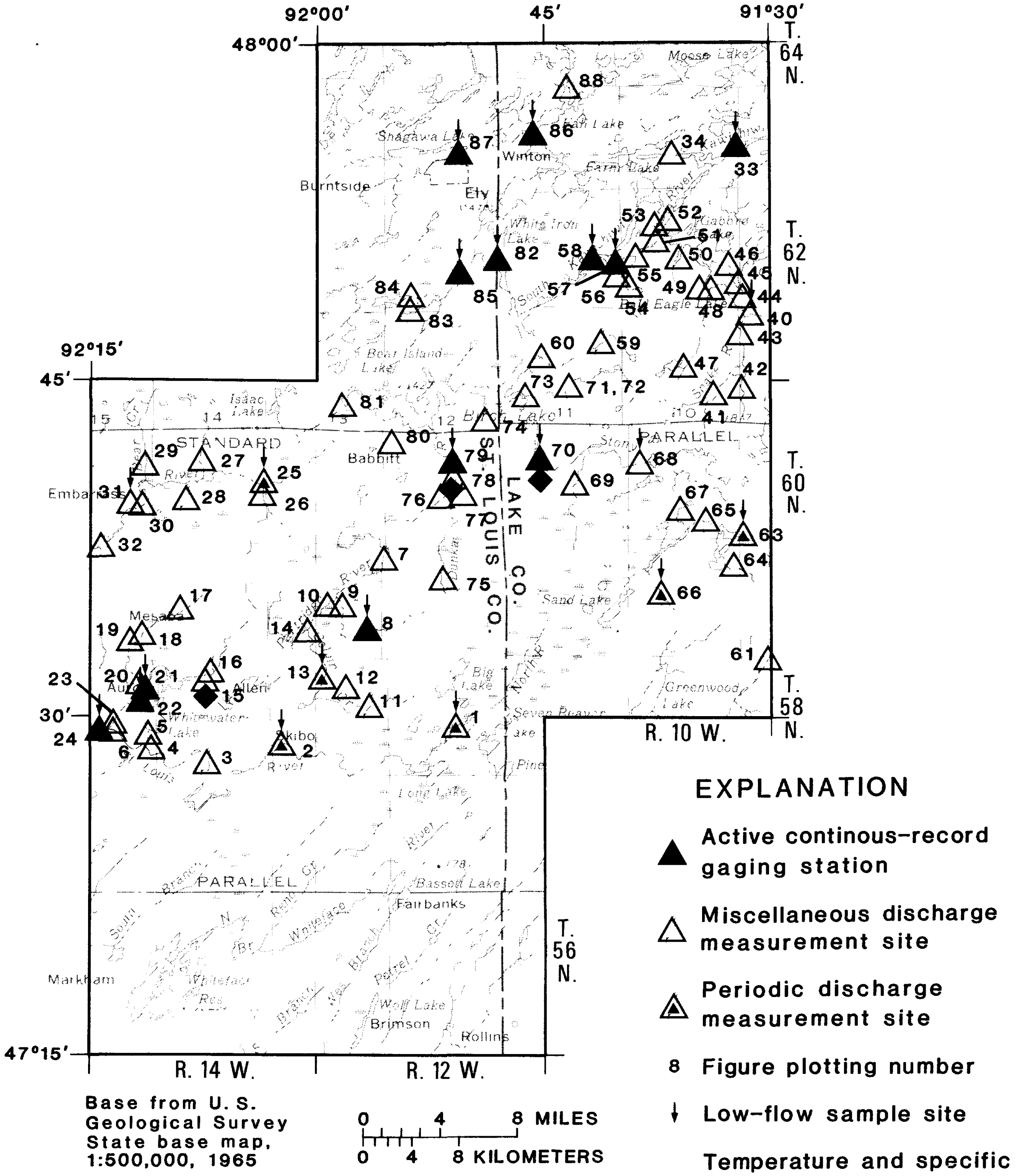

Figure 14.--Map showing location of surface-water data stations including low-flow sample sites

Major tributaries to the Kawishiwi River are the Stony and Isabella Rivers, both flowing generally from east to west to Gabbro and Birch Lakes, respectively. Major tributaries to the St. Louis River are the Embarrass and Partridge Rivers, which also flow generally from east to west. Both basins have a high density of lakes and wetlands that are connected by streams. For example, more than 33 miles of the Kawishiwi River is composed of on-channel lakes, about 40 percent of the total river length. The St. Louis River basin has a high density of wetlands, ranging from a few acres to several square miles in area.

Drainage areas for all gaging stations and miscellaneous water-data sites are given in tables 8 and 9.

Channel profiles (figs. 15a, b, c, and d) illustrate variations in river gradients caused by on-channel lakes and wetlands. For example, although the average gradient of the Kawishiwi River is 4.3 ft/mi, the central part of its profile has a gradient of only 2.5 ft/mi because of on-channel lakes.

Stony and Isabella Rivers have similar channel profiles. Average gradients are 11.4 ft/mi for the Stony River and 10.1 ft/mi for the Isabella River.

The St. Louis River has an average gradient of 7.9 ft/mi from its headwater to near Aurora. Where lakes and wetlands occur in its headwater, the channel gradient is only 1.6 ft/mi. The step like pattern in the profile of the Partridge River is caused by Colby Lake.

The segment of the Embarrass River located in the study area has an average gradient of 3.7 ft/mi. The tributaries to the Kawishiwi River, Filson Creek, Dunka River, and Bear Island River have average gradients of 16.2, 15.9, and 7.4 ft/mi, respectively.

The Kawishiwi River is regulated a few hundred feet upstream from its mouth at Fall Lake by a hydroelectric powerplant dam. The powerplant dam creates a reservoir pool that extends upstream to include Garden, Farm, and South Farm Lakes. Backwater from the reservoir pool provides additional storage in White Iron Lake. A second reservoir is located on South Kawishiwi River at Birch Lake. Flow from this reservoir is controlled by a dam at the Birch Lake outlet. Flow at the powerplant is completely regulated up to the maximum discharge capacity of the turbines, which is just under 1,000 ft^3/s. During periods of high runoff, excess flow at the powerplant is discharged through a spillway.

The Partridge River is mostly regulated at Colby Lake, where water is appropriated for iron-ore processing and for cooling at a thermoelectric powerplant. Partridge Reservoir, constructed in 1955, stores water during periods of high runoff, which is later released to Colby Lake when flow in the Partridge River is not adequate for maintaining the elevation of the lake. Water from Partridge Reservoir seeps to the Partridge and St. Louis Rivers. Seepage varies with stage in the reservoir.

Table 8.--Streamflow data at gaging stations

Figure plotting number	Station I.D. number	Station name	Drainage area (mi^2)	Period of record	Maximum discharge Date	Maximum discharge (ft^3/s)	Minimum discharge Date	Minimum discharge (ft^3/s)	Years of record	Average discharge (ft^3/s)	Mean annual runoff (inches)
8	04015455	South Branch Partridge River near Babbitt	18.5	June 1977-present	9-26-77	a82	—	No flow at times	<1	—	—
21	04015500	Second Creek near Aurora	29.0 nc6.6	Mar. 1955-present	4-22-61	254	10-17-76	1.2	22	22.4	—
22	04016000	Partridge River near Aurora	161 nc13	Aug. 1942-present	5-10-50	3230	1-30-61 1-31-61	2.2	35	*126	*10.83
24	04016500	St. Louis River near Aurora	290 nc13	Aug. 1942-present	5-14-50	5380	10- 1-40 Jan. 29-Feb. 10, 1977	4.0	35	*244	*11.51
30	04017000	Embarrass River at Embarrass	88.3	Aug. 1942-Dec. 1964	5- 8-50	1740	Jan. 28-Feb. 5, 1963	0.90	22	64.4	9.90
33	05124480	Kawishiwi River near Ely	253	June 1966-present	4-24-76	1720	Jan. 31 Feb. 1, 2, 1977	4.5	11	223	11.97
40	05124500	Isabella River near Isabella	341	Oct. 1952-Sept. 1961, Apr. 1976-Nov. 1977	4-19-76	3900	Aug. 21, 22, 1961, Sept. 11-13, 1976	24	10	272	10.83
57	05124990	Filson Creek near Ely	9.66	Oct. 1974-present	4-25-75	129	—	No flow at times	3	6.17	8.67
58	05125000	South Kawishiwi River near Ely	—	Oct. 1951-Sept. 1961, Apr. 1976-present	5- 4-54	5130	Oct. 12, 1960	25	11	419	—
68	05125500	Stony River near Isabella	180	Oct. 1952-Dec. 1964	4-27-57	b2040	Aug. 22, 1961	5.6	12	127	9.58
70	05125550	Stony River near Babbitt	210	Aug. 1975-present	4-19-76	2490	Nov. 29, 1976	6.4	2	136	8.43
79	05126000	Dunka River near Babbitt	53.4 nc4	Oct. 1951-Sept. 1962, Feb. 1975-present	4-16-54	691	—	No flow at times	13	36.6	9.29
82	05126210	South Kawishiwi River above White Iron Lake near Ely	—	Aug. 1975-present	4-22-76	8080	Mar. 22, 1977	19	2	608	—
85	05126500	Bear Island River near Ely	68.3	Oct. 1952-Sept. 1962, Mar. 1975-Sept. 1977	5- 3-54	423	—	No flow at times	12	41.2	8.17
86	05127000	Kawishiwi River near Winton	1229	June 1905-June 1907, Oct. 1912, Sept. 1919, Sept. 1923-present	5-18-50	16,000	—	No flow at times	58	1019	11.26
87	05127230	Shagawa River at Ely	99	May 1967-present	6-12-70	640	Nov. 11, 1976	0.17	10	86.6	11.88

a - 148 ft^3/s measured April 12, 1976.
b - 2,260 ft^3/s measured April 20, 1976.
* - Adjusted for storage and diversion from Colby Lake.
nc - Noncontributing drainage area with respect to surface runoff.

Table 9.--Streamflow data at periodic measurement sites

Figure plotting number	Station I.D. number	Station name	Drainage area (mi^2)	Period of discharge measurements	Range of discharge (ft^3/s) maximum	minimum
1	04015430	St. Louis River below Seven Beaver Lake near Fairbanks	60.6	July 1976-Oct. 1977	185	0.19
2	04015438	St. Louis River near Skibo	94	July 1976-Oct. 1977	238	0.22
8	04015455	South Branch Partridge River near Babbitt	18.5	Dec. 1975-June 1977[a]	148	0
13	04015461	Colvin Creek near Hoyt Lakes	18.3	Dec. 1975-Oct. 1977	136	0.25
25	04016900	Embarrass River near Babbitt	17.6	Dec. 1975-Oct. 1977	124	0
30	04017000	Embarrass River at Embarrass	88.3	Aug. 1975-Oct. 1977[b]	449	1.39
63	05125400	Stony River near Murphy City	62	Dec. 1975-Aug. 1977	1100	0.94
66	05125450	Greenwood River near Isabella	48.2	Jan. 1976-Aug. 1977	686	0
68	05125500	Stony River near Isabella	180	Aug. 1975-Oct. 1977[b]	2260	4.93

[a]Converted to continuous record gaging station June 1977.
[b]At discontinued gaging station.

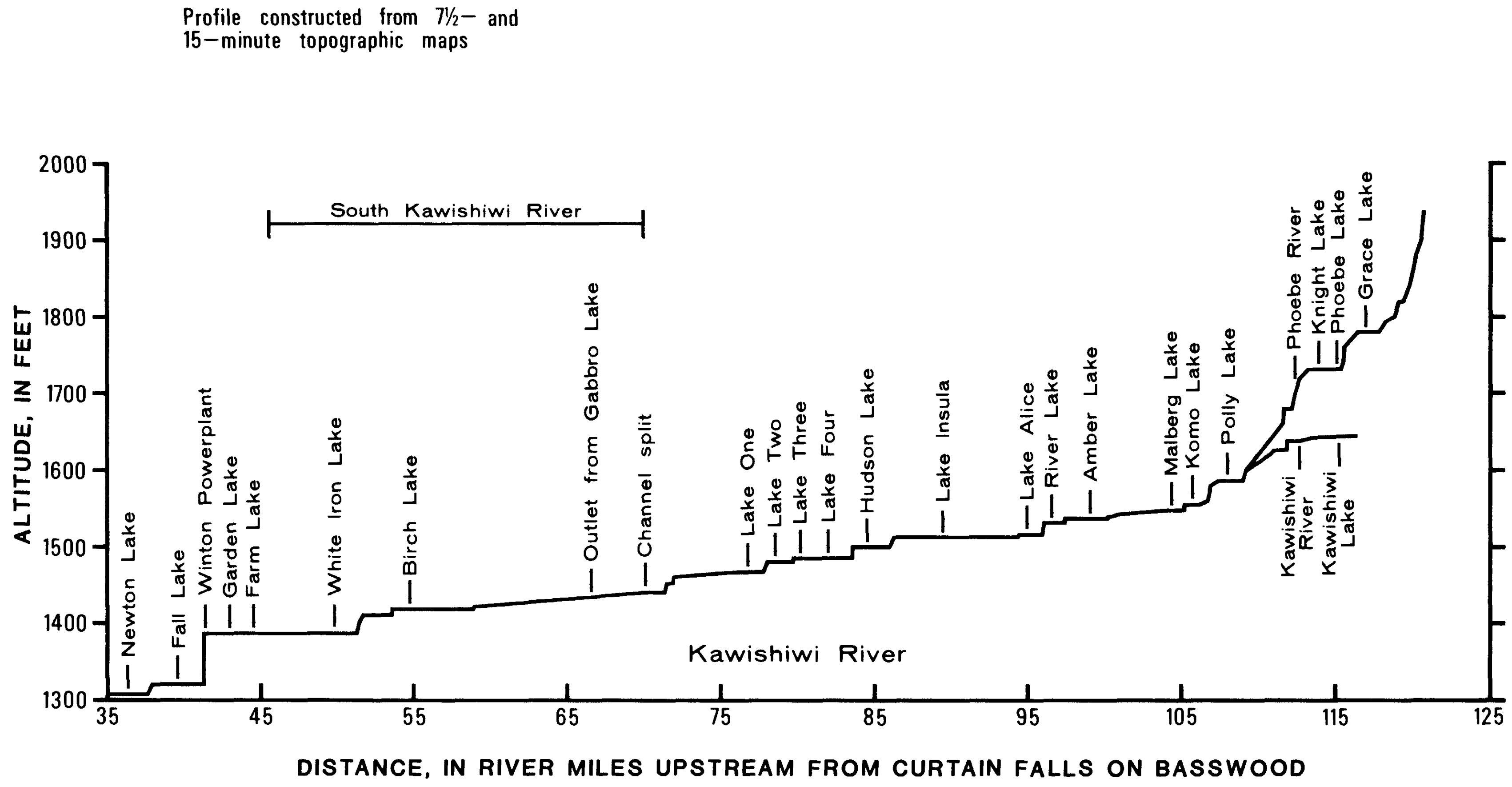

Figure 15a.--Channel profile of the Kawishiwi River in the Copper-Nickel study region

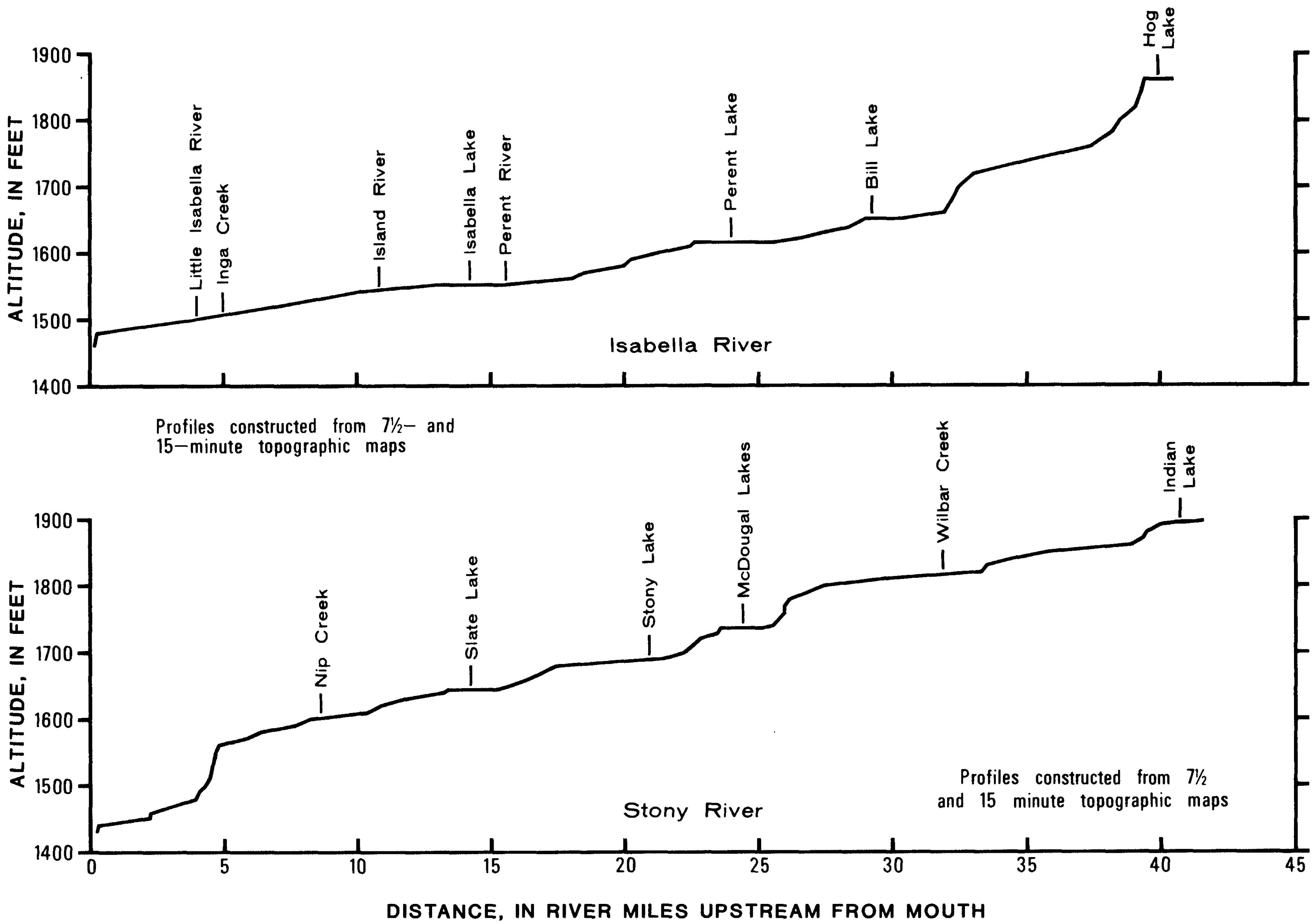

Figure 15b.--Channel profiles of the Stony and Isabella Rivers in the Copper-Nickel study region

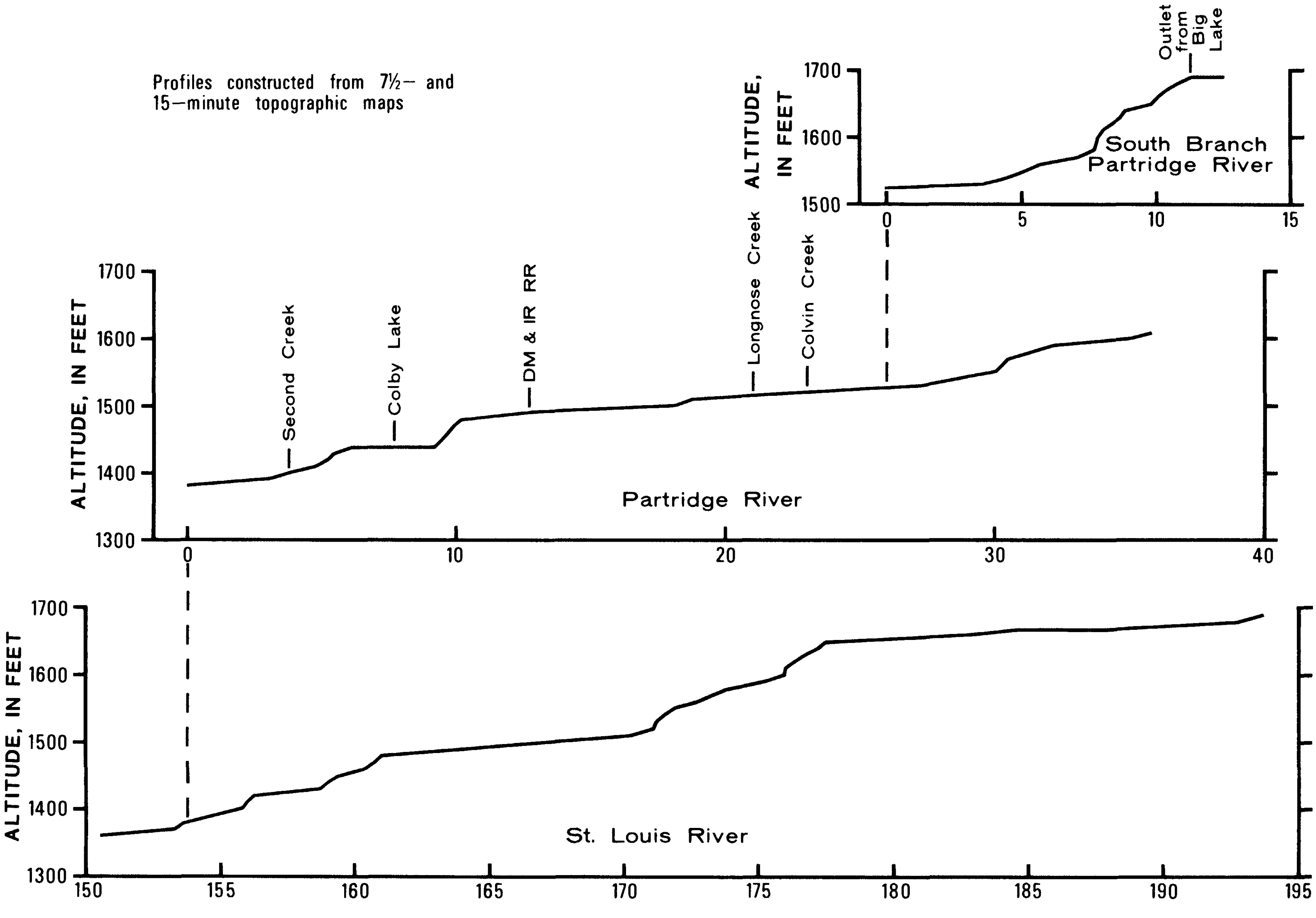

Figure 15c.--Channel profiles of the St. Louis and Partridge Rivers in the Copper-Nickel study region

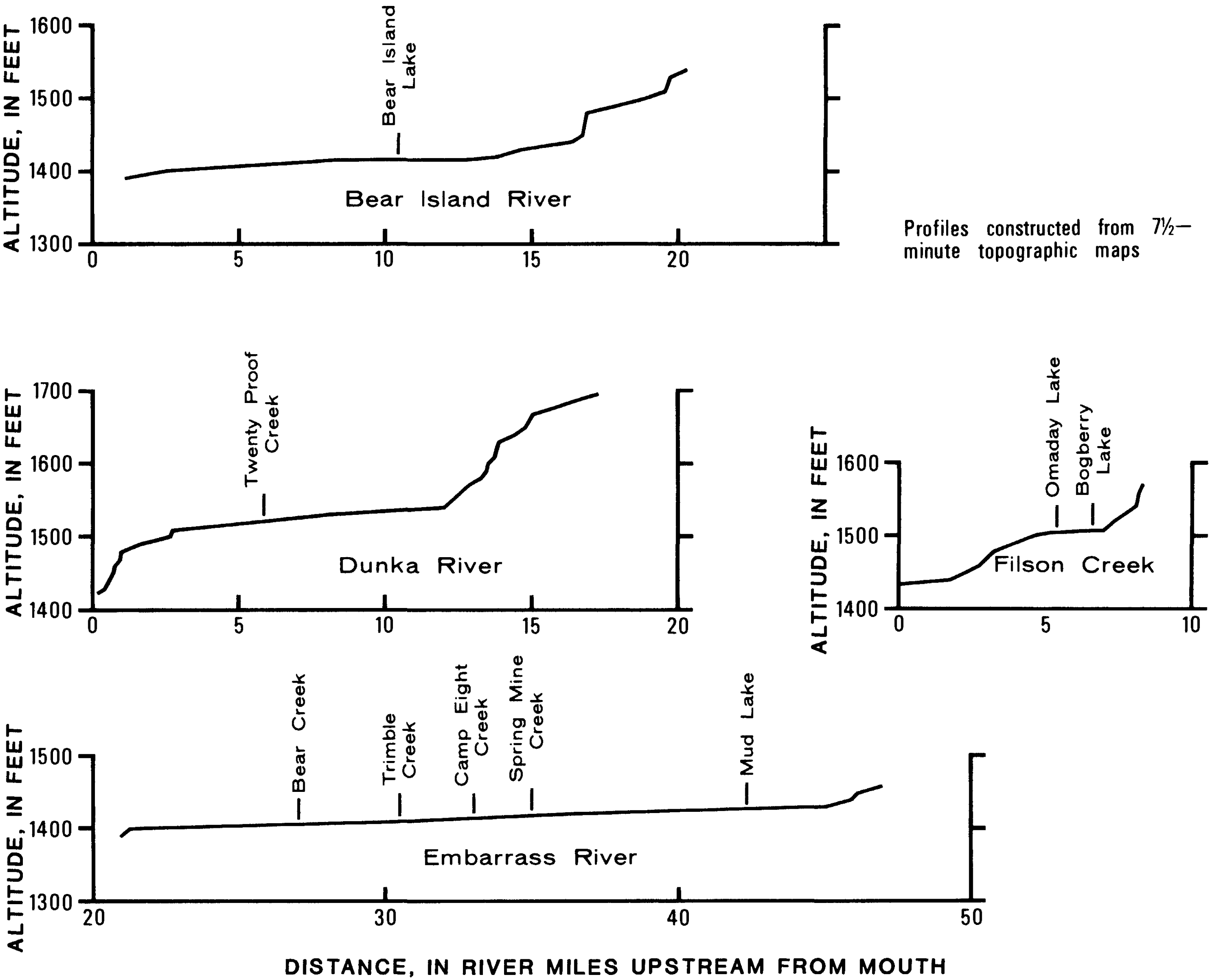

Figure 15d.--Channel profiles of the Embarrass, Dunka and Bear Island Rivers and Filson Creek in the Copper-Nickel study region

The Kawishiwi River, Partridge River, and Second Creek are partly regulated by industry. Second Creek is mostly affected by dewatering of open-pit mines, which by 1969 increased the discharge by several cubic feet per second. Water is also appropriated from Second Creek for industrial use at a rate several times less than that added by mine-dewatering.

Flow Characteristics

Both seasonal variations in flow and effects of regulation are illustrated in annual hydrographs of the South Kawishiwi, Partridge, Embarrass, and Stony Rivers (figs. 16 and 17) for years when annual runoff was below, near, and above normal. The hydrographs show that streamflow generally recedes slowly in late fall and through the winter, rises sharply during spring snowmelt, and again recedes during the summer, except during occasionally heavy storms.

Baseflow is small during the winter because ground-water discharge is minimal. The largest aquifer in the study area is located in the Embarrass River basin but baseflow is not sustained at a very high rate, even in wet years.

Flood peaks of the Kawishiwi River near Ely are reduced because large volumes of runoff are stored in on-channel lakes. The lakes later release the stored water to sustain relatively high flows on the descending limb of flood peaks.

Mine discharge supplements baseflow to the Partridge River. Consequently, baseflow during the dry 1976 water year was near normal.

Continuous long-term hydrographs (fig. 18) illustrate the effect of regulation. Compared to the unregulated Embarrass River, baseflow of Second Creek and Partridge River increased as a result of mine-dewatering after 1964. Because of hydroelectric regulation, the range of annual discharge of the Kawishiwi River is about equal to that of the Stony River, even though the Kawishiwi River has a drainage area about ten times greater.

Another way of illustrating streamflow is by use of flow-duration curves. Flow-duration curves are cumulative frequency curves that show the percentage of time specified discharges are equalled or exceeded during a given time period, independent of sequence of occurrence.

Flow-duration curves for major streams are plotted with the ordinate expressed both as daily mean discharge (figs. 19 and 20), and as daily flow per square mile in figures 21 and 22. The lowest unit flows for durations exceeding 90 percent are at Dunka River near Babbitt and Shagawa River at Ely. The highest unit flows are at the Isabella River near Isabella and Stony River near Isabella.

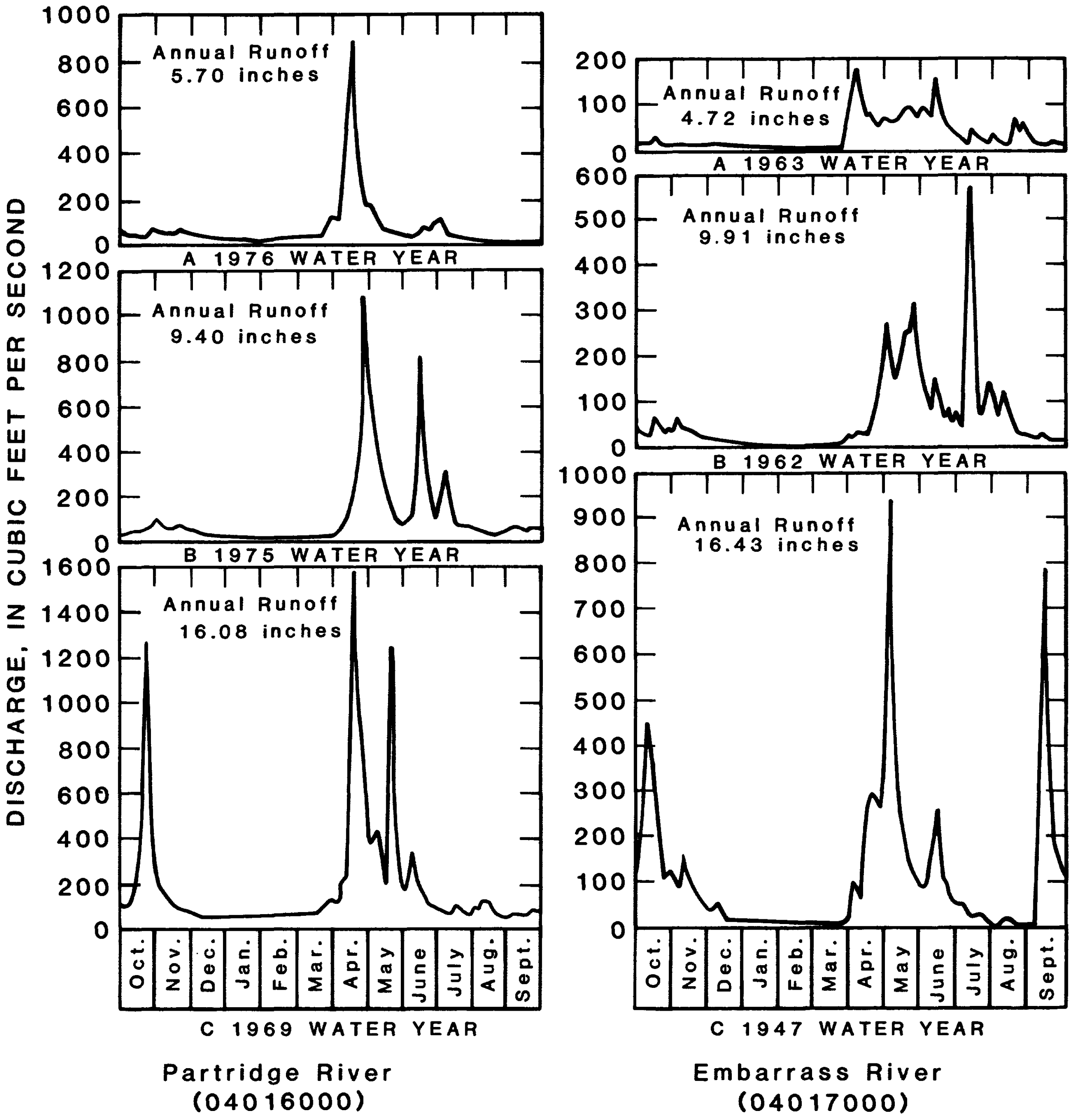

Figure 16.--Annual hydrographs of streams in the St. Louis River basin

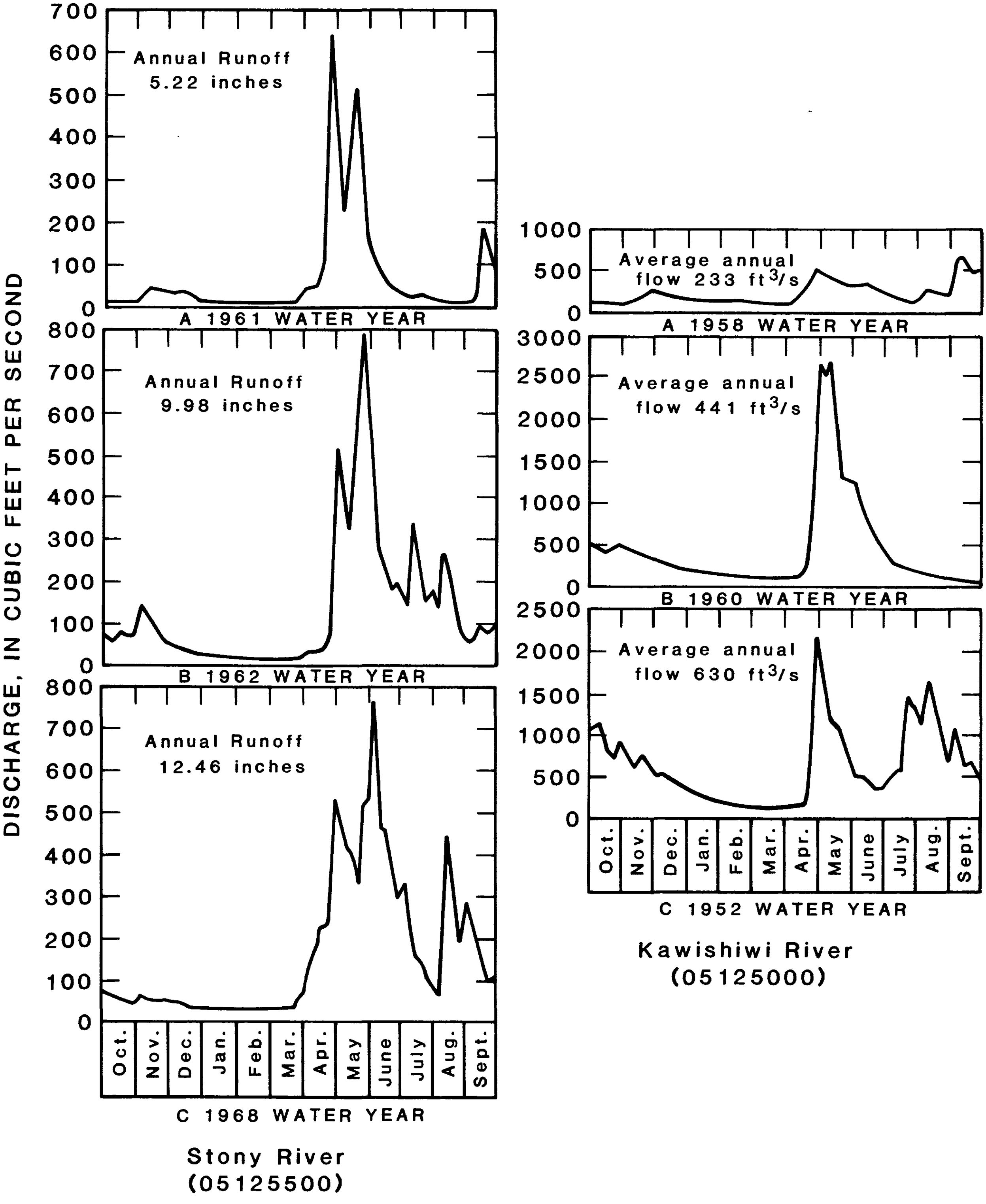

Figure 17.--Annual hydrographs of streams in the Kawishiwi River Basin

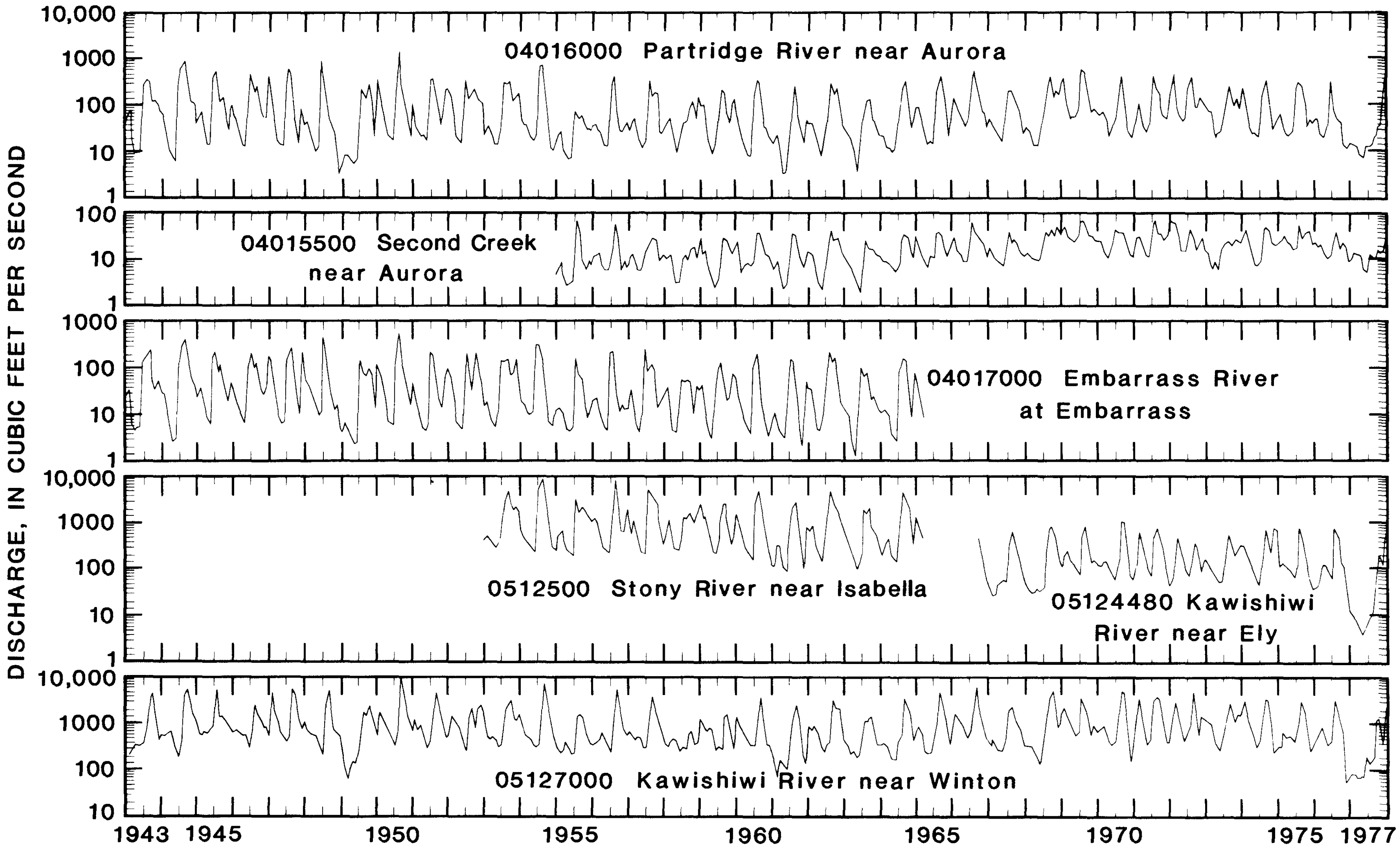

Figure 18.--Long-term hydrographs of selected streams in the Copper-Nickel study region

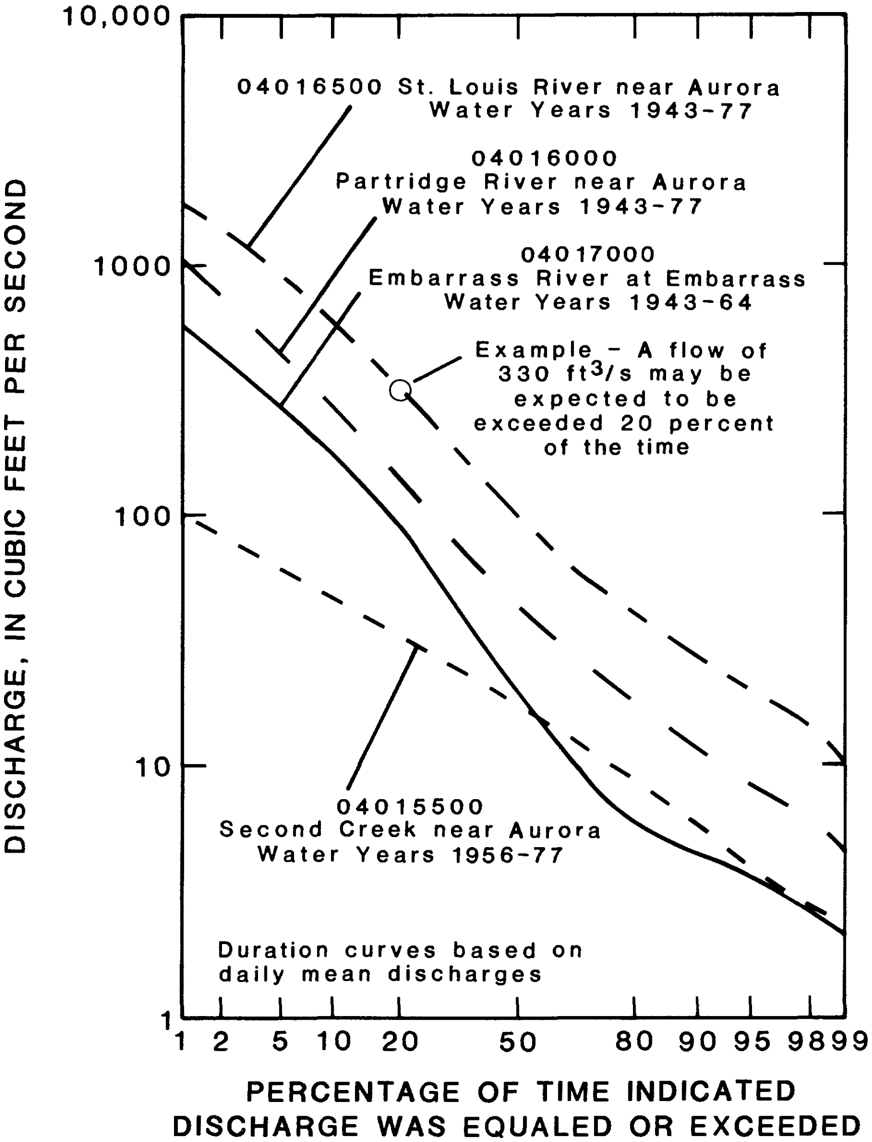

Figure 19.--Duration curves of daily flow in streams in the St. Louis River Basin

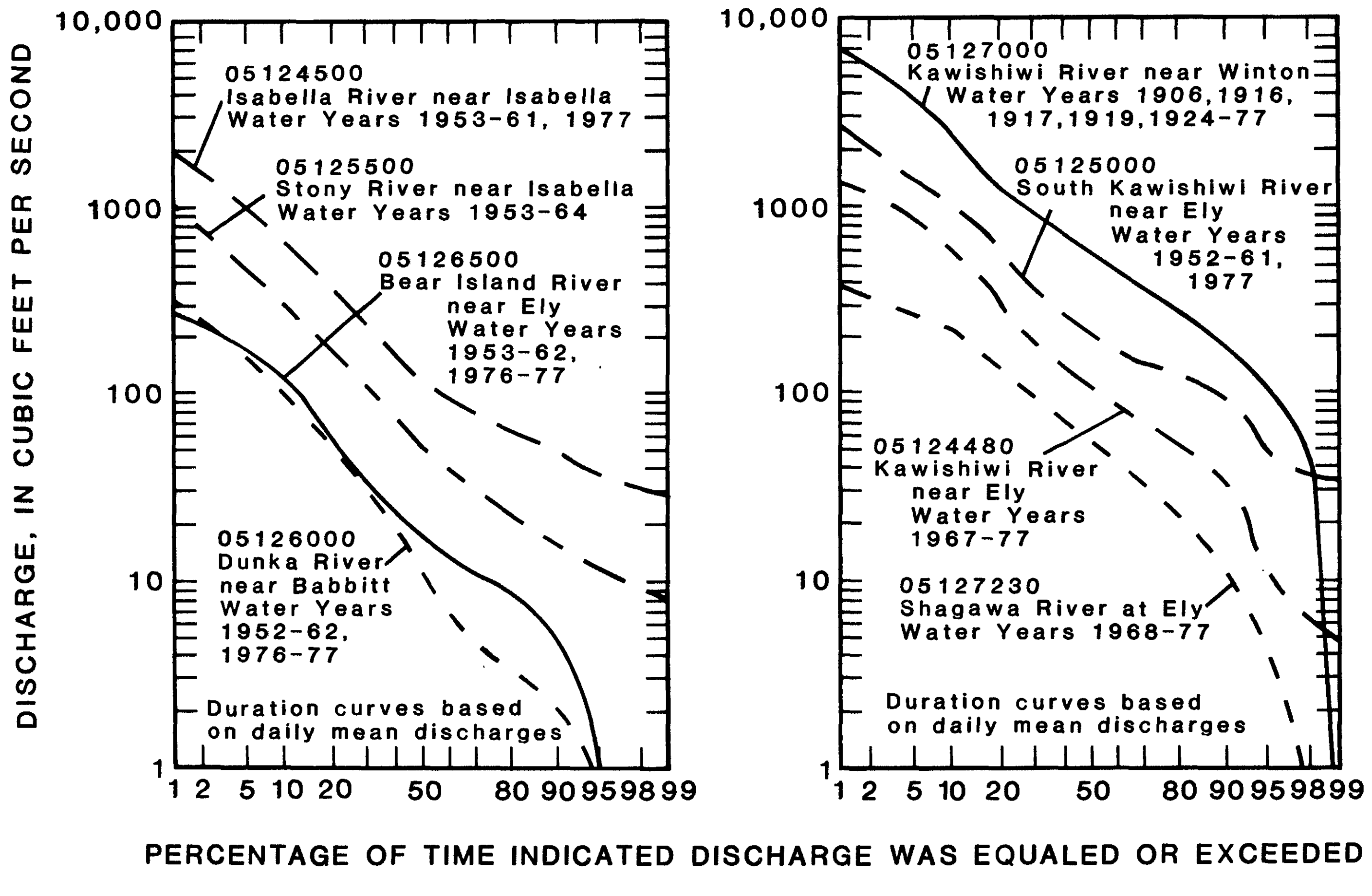

Figure 20.--Duration curves of daily flow of streams in the Kawishiwi River basin

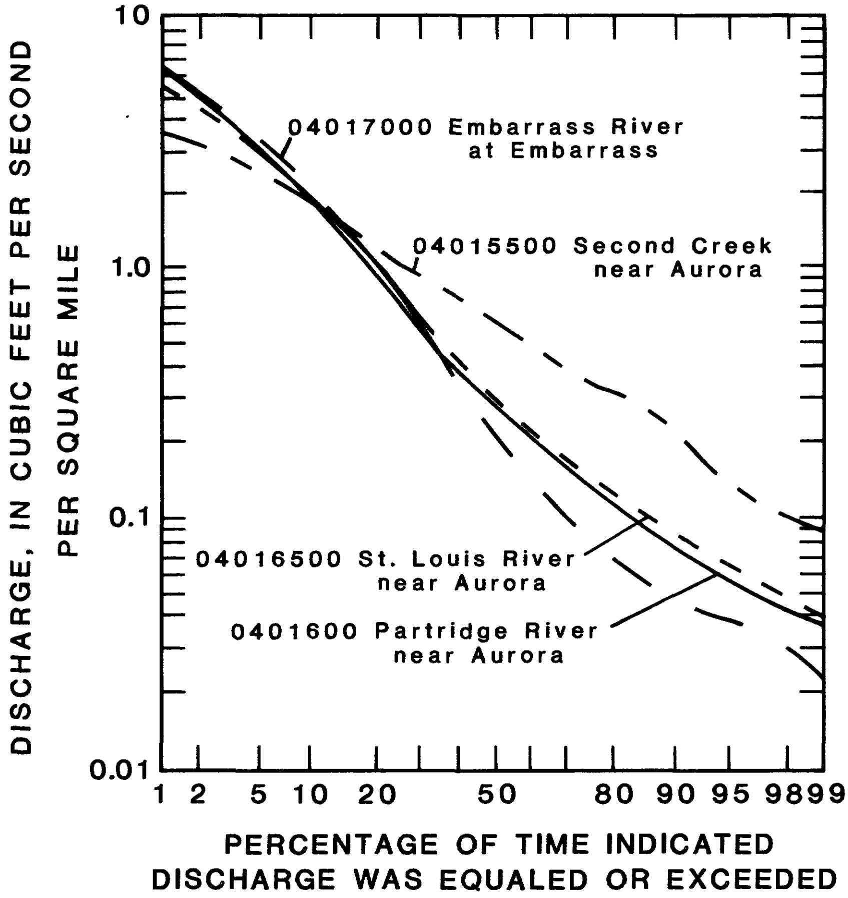

Figure 21.--Duration curves of daily flow per square mile of streams in the St. Louis River basin

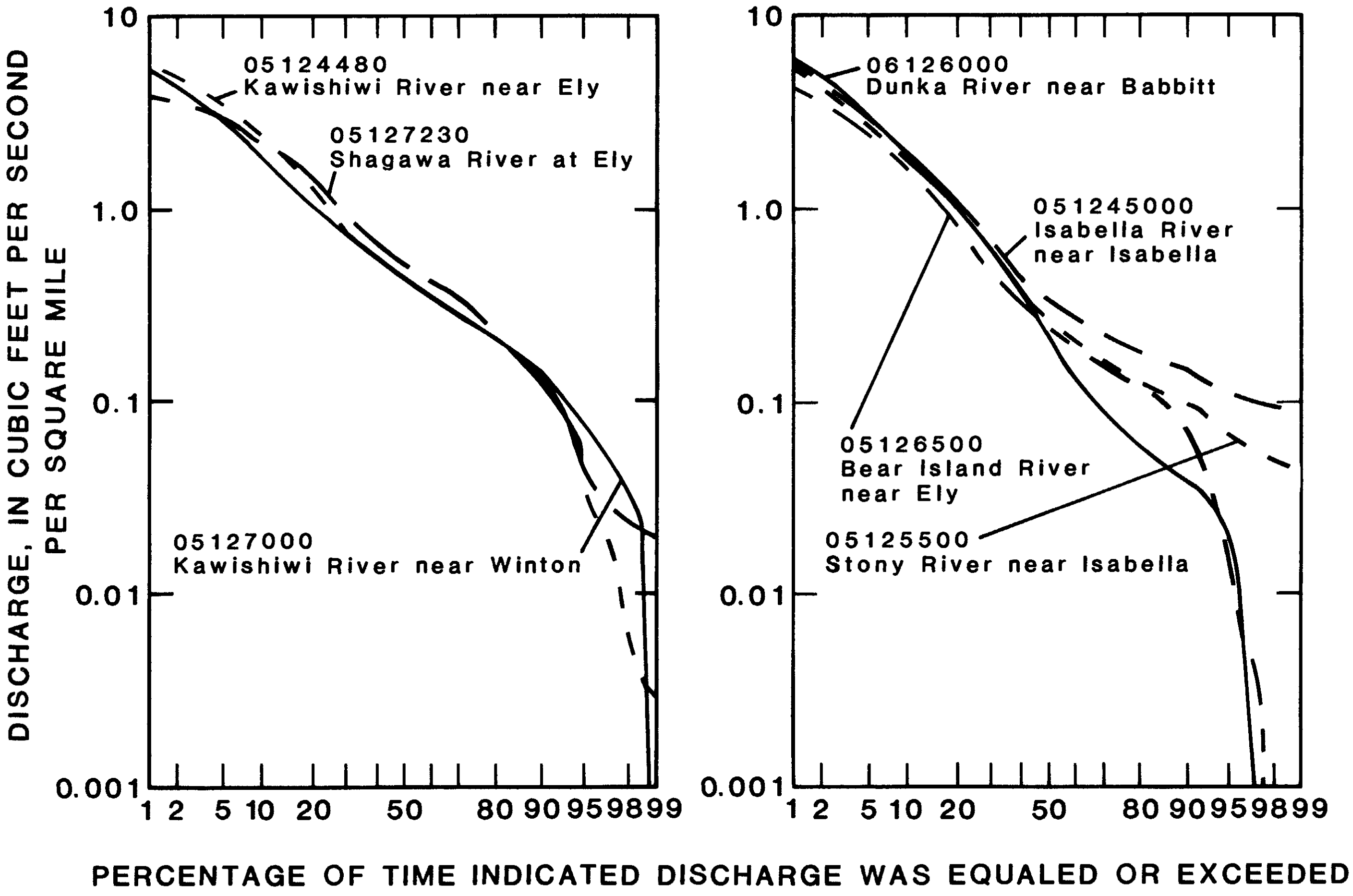

Figure 22.--Duration curves of daily flow per square mile of streams in the Kawishiwi River basin

A useful method to predict the extremes of streamflow is by frequency analysis of daily discharge. High-flow and low-flow frequency curves were prepared for selected time periods for all major streams by use of log-Pearson type III and graphical analysis. Figures 23 and 24 illustrate typical high-flow and low-flow curves. Data obtained from these curves and curves for other streams are given in tables 10 and 11.

Seven-day low flows at 2-year and 10-year recurrence intervals were also estimated for eight periodic measurement sites where there was insufficient or no continuous streamflow records. Least-squares regressions were determined between base-flow discharges measured at these periodic sites and concurrent discharges at nearby gaging stations. Seven-day low-flow values at 2-year and 10-year recurrence intervals at the gaging stations were then used in the regression equations to determine the 7-day low flows at the periodic sites (table 12).

For streams with 10 or more years of record, flood frequency curves (fig. 25) were also developed through the use of log-Pearson type III analysis Data from these curves are in table 13. These curves show the recurrence intervals for the maximum mean daily discharges.

Floods are not a serious problem in most years because the area is sparsely populated, and encroachment on flood plains has been minimal. Some secondary roads are subject to occasional flooding and may be impassable for several days during snowmelt periods in the spring and after intense rainfall. The more severe floods cause considerable damage to culverts, bridges, and road grades. Some permanent residences and summer homes located on low areas adjacent to lakes or streams are flooded at times. Over 60 percent of the annual maximum floods occur in spring when the accumulated snowpack melts.

The flood in May 1950 was the maximum of record at all four gaging stations in operation. The record flood resulted from a combination of wet antecedent conditions, above normal snowfall, cold temperatures in April with sudden change to higher temperatures in May, and precipitation during the flood.

Records of streamflow for only a few years generally are inadequate to estimate flood magnitudes by the log-Pearson method, and other methods must be used. From data given in table 13, a plot of flood discharge versus contributing drainage area was made for each recurrence interval. Well-defined least-squares linear regressions occurred when data for stations downstream from large lakes was deleted. Based on these regression equations, flood discharges were estimated for streams for which only periodic discharge data or short records from gaging stations are available (table 14). Flood-frequency relationships for gage locations downstream from large lakes were used as a basis to estimate flood discharge for St. Louis River below Seven Beaver Lake near Fairbanks.

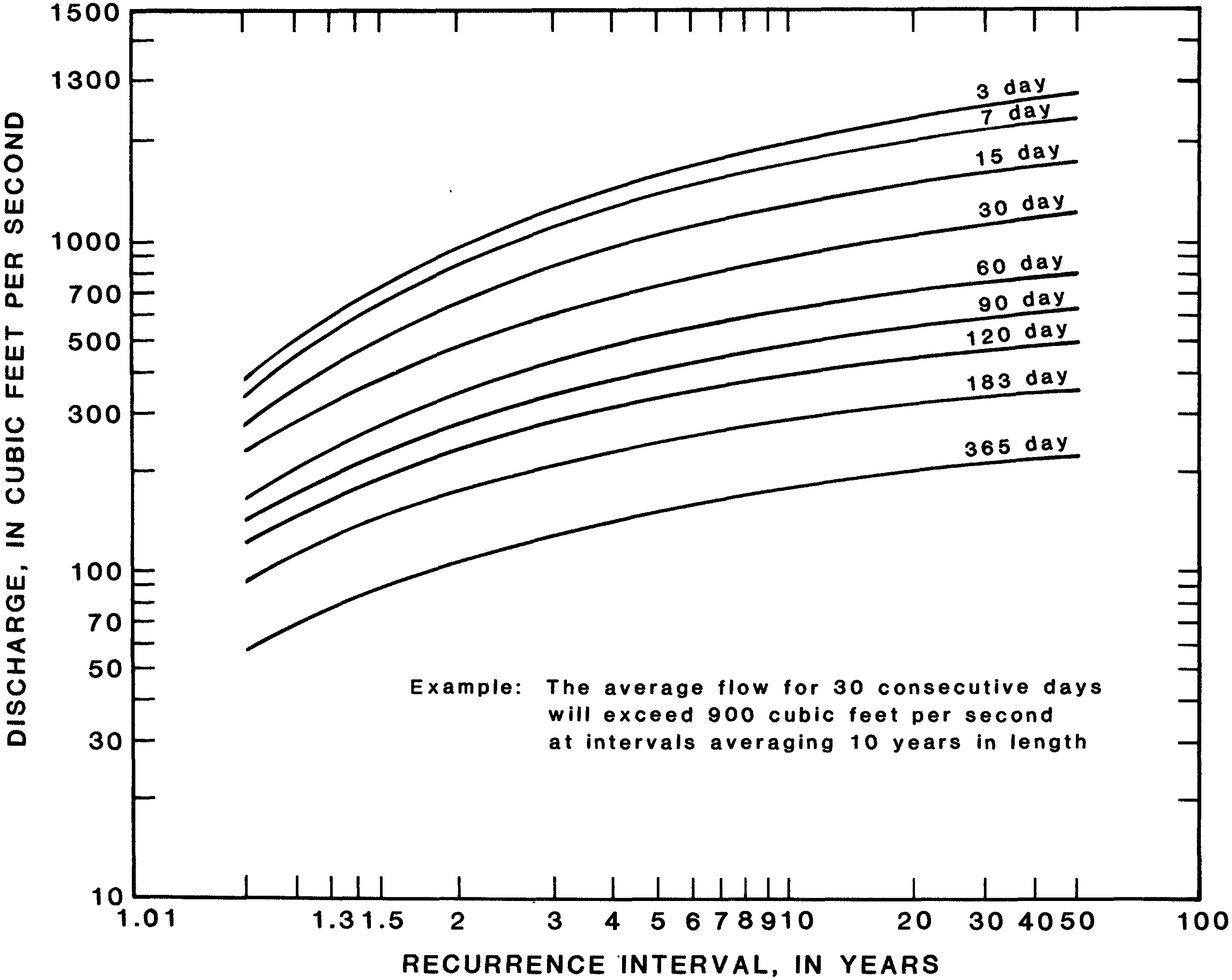

Figure 23.--High-flow frequency curves of the Partridge River near Aurora, 1943-77

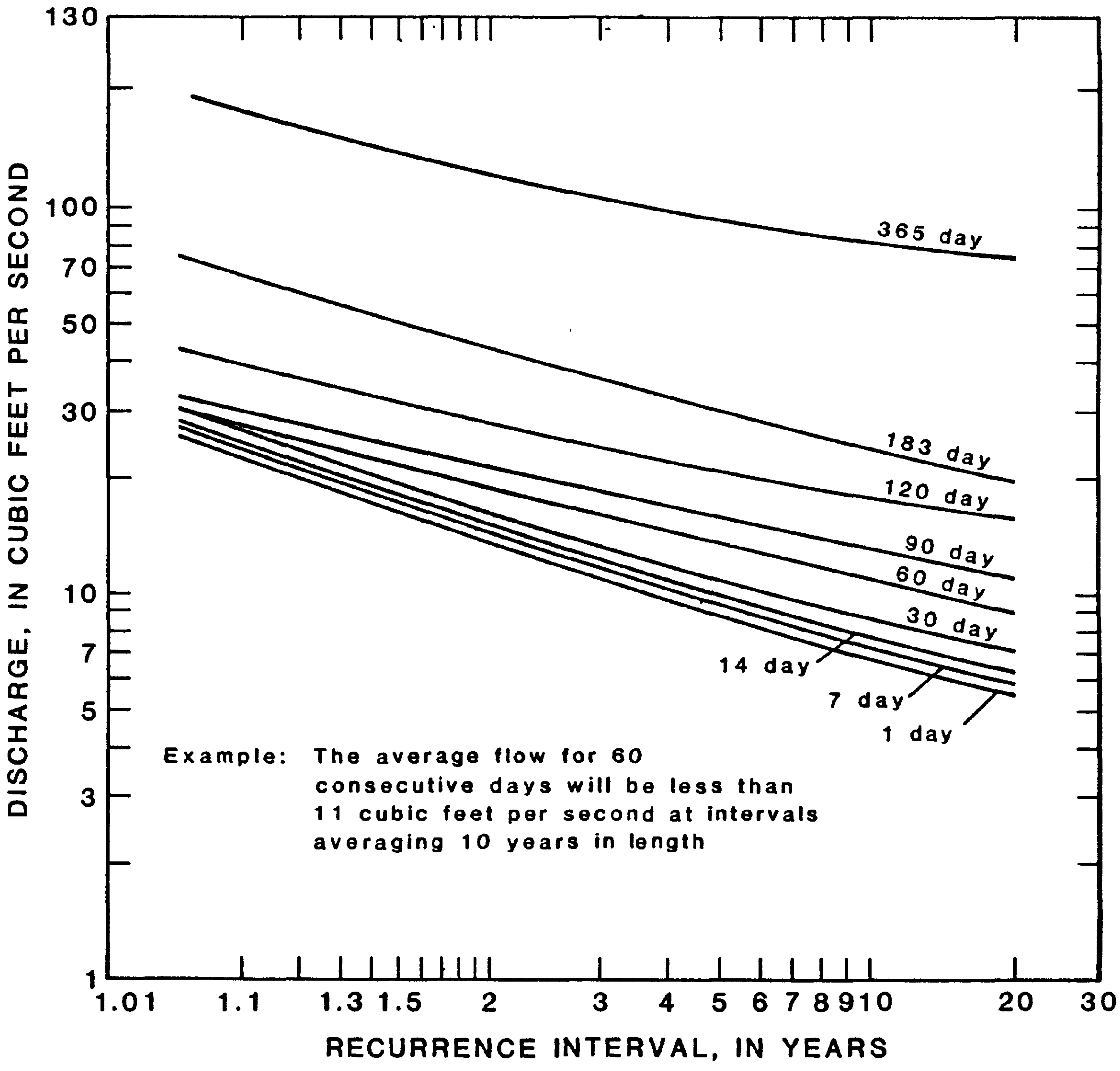

Figure 24.--Low-flow frequency curves of the Stony River, near Isabella, 1959-77

Table 10.—High-flow characteristics of streams in the study region

Figure plotting number	Station I.D. number	Station name	Period of record (climatic years)	Recurrence interval (years)	Frequency of annual high-flow events for given number of consecutive days at various recurrence intervals (discharge in ft³/s) 1	3	7	15	30	60	90	120	183	365
21	04015500	Second Creek near Aurora	1956–77	2	106	96.7	84.3	71.4	58.7	46.4	40.7	35.7	29.8	20.9
				5	146	133	114	92.6	73.2	57.6	49.8	43.7	36.9	27.5
				10	177	161	134	105	81	63.6	54.7	48.4	41.4	32.2
				25	223	203	161	119	89.4	70	59.8	53.7	46.6	38.5
22	04016000	Partridge River near Aurora	1943–77	2	950	930	842	654	482	346	279	230	172	107
				5	1600	1560	1367	1033	741	516	406	330	241	150
				10	2080	1979	1699	1265	902	617	484	389	281	176
				25	2613	2460	2087	1532	1093	732	572	458	326	206
				50	2992	2795	2352	1710	1225	808	632	504	356	226
24	04016500	St. Louis River near Aurora	1943–77	2	1482	1451	1334	1123	902	678	554	461	348	220
				5	2306	2250	2063	1718	1336	966	766	620	458	293
				10	2942	2852	2598	2141	1636	1155	904	724	528	338
				25	3852	3694	3332	2703	2029	1391	1077	856	613	391
				50	4609	4381	3917	3139	2331	1565	1205	954	675	428
30	04017000	Embarrass River at Embarrass	1943–64	2	563	529	452	358	282	205	166	139	104	60.4
				5	963	896	750	579	441	302	236	194	142	82.9
				10	1268	1174	971	734	548	363	280	228	165	97.7
				25	1692	1559	1275	934	680	437	336	270	193	116
				50	2034	1867	1516	1086	777	490	377	300	212	130
33	05124480	Kawishiwi River near Ely	1967–77	2	1190	1170	1157	1084	915	691	539	438	334	229
				5	1497	1483	1437	1319	1113	873	691	557	410	283
				10	1654	1642	1589	1440	1213	969	784	630	448	304
				25	1823	1814	1753	1563	1315	1069	895	718	486	321
40	05124500	Isabella River near Isabella	1953–61 1977	2	1773	1713	1511	1288	1070	809	673	559	425	267
				5	2709	2620	2313	1946	1568	1151	933	748	541	333
				10	3351	3249	2895	2412	1897	1351	1074	849	609	370
				25	4178	4064	3684	3030	2306	1575	1223	953	686	412
58	05125000	South Kawishiwi River near Ely	1952–61 1977	2	2127	2063	1905	1726	1511	1143	939	808	618	401
				5	3497	3407	3186	2844	2334	1699	1364	1136	834	540
				10	4470	4382	4152	3666	2870	2032	1619	1320	964	625
				25	5746	5687	5492	4781	3556	2411	1911	1518	1116	726
68	05125500	Stony River near Isabella	1953–64	2	796	783	731	628	513	382	314	260	200	125
				5	1295	1266	1161	979	757	541	442	357	263	158
				10	1679	1636	1485	1235	933	648	528	421	303	176
				25	2224	2159	1936	1580	1170	785	640	505	352	195
79	05126000	Dunka River near Babbitt	1952–62 1976–77	2	315	297	254	202	158	108	88.1	75.3	57.7	34.8
				5	457	429	367	287	219	148	122	102	73.7	43.7
				10	558	523	446	343	267	178	148	121	85.7	49.6
				25	695	647	549	414	335	219	185	147	103	57.3
85	05126500	Bear Island River near Ely	1953–62 1976–77	2	234	230	221	206	179	129	107	90.8	68	40.2
				5	329	324	311	293	250	180	147	123	90.5	52.5
				10	368	363	349	345	281	205	167	139	102	59.6
				25	450	445	410	400	335	252	186	155	112	67.6
86	05127000	Kawishiwi River near Winton	1906,	2	4950	4840	4763	4445	3779	2843	2327	1943	1481	999
			1916,	5	7410	7300	7186	6661	5507	4065	3254	2659	1986	1330
			1917,	10	8900	8800	8696	7986	6506	4738	3753	3057	2250	1505
			1919,	25	11100	10900	10500	9650	7610	5451	4273	3486	2520	1687
			1924–77	50	12700	12600	12400	11000	8329	5897	4594	3759	2685	1798
				100	14600	14400	14200	12200	8970	6281	4868	4000	2824	1893
87	05127230	Shagawa River at Ely	1968–77	2	333	331	323	310	273	217	185	161	126	87.5
				5	436	432	415	382	342	282	243	205	156	112
				10	508	501	476	422	382	323	270	232	173	124
				25	603	592	553	466	430	372	324	265	190	134

Table 11.--Low-flow characteristics of streams in the study region

Figure plotting number	Station I.D. number	Station name	Period of record (climatic years)	Recurrence interval (years)	Frequency of annual low-flow events for given number of consecutive days at various recurrence intervals (discharge in ft^3/s): 1	3	7	15	30	60	90	120	183	365
21	04015500	Second Creek near	1956–77	2	4.79	4.9	5.3	5.63	6.11	7	7.89	8.79	12.2	20.9
		Aurora		5	2.51	2.66	2.95	3.12	3.4	3.89	4.6	5.42	7.78	16.2
				10	1.77	1.93	2.18	2.29	2.49	2.84	3.46	4.24	6.25	14.5
				20	1.32	1.47	1.68	1.77	1.92	2.17	2.73	3.48	5.26	13.2
22	04016000	Partridge River	1944–77	2	10.4	10.7	11.1	11.8	12.7	14.3	16.4	21.4	35.5	109
		near Aurora		5	5.89	6.11	6.44	6.76	7.27	8.36	10.1	13.6	19.7	74.8
				10	4.22	4.41	4.71	4.93	5.36	6.27	7.9	10.7	14.4	60.0
				20	3.14	3.31	3.58	3.75	4.15	4.93	6.43	8.76	11.2	49.4
				50	2.21	2.35	2.59	2.72	3.08	3.74	5.11	6.96	8.36	39.2
24	04016500	St. Louis River	1944–77	2	24.2	25.2	25.5	27.4	29.2	33.8	40.3	50.6	80.3	223
		near Aurora		5	13.4	14.0	14.2	15.2	16.5	19.4	23.8	31.1	43.2	169
				10	9.38	9.7	9.92	10.6	11.6	13.6	16.9	22.9	30.5	149
				20	6.79	6.96	7.16	7.57	8.4	9.8	12.3	17.2	22.5	128
				50	4.58	4.64	4.81	5.03	5.64	6.52	8.28	12.1	15.8	111
30	04017000	Embarrass River	1944–64	2	3.02	2.15	3.3	3.68	3.95	4.65	5.55	8.1	15.2	59
		at Embarrass		5	1.78	1.84	1.9	2.13	2.32	2.82	3.38	4.75	7.35	43.1
				10	1.3	1.35	1.4	1.58	1.73	2.19	2.61	3.6	5.58	35.1
				20	1.02	1.05	1.09	1.24	1.38	1.77	2.22	2.89	4.4	31
				40	0.83	0.87	0.9	1.02	1.13	1.48	1.78	2.4	3.75	27.9
33	05124480	Kawishiwi River	1968–77	2	43.8	44.7	46.5	49.3	52.1	58.9	69.3	85.8	116	225
		near Ely		5	22.4	22.9	23.7	24.5	25.9	27.8	31.6	36.5	44.9	173
				10	12.9	13.1	13.5	13.8	14.4	15.2	16.9	18.8	22.6	150
				20	7.28	7.38	7.58	7.63	7.84	8.19	8.88	9.59	11.5	134
40	05124500	Isabella River	1954–61	2	49.8	50.6	52.2	53.9	57.4	62.8	69.5	84.4	108	277
		near Isabella	1977	5	37.5	38.1	38.2	39.2	41.7	46.5	50.9	60.1	67.6	231
				10	31	31.4	31.6	32	33.8	38.1	41.2	46.5	48.9	208
58	05125000	South Kawishiwi	1953–61	2	93.2	94.3	96.7	100	105	121	137	154	173	419
		River near Ely	1977	5	55.3	56	57.7	60.1	63.2	73.8	85.5	96.6	99.9	336
				10	38.6	39.1	40.5	42.6	44.5	51.9	60.7	68	69	298
68	05125500	Stony River near	1954–64	2	11.8	12.2	12.8	13.4	14	17.2	21.8	27.8	43.5	119
		near Isabella		5	7.5	7.75	8	8.3	8.6	10.9	13.1	17.8	28.9	86
				10	5.9	6.1	6.24	6.5	6.7	8.5	10.2	13.2	23.1	72.9
				20	4.7	5	5.35	5.3	5.5	7.1	8.2	10.2	19	66.2
79	05126000	Dunka River near	1953–62	2	1.82	1.96	2.1	2.35	2.55	2.96	3.7	4.95	10	32.5
		near Babbitt	1976–77	5	1.16	1.2	1.28	1.55	1.68	1.97	2.48	3.15	4.85	27.2
				10	0.82	0.84	0.90	1.13	1.25	1.47	1.78	1.95	2.45	25.2
85	05126500	Bear Island	1954–62	2	2.53	2.79	3.3	3.9	5	7.98	10.1	12.5	15.7	40
		River near Ely	1976–77	5	0.82	0.9	1.26	1.71	2.05	3.8	6.1	6.75	7.55	28.5
				10	0.39	0.46	0.65	0.96	1.1	1.81	2.97	3.25	3.5	23.8
86	05127000	Kawishiwi River	1907,	2	32	142	186	202	240	275	331	389	473	985
		near Winton	1914,	5	0	68	106	120	143	169	213	244	279	749
			1917,	10	—	10	25	40	82	123	161	182	206	648
			1925–77	20	—	0	0	12	42.5	91.8	125	138	157	575
				50	—	—	—	2.8	19.3	63.6	91.4	98.3	114	503
87	05127230	Shagawa River at	1969–77	2	21	21.2	22.2	24.1	27.6	32	35.1	39.7	47.5	90.2
		Ely		5	5.17	5.27	5.45	5.81	6.68	7.72	9.24	11.3	13.7	61.4
				10	1.62	1.66	1.7	1.79	2.02	2.34	3.06	4.09	5.52	48.4
				20	0.48	0.50	0.51	0.53	0.58	0.67	0.97	1.45	2.25	38.9

Table 12.--Estimated low-flow characteristics at periodic measurement sites

Station name	Estimated 7-day Q_2 (ft^3/s)	Estimated 7-day Q_{10} (ft^3/s)
St. Louis River below Seven Beaver Lake near Fairbanks	1.2	0.3
St. Louis River near Skibo	2.0	0.5
South Branch Partridge River near Babbitt	0.3	0
Colvin Creek near Hoyt Lakes	0.8	0.5
Embarrass River near Embarrass	0.1	0
Stony River near Murphy	3.0	1.5
Greenwood River near Isabella	0.5	0.1

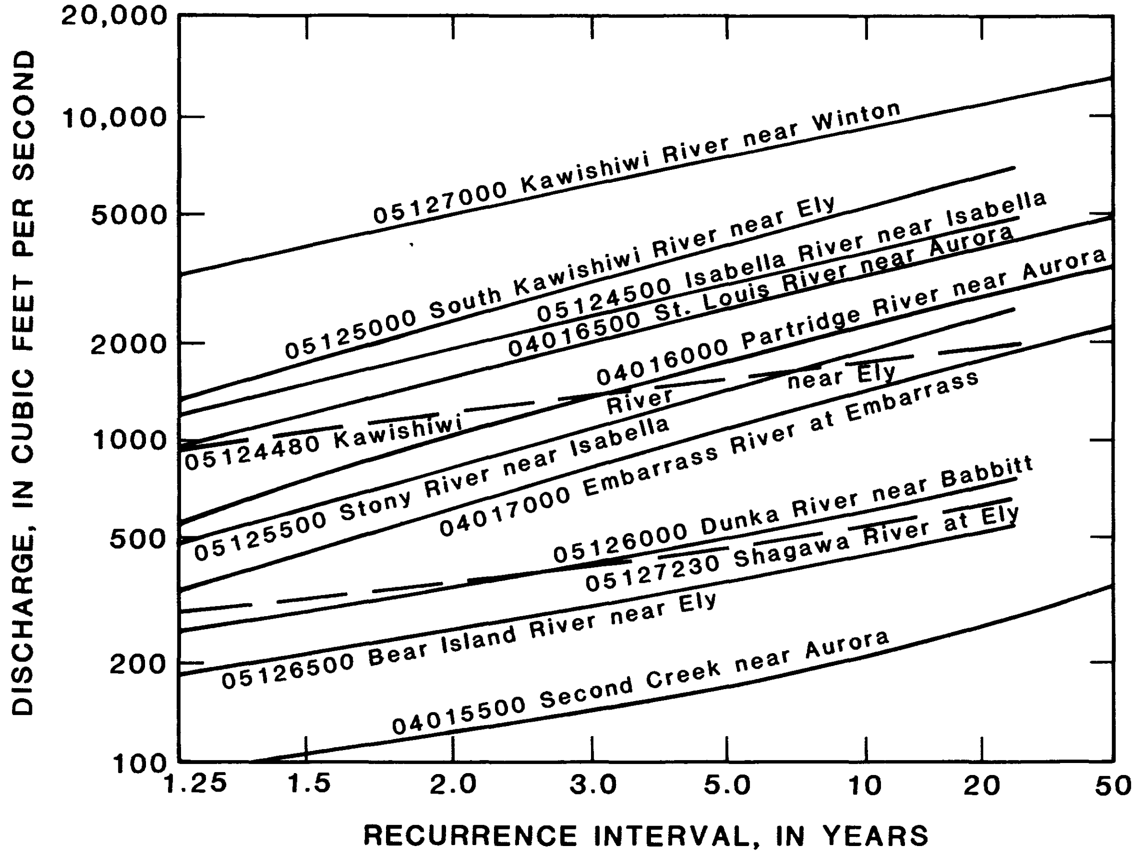

Figure 25.--Flood-frequency curves at gaging stations having 10 or more years of record

Table 13.--Flood-frequency characteristics at gaging stations having 10 or more years of record

Figure plotting number	Station I.D. number	Station name	Drainage area (mi^2)	Years of record	Discharge in cubic feet per second for indicated recurrence interval, in years				
					Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}
21	04015500	Second Creek near Aurora	29 nc6.59	23	123	168	214	278	344
22	04016000	Partridge River near Aurora	161 nc13.3	35	1020	1690	2220	2960	3550
24	04016500	St. Louis River near Aurora	290 nc13.3	35	1580	2460	3140	4100	4860
30	04017000	Embarrass River at Embarrass	88.3	22	610	1050	1390	1800	2200
33	05124480	Kawishiwi River near Ely	253	11	1220	1540	1740	1980	---
40	05124500	Isabella River near Isabella	341	11	1930	3010	3780	4820	---
58	05125000	South Kawishiwi River near Ely	---	11	2330	4000	5130	6640	---
68	05125500	Stony River near Isabella	180	12	830	1430	1900	2530	---
79	05126000	Dunka River near Babbitt	53.4 nc4.0	12	344	493	598	740	---
85	05126500	Bear Island River near Ely	68.5	12	250	357	432	536	---
86	05127000	Kawishiwi River near Winton	1229	63	5000	7500	9200	11200	13000
87	05127230	Shagawa River at Ely	99	10	360	470	542	635	---

nc - Noncontributing drainage area with respect to surface runoff.

Table 14.--Estimated flood-frequency characteristics at periodic-measurement sites and gaging stations having less than 10 years of record

Figure plotting number	Station I.D. number	Station name	Drainage area (mi^2)	Discharge in cubic feet per second for indicated recurrence interval, in years			
				Q_2	Q_5	Q_{10}	Q_{25}
1	04015430	St. Louis River below Seven Beaver Lake near Fairbanks........................	60.6	192	312	408	510
2	04015438	St. Louis River near Skibo................	94	444	621	813	1140
8	04015455	South Branch Partridge River near Babbitt................................	18.5	172	282	405	---
13	04015461	Colvin Creek near Hoyt Lakes..............	18.3	170	280	400	---
25	04016900	Embarrass River near Babbitt..............	17.6	165	270	390	---
57	05124990	Filson Creek near Ely.....................	9.66	102	168	250	---
63	05125400	Stony River near Murphy City..............	62	460	740	990	1330
66	05125450	Greenwood River near Isabella.............	48.2	372	605	820	---
70	05125550	Stony River near Babbitt..................	219	970	1630	2140	2850

Flood-frequency characteristics at a gaged site can be transferred upstream or downstream by the relationship derived from ratio of drainage areas as follows:

$$Q_u = Q_g\ (A_u/A_g)^{0.6}$$

where: Q_u is flood-frequency estimate for ungaged site,
Q_g is flood-frequency value of gaged site,
A_u is drainage area for ungaged site,
A_g is drainage area for gaged site.

Use of the formula is limited to sites that differ in drainage area size by no more than 40 percent from that of the gaged site. Care should be used in transferring flood-frequency characteristics. For example, peak-flow data should not be transferred upstream or downstream across large lakes or reservoirs.

Mean and annual discharges at gaging stations are listed in table 15. The mean discharge for each calendar month defines the average flow pattern at a station. The quartiles of mean monthly discharges indicate the extent of variation from these monthly values. An example of nearly constant winter mean discharges is at Embarrass River at Embarrass (fig. 26) which is sustained by discharge from ground water during the winter. The mean discharge for January is 6.74 ft^3/s, and the 25th and 75th percentiles are 4.88 and 8.08 ft^3/s, respectively. At the other extreme, the mean May discharge at Kawishiwi River near Winton is 3,185 ft^3/s, the 25th percentile is 1,714 ft^3/s, and the 75th percentile is 4,332 ft^3/s, a range of 2,618 ft^3/s.

Nearly 57 percent of the annual runoff occurs in April, May, and June, whereas flows during the winter months account for less than 11 percent of the annual runoff.

Monthly and annual average discharges were estimated for the periodic measurement sites by hydrographic comparison with nearby gaging stations and are listed in table 16. The user is cautioned that there could be considerable error in the estimated values for some months.

Average annual discharge can be estimated from the size of the drainage basin. Least-squares fit of average annual discharge and drainage area resulted in the following relationship:

$$\overline{Q}_A = 0.79a$$

where: $\overline{Q}_A$ = average annual discharge, in ft^3/s,
a = drainage area, in mi^2,
correlation coefficient = 0.99.

Use of the formula is limited to drainage areas exceeding 50 mi^2.

Table 15.--Statistics of monthly and annual discharges for gaging stations with 9 or more years of streamflow records available

[Discharge and percentile measurements in ft^3/s]

		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
04015500	Average discharge	23.8	19.8	12.3	9.15	8.87	16.2	47.1	34.9	29.8	22.6	19.2	22.9	22.4
Second	Percent annual flow	8.94	7.42	4.61	3.43	3.33	6.08	17.7	13.1	11.2	8.48	7.19	8.59	---
Creek	25th percentile	11.1	11.4	6.97	4.19	3.52	9.81	29.6	22.6	20.0	14.8	10.8	12.3	16.1
near	50th percentile	16.7	15.7	9.43	8.15	7.84	13.9	47.8	39.2	28.5	21.1	17.0	23.6	19
Aurora	75th percentile	28.6	27.2	15.0	10.2	12.7	21.2	54.8	46.8	38.3	27.5	22.4	31.9	27.4
04016000	Average discharge	97.1	71.0	34.3	20.5	17.4	40.5	271	333	210	101	64.4	80.7	112
Partridge	Percent annual flow	7.24	5.29	2.56	1.53	1.30	3.02	20.2	24.8	15.7	7.55	4.80	6.02	---
River	25th percentile	35.9	38.4	22.5	12.1	8.40	14.7	85.7	173	134	46.0	27.6	25.5	73.7
near	50th percentile	50.6	50.3	29.3	16.7	14.1	19.1	234	287	179	76.9	39.9	56.1	102
Aurora	75th percentile	95.0	79.3	42.6	24.0	24.7	38.1	386	434	272	135	92.2	111	135
04016500	Average discharge	193	157	78.5	47.7	35.6	75.2	526	696	425	214	138	161	230
St. Louis	Percent annual flow	7.03	5.72	2.86	1.74	1.30	2.74	19.1	25.3	15.5	7.79	5.04	5.87	---
River	25th percentile	67.9	76.0	51.7	35.3	24.0	30.9	321	372	279	130	62.0	50.0	168
near	50th percentile	118	126	70.7	44.9	32.0	46.1	408	647	367	164	88.8	103	218
Aurora	75th percentile	208	185	98.9	53.9	43.8	69.3	685	895	548	293	173	247	270
04017000	Average discharge	45.8	32.8	14.0	6.74	5.00	22.0	190	194	114	63.2	31.3	49.9	64.4
Embarrass	Percent annual flow	5.96	4.27	1.82	0.88	0.65	2.86	24.8	25.2	14.8	8.21	4.07	6.49	---
River at	25th percentile	15.5	17.2	9.55	4.88	3.10	4.91	101	84.3	61.5	19.3	9.27	15.0	39.5
Embarrass	50th percentile	29.7	26.0	12.5	6.31	5.05	7.53	170	165	95.3	42.5	18.1	41.1	55.8
	75th percentile	55.1	46.2	19.3	8.08	6.36	13.7	238	233	137	80.1	36.5	57.1	75.1
05124480	Average discharge	112	204	143	95.5	71.6	58.5	315	729	450	212	119	140	223
Kawishiwi	Percent annual flow	4.23	7.70	5.41	3.60	2.70	2.21	11.9	27.5	17.0	8.00	4.50	5.27	---
River	25th percentile	38.6	31.8	39.1	57.0	58.5	52.8	141	579	234	134	72.4	41.5	167
near Ely	50th percentile	102	145	133	107	78.1	61.6	266	777	344	182	98.0	65.6	218
	75th percentile	132	270	168	133	93.2	74.6	515	906	666	280	160	172	259
05124500	Average discharge	144	167	120	80.3	66.9	73.4	631	818	502	225	143	301	272
Isabella	Percent annual flow	4.42	5.10	3.66	2.45	2.06	2.24	19.3	25.0	15.3	6.89	4.38	9.19	---
River	25th percentile	78.5	106	100	67.6	51.3	60.7	334	415	362	97.2	68.4	74.3	187
near	50th percentile	130	175	124	81.6	69.6	67.2	581	706	478	202	121	223	246
Isabella	75th percentile	186	229	147	102	84.4	87.3	869	1197	674	348	202	456	331
05125000	Average discharge	280	257	218	164	129	114	712	1308	729	430	285	407	419
South	Percent annual flow	5.57	5.12	4.33	3.25	2.57	2.27	14.1	26.0	14.5	8.54	5.66	8.09	---
Kawishiwi	25th percentile	140	162	165	136	112	101	327	701	437	239	138	100	236
River	50th percentile	189	212	210	170	147	118	615	1135	718	358	197	335	362
near Ely	75th percentile	357	337	255	193	155	131	925	1803	870	567	294	712	596
05125500	Average discharge	74.7	74.8	47.2	27.0	21.0	20.7	237	449	259	116	82.3	111	127
Stony	Percent annual flow	4.91	4.92	3.11	1.78	1.38	1.36	15.6	29.5	17.0	7.65	5.41	7.32	---
River	25th percentile	54.1	39.9	37.0	22.2	17.5	15.0	147	219	156	58.0	30.7	34.7	85.6
near	50th percentile	64.4	69.4	42.0	27.6	22.0	20.5	205	449	258	77.6	62.3	89.8	112
Isabella	75th percentile	121	105	58.7	32.7	27.2	24.4	296	541	354	197	138	170	153
05126000	Average discharge	20.8	23.8	9.60	3.99	2.72	7.04	116	95.7	64.4	34.2	19.8	44.3	36.6
Dunka	Percent annual flow	4.71	5.38	2.17	0.90	0.62	1.59	26.2	21.7	14.6	7.73	4.47	10.0	---
River	25th percentile	10.1	13.3	6.15	2.82	1.88	3.25	53.9	49.5	41.0	14.7	5.31	11.7	26.8
near	50th percentile	16.3	17.7	7.99	4.31	2.90	5.24	115	89.1	58.4	27.0	13.76	30.4	33.5
Babbitt	75th percentile	35.5	34.0	12.2	5.30	3.65	8.95	149	130	87.9	47.9	27.6	81.2	40.1
05126500	Average discharge	17.7	19.7	19.0	13.4	10.3	12.0	92.3	133	78.6	49.6	18.8	36.6	41.2
Bear	Percent annual flow	3.52	3.92	3.79	2.67	2.06	2.39	18.4	26.6	15.7	9.90	3.75	7.31	---
Island	25th percentile	6.83	13.2	13.1	9.31	7.60	8.51	38.2	73.3	51.1	24.7	6.86	4.46	27.2
River	50th percentile	9.90	20.2	19.2	13.1	10.3	11.4	87.9	127	65.0	30.1	11.1	14.3	37.9
near Ely	75th percentile	36.0	25.3	23.5	16.4	12.6	14.5	134	186	103	77.4	25.6	40.7	46.7
05127000	Average discharge	527	712	560	436	330	342	1175	3185	2020	1121	663	713	1019
Kawishiwi	Percent annual flow	6.85	5.89	4.63	3.61	2.73	2.83	9.72	26.4	16.7	9.28	5.49	5.90	---
River	25th percentile	327	321	317	256	232	230	439	1714	1148	670	388	348	599
near	50th percentile	533	581	540	445	303	331	844	2949	1611	971	537	552	883
Winton	75th percentile	1036	884	766	582	396	420	1541	4332	2547	1363	789	907	1118
05127230	Average discharge	64.5	73.2	61.3	39.4	34.7	32.6	112	212	173	109	61.4	60.0	86.6
Shagawa	Percent annual flow	6.31	7.16	5.02	3.85	3.40	3.19	11.0	20.7	16.9	10.6	6.00	5.86	---
River at	25th percentile	14.8	15.2	13.3	16.1	14.1	21.8	74.3	151	96.2	79.4	33.4	20.3	45.5
Ely	50th percentile	33.8	51.0	41.7	37.6	33.5	31.0	98.9	236	146	94.1	56.0	33.0	83.4
	75th percentile	139	126	84.1	68.5	53.2	47.7	172	270	268	105	78.8	72.5	107
Annual percentage of annual flow for all 12 stations		5.81	5.66	3.66	2.47	2.01	2.73	17.3	24.2	15.4	8.38	5.06	7.16	---

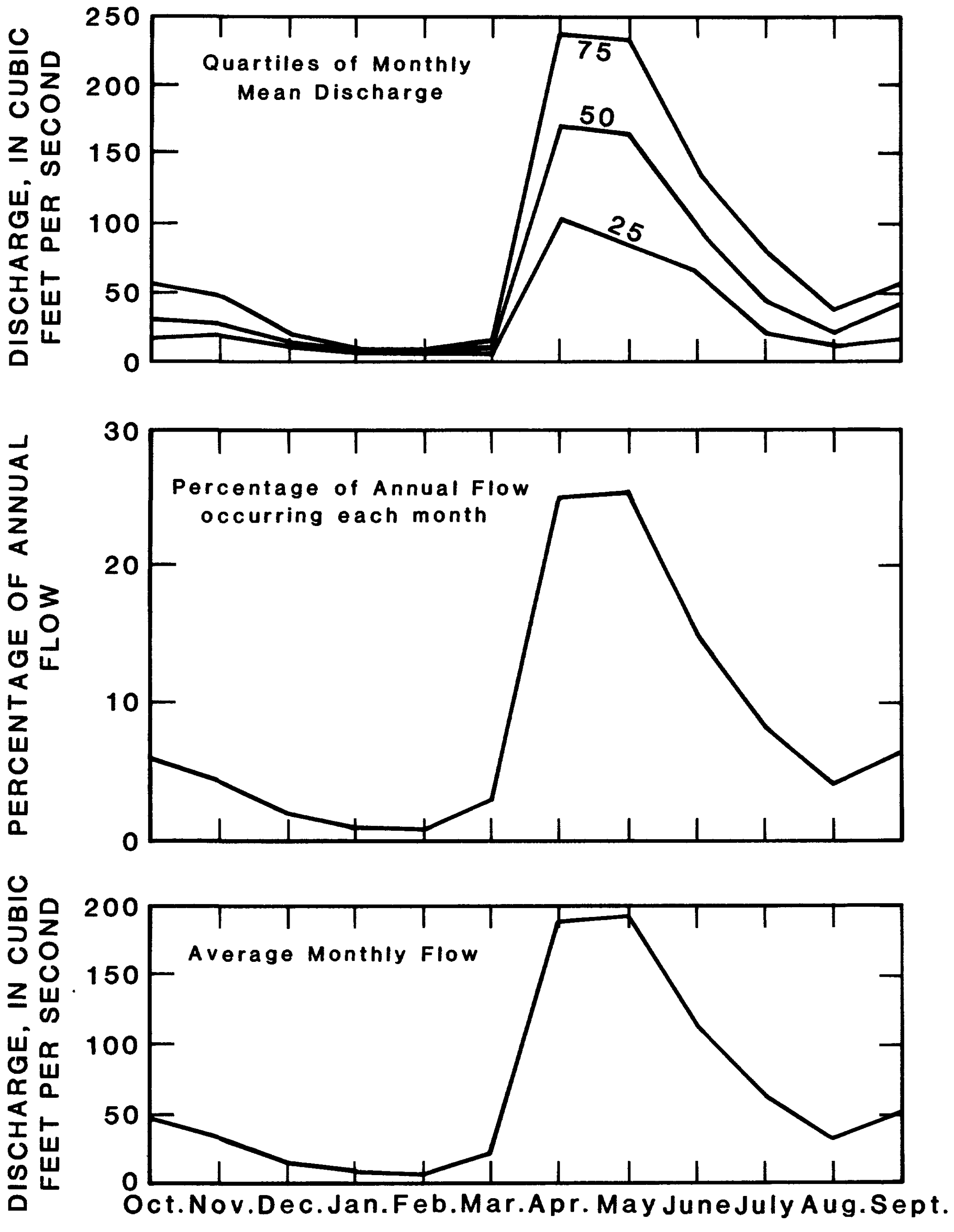

Figure 26.--Statistics on monthly average discharge of the Embarrass River

Table 16.--Estimated monthly and annual average discharges at periodic measurement sites for 1976-77 water years

Figure plotting number	Station I.D. number	Station name	Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
				Estimated average discharges, in cubic feet per second												
1	04015430	St. Louis River below Seven Beaver Lake near Fairbanks	1976	---	---	---	---	---	---	---	---	---	33	1.3	0.4	---
			1977	0.5	0.2	0.3	1.0	0.4	1.4	1.5	3.7	34	53	13	190	25
2	04015438	St. Louis River near Skibo	1976	---	---	---	---	---	---	---	---	---	49	2.5	0.5	---
			1977	0.6	0.4	0.4	1.2	0.2	4.6	12	21	79	82	25	265	41
8	04015455	South Branch Partridge River near Babbitt[a]	1976	1.7	3.2	2.3	1.0	0.9	1.7	84	7.0	3.7	3.2	0.1	0	9.0
			1977	0	0	0	0	0	0.2	3.2	5.3	15	7.98	5.59	44.9	6.8
13	04015461	Colvin Creek near Hoyt Lakes	1976	2.2	5.3	3.8	1.9	1.7	2.8	70	4.9	6.7	5.5	0.7	0.3	8.7
			1977	0.6	0.9	0.8	0.5	0.4	1.2	5.0	7.0	13	10	12	68	9.9
25	04016900	Embarrass River near Babbitt	1976	3.8	5.7	2.5	1.1	1.2	5.3	75	5.3	7.4	1.9	0.2	0.02	9.0
			1977	0.05	0.11	0.05	0	0	1.4	2.8	3.9	10	4.9	3.7	27	4.4
30	04017000	Embarrass River at Embarrass[b]	1976	42	62	27	12	10	19	332	47	72	21	3.3	1.7	55
			1977	5.3	4.5	1.5	1.5	1.7	15	27	38	94	56	67	212	44
63	05125400	Stony River near Murphy City	1976	27	47	22	8.7	8.9	17	410	50	40	20	1.9	0.9	54
			1977	3.2	3.2	2.3	1.2	0.9	10	36	30	100	62	13	350	60
66	05125450	Greenwood River near Isabella	1976	20	32	18	8.7	5.4	5.0	265	51	44	30	0.7	0.1	40
			1977	0	0	0	0	0	0.4	5.3	5.7	42	49	8.6	118	19
68	05125500	Stony River near Isabella[b]	1976	100	162	84	41	30	38	893	218	166	105	13	4.6	154
			1977	5.4	8.1	8.3	7.7	7.0	19	50	45	185	157	28	402	76

[a]Converted to continuous record gaging station June 1977.
[b]At discontinued gaging station, continuous stage record available.

Base flow of a stream is a measure of the amount of ground-water and surface-water discharge from storage that sustains streamflow during periods of little precipitation. Base flows measured from August 23-27, 1976, at gaging stations on unregulated streams fall between 88 and 99 percent duration values on flow-duration curves for those stations. Data for 88 other baseflow measurement sites are listed in table 17. Most of the sites are shown in figure 14.

Some of the measurements do not represent natural base flow because of diversion, augmentation, or other factors. All measurements in Second Creek and Partridge River (sites 17-24) were affected by mining activities. In the Kawishiwi River basin, dams controlled the flow at sites 82 and 86.

Streamflow increased downstream in most streams. The few channel reaches that had decreases in flow were scattered and losses were generally small. The discharge measurements were made during a period when evapotranspiration losses were high, which probably accounts for some of the flow losses. Some of the 4.15 ft^3/s increase in flow of the St. Louis River between sites 4 and 6 is attributed to seepage from Partridge Reservoir.

Streamflow decreased 0.7 ft^3/s in the 2.8 mile reach of Dunka River between sites 78 and 79. Subsequent baseflow measurements at these two sites indicated flow losses as much as 1.38 ft^3/s. A sand and gravel aquifer that underlies the Dunka River is exposed in an open-pit mine only a few hundred feet from the river. Mine drainage has lowered heads in the aquifer below the level of the Dunka River, inducing flow from the river.

Water Quality

Suspended sediment was measured periodically from Dunka, Bear Island, Stony, and Kawishiwi Rivers to estimate the average annual sediment loss from typical watersheds (table 18). These estimates were determined through flow-duration data and correlations between suspended-sediment discharge and stream discharge.

The average suspended-sediment yield of about 5 $(tons/mi^2)/yr$ of the Dunka, Bear Island, and Kawishiwi River stations and about 4 $(tons/mi^2)/yr$ of the Stony River is low compared with yields of nearby basins. For example, the estimated annual suspended-sediment yields of the Pigeon River near Grand Portage and the St. Louis River near Forbes are 12 and 9.2 $(tons/mi^2)/yr$, respectively. Yields in the study region probably are low because of sediment deposition in wetlands and on-channel lakes.

Water temperature and specific conductance were monitored continuously from 1 to 3 years at Partridge River above Colby Lake at Hoyt Lakes, Stony River near Babbitt, and Dunka River near Babbitt. At Kawishiwi River near Ely, a continuous record of water temperature has been collected since July 1966. In addition to the continuous records, water temperature and specific conductance, were periodically measured when discharge was measured.

Table 17.—Baseflow, specific conductance, and water temperature measurements in streams in the Copper-Nickel study region, August 23-27, 1976

Figure plotting number	Station I.D. number	Stream	Location	Drainage area (mi^2)	River mile location	Discharge (ft^3/s)	Water temperature (°C)	Specific conductance (umho/cm at 25°C)	Base flow yield [(ft^3/s)/mi^2]
1	04015430	St. Louis River	At Reserve Mining RR bridge, 1.3 miles downstream from Seven Beaver Lake and 9.3 miles northeast of Fairbanks.	60.6	183.7	0.52	22.5	46	0.009
2	04015438	do	At Forest Service Road 133, 2 miles southeast of Skibo.	94.0	170.9	.95	23.0	93	.010
3		do	At County Highway 346, 3.6 miles southeast of Hoyt Lakes.	114	161.1	1.06	20.5	70	.009
4		do	2.5 miles upstream from Partridge River and 3 miles southwest of Hoyt Lakes.	123	156.3	.87	24.0	80	.007
5		Levee drain	At Whitewater Lake outlet, 2.5 miles southwest of Hoyt Lakes.	—	—	—	—	—	—
6		St. Louis River	150 feet upstream from Partridge River and 1.5 miles south of Aurora.	126	153.9	5.02	20.0	210	.040
7	04015447	Partridge River	At Erie Mining Road, 6.5 miles south of Babbitt.	18.2 nc 5.8	184.0	.27	20.0	300	.015
8	04015455	South Branch Partridge River	At National Forest Road 116, 10 miles northeast of Hoyt Lakes.	18.5	184.2	0	—	—	—
9		South Branch Partridge River	0.6 mile upstream from mouth and 9 miles southwest of Babbitt.	28.9	180.3	.04	17.5	110	.001
10		Partridge River	0.8 mile downstream from South Branch Partridge River, and 9.4 miles southwest of Babbitt.	56.0 nc 5.8	178.8	.07	18.5	340	.001
11		Colvin Creek	At County Highway 680, 2.7 miles northeast of Skibo.	4.57	9.0	.002	18.0	122	.0004
12		Colvin Creek tributary	At National Forest Road 420, 1 mile upstream from mouth and 8.3 miles east of Hoyt Lakes.	4.21	—	0	—	—	0
13	04015461	Colvin Creek	At Forest Service Road 420, 7 miles east of Hoyt Lakes.	18.3	3.9	.25	22.5	106	.014
14		Colvin Creek	0.1 mile upstream from mouth, and 11 miles northeast of Aurora.	22.0	0.1	.22	26.0	79	.010
15	04015474	Partridge River	At County Highway 110, 1 mile northeast of Hoyt Lakes.	106 nc 6	163.3	.50	22.0	185	.005
16		Wyman Creek	At County Highway 110, 0.5 miles upstream from mouth, and 1.7 miles northeast of Hoyt Lakes.	10.4 nc 0.9	—	.20	19.0	370	.019
17		Second Creek	At County Highway 666, 4 miles north of Hoyt Lakes.	7.56 nc 2.50	—	5.89	19.5	610	.779
18		Second Creek	At County Highway 110, 3.0 miles northeast of Aurora.	10.6 nc 2.9	—	2.87	22.0	700	.271
19		Stephens Creek	At County Highway 110, 2.5 miles northeast of Aurora.	3.91 nc 3.05	—	.44	20.0	380	.113
20		First Creek	0.1 mile upstream from mouth and 2 miles east of Aurora.	5.74 nc 0.68	—	3.46	20.5	1250	.603
21	04015500	Second Creek	0.1 mile downstream from First Creek, 0.4 mile upstream fro 2.1 miles east of Aurora.	29.0	—	9.28	—	—	.350
22	04016000	Partridge River	At County Highway 110, 1,000 feet downstream from Second Creek, and 2.5 miles east of Aurora.	161 nc 13	157.6	[b]10.3	—	—	.085
23		Partridge River	0.1 mile upstream from mouth, and 2 miles south of Aurora.	164 nc 13	153.8	10.3	21.0	670	.064
24	04016500	St. Louis River	At County Highway 100, 1.5 miles south of Aurora.	290 nc 13	153.4	[b]20	—	—	.066
25	04016900	Embarrass River	At County Highway 620, 100 feet upstream from Spring Mine Creek, and 5.9 miles southwest of Babbitt.	17.6	43.7	.02	19.5	216	.001

Table 17.--Baseflow, specific conductance, and water temperature measurements in streams in the Copper-Nickel study region, August 23-27, 1976--Continued

Figure plotting number	Station I.D. number	Stream	Location	Drainage area (mi^2)	River mile location	Discharge (ft^3/s)	Water temperature (°C)	Specific conductance (umho/cm at 25°C)	Base flow yield [(ft^3/s)/mi^2]
26		Spring Mine Creek	At mouth, about 6.0 miles southwest of Babbitt.	6.08	---	.25	16.5	136	.042
27		Camp Eight Creek	At County Highway 21, 0.7 mile upstream from mouth, and 4 miles northeast of Embarrass.	5.22	---	0.02	16.0	122	.004
28		Trimble Creek	At County Highway 104, 2.6 miles east of Embarrass.	6.34	---	.44	20.5	636	.069
29		Bear Creek	At County Highway 21, 0.7 mile upstream from mouth, and 2.1 miles north of Embarrass.	30.1	---	.31	22.5	122	.010
30	04017000	Embarrass River	At County Highway 362, in Embarrass.	88.3	28.1	1.76	23.5	232	.020
31		Embarrass River tributary	At County Highway 21, 0.3 mile west of Embarrass.	4.04	---	0	---	---	0
32		Embarrass River	At State Highway 135, 3 miles southwest of Embarrass.	110	24.6	4.61	23.5	373	.042
33	05124480	Kawishiwi River	2 miles upstream from South Kawishiwi River, 14 miles east of Ely.	253	70.2	[a]37	---	---	.146
34		Kawishiwi River (North Channel)	2.8 miles below (anabranch) South Kawishiwi River, and 8.7 miles east of Winton.	---	---	24	20.5	<50	.183
*35		Inga Creek	At National Forest Road 377, 9.7 miles northwest of Isabella.	6.75	---	1.03	24.0	136	.153
*36		Inga Creek	At National Forest Road 381, 12 miles northwest of Isabella.	3.38	---	.61	22.0	127	.180
*37		Little Isabella River	At culvert between Flathorn and Rat Lakes, 5.4 miles southwest of Kelly Landing.	31.5	---	6.16	17.5	125	.196
*38	05124497	do	At National Forest Road 173, 7 miles upstream from mouth, and 11 miles northwest of Isabella.	48.3	---	6.93	22.0	95	.143
*39		do	At National Forest Road 381, 3 miles upstream from mouth, and 12 miles northwest of Isabella.	53.2	---	8.75	24.5	85	.164
40	05124500	Isabella River	200 feet upstream from Bald Eagle Lake and 14.5 miles northwest of Isabella.	341	0	[a]36	---	---	.106
41		Snake River	At National Forest Road 173, 13 miles northwest of Isabella.	7.17	---	1.47	21.0	188	.205
42		Snake Creek	At National Forest Road 173, 1 mile upstream from mouth, and 12 miles northwest of Isabella.	3.49	---	.82	19.5	117	.235
43	05124600	Snake River	1.0 mile upstream from mouth and 16 miles southeast of Ely.	16.2	---	1.60	22.0	150	.099
44		Bald Eagle Lake tributary	At mouth, 16 miles southeast of Ely.	3.21	---	0	---	---	0
45		Bald Eagle Lake tributary No. 2	At mouth, 15 miles southeast of Ely.	9.36	---	.10	19.0	50	.011
46		Bald Eagle Lake tributary No. 3	At mouth, 14 miles southeast of Ely.	.80	---	.01	20.0	60	.012
47		August Creek	At National Forest Road 388, 16 miles northeast of Babbitt.	7.44	---	.05	23.0	100	.007
48	05124650	August Creek	300 feet upstream from Bald Eagle Lake and 13 miles southeast of Ely.	14.7	---	.71	19.0	130	.048
49	05124700	Bald Eagle Creek	0.2 miles upstream from Bald Eagle Lake and 13 miles southeast of Ely.	4.33	---	.19	18.0	130	.044
50	05124840	Cobalt Creek	0.1 mile upstream from Gabbro Lake and 12 miles southeast of Ely.	2.94	---	0	---	---	0

Table 17.--Baseflow, specific conductance, and water temperature measurements in streams in the Copper-Nickel study region, August 23-27, 1976--Continued

Figure plotting number	Station I.D. number	Stream	Location	Drainage area (mi²)	River mile location	Discharge (ft³/s)	Water temperature (°C)	Specific conductance (umho/cm at 25°C)	Base flow yield [(ft³/s)/mi²]
51	05124880	Nickel Creek	0.1 mile upstream from Gabbro Lake and 20 miles northwest of Isabella.	1.89	—	.007	23.0	<50	.004
52	05124890	Gabbro Lake outlet (dam No. 1)	At Gabbro Lake dam No. 1, 12 miles southeast of Ely.	416	—	52.2	21.5	60	.134
53	05124900	Gabbro Lake outlet (dam No. 2)	At Gabbro Lake dam No. 2, 11 miles southeast of Ely.	416	—	3.75	24.0	60	.134
54		Filson Creek	3/4 mile downstream from Omaday Lake outlet, and 15 miles northeast of Babbitt.	3.61	4.4	.02	22.0	<50	.006
55	05124980	Filson Creek	At National Forest Road 181, 9 miles southeast of Winton.	4.96	2.6	.02	16.0	<50	.004
56		Filson Creek tributary	0.1 mile upstream from mouth and 10 miles southeast of Ely.	3.03	—	0	—	—	0
57	05124990	Filson Creek	At National Forest Road 181, 0.8 miles upstream from mouth and 10 miles southeast of Ely.	9.66	.8	[a].07	20.0	52	.007
58	05125000	South Kawishiwi River	5 miles upstream from Birch Lake and 9 miles southeast of Ely.	—	60.0	[a]89	—	—	—
59		Keeley Creek	At State Highway 1, 12 miles southeast of Ely.	4.23	—	0	—	—	0
60	05125040	Keeley Creek	0.1 mile upstream from mouth and 10 miles northeast of Babbitt.	11.2	—	.02	—	—	.002
61		Stony River	At Erie Mining RR bridge, 3 miles downstream from Spur End Creek and 7 miles northeast of Whyte.	27.1	35.0	.25	22.0	90	.009
*62		do	At National Forest Road 393, 6 miles southwest of Isabella.	57.2	29.9	1.01	19.5	110	.018
63	05125400	do	At National Forest Road 106, 0.8 mile upstream from McDougal Lake, and 8 miles west of Isabella.	62.0	26.2	1.24	23.5	80	.020
64		Coyote Creek	At National Forest Road 106, 0.4 mile upstream from McDougal Lake, and 9 miles west of Isabella.	8.18	—	<.01	—	—	.001
65		Stony River	0.4 mile downstream from McDougal Lake outlet, and 10 miles northwest of Isabella.	80.1	23.2	1.70	26.0	60	.021
66	05125450	Greenwood River	At bridge on logging road, 4.5 miles downstream from Greenwood Lake and 13 miles west of Isabella.	48.2	—	.48	25.5	45	.010
67		Stony River	At State Highway 1, 0.5 mile upstream from Camper's Lake outlet, and 15 miles southeast of Babbitt.	163	19.2	1.95	21.0	100	.012
68	05125500	Stony River	At State Highway 1, 11 miles upstream from Birch Lake, and 12.8 miles northwest of Isabella.	180	13.4	[a]6.6	—	—	.037
69		Nip Creek	At National Forest Road 178, 1 mile downstream from Jackpot Creek, and 18 miles northwest of Isabella.	24.8	—	1.28	26.0	85	.052
70	05125550	Stony River	At National Forest Road 424, 4.7 miles upstream from mouth, and 8.5 miles southeast of Babbitt.	219	4.9	12.4	22.0	90	.057
71	05125600	Denley Creek	0.1 mile upstream from Nira Creek and 13 miles southeast of Ely.	4.34	—	<.01	—	—	.002
72	05125620	Nira Creek	0.1 mile upstream from mouth, and 13 miles southeast of Ely.	10.5	—	.60	19.5	95	.057
73	05125650	Stony River	0.1 mile upstream from Birch Lake and 14 miles southeast of Ely.	244	.1	9.33	25.0	90	.038
74	05125730	Birch Lake tributary	0.1 mile upstream from Bob Bay on Birch Lake, and 6 miles east of Babbitt.	4.32 nc 0.69	—	.68	20.0	70	.157
75	05125950	Dunka River	At National Forest Road 116, 15 miles northeast of Hoyt Lakes.	8.26	13.4	.004	24.0	130	.0005

Table 17.--Baseflow, specific conductance, and water temperature measurements in streams in the Copper-Nickel study region, August 23-27, 1976--Continued

Figure plotting number	Station I.D. number	Stream	Location	Drainage area (mi^2)	River mile location	Discharge (ft^3/s)	Water temperature (°C)	Specific conductance (umho/cm at 25°C)	Base flow yield [(ft^3/s)/mi^2]
76		Langley Creek	At Erie Mining Company road, 5 miles southeast of Babbitt.	8.92 nc 3.50	---	.05	27.5	422	.006
77		Twenty Proof Creek	At National Forest Road 112, 6 miles southeast of Babbitt.	2.99	---	.09	22.0	136	.030
78		Dunka River	At National Forest Road 424, 5 miles southeast of Babbitt.	43.8 nc 3.5	4.5	.76	24.5	260	.017
79	05126000	Dunka River	1.8 miles upstream from Birch Lake, and 3.8 miles southeast of Babbitt.	53.4 nc 4.0	1.7	.06	27.0	---	.001
80		Birch Lake tributary	At National Forest Road 112, 1 mile northeast of Babbitt.	3.02	---	0	---	---	0
81		Birch River	At County Highway 21, 1.5 miles northwest of Babbitt.	27.8	---	.39	19.0	136	.014
82	05126210	South Kawishiwi River	0.5 mile upstream from White Iron Lake, and 5.0 miles southeast of Ely.	---	50.6	35.8	25.0	75	---
83		Bear Island River	At County Highway 21, 7 miles northeast of Babbitt.	37.8	---	.28	23.0	60	.007
84		Johnson Creek	At County Highway 21, 8 miles northeast of Babbitt.	10.4	---	<.01	24.5	95	.001
85	05126500	Bear Island River	At State Highway 1, 1.2 miles upstream from mouth, and 5.0 miles south of Ely.	68.5	---	1.80	24.5	55	.026
86	05127000	Kawishiwi River	At Minnesota Power and Light Company powerplant, 1.8 miles east of Winton.	1229	41.4	[c]0	---	---	0
87	05127230	Shagawa River	300 feet downstream from outlet of Shagawa Lake, and 3 miles upstream from Fall Lake.	99.0	---	11.5	23.5	75	.116
88	05127250	Kawishiwi River	At Fall Lake outlet, 5 miles northeast of Winton.	1352	37.8	77.0	20.5	55	.057

* -- Site not shown on plate.
[a] -- Determined from rating table.
[b] -- Mean-daily discharge for August 24-27, 1976.
[c] -- Regulated.
nc - Noncontributing drainage area with respect to suface runoff, drainage area listed for site includes noncontributing drainage area.

Table 18.—Meaurements of suspended-sediment discharge

Date	Time	Water temper-ature (°C)	Instan-taneous discharge (ft^3/s)	Suspended sediment (mg/L)	Suspended sediment discharge (tons/d)
05124480 Kawishiwi River near Ely					
1- 3-68	—	.5	33	1	0.09
5- 2-68	—	—	1030	2	5.6
5-29-68	1020	11.0	547	3	4.4
6-19-68	1020	17.0	1200	4	13
7- 3-68	—	16.0	698	4	7.5
8- 6-58	1400	21.5	204	2	1.1
9-11-68	1230	16.5	100	2	0.54
10-23-68	1430	9.0	373	2	2.0
12-30-68	1500	.0	139	1	0.38
5- 6-69	1200	14.0	1230	2	6.6
7-24-69	1100	21.0	126	4	1.4
8-27-69	1130	22.0	154	2	0.77
9-30-69	1515	13.0	121	1	0.33
05126500 Bear Island River near Ely					
11- 7-75	1145	9.5	22	8	.48
12-17-75	1600	.0	36	11	1.1
3- 4-76	1750	.0	16	5	.22
4- 5-76	1450	3.5	96	9	2.3
4-13-76	1640	7.5	243	7	4.6
4-27-76	1540	8.0	184	16	7.9
5-27-76	1500	16.5	29	5	.39
7- 9-76	0830	11.0	45	4	.49
8-17-76	1630	24.5	4.7	71	.90
11- 9-76	1140	1.5	.28	10	.01
3-14-77	1625	.50	2.4	8	.05
3-23-77	0915	.50	2.6	5	.04
4-25-77	1630	13.5	6.0	4	.06
6- 9-77	1735	20.0	118	4	1.3

Date	Time	Water temper-ature (°C)	Instan-taneous discharge (ft^3/s)	Suspended sediment (mg/L)	Suspended sediment discharge (tons/d)
05125550 Stony River near Babbitt					
11- 3-75	1615	5.5	128	8	2.8
12-19-75	1100	.0	62	3	0.50
1-30-76	1205	.5	49	5	0.66
3- 2-76	1620	.5	40	1	0.11
4- 7-76	1255	.0	278	2	1.5
4-12-76	1515	2.5	695	3	5.6
4-14-76	1600	5.0	961	5	13
4-20-76	1528	8.0	2380	4	26
4-26-76	1440	11.5	1220	6	20
5-27-76	1100	19.2	83	5	1.1
7- 8-76	1310	23.0	171	6	2.8
8- 4-76	1300	19.5	23	9	0.56
8-18-76	1200	19.0	16	2	0.09
9-28-76	1530	12.0	7.8	4	0.08
10-10-76	1530	.5	12	2	0.06
12-15-76	1510	.5	11	3	0.09
3-23-77	1330	.5	33	2	0.18
4-27-77	1220	13.5	125	2	.68
6- 9-77	1015	18.5	306	6	5.0
05126000 Dunka River near Babbitt					
11- 3-75	1345	5.0	26	8	.56
12-15-75	1500	.0	16	2	.09
1-30-76	1530	.5	3.7	2	.02
3- 4-76	1530	.5	6.6	3	.05
4- 7-76	0945	.0	277	17	13
4-14-76	1000	5.5	299	7	5.6
5-25-76	1100	16.5	8.6	8	.19
7- 8-76	1015	20.5	8.5	2	.05
8-20-76	1145	24.0	.05	2	.00
9-28-76	1300	9.2	.63	2	.00
11- 9-76	1645	.0	.30	6	.00
4-28-77	1515	12.5	16	10	.43
6- 9-77	1550	17.0	78	3	.63

The daily mean discharge, and daily range of water temperatures and specific conductance were measured during the 1976 water year for Stony River near Babbitt (fig. 27), a stream unaffected by regulation. An inverse relationship, in general, exists between discharge and specific conductance (fig. 28). Specific conductance is at a minimum when most of the water is from surface runoff during high-flow. During low-flow periods when streamflow is largely ground-water discharge, specific conductance is at a maximum.

The maximum specific conductance observed at the Stony River gage near Babbitt from May 1975 to June 1978 was 160 micromhos on December 15, 1977. Minimum specific conductance observed during the period was 39 micromhos on May 10, 1978.

The daily mean discharge, and daily range of water temperatures and specific conductance during the 1976 water year for Dunka River near Babbitt (fig. 29) are representative of a stream affected by mining activities. During periods of low flow, the large daily flucutations in specific conductance are caused by the addition of water with high specific conductance from open-pit mines. During periods of high flow, overland runoff dilutes the mine discharge, and specific conductance is low, similar to the Stony River.

Monthly and annual statistics on water-temperature data obtained at stream-gaging stations equipped with continuous water-temperature recorders are listed in table 19. The annual mean water temperatures of the four streams are similar for the 1976-77 water years. The 0.6 to 0.8°C higher annual mean water temperatures at Kawishiwi River near Ely is caused by thermal storage in on-channel lakes. Similarly, because of thermal storage, temperature is a few degrees lower than that of other streams in the spring and a few degrees higher in the fall.

Variations in mean monthly water temperature of the Kawishiwi River near Ely and air temperatures for Northeastern Division are shown in figure 30. The largest difference in monthly values occurs in the winter when air temperatures are below freezing. Average monthly stream temperatures exceed air temperatures every month except April, when they are identical. For water years 1967-77, the annual mean water temperature at Kawishiwi River near Ely exceeded the annual mean air temperature of the Northeast Division by an average of 5.8°C.

Stream temperature fluctuated diurnally at the four continuous-temperature record sites, Partridge River near Hoyt Lakes, Kawishiwi River near Ely, Stony River near Babbitt, and Dunka River near Babbitt, during ice-free periods. Specific conductance did not change appreciably on a diurnal basis.

Typical graphs of water temperature, specific conductance, and discharge (fig. 31) were constructed from hourly data collected at Stony River near Babbitt for July 26-August 1, 1976. During the 7-day period, there was a gradual decline in discharge and a corresponding increase in specific conductance. Diurnal fluctuations of water temperature were significant throughout the week.

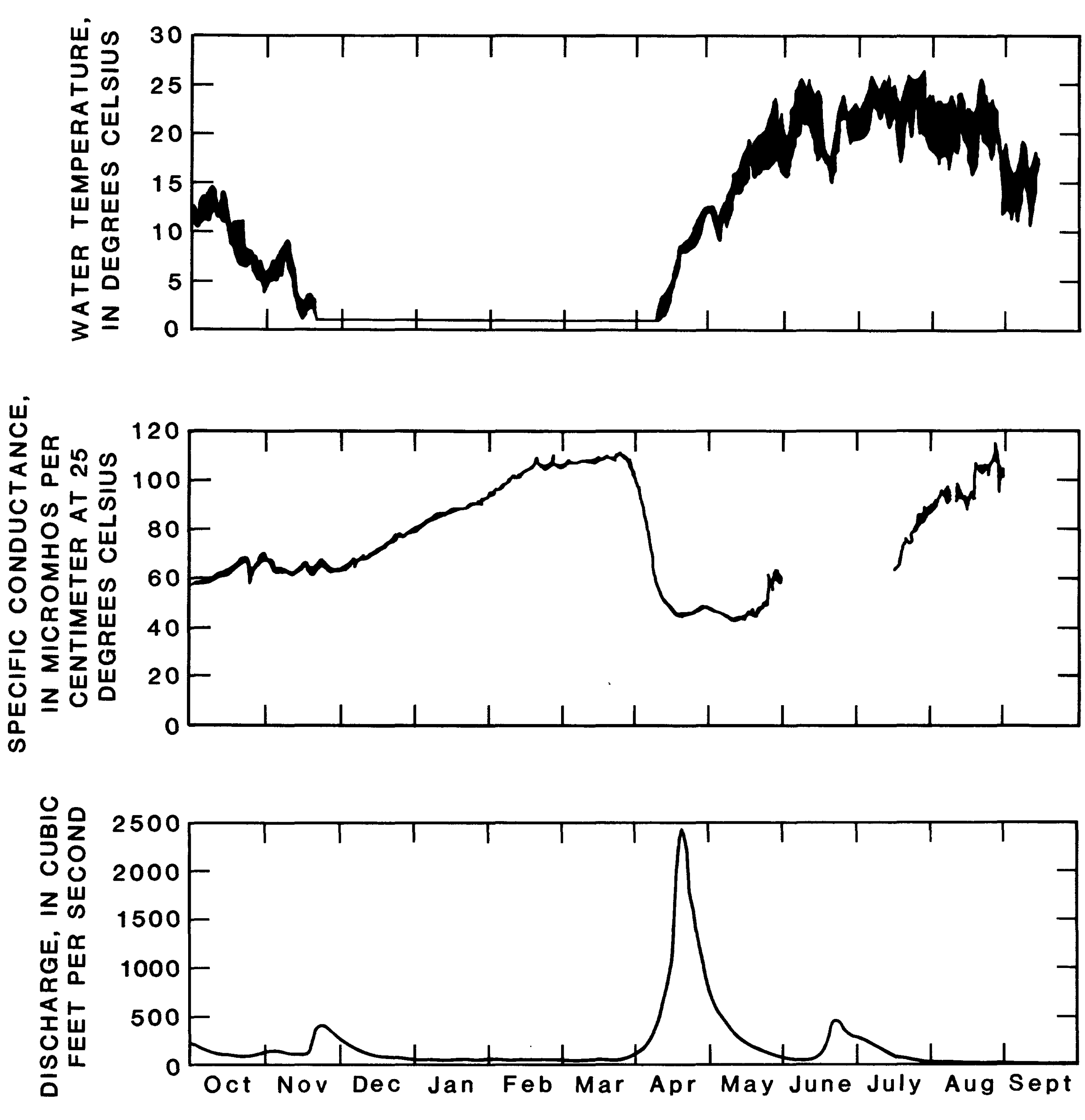

Figure 27.--Daily range of water temperature, specific conductance, and daily mean discharge of the Stony River near Babbitt, Minnesota, 1976 water year

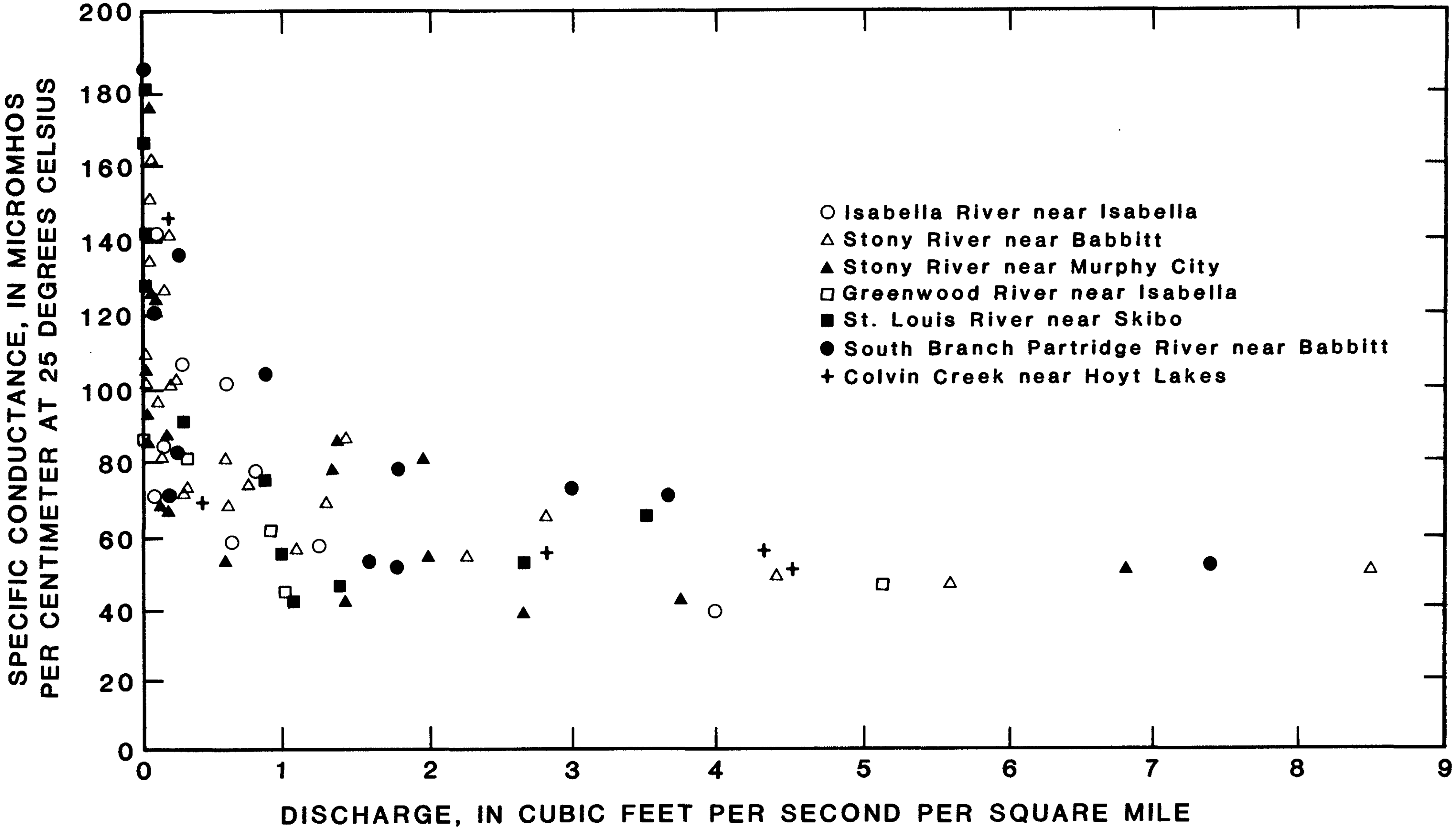

Figure 28.--Specific conductance-discharge relationship for unregulated streams

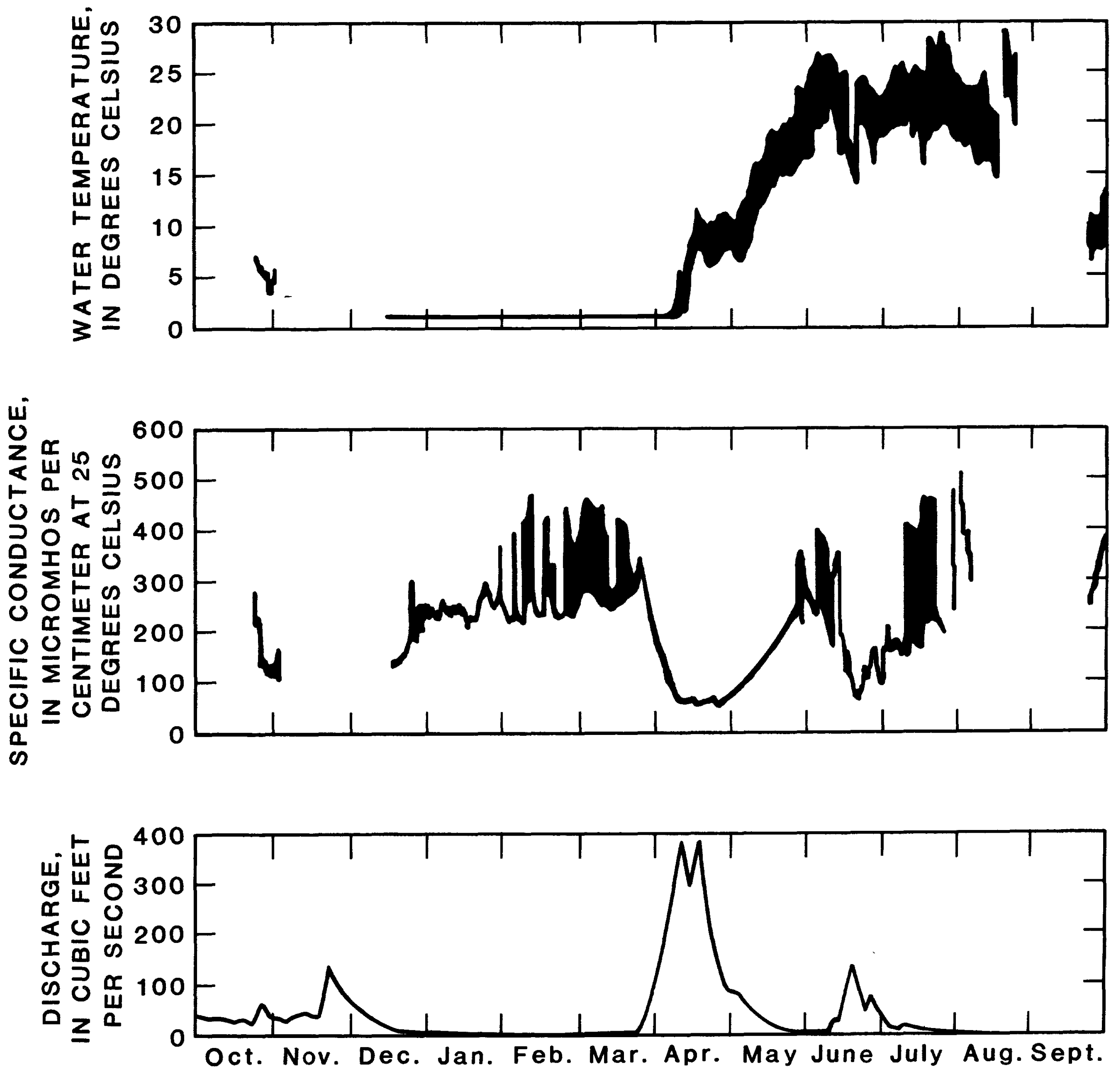

Figure 29.--Daily range of water temperature, specific conductance, and daily mean discharge of the Dunka River near Babbitt, Minnesota, 1976 water year

Table 19.--Annual and monthly statistics for air and water temperatures in study area

Site no.	Station name	Annual (water year) mean water temperature (°C)										
		1977	1976	1975	1974	1973	1972	1971	1970	1969	1968	1967
8	Partridge River near Hoyt Lakes..........	*9.4	*9.5	---	---	---	---	---	---	---	---	---
33	Kawishiwi River near Ely.................	10.0	10.1	9.9	9.8	9.0	8.9	8.7	7.8	8.4	8.5	8.7
70	Stony River near Babbitt............	---	9.5	---	---	---	---	---	---	---	---	---
79	Dunka River near Babbitt............	*9.2	*9.5	---	---	---	---	---	---	---	---	---
		Annual (water year) mean air temperature (°C)										
	Northeast Division....	2.9	4.3	3.7	2.9	3.7	2.4	2.9	3.2	3.6	3.4	2.3

*Estimated for part of year.

Station name	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
Mean monthly and annual water temperature (°C) for 1969-77 water years													
Kawishiwi River near Ely..........	9.6	4.0	1.2	0.6	0.7	1.2	3.7	11.4	17.8	20.9	20.6	17.3	9.1
Mean monthly and annual air temperature (°C) for 1969-77 water years													
Northeast Division..	6.3	-2.7	-10.8	-14.9	-11.4	-4.5	3.7	10.2	15.2	18.3	17.2	12.1	3.2
Mean monthly and annual air temperature (°C) for 1941-70 calendar years													
Babbitt 2 SE[a].......	7.2	-3.0	-10.6	-14.1	-11.6	-4.7	3.9	11.0	16.3	19.1	17.9	12.4	3.6
Northeast Division[a].	7.4	-2.1	-9.8	-13.2	-11.1	-4.5	3.9	10.1	15.1	18.3	17.1	12.5	3.7

[a]NOAA climatological station.
NOTE.--Air temperature data from NOAA "Climatological Data - Minnesota".

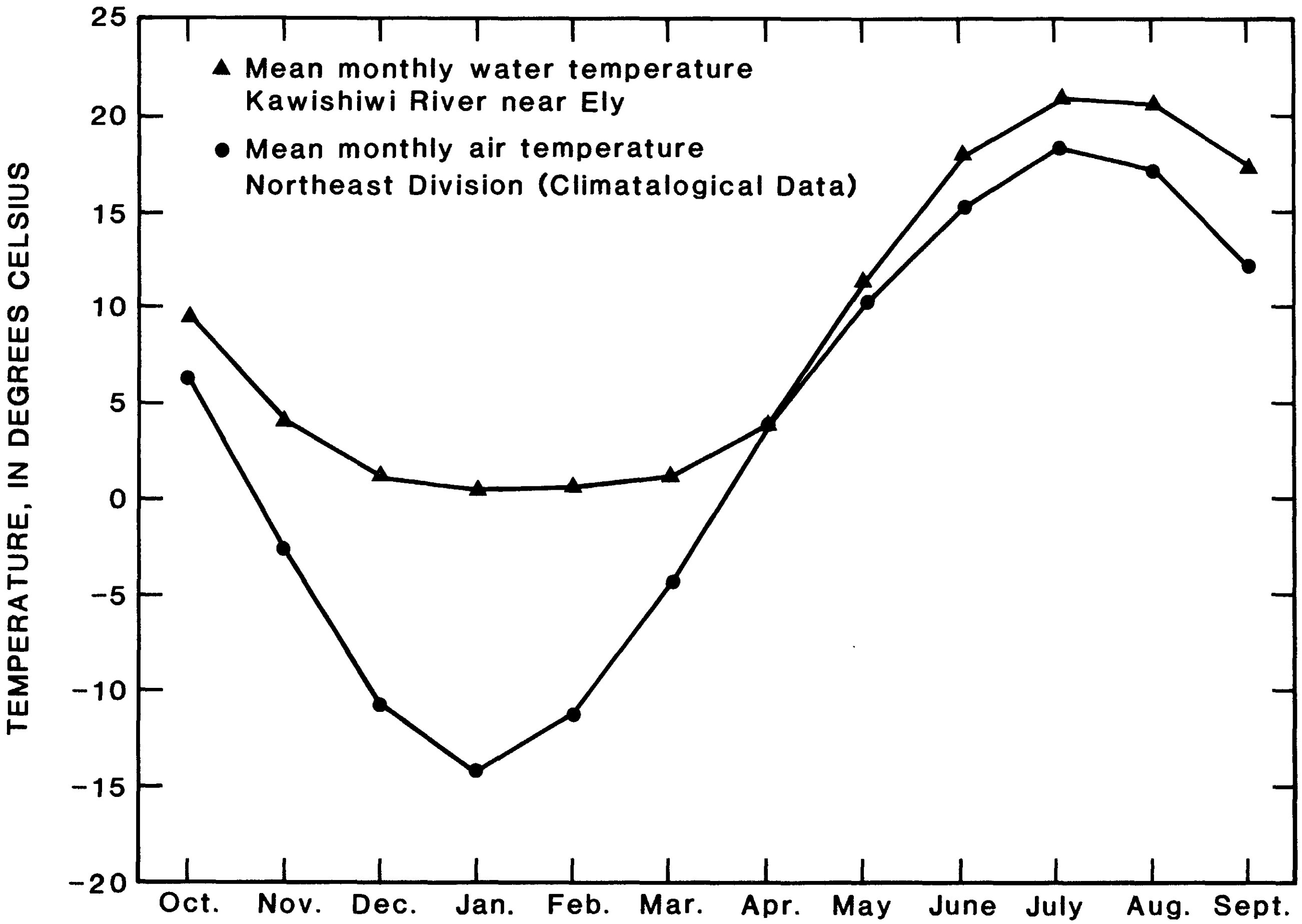

Figure 30.--Average monthly air and water temperature at the Kawishiwi River near Ely, Minnesota, 1967-77 water years

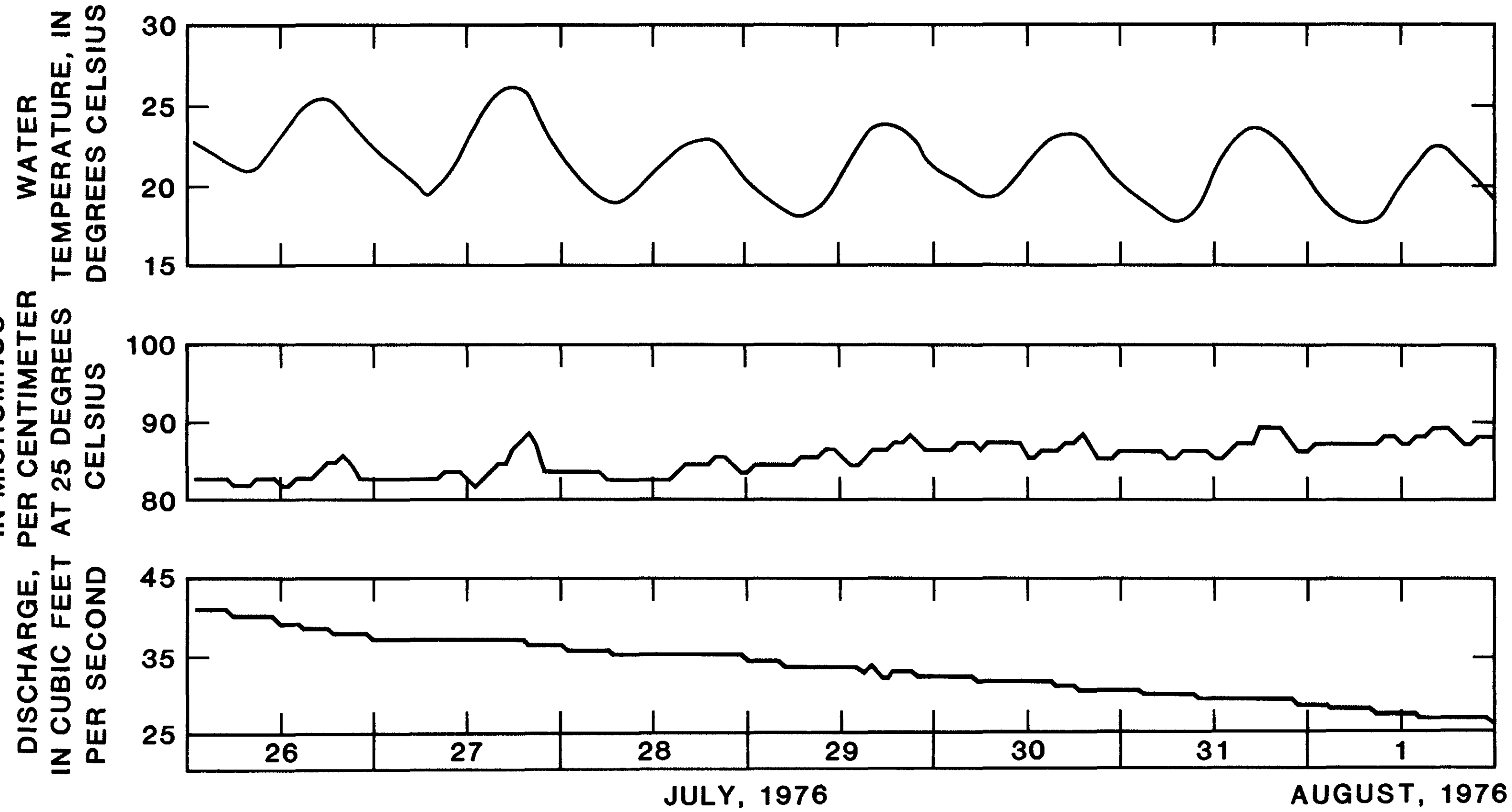

Figure 31.--Discharge, specific conductance and water temperature of the Stony River near Babbitt, Minnesota, July 26 to August 1, 1976

Daily variations in water temperature at Kawishiwi River near Ely are smaller than other streams during open-water periods and seldom exceed 2°C. Daily water temperatures fluctuate less probably because of temperature stratification in the on-channel lake several hundred yards upstream from the gage.

HYDROLOGIC BUDGET

The similarity of annual hydrologic budgets (table 20) for the Kawishiwi River watershed above Winton and the St. Louis River watershed above Aurora (fig. 32) suggest that hydrologic conditions in the two areas are not very different. The budgets, based on average annual data for 1955-76, present water gain, storage, and loss for the watersheds. Hydrologic factors that were considered in the water budget are given in the following equation:

$$\text{Precipitation} = \text{runoff} + \text{evapotranspiration} \pm \text{underflow} \pm \text{changes in storage}$$

On a long term basis, underflow and changes in storage can be assumed to be negligable (Lindholm and others, 1978). Based on available data, it is assumed that ground-water divides are coincident with surface-water divides and that ground water does not move across divides. Ground-water storage changes continuously, but, over a long period of time, increases in storage tend to equal decreases.

Average annual precipitation for the watersheds was based on 22 years of record, 1955-76, at Babbitt and Whiteface Reservoir. Average annual runoff was based on gaging station records (1955-76) at Winton and near Aurora.

Evapotranspiration was calculated as the difference between precipitation and runoff. Potential evapotranspiration for Babbitt was calculated by the Thornthwaithe equation (Gray, 1970). Potential evapotranspiration was 21.4 inches and favorably compares to residual values of 18.1 inches for the Kawishiwi River watershed and 17.6 inches for the St. Louis River watershed. Both watersheds have similar vegetation and are generally underlain by similar types of drift. Runoff per square mile of watershed is nearly identical.

WATER USE

Water-use data were obtained from State, municipal, and private sources. Appropriation permits provided by the Minnesota Department of Natural Resources were the main source of data on water use applicable to municipal supply systems, irrigation wells, thermoelectric power generation, mine dewatering, and ore processing. It was assumed that most of the water removed for mine operations was from ground-water storage rather than from precipitation or surface-water runoff.

Table 20.--Approximate annual water budgets, in inches, for the Kawishiwi River watershed above Winton and the St. Louis River watershed above Aurora

	Precipitation	Runoff	Evapo-transpiration	Underflow and change in storage
Kawishiwi River watershed...........	27.5	9.4	18.1	0
St. Louis River watershed...........	27.2	9.6	17.6	0

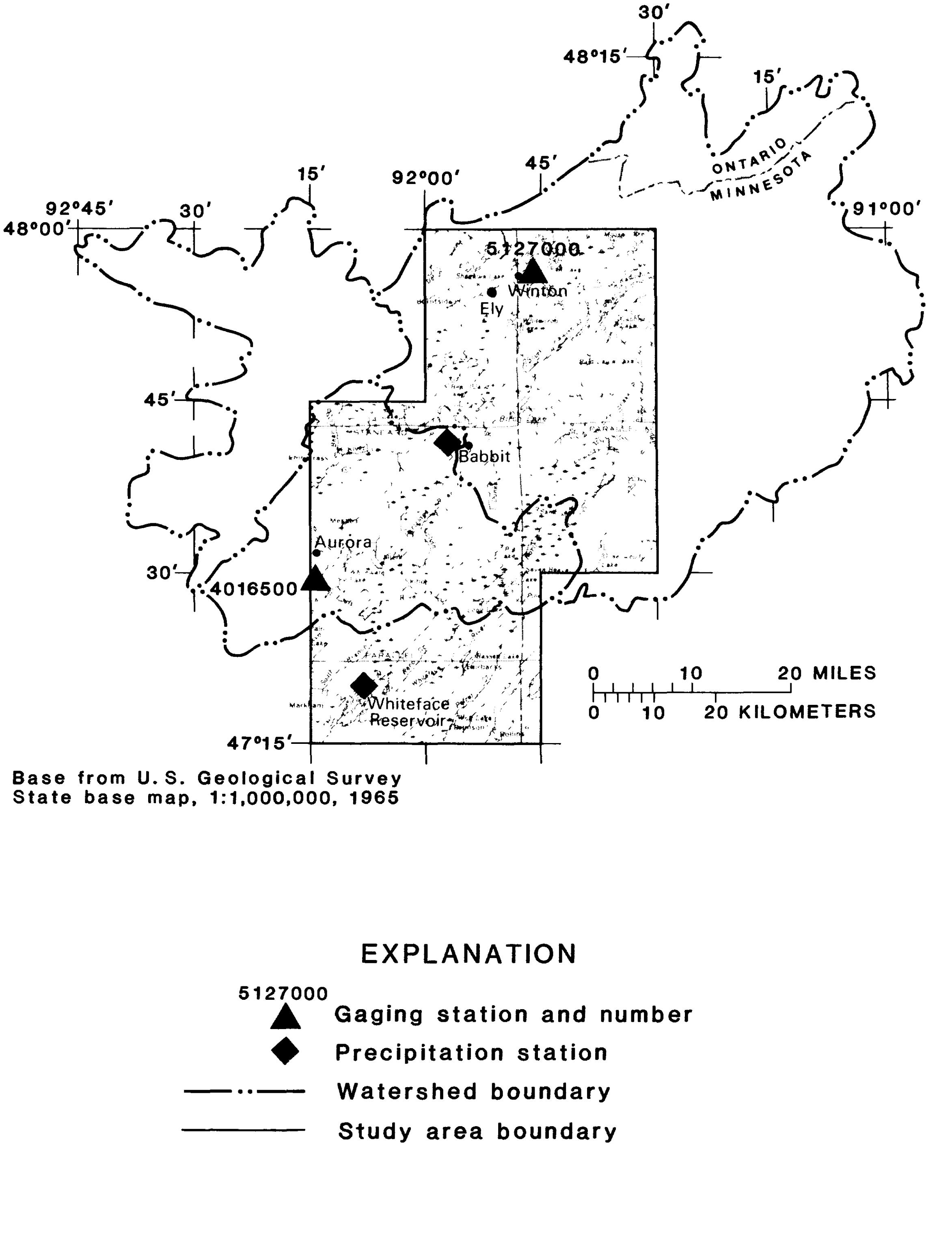

Figure 32.--Locations of the stream gages and precipitation stations for the Kawishiwi River watershed above Winton, and the St. Louis River watershed above Aurora, Minnesota

Rural and other domestic uses were estimated by multiplying an average per capita use of 75 gal/d by population (1970 census) of individual townships and unorganized townships. Water use by tourists was estimated by visitor days per resort. Water use by hydroelectric generation was obtained from Geological Survey streamflow records (1971-77). Stock watering was estimated from estimated animal population determined for parts of counties within the region.

Total water use was nearly constant during 1971-75, ranging from about 200 to 250 billion gallons per year. During the drought of 1976, total water use decreased to about 170 billion gallons per year. Data summarizing water use between 1971-76 are given in table 21. Locations of major water use are shown in figure 33.

During 1971-75, between 69 and 75 percent of water used was related to hydroelectric power generation at Winton (fig. 34). Another 17 to 30 percent (also nonconsumptive) was for thermoelectric power generation at Colby Lake. During 1976, total water use for hydroelectric power generation decreased to 61 percent, while water use for thermoelectric power generation increased to 30 percent. Less than 3 percent of water used during 1971-76 was for municipal, rural, and irrigation needs. Mine dewatering accounted for between 2 and 6 percent of total water use.

Between 1971 and 1976, mine dewatering used between 5 and 12 billion gallons per year, about 95 percent of the ground-water use in the region (fig. 35). The combined ground-water use for municipal and rural supplies accounted for about 5 percent of the total ground water usage. About half of this use, between 200 and 300 million gallons per year, was withdrawn by the village of Aurora and the city of Babbitt.

Ground-water use remained fairly constant during 1971-76 (fig. 36). It is likely that ground-water use will temporarily increase with additional mining. Total use in 1974 nearly doubled as a temporary effect of eight new taconite mine operations, but long-term use did not appreciably increase.

Additional mining associated with copper and nickel exploration and development may increase withdrawal of ground water by 10 to 20 percent if open-pit operations intersect thick saturated surficial sand and gravel aquifers in the center of the Dunka River Basin or near the mouth of the Partridge River.

Projection of increased ground-water use by new and expanded cities will depend upon population increases. Due to limitations of ground-water availability, such use will necessarily be confined to sand and gravel aquifers underlying the Embarrass and Dunka Rivers and near the mouth of the Partridge River.

Almost all surface water is used for generation of power. Between 1971 and 1976 approximately 97 percent of surface-water use was for combined hydrolectric and thermoelectric power generation at Winton and at Colby Lake. Mine operations used 3 percent. Less than 1 percent was used by the city of Ely for municipal supply.

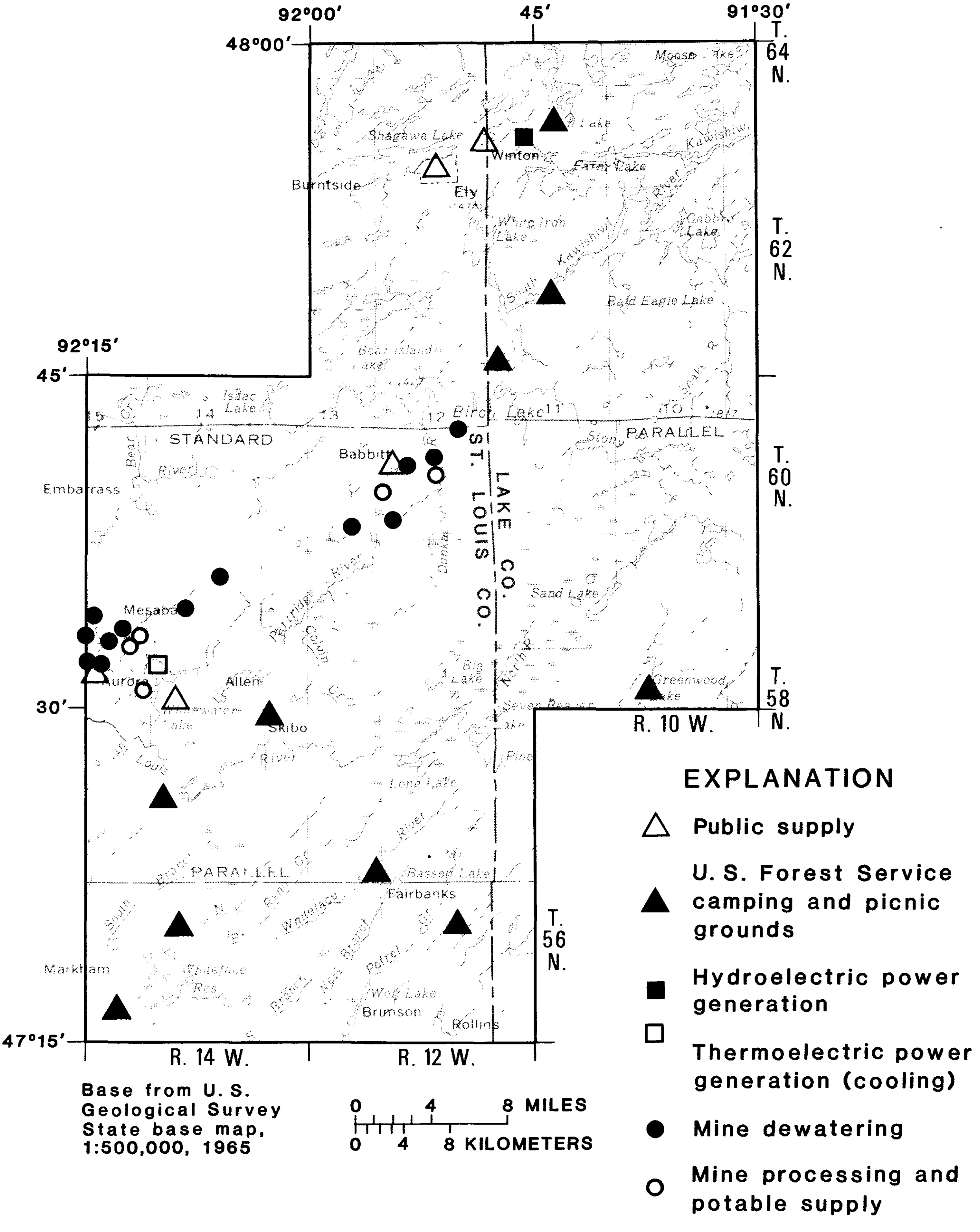

Figure 33.--Location of water use

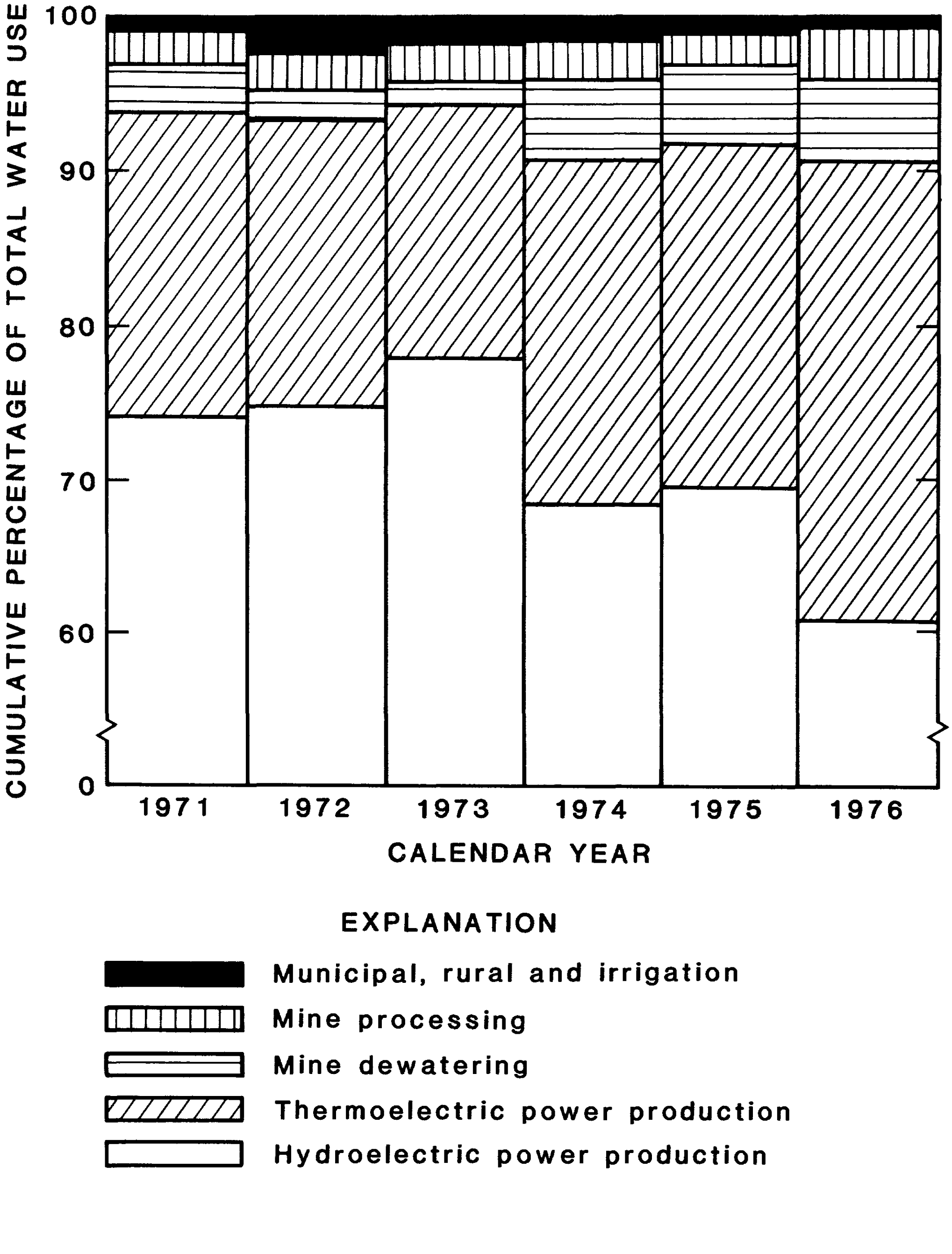

Figure 34.--Total water use expressed as cumulative percentage

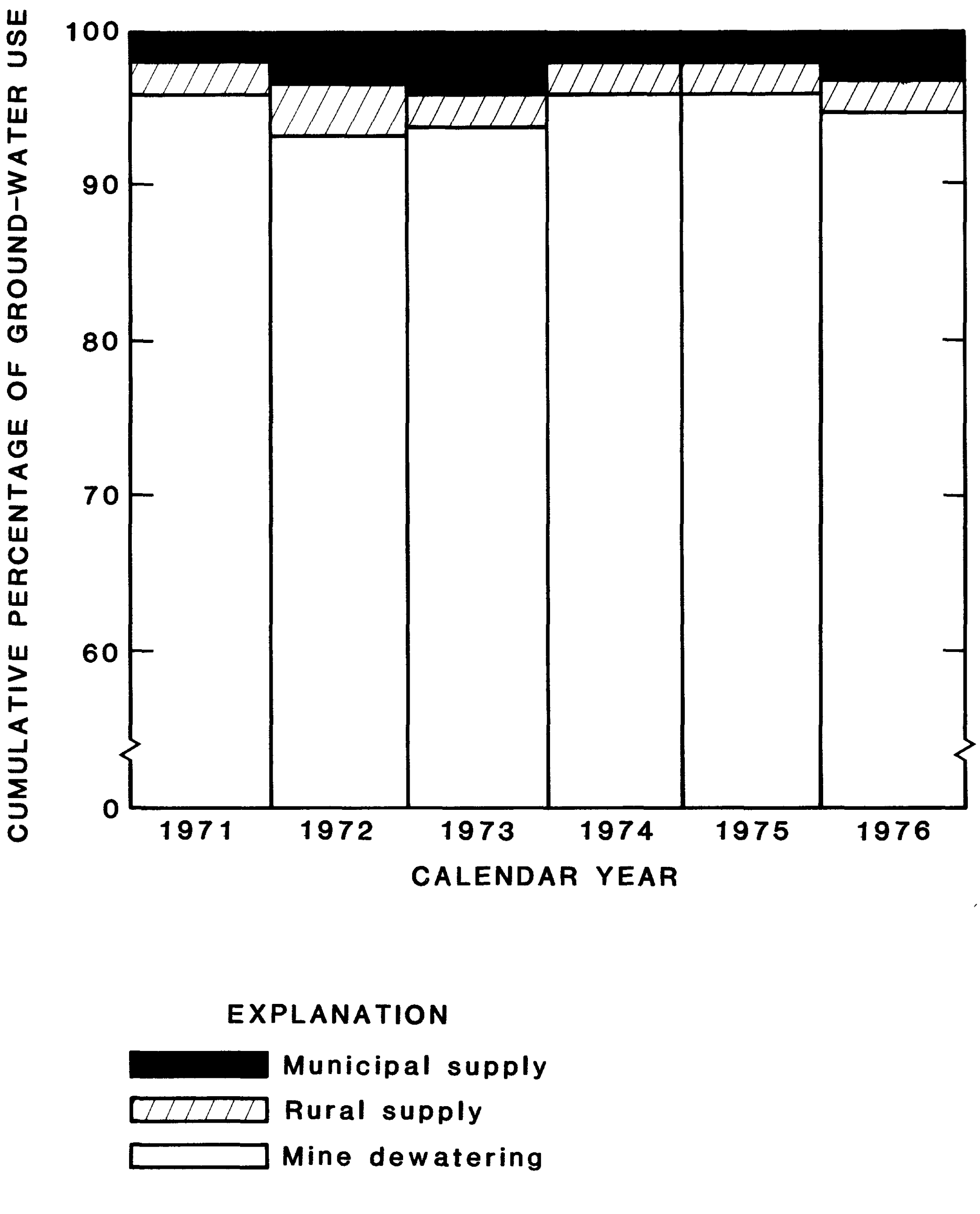

Figure 35.--Ground-water use expressed as cumulative percentage

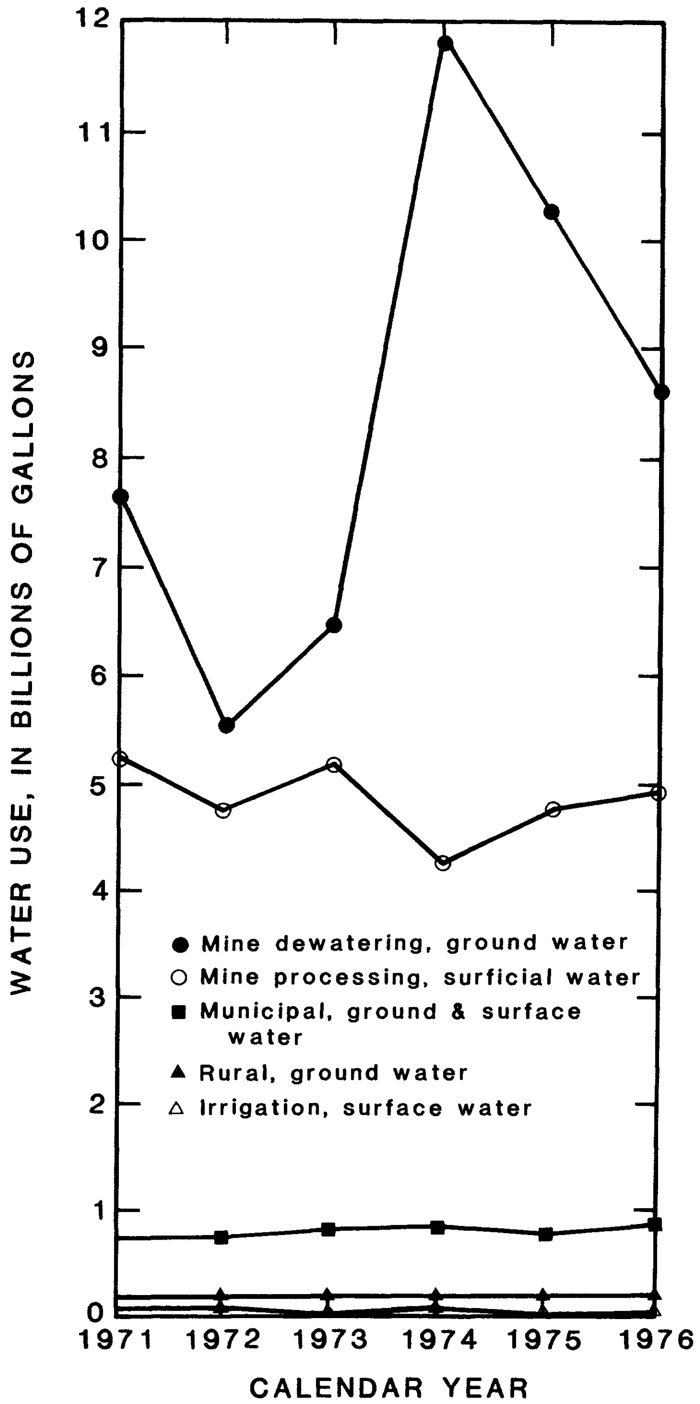

Figure 36.--Total water use, 1971-76, by major use (excluding hydroelectric and thermoelectric usage)

The largest industrial user of surface water was Erie Mining Company, which removed between 4 and 6 million gallons per year from Knox Creek and Whitewater Reservoir during 1971-76.

POTENTIAL IMPACTS OF MINING ON THE HYDROLOGIC SYSTEM

The impacts on the hydrologic system of potential copper and nickel mining and associated development include (1) aquifer dewatering and surface-water diversions by open-pit activities, (2) increased use of water by new and expanded cities, and (3) water-quality changes caused by mine discharge and tailings ponds. The data gathered for this study were for regional evaluation. Additional studies would be necessary to evaluate the potential impacts of mining at specific sites.

Mine Dewatering

In general, the effects of mine dewatering on ground-water levels will be minimal for new open pit or underground mines. The bedrock and overlying surficial materials along the contact zone between the Duluth Complex and older bedrock generally have low permeability. Dewatering of individual underground mines will be less than about 25 gal/min because fracture permeability in most of the Duluth Complex is low and discontinuous. Because of its extreme depth, little is known about the permeability of the Biwabik Iron-formation underlying the Duluth Complex. Water under confined conditions could seep upward to mines in the Duluth Complex if the mine penetrated near or into the Biwabik Iron-formation.

Mine dewatering may be significant from open-pit operations that intersect buried channels filled with sand and gravel, or if the pits are in hydrologic communication with streams, thick saturated sand and gravel aquifers, or leached zones in the Biwabik Iron-formation. The areal extent of the effect of mine dewatering on the water table will depend on local hydraulic gradients, hydraulic conductivity of the aquifer, and total saturated thickness intersected by the mine walls.

Table 22 presents calculated ground-water discharges from surficial materials to hypothetical open-pit mines shown in figure 37. The discharges were calculated by one-dimensional analysis and Darcy's law and utilized the surficial geology and drift thickness data given in plates 2 and 3 of Olcott and Siegel (1978). Hydraulic gradients were assumed to range from 10 to 40 feet per mile. Hydraulic conductivity values are from table 7 of this report. Because of the lack of site-specific data, potential discharges have been calculated conservatively to determine the possible extreme values. Accurate estimates for specific mines will require site-specific studies.

Ground-water discharge to hypothetical mines in areas 1, 4, 5, and 6 should be minimal owing to the relative impermeability and thin saturated thickness of the material in the drift. Ground-water discharge to an open-pit mine in area 3 potentially could have significant long-term impacts upon mining operations and the local ground-water system. Underlying the terminal moraine south of the proposed mine site are sand and gravel deposits, up to

Table 22.--Ground-water discharge to hypothetical open-pit mines

Map Key	Approximate location	Estimated range of saturated thickness of drift on mine wall, in feet	Drift type	Estimated sustained ground-water discharge, in gallons per minute	
				240-acre open-pit mine	400-acre open-pit mine
1,2	T.61N.,R.11W., Sec.24	5 to 10	Till.	As much as 100	As much as 200
3	T.60N.,R.12W., Sec.2	5 to 50	Till and peat in northern half, sand and gravel in southern half.	100 to 1,000	200 to 2,000
4	T.60N.,R.12W., Sec.29	5 to 15	Till; sand and gravel on north and east sides.	As much as 200	As much as 400
	T.60N.,R.12W., Sec.31	5 to 10	Till and peat.	As much as 100	As much as 200
5	T.59N.,R.14W., Sec.35	5 to 20	Till and peat; possible sand on NW margin.	As much as 200	As much as 400
6	T.57.,R.14W., Sec.14	20 to 100	Till and peat.	As much as 200	As much as 500

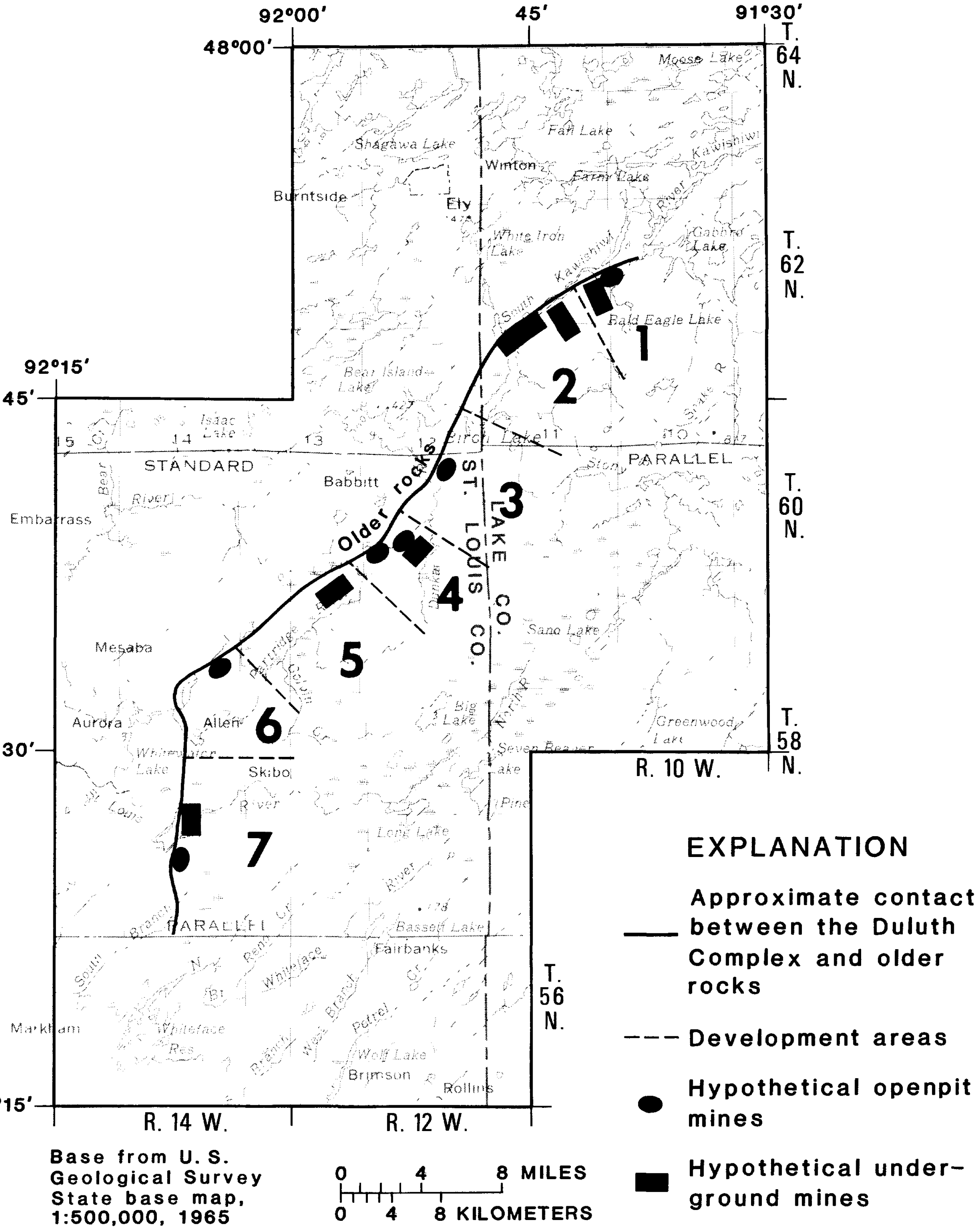

Figure 37.--Hypothetical mining areas and mine sites (from data supplied supplied by the Regional Copper-Nickel Study Staff, 1978)

50 feet thick, which are in hydraulic connection with the aquifer underlying the Dunka River basin. Discharge to the mine from these deposits could be as much as 2,000 gal/min. Such continuous discharge could ultimately displace the Dunka Basin ground-water divide southward and divert streamflow from the Dunka River to the mine. A similar diversion west of the hypothetical open-pit operation occurs from springs that discharge as much as 500 gal/min to the Erie Dunka Mine Pit. The source of the springs is buried sand and gravel that is exposed on the mine wall.

Additional Water Use

Increased ground-water withdrawals from surficial aquifers for municipal or other needs will depress the water table around pumping wells. Sand and gravel deposits underlying the Embarrass, Dunka, and Lower Partridge Rivers are the only eligible aquifers for extensive development. Of these, the surficial aquifer underlying the Embarrass River offers the best potential. Standard engineering practice in well-field design generally limits drawdown at a pumping well to two-thirds the saturated thickness of the aquifer. Therefore, assuming a minimum saturated thickness of about 150 feet, it would be theoretically possible to pump 2,000 gal/min continuously for a year from a well in the aquifer underlying the Embarrass River valley before the engineering limit is reached (fig. 38). The city of Babbitt, with a current population of about 2,900, used about 130 million gallons of ground water in 1976. This would be equivalent to 45 days of pumping at 200 gal/min. Projections of increased population by the year 2000 as a result of both copper and nickel mining and expanded taconite production is as much as 15,000 (Eric Bauman, written commun., 1978). Assuming that the additional population were to live in Babbitt, the five-fold increase in ground-water usage would still be well within the limits of the aquifer. As some of the additional population will be dispersed, impact on the aquifer would be less.

Water Quality

Water-quality impacts from mining activities upon the ground water and surface-water systems can be best evaluated with respect to the siting of potential point sources of chemical contamination to the natural system, such as mines, tailings ponds, lean-ore stockpiles, and waste-rock dumps. Leachates from these sources may contain concentrations of trace metals much greater than median concentrations in ground water. For example, copper and nickel concentrations from ground-water discharging from a bulk-ore sample site (T. 62 N., R. 11 W., sec. 25) near Filson Creek are as great as 700 ug/L. Concentration in water from nearby wells are less than 25 ug/L. Water from observation well H-2, finished at the base of the sample site, had copper and nickel concentrations of 370 and 3,800 ug/L, respectively, in April 1976. Cobalt concentration was 440 ug/L, over two orders of magnitude greater than the median concentration. Optimum location of sites for tailings basins, stockpiles, and other similar facilities would utilize natural hydrogeologic controls to minimize water contamination.

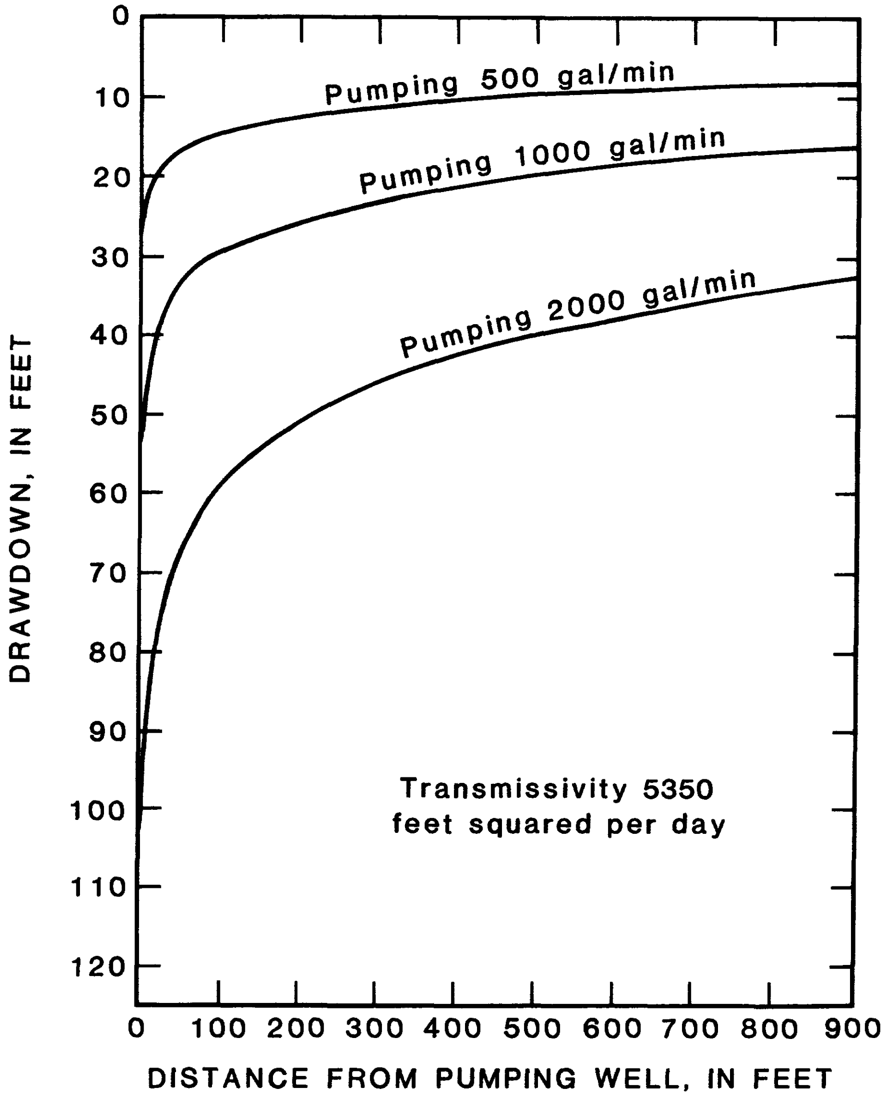

Figure 38.--Theoretical distance-drawdown curves for a well pumping from the aquifer underlying the Embarrass River

The potential for contamination of ground water is reduced where natural barriers prevent vertical ground-water flow. To guide discussion of possible impacts on the natural environment, the Regional Copper-Nickel Study Staff has delineated hypothetical mine development sites (fig. 37) adjacent to the contact between the Duluth Complex and older rocks. With the exceptions of areas 3 and 4 the surficial materials east of the contact are generally either till or peat, which restrict infiltration and ground-water movement. Drift in areas 1, 2, 5, 6, and 7 is generally less than 10 feet thick along and east of the contact and is underlain by bedrock of low permeability. Seepage from tailings basins and stockpiles into the ground-water system would be minimal in these areas. By placing potential sources of leachate in small wetland basins, contamination may be further reduced by the natural removal of some potentially toxic metals by organic compounds.

In the Dunka River basin, water bearing sand and gravel deposits are greater than 50 feet thick (Olcott and Siegel, 1978). Contamination of the ground-water system in these areas by mining activities could be minimized by placing stockpiles and tailings basins several miles to the east or south where bedrock is at the surface or is covered by thin deposits of till or peat.

SUMMARY AND CONCLUSIONS

Data were collected to identify the location and nature of ground-water resources, determine the flow characteristics and general quality of major streams, and to determine possible hydrologic effects of future mining of copper and nickel.

Ground-water investigations indicate that water generally occurs in local flow systems within surficial deposits along flow paths between 1 and 2 miles long from topographic highs to streams, lakes, and wetlands. Hydraulic gradients range from about 600 ft/mi along the flanks of the Embarrass Mountains to about 5 ft/mi in wetland areas. Hydraulic conductivities range from 10 to 3,500 ft/d for sand and gravel aquifers and from 10^{-5} to 10^{-1} ft/d for the sandy till and discontinuous peat that mantles most of the study area.

Water in bedrock generally occurs in fractures in the upper few hundred feet of bedrock units. Near its outcrop, the Biwabik Iron-formation has additional secondary porosity resulting from the leaching of hydrous minerals.

The water table decline during the drought between spring 1976 and summer 1977 averaged from 4 feet in sand and gravel to about 6 feet in till.

Availability of ground water is highly variable. Small water supplies of 1 to 5 gal/min are obtained over most of the area from shallow dug wells in drift or in the upper fractured zone of bedrock. The large sand and gravel deposits underlying the Dunka River and Embarrass River sand plain (Olcott and Siegel, 1978) are capable of yielding up to 1,000 gal/min to properly constructed wells.

The quality of ground water is generally good. Most water in the surficial deposits is moderately hard to hard and is a calcium magnesium bicarbonate type. Oxidation of copper and nickel sulfides increases the sulfate concentration in water near the mineralized contact zone between the Duluth Complex and older rocks.

Average concentrations of most major constituents in water in till are about twice that in water in sand and gravel. Concentrations of major constituents in water from surficial deposits do not significantly change during the year.

Concentrations of chromium, cadmium, lead, silver, mercury, and selenium are less than 5 ug/L in water from surficial deposits. Concentrations of copper, nickel and cobalt are generally less than 5 ug/L but may exceed 25 ug/L over the mineralized zone.

The quality of water in the Duluth Complex is highly variable. Sodium chloride type water occurs at depth, and may have a specific conductance greater than 4,000 umho/cm at 25°C. Water in the near-surface fractures within the Duluth Complex, Giants Range Granite, and Animikie Group has a quality similar to that of water from the overlying surfical material. In general, specific conductance of all ground water in the area can be correlated with hardness and dissolved solids.

Surface-water studies indicate that the average annual runoff from streams is about 10 inches, which is exceeded in Minnesota only by streams on the North Shore of Lake Superior. High precipitation, low evapotranspiration, and bedrock near or at land surface in much of the area are factors contributing to the high runoff.

The streams have similar patterns of flow except where regulation is extensive. About 60 percent of the annual runoff occurs during snowmelt in April, May, and June, whereas less than 11 percent occurs during the low-flow period from December through March.

Streamflow is affected significantly by the large volume of surface storage available in lakes and wetlands. Wetlands are located throughout the area, but lakes are concentrated primarily in Kawishiwi and Shagawa River basins. As water levels recede, streamflow is sustained by water released from surface storage.

Discharge of ground water to most streams is small because aquifers are generally small and discontinuous. For example, the average base-flow yield at most nonregulated low-flow measurement sites in August 1976 was less than 0.1 $(ft^3/s)/mi^2$.

The estimated average suspended-sediment yield at sediment stations on Kawishiwi, Dunka, and Bear Island Rivers is approximately 5 $(ton/mi^2)/yr$, which is less than that of most streams in the State. On-channel lakes upstream from the Kawishiwi and Bear Island stations trap suspended sediment and decrease the average yield.

Specific conductance of unregulated streamflow is inversely proportional to discharge. In periods of low flow, specific conductance can be as high as 200 umho. However, specific conductance is generally less than 60 umho when flows are high.

Water use was nearly constant during 1971-75, ranging from about 200 to 250 billion gallons per year. Between 85 and 95 percent was used for hydroelectric power generation at Winton and thermoelectric power generation at Colby Lakes. The remaining percentage reflects mine dewatering and domestic use. Mine dewatering accounts for about 95 percent of ground-water use. Projected increases of ground-water use by new and expanded cities will not adversely affect the major aquifers underlying the Embarrass River valley and near the Partridge River near Aurora. Unless new mining activities intersect thick sand and gravel deposits, the effects of mine dewatering upon the water table should be minimal.

Estimated ground-water discharge to projected underground mines is less than 25 gal/min. Ground-water discharge to projected open-pit mines ranges from about 100 gal/min, for mine sites underlain by thin till or peat, to about 2,000 gal/min for mine sites underlain by thick sand and gravel.

If tailings basins and ore stockpiles are located on sand and gravel deposits, such as near the Dunka and Embarrass Rivers, the introduction of trace metals to the ground-water system is possible. These impacts would be minimized by placing these facilities in parts of the study area having till and peat less than 10 feet thick and which are underlain by the relatively impermeable rocks of the Duluth Complex.

REFERENCES

Brown, E., Skougstad, M. W., and Fishman, M. J., 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A1, 160 p.

Cotter, R. D., Young, H. L., Petri, L. R., and Prior, C. H., 1965, Water-resources in the vicinity of municipalities on the western Mesabi Iron Range, northeastern Minnesota: U.S. Geological Survey Water-Supply Paper 1759-B, 36 p.

Erskine, C. F., 1975, Report on glacial drift pumping tests performed at the Minnamox Project, February 22 to 26, 1975: Amax Inc., Environmental Services Group, Denver, Colorado, 32 p.

Gray, D. M., ed., 1970, Handbook on the principles of hydrology: Water Information Center, Inc., Port Washington, New York.

Hem, J. D., 1975, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Krumbein, W. C. and Monk, C. D., 1943, Permeability as a function of the size parameters of unconsolicated sand: American Institute of Mining and Metallurgical Engineering Transactions, Petroleum Division, v. 151, p. 153-163.

Lindholm, G. F., Ericson, D. W., Broussard, W. L., and Hult, M. F., 1978, Water-resources of the St. Louis River watershed northeastern Minnesota: U.S. Geological Survey Hydrologic Investigations Atlas HA-586.

Maclay, R. W., 1966, Reconnaissance of the geology and ground-water resources in the Aurora area, St. Louis County, Minnesota: U.S. Geological Survey Water-Supply Paper 1809-U, 20 p.

Olcott, P. G. and Siegel, D. I., 1978, Physiography and surficial geology of the Copper-Nickel study region northeastern Minnesota: U.S. Geological Survey Water-Resources Investigations 78-51, 41 p.

Stark, J. R. 1977, Surficial geology and ground-water geology of the Babbitt-Kawishiwi area, northeastern Minnesota with planning implications: Madison, University of Wisconsin, unpublished master's thesis, 110 p.

U.S. Geological Survey, 1976, Water resources data for Minnesota, water year 1975: U.S. Geological Survey Water-Data Report MN-75-1, 513 p.

____ 1977, Water resources data for Minnesota, water year 1976: U.S. Geological Survey Water-Data Report MN-76-1, 896 p.

____ 1978, Water resources data for Minnesota, water year 1977: U.S. Geological Survey Water-Data Report MN-77-1, 276 p.

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Table 21.--Water-use data for the Copper-Nickel study region, Minnesota, 1971-76

[In thousands of gallons]

Map ID#	Use category and user	1971 Surface	1971 Ground	1972 Surface	1972 Ground	1973 Surface	1973 Ground	1974 Surface	1974 Ground	1975 Surface	1975 Ground	1976 Surface	1976 Ground	Disposal
	MUNICIPAL SUPPLY SYSTEM													
1	Village of Aurora	---	102,000	---	122,800	---	178,600	---	205,500	---	132,500	---	140,900	Treatment plant; creek to St. Louis River.
2	Village of Babbitt	---	110,000	---	101,900	---	98,600	---	108,100	---	107,200	---	128,100	Treatment plant; Embarrass River.
3	City of Ely	402,700	---	387,800	---	398,000	---	402,500	---	409,400	---	409,400	---	Treatment plant; Shagawa Lake.
4	Village of Hoyt Lakes	117,400	---	126,300	---	123,500	---	123,200	---	120,100	---	147,500	---	Treatment plant; Colby Lake.
		3,100	---	1,000	---	1,400	---	1,800	---	1,600	---	1,700	---	do
5	Village of Winton	7,500	---	9,700	---	7,100	---	7,500	---	7,400	---	8,800	---	Treatment plant; swamp to Fall Lake.
	TOTALS	530,700	212,000	524,800	224,700	530,000	277,200	535,000	313,600	538,500	239,700	567,400	269,900	
	RURAL SUPPLY, SELF-SUPPLIED DOMESTIC													
	Townships and unorganized territories													
	Part of Ault Township	---	500	---	500	---	500	---	500	---	500	---	500	Mainly returned to aquifer via private sewage systems. A treatment facility at Fall Lake Campgrounds includes a land-disposal system.
	Village of Babbitt	---	13,000	---	13,000	---	13,000	---	13,000	---	13,000	---	13,000	
	Babbitt Township	---	1,100	---	1,100	---	1,000	---	1,100	---	1,100	---	1,100	
	Part of unorganized territory of Birch Lake	---	16,400	---	16,400	---	16,400	---	16,400	---	16,400	---	16,400	
	Part of Colvin Township	---	6,600	---	6,600	---	6,600	---	6,600	---	6,600	---	6,600	
	Part of Embarrass Township	---	21,900	---	21,900	---	21,900	---	21,900	---	21,900	---	21,900	
	Fairbanks Township	---	2,200	---	2,200	---	2,200	---	2,200	---	2,200	---	2,200	
	Part of Fall Lake Township	---	5,500	---	5,500	---	5,500	---	5,500	---	5,500	---	5,500	
	Village of Hoyt Lakes	---	300	---	300	---	300	---	300	---	300	---	300	
	Part of Kugler Township	---	2,500	---	2,500	---	2,500	---	2,500	---	2,500	---	2,500	
	Part of unorganized territory of northeast St. Louis	---	13,100	---	13,100	---	13,100	---	13,100	---	13,100	---	13,100	
	Part of Morse Township	---	30,100	---	30,100	---	30,100	---	30,100	---	30,100	---	30,100	
	Wansa Township	---	12,000	---	12,000	---	12,000	---	12,000	---	12,000	---	12,000	
	Part of unorganized territory of West Lake	---	13,700	---	13,700	---	13,700	---	13,700	---	13,700	---	13,700	
	Part of White Township	---	35,600	---	35,600	---	35,600	---	35,600	---	35,600	---	35,600	
	Part of unorganized territory of Whiteface Reservoir	---	1,100	---	1,100	---	1,100	---	1,100	---	1,100	---	1,100	
	Stock watering	---	18,000	---	18,000	---	18,000	---	17,000	---	15,500	---	14,000	
	Tourism													
	Campgrounds (USFS)	100	200	300	200	200	200	200	300	200	300	200	300	
	Campgrounds (others, estimated	100	200	100	200	100	200	100	200	100	200	100	200	
	Resorts and cabins (estimated)	---	5,000	---	5,000	---	5,000	---	5,000	---	5,000	---	5,000	
	TOTALS	200	199,000	400	199,000	300	199,000	300	199,100	300	196,600	300	195,500	
	Irrigation													
	Mackie	---	---	3,100	---	3,400	---	5,000	---	2,300	---	9,900	---	Evaporation to atmosphere.
	Wahlberg	100	---	---	---	---	---	---	---	---	---	---	---	
	Zumbrunnen	83,200	---	55,100	---	9,800	---	34,600	---	---	---	---	---	
	TOTALS	83,300	---	58,200	---	13,200	---	39,600	---	2,300	---	9,900	---	
	HYDROELECTRIC POWER													
	Minnesota Power & Light Company													
	Winton Dam	174,042,300	---	180,974,300	---	196,454,400	---	138,220,100	---	149,082,000	---	104,163,200	---	Colby Lake and Partridge River.
	THERMOELECTRIC POWER													
	Minnesota Power & Light Company	44,174,700	---	43,798,200	---	42,800,100	---	44,200,200	---	49,289,900	---	50,237,000	---	Colby Lake and Partridge River.
88	INDUSTRIAL-MINE DEWATERING													
	U.S. Steel - Stephens Mine (69-0088)	---	762,400	---	371,200	---	464,200	---	529,600	---	431,300	---	184,800	Second Creek.
	(69-0152)	---	---	---	---	---	---	---	---	---	---	---	831,800	Second Creek.
110	Pittsburg Pacific Co-Lincoln (D Mine)	---	231,700	---	274,400	---	251,500	---	241,500	---	---	---	298,100	Second Creek.
	Knox Mine	---	---	---	---	---	---	---	---	---	1,374,500	---	791,600	First Creek.
154	Erie Mining Company - Area 1	---	---	---	---	---	---	---	2,309,100	---	1,212,700	---	730,900	
156	Area 2	---	---	---	---	---	---	---	---	---	435,100	---	214,800	Wyman Creek.
	Area 3	---	---	---	---	---	---	---	333,000	---	257,100	---	168,100	First Creek.
157	Area 6	---	---	---	---	---	---	---	846,200	---	177,000	---	[illegible]	Unnamed Creek to Birch Lake.
158	Area 8	---	---	---	---	---	---	---	855,700	---	766,500	---	625,900	First Creek.
159	Area 9	---	---	---	---	---	---	---	294,800	---	132,500	---	9,600	First Creek.
160	Area 9 South	---	---	---	---	---	---	---	322,300	---	352,400	---	269,200	First Creek.
122	Wentworth	---	434,300	---	587,800	---	720,400	---	605,300	---	574,300	---	[illegible]	(?)
	Areas 16 & 17	---	---	---	---	---	---	---	---	---	---	---	[illegible]	Unnamed Creek to Dunka River.
001	Reserve Mining Co. (P.M.M.) 001	---	1,700,900	---	942,800	---	1,053,900	---	987,900	---	1,363,700	---	718,300	Langley Creek to Dunka River.
002	002	---	389,000	---	1,003,100	---	862,500	---	1,541,800	---	872,200	---	722,000	Partridge River.
003	003	---	4,119,200	---	2,323,800	---	3,143,900	---	2,949,600	---	2,318,000	---	1,615,800	
	TOTALS	---	7,636,500	---	5,503,100	---	6,406,400	---	11,816,800	---	10,267,300	---	8,559,300	
	INDUSTRIAL-MINE PROCESSING AND OPERATIONS AND POTABLE SUPPLY													
68	U.S. Steel - Stephens Mine Well	---	200	---	100	---	100	---	100	---	600	---	300	Second Creek.
166	Pittsburg Pacific Company	---	---	---	---	---	---	---	---	71,000	---	15,300	---	First Creek.
01	Erie Mining Company - 01	5,230,300	---	4,741,000	---	5,135,000	---	4,207,400	---	4,637,200	---	5,356,800	---	
86	Reserve Mining - (69-0086)	29,600	---	28,000	---	26,000	---	32,100	---	11,900	---	[illegible]	---	Evaporation to atmosphere.
165	(69-0165)	---	---	---	---	---	---	---	---	23,500	---	[illegible]	---	Langley Creek to Dunka River.
	well	---	---	---	---	---	---	---	---	---	700	---	---	Unnamed Creek to Dunka River
	AMAX (69-0177)	---	---	---	---	---	---	---	---	---	---	2,900	---	Evaporation, infiltration
	TOTALS	5,259,900	200	4,769,000	100	5,161,000	100	4,239,500	100	4,743,600	13,000	[illegible]	300	
	INDUSTRIAL - OTHER													
	Wold, Clifford	---	---	---	---	---	---	---	400	---	1,000	---	---	Infiltration to aquifer.
	TOTAL REGIONAL WATER USE	224,091,100	8,047,700	230,124,900	5,926,900	244,959,000	6,972,700	87,234,700	12,330,000	203,656,600	10,706,800	160,883,900	9,023,800	

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
MINNESOTA ENVIRONMENTAL QUALITY BOARD AND
THE MINNESOTA DEPARTMENT OF NATURAL RESOURCES

WATER-RESOURCES INVESTIGATIONS 80-739
OPEN-FILE REPORT
PLATE 1

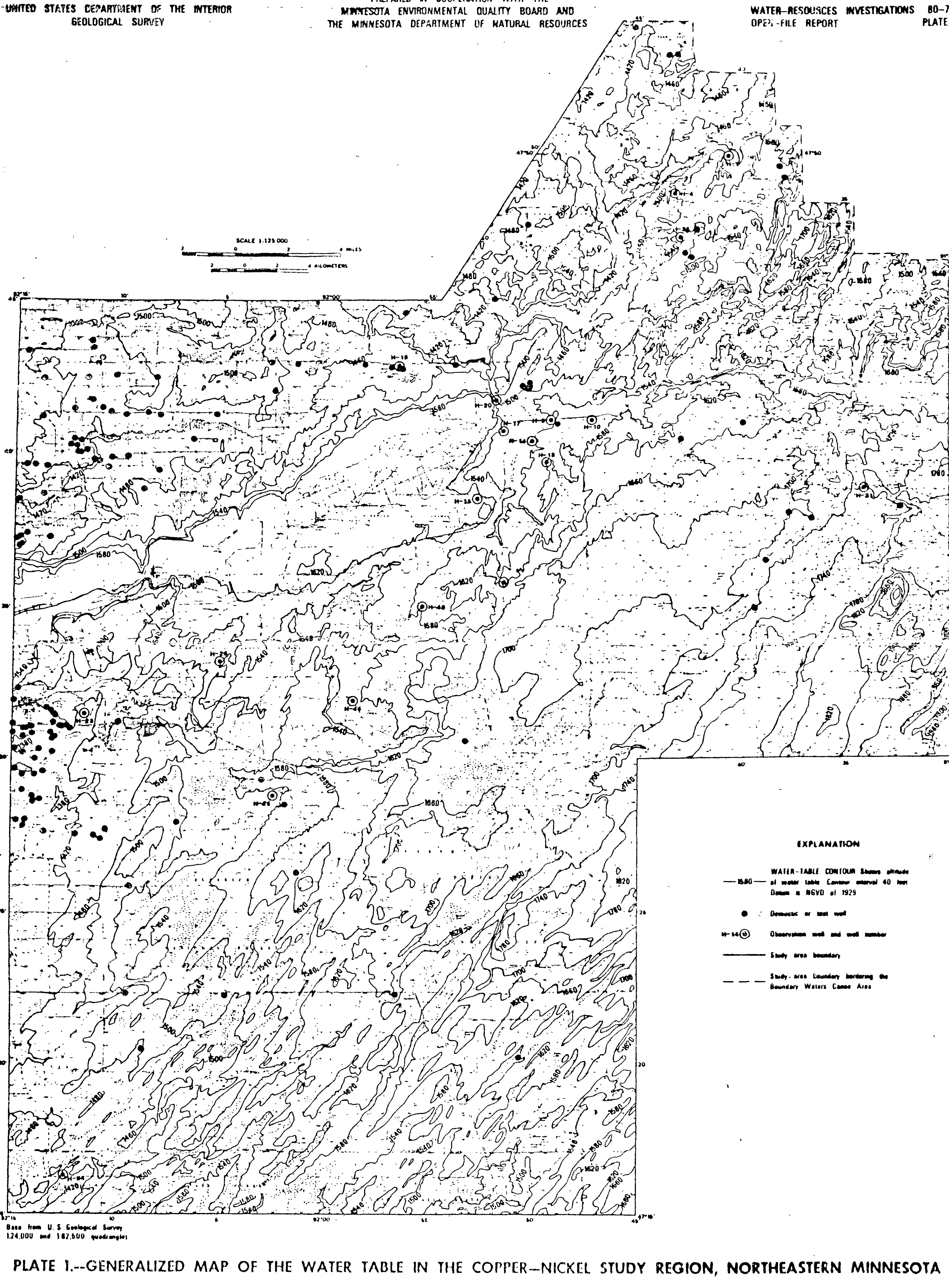

PLATE 1.--GENERALIZED MAP OF THE WATER TABLE IN THE COPPER-NICKEL STUDY REGION, NORTHEASTERN MINNESOTA