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

4

By Donald I. Siegel and Donald W. Ericson

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 78-

Open-File Report

Prepared in cooperation with

Minnesota Environmental Quality Board

Copper-Nickel Study Staff

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

Open-File Report

For additional information write to:

U.S. Geological Survey
702 Post Office Building
St. Paul, Minnesota 55101

CONTENTS

ILLUSTRATIONS

TABLES

TABLES--Continued

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 impact study, this report and a companion report on the physiography and surficial geology of the region (Olcott and Siegel, 1978) summarize the study during 1975-78 by the U.S. Geological Survey in cooperation with the Minnesota Environmental Quality Board (MEQB), Regional Copper-Nickel Study Staff, and the Minnesota Department of Natural Resources.

The Copper-Nickel Study Region is centered on about 40 miles of the lower contact of the Duluth Complex between Hoyt Lakes and the Border of the BWCA (fig. 1). It

---

Figure 1.--Near here

---

includes 1,400 square miles in parts of St. Louis and Lake Counties about 60 miles north of Duluth and 100 miles southeast of International Falls, Minn.

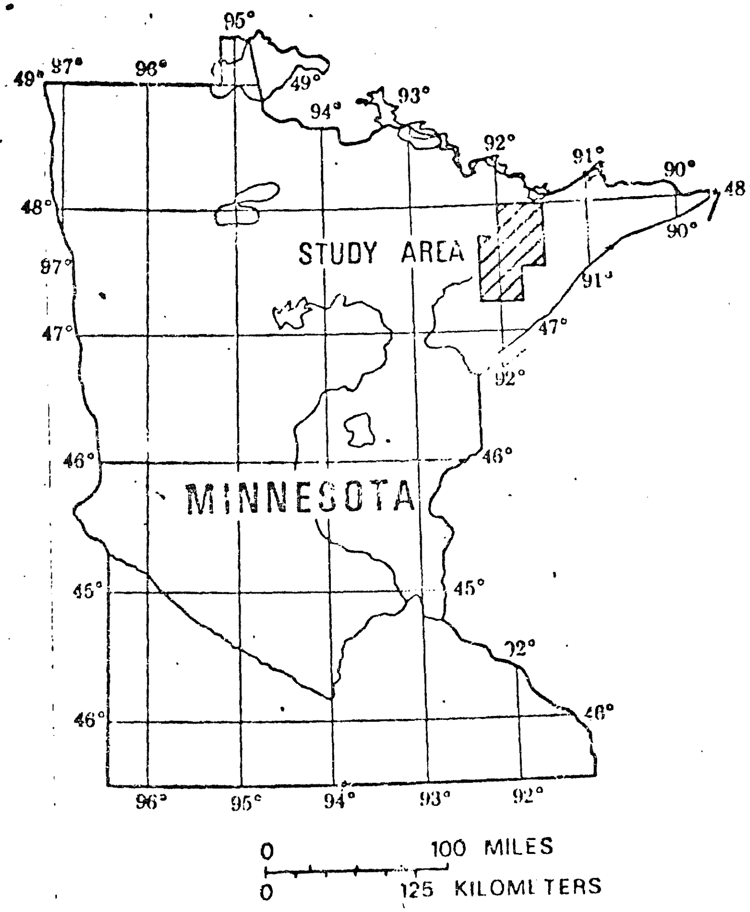


Figure 1.--Location of copper-nickel mining region in Minnesota

The purpose of this study was to determine the location and extent of aquifers in the region; the occurrence and movement of ground water, including the sources of recharge and areas of discharge; the chemical quality of the ground water; the amount of water available from storage in the various aquifers; surface-water resources and flow characteristics; and potential impacts of mining on the hydrologic system. Combined with the companion report (Olcott and Siegel, 1975), this report will provide predevelopment-baseline data necessary for evaluation of postdevelopment-hydrologic changes.

The information presented was developed from logs of wells and core holes, U.S. Geological Survey topographic maps, field observations, test augering, and literature pertaining to the geology or water resources of the region. Water samples were collected and analysed from U.S. Geological Survey and U.S. Forest Service wells, other data were obtained from files of the Minnesota Department of Health, U.S. Geological Survey, U.S. Forest Service, and private sources.

GROUND WATER

Occurrence, Movement, and Changes in Storage

Surficial deposits

Ground water in the unconsolidated surficial deposits, which consist of sand and gravel, till, and peat, generally occurs under unconfined conditions. Confined to partially confined conditions resulting from heterogeneous stratigraphy of the surficial sediments occur locally and in the southwestern part of the region where clay-rich till of the Des Moines Lobe overlies older sand and gravel deposits (Maclay, 1966).

The ground water moves slowly through the aquifers 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 (slope) of the water table or potentiometric surface.

Hydraulic conductivities (K) vary for surficial materials in the region depending on the particle-size distribution and degree of stratification. From laboratory experiments, Stark (1977) estimated hydraulic conductivities 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 calculated from particle-size distributions (Krumbein and Monk, 1943) of 8 samples of sand and gravel ranged from 0.004 to 15.5 ft/d; while hydraulic conductivities calculated for 4 samples of Rainy Lobe till ranged from 2.1 x 10^{-5} to 0.13 ft/d.

Results from seven aquifer tests in the sandy drift in 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, estimated hydraulic conductivities in the region 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 till deposited by the Des Moines Lobe and peat.

The saturated thickness of surficial aquifers is dependent on the position of the water table, which may be considered a subdued replica of the topographic surface. For sand and gravel or till aquifers, the water table is generally deeper under topographically high areas than under topographically low areas underlain by similar material. In the topographic lows and wetland areas, the water table is usually near or at the surface.

The hydraulic gradient for surficial aquifers can be determined from the contour map (pl. 4) of the generalized water table. Ground-water divides on the water table underlie topographic highs and approximately coincide with them, and generally delineate local ground-water flow systems in the glacial drift.

Within the physiographic areas (fig. 2), which are de-

Figure 2.--Near here

---

fined by Olcott and Siegel (1978), the hydraulic gradients can vary considerably. The most extreme range of hydraulic gradient is in the Embarrass Mountains-Taconite Mining Physiographic Area, which has a steep topography and a large wetland along the southern margin of the Embarrass Mountains. Gradients range from 640 ft/mi for short distances at the northeastern end of the Embarrass Mountains to less than 5 ft/mi in wetlands in the center of the area.

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.

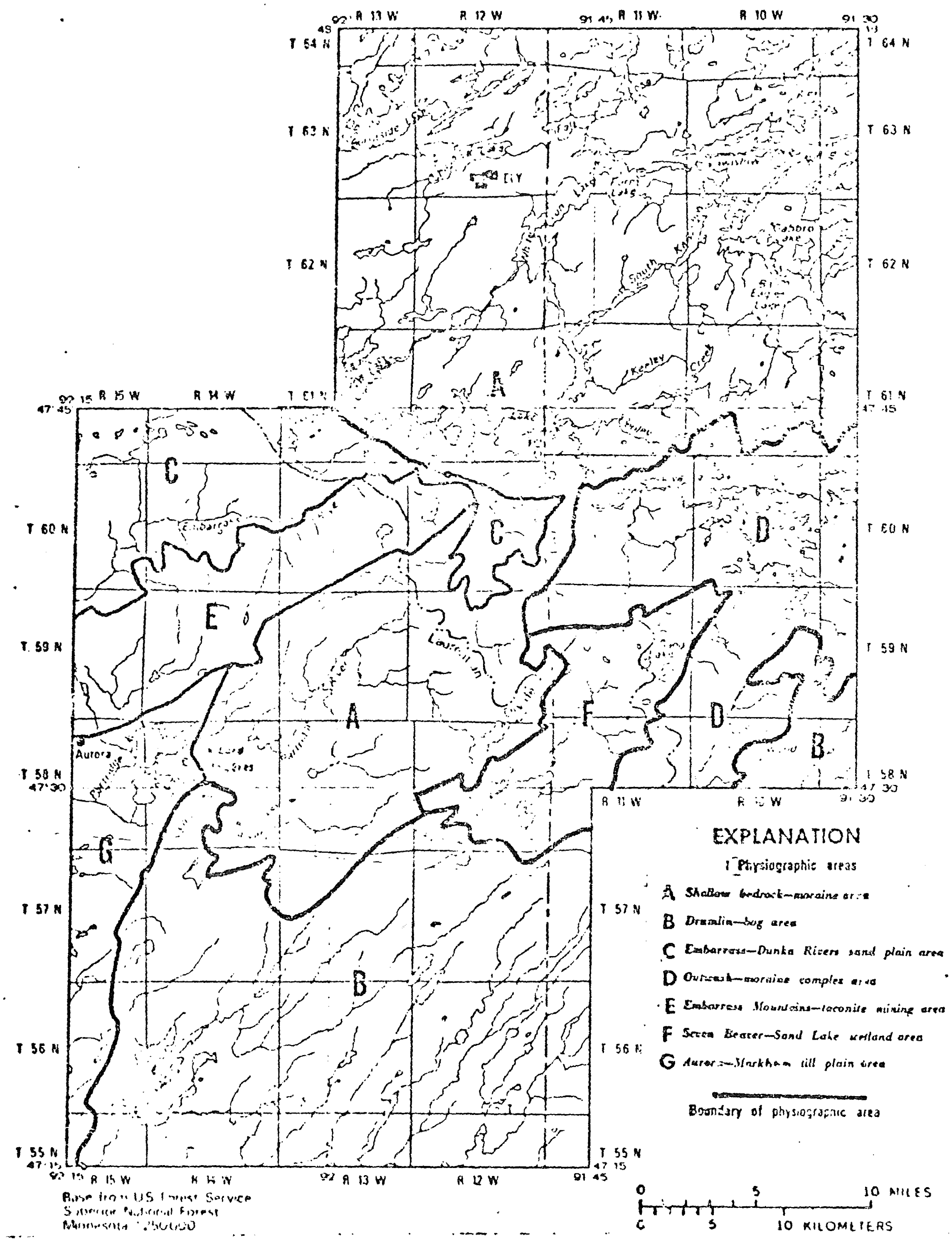


Figure 2 Physiographic areas of the Copper-Nickel Study Region (from plate 2)

Ground-water flow is perpendicular to the water table contours and occurs within local ground-water flow systems that are defined by stratigraphy and topography. The length of flow paths from subbasin divides to streams, lakes, and wetlands generally are 1 to 2 miles. The local flow systems are interconnected such that the regional ground-water movement is northward from the Laurentian Divide to the Kawishiwi River system and westward and southwestward to the St. Louis River. Ground-water moves locally from basin and subbasin divides to streams, lakes, and wetlands where it is discharged.

In the Shallow Bedrock-Moraine and Outwash-Moraine Complex Physiographic Areas, ground-water movement is toward the Stony and Kawishiwi River systems. Movement is generally very slow both because the till and peat are relatively impermeable, and because the flow system in the surficial materials is disrupted by bedrock outcrop. Ground-water velocity through sand and gravel is higher, but the volume of flow is limited because the saturated thickness is generally less then 10 feet. Ground-water movement is toward the larger streams and lakes in the Drumlin-Bog and Seven Beaver-Sand Lake Physiographic Areas.

Ground water within the Toimi Drumlin field generally moves perpendicular to the NE-SW strike of the drumlins. Movement within wetlands that are interspersed between the drumlins and associated with the Seven Beaver-Sand Lake Wetland Area follows the trends of surface water drainage toward the southward flowing Whiteface, Cloquet, and St. Louis Rivers.

The ground-water systems within the sand and gravel deposits which underlie the Embarrass-Dunka Rivers Sand Plain Area have boundaries well delineated by till and moraines and the Embarrass Mountains. Ground-water moves from these areas toward the Embarrass and Dunka Rivers. Once in the sand and gravel deposits, movement is probably rapid because of high hydraulic conductivities.

Recharge to ground water in the surficial deposits mostly is directly from precipitation. Part of the water that falls on the earth is returned to the atmosphere by evaporation, part runs off to streams, and a part infiltrates into the ground. Infiltration rates are greatest in the Embarrass and Dunka River basins, which are underlain by permeable sand and gravel deposits and least in the wetland areas which are always saturated near the land surface.

Recharge to surficial aquifers from underlying bedrock aquifers is not important because the major bedrock units are relatively impermeable. However,in the southern part of the study region near Aurora, semi-confined sand and gravel aquifers may locally discharge ground water to overlying aquifers where confining beds are discontinuous, and seepage from the Whitewater Reservoir at high stage artificially recharges adjacent sand and gravel aquifers.

Ground water discharges to streams, lakes, and wetlands. On a local scale, the amount of ground-water discharge depends on the hydrologic head distribution within local flow systems, the thickness of the aquifer and the hydraulic conductivities of the aquifer material. Ground-water discharge is greatest in those areas having high hydraulic gradients and hydraulic conductivities.

Ground water maintains the base flow of streams and contributes a small part to the yearly surface-water discharge. For example, during 1976, a year of low rainfall, ground-water discharge maintained base flow in the large streams but contributed less than 10 percent of the total surface-water discharge during the year. Because parts of their watersheds are underlain by sand and gravel deposits, the Partridge, Dunka, and Embarrass Rivers probably receive more ground-water discharge than the South Kawishiwi River and Stony Rivers.

Due to continually changing iron-mining activities, which include diversions for iron-ore processing and dewatering of mine pits, the base flow of the Dunka and Partridge Rivers attributable to ground-water discharge during low-flow conditions can not be adequately estimated. Base flow measured on August 8, 1976 for the Embarrass River near Embarrass was 1.76 ft^3/s.

Springs discharge from sand and gravel filled channels within the Rainy Lobe drift that are exposed on the walls of the open-pit mine north of the Dunka River (pl.). Hydraulic conductivities of these deposits may be as much as 16 ft/d. Low-flow measurements indicate that flow from the Dunka River, which is located about 100 feet from the mine wall, is being diverted through the ground-water system to these springs. Low-flow measurements of the Dunka River above and below the mine area indicated that about 1.5 ft^3/s was moving from the river to the mine in late August 1977.

Depending on the water elevation, seepage from Whiteface Reservoir ranges from less than 1 to 10 million gallons per day to the Partridge and St. Louis Rivers through springs and sand and gravel deposits. Ground water seeps from a bulk-sample excavation site at about 0.33 gal/min in the Filson Creek basin (T.61 N., R.12 W., sec.3).

Changes in storage within the surficial aquifers are reflected by the water-table hydrographs (figs. 3 and 4) for

---

Figures 3 and 4.--Near here

---

observation wells monitored from 1975 through spring 1978. The hydrographs show that the water table fluctuated parallel with and as much as 1 to 1-1/2 months behind major trends in the cumulative departure from mean monthly precipitation as recorded at Babbitt between 1956 through 1974 (fig. 5).

Figure 5.--Near here

The water-table decline during the drought from spring 1976 to summer 1977 averaged 4.3 feet for sand and gravel aquifers to about 6 feet for till aquifers. The greater water-table decline in till aquifers reflects the lower storage in the till as compared to sand and gravel. Because of this lower storage, till aquifers respond more quickly to recharge events or water-table decline due to drought conditions.

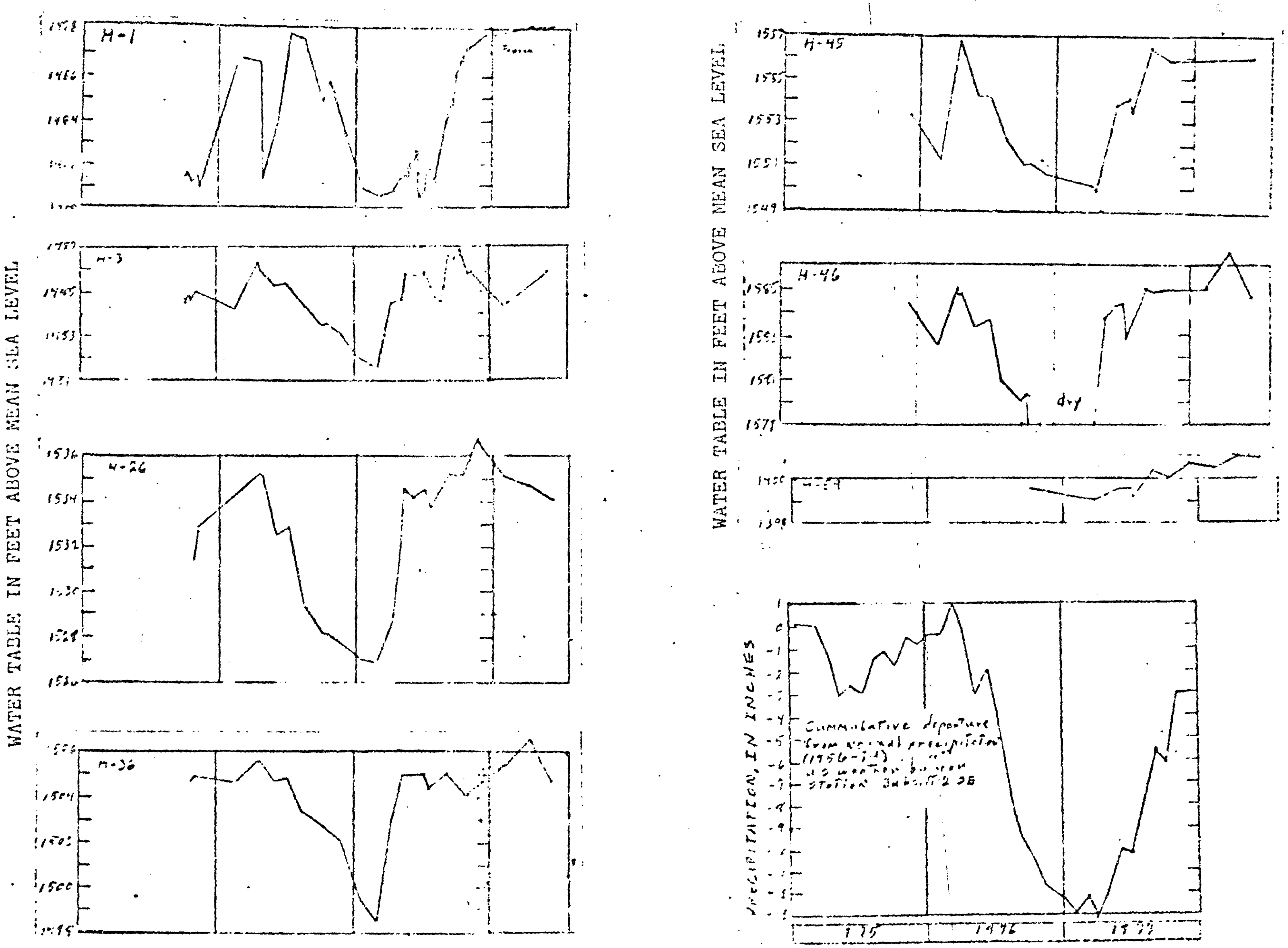


Figure 3 water-table hydrographs in till apuifers and cumulative departure curve from mean monthly precipitation (1956-1974) at Babbitt, Minnesota.

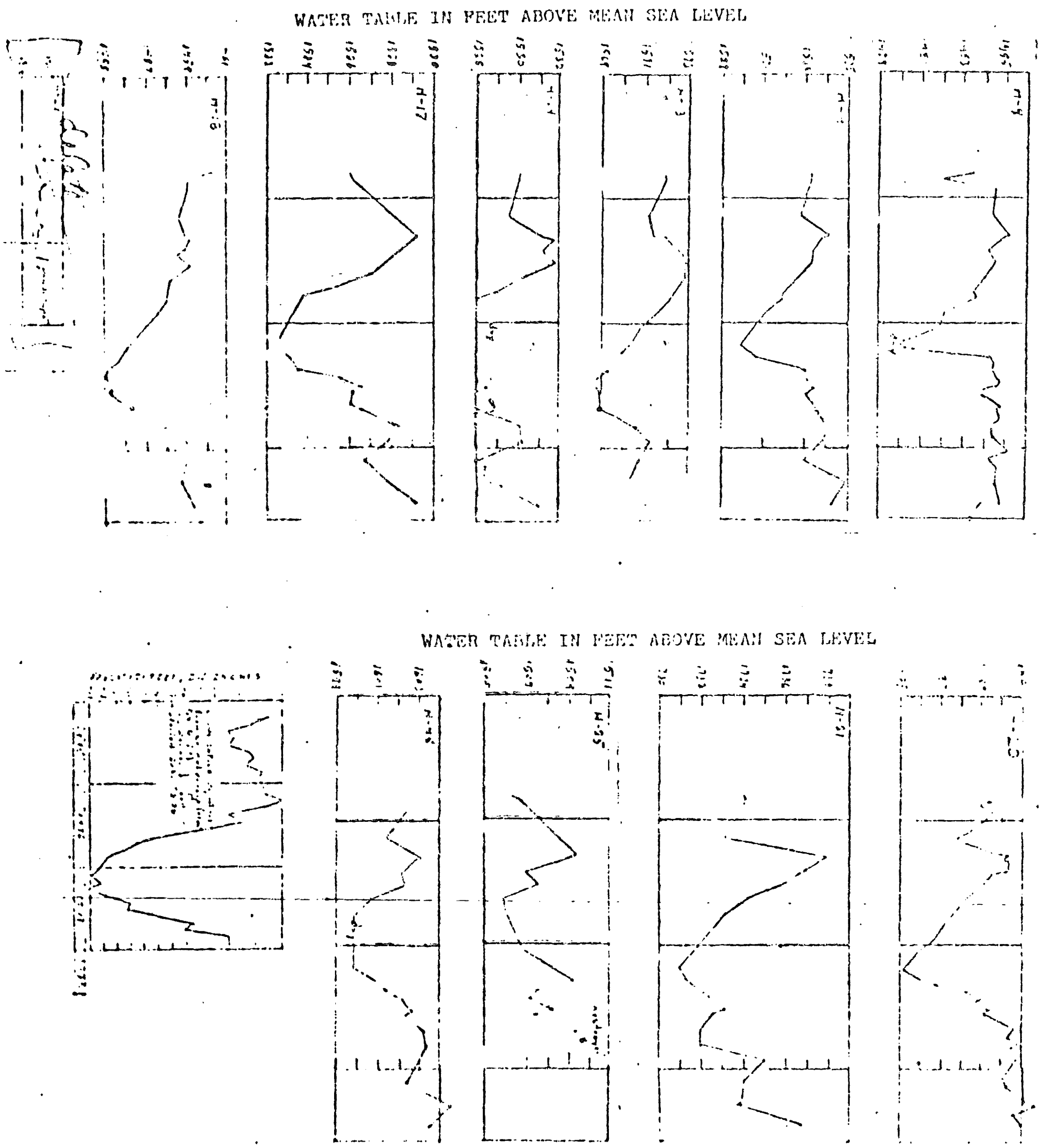


Figure 4 water table hydrographs in sand and gravel aquifers and cumulative departure curve from mean monthly precipitation (1956-1974) at Bemidji, Minnesota.

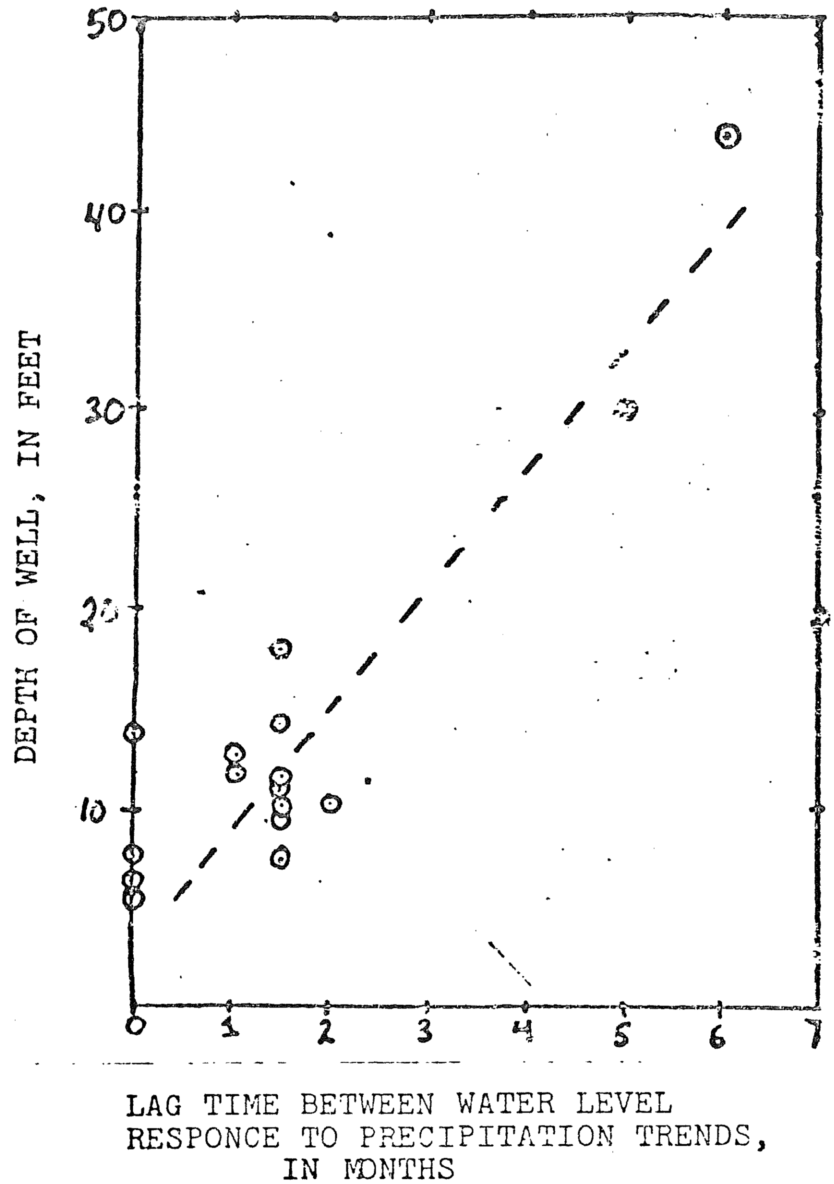


FIGURE 5.--Graph showing relation between depth of observation well and lag time in water-level response to major trends in cumulative departure from normal precipitation. at Babbitt, Minnesota for 1976-77. (Curve visually drawn.)

Bedrock aquifers

Ground 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.

The major fracture and joint systems in part of the mining area have been mapped (Cooper, 1978). These openings probably extend to considerable depths but are more extensive in the upper 200 to 300 feet of the rock units. The fractures in the upper part are interconnected and provide local secondary permeability.

Large quantities of ground water occur in the Biwabic Iron-formation in its area of outcrop. Oxidation and hydration of taconite minerals, coupled with leaching, have produced extensive secondary porosity as high as 50 percent (Cotter and others, 1965).

Near surface bedrock aquifers are under unconfined conditions except where overlain by drift with low permeability. The deeper aquifers tend to be under confined conditions. For example, several core holes that penetrate through the Duluth Complex and into the underlying Biwabik Iron-Formation at the Amax Mining Company shaft site, (T.60 N., R.12 W., secs.28,29) flow at land surface.

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

Recharge to the bedrock aquifers is from leakage from overlying surficial aquifers and infiltration of precipitation in outcrop areas. The flowing wells of the Biwabik Iron-formation are recharged by rain and snowmelt in the outcrop area.

The extent of ground-water discharge from bedrock aquifers is unknown, but probably is minimal due to the limited areal extent of fractures and other secondary permeability. Ground water discharge from bedrock occurs in the taconite mines. For example, discharge from the Biwabik Iron-Formation and surficial aquifers, has created a small lake in an abandoned open-pit mine near Aurora and in other abandoned mines in the Iron Range.

Information on water-level fluctuations for bedrock wells is limited. Stark (1977) reports a 1- to 1-1/2-month delay in water level response to precipitation events for a bedrock test hole in the Duluth Complex during 1975. However, since the test hole was uncased, the water level was probably a composite of both the potentiometric surface in the bedrock, if present, and unconfined conditions within the overlying surficial sediments.

Water levels in the bedrock aquifers will respond similarily to water-table fluctuations where communication exists between bedrock and surficial aquifers.

HYDROLOGIC BUDGET

Nearly identical annual hydrologic budgets (table) for the Kawishiwi River watershed above Winton and the St. Louis River watershed above Aurora (fig. 6) suggest that

---

Figure 6.--Near here

---

hydrogeologic conditions in the two areas are similar. The budgets, which are based on average figures for 1955-76, present a representative outline of water gain, storage, and loss for the watersheds. Components considered in the water budget are given in the following equation:

Precipitation = runoff + evapotranspiration + underflow + changes in storage

On a long term basis, underflow and changes in storage can be assumed to be negligable (Lindholm and others, 1978). There are no known cases of underflow in these watersheds. However, a small amount of water may be moving in river alluvium or through bedrock across basin boundaries. Although changes in ground-water storage occur continuously, over a long period of time increases in storage tend to equal decreases in storage and the net change is zero.

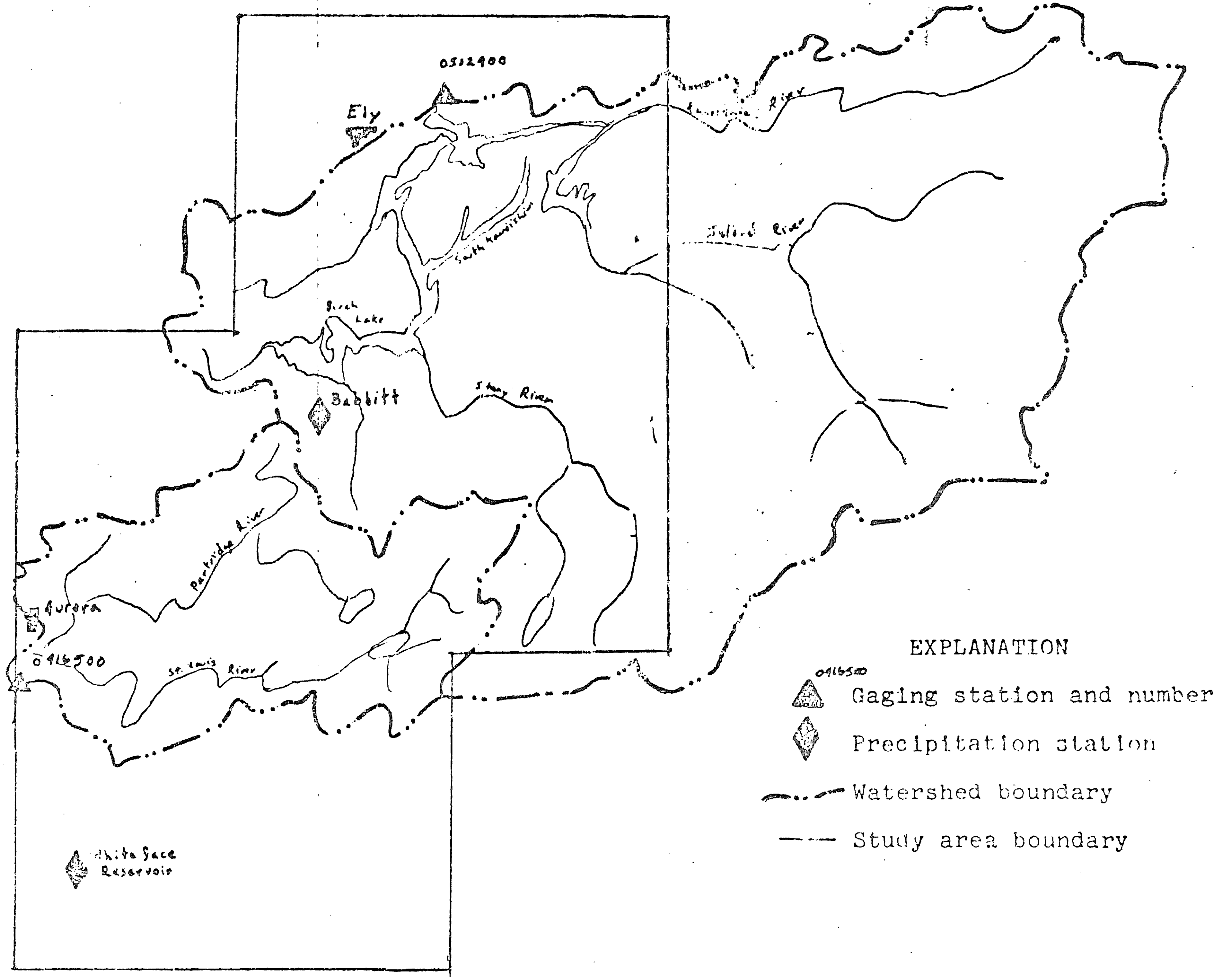


Figure 6.-Stream gages and precipitation stations for the Kawishiwi River watershed above Winton and St. Louis River watershed near Aurora

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

Actual evapotranspiration was calculated as a residual value, and potential evapotranspiration for Babbitt was calculated using the Thornthwaithe equation (Gray, 1970). Potential evapotranspiration was 21.4 inches, and favorably compares to residual values of 18.1 inches for the Kawishiwi watershed and 17.6 inches for the St. Louis watershed. Both watersheds have similar vegetation and are underlain by similar types of drift. Runoff per square mile of watershed is nearly identical (table 1).

Table 1.--Near here

Table 1. Approximate annual-Water Budgets for the Kawishiwi River watershed above Winton and the St. Louis River watershed above Aurora

	Precipitation, in inches	Runoff, in inches	Evapotranspiration, in inches	Underflow and change in storage, in inches
Kawishiwi River	27.6	9.4	18.1	0
St. Louis River	27.2	9.6	17.6	0

Availability

The availability of ground water in this thin drift-crystalline bedrock region is highly variable (fig. 7)

Figure 7.--Near here

---

and, except in a few areas, only small quantities can be obtained. Small water supplies of 1 to 5 gal/min are obtained over most of the area from shallow dug wells in drift that tap water in a thin zone at the bedrock surface. Although vulnerable to drought, these supplies are adequate for domestic use most of the time. Similar small supplies are obtained from wells drilled into crystalline bedrock but many of the attemped wells are dry. The U.S. Forest Service, with adequate exploration and development proceedures, obtains as much as 30 gal/min from several wells in camp and picnic grounds. Outwash and ice-contact sand and gravel deposits, depending on extent and saturated thickness, yield from less than 5 to about 1,000 gal/min to properly constructed wells. 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 in the region is summarized in table 2.

Table 2.--Near here

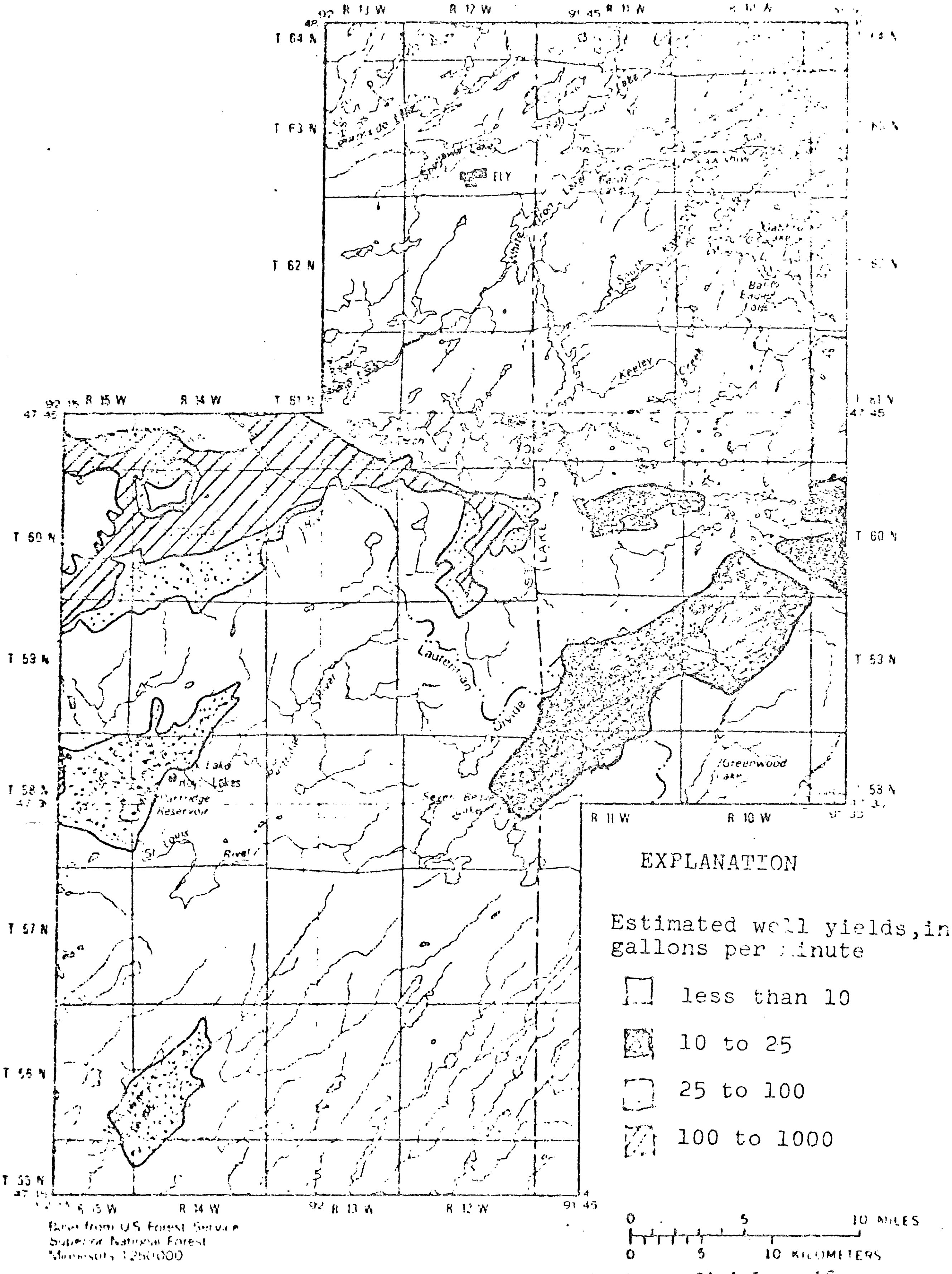


Fig. 7.--Estimated average yields of wells in surficial aquifers

Table 5.--Geologic units and their lithologic and water-bearing characteristics

System	Major units	Subdivision	Estimated maximum thickness (ft)	Description	Estimated range of Hydraulic conductivities in ft/day	Water supply and water-bearing characteristics.
Quaternary	Holocene	Peat deposits	40±	Peat, locally contains clay, silt and fine sand	10^{-3} to 10^{-1}	Not a significant source of water
		Aluvial 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 a 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 deposites composed largely of poorly sorted sand, gravel, and boulders. Channel deposits of clay, silt, sand, and fine to coarse gravel.	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 water to domestic wells. Yields to domestic wells commonly 5-10 gal/min.
Precambrian		Duluth Complex	(?)	Largely troctolite	- - -	May yield 5-15 gal/min from fractured zones near its upper surfaces.
	Animikie Group	Virginia Argillite	2,000±	Thinly bedded, gray to black argillite.	- - -	May yield up to 30 gal/min from fractured zones near its upper surface. Utilized for numerous domestic supplies.
		Biwabik Iron-Formation	800+	Taconite--dark-colored hard dense iron-bearing silicic 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 numerous municipal and industrial supplies.
		Pokegama Quartzite	350±	Varicolored vitreous quartzite.	- - -	May yield 5-15 gal/min from fractured zones near its upper surface.
		Giants Range Granite	(?)	Largely granodiorite		May yield 5-15 gal/min from fractured zones near its upper surface.

Specific capacity, (well yield per foot of drawdown in water level) of wells in the region is given in tables 3 and 4. The values are an indication of the maximum

Tables 3 and 4.--Near here

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 per min per ft and in bedrock from 0.02 to 0.11 gal per min per ft. Wells in the Biwabik Iron-Formation, where fractured and leached, have specific capacities of 0.24 to 13.

Table 3.--Specific capacities for wells in [illegible] aquifers

Well locations	Well Depth (in feet)	Diameter (in inches)	Pumping period (in hours)	Specific capacity [illegible] [(gal/min)/ft]
56-14-17cda	90	6	8	0.19
56-14-17cdc	80	6	8	0.03
56-14-20bab	35	6	8	1.88
57-12-31baa	70	6	8	0.05
57-14-8 ba	37	6	8	0.32
57-15-22cdb	80	4	24	0.57
58-15-3 bcc	70	6	3	25
58-1[illegible]-3 b[illegible]c	70	6	10	23
58-15-4 dba	35	5	.5	7.1
59-10-[illegible]db	48	6	6	0.[illegible]4
59-15-31dac	64	18	1 week	1[illegible]
60-9-18 aab	23	7	8	11
60-9-27 bac	78	6	8	0.25
60-9-27 cac	30	6	8	10
60-10-21bbb	49	6	8	7.5
60-10-36dab	28	6	8	18.
60-12-5 baa2	13	12	4	4.0
60-13-1 bab1	138	26	8	38.
60-13-1 bab3	128	12	8	13.
60-13-1 bab4	157	16	11.5	5.9
60-13-1 bba	67	24	10	19.
61-14-2 db	40	20	4	30
61-14-4 cca	98	20	4	13.
63-11-31aac	16	24	1	10
63-13-27acc	70	6	12	1

Table 4 .--Specific Capacities for Some Wells Completed in Bedrock

Water-bearing unit	Well location	Pumping period (in hours)	Depth (in feet)	Specific Capacity ((gal/min)/ft)
Biwabik Iron-Formation	58-15-3 cca2	6	455	3.0
	59-15-26dbc	24	299	0.24
	59-15-26dbc	45	398	0.25
	60-12-17aad	20	110	6.55
Giants Range Granite	59-14-2 adcc	8	197	0.03
Duluth Complex	61-11-19bdc	4	125	0.11
	61-11-34bbc	4	225	0.02

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

Well locations	Well Depth (in feet)	Diameter (in inches)	Pumping period (in hours)	Specific capacity, in [(gal/min)/ft]
56-14-17cda	90	6	8	0.19
56-14-17cdc	80	6	8	0.03
56-14-20bab	35	6	8	1.88
57-12-31baa	70	6	8	0.05
57-14-9 ba	37	6	8	0.32
57-15-22cdb	80	4	24	0.57
58-15-3 ccc	70	6	3	25
58-15-3 bcc	70	6	10	23
58-15-4 dba	35	6	.5	7.1
59-10-18cdb	48	6	6	0.14
59-15-31dac	64	18	1 week	18
60-9-18 aab	23	7	8	11
60-9-27 bac	78	6	8	0.25
60-9-27 cac	30	6	8	10
60-10-21bbb	49	6	8	7.5
60-10-36dab	28	6	2	18.
60-12-5 baa2	13	12	4	4.0
60-13-1 bab1	138	26	8	38.
60-13-1 bab3	128	12	8	13.
60-13-1 bab4	157	16	11.5	5.9
60-13-1 bba	67	24	10	19.
61-14-2 db	40	20	4	30
61-14-4 cca	98	20	4	13.
63-11-31aac	16	24	1	10
63-13-27acc	70	6	12	[illegible]

Well yields by physiographic areas

In the following discussion, the physiographic areas (fig. 8) delineated in part 1 of this report (Olcott and

---

Figure 8.--Near here

Siegel, 1978) provide the framework for delineation of ground-water availability in the study region. Table 5 summarizes

---

Table 5.--Near here

---

ground-water availability by physiographic areas.

The shallow bedrock-moraine area is characterized by numerous bedrock outcrops and thin drift. Unconsolidated deposits, which are generally less than 10 feet thick, consist largely of ground moraine. Lenses of sand and gravel occur locally and a discontinuous clay layer, 1 to 3 feet thick, overlies bedrock in topographically low areas.

Well yields in much of the area are generally less than 10 gal/min because drift aquifers are thin and relatively impermeable. Wells in fractured bedrock generally yield 1 to 5 gal/min.

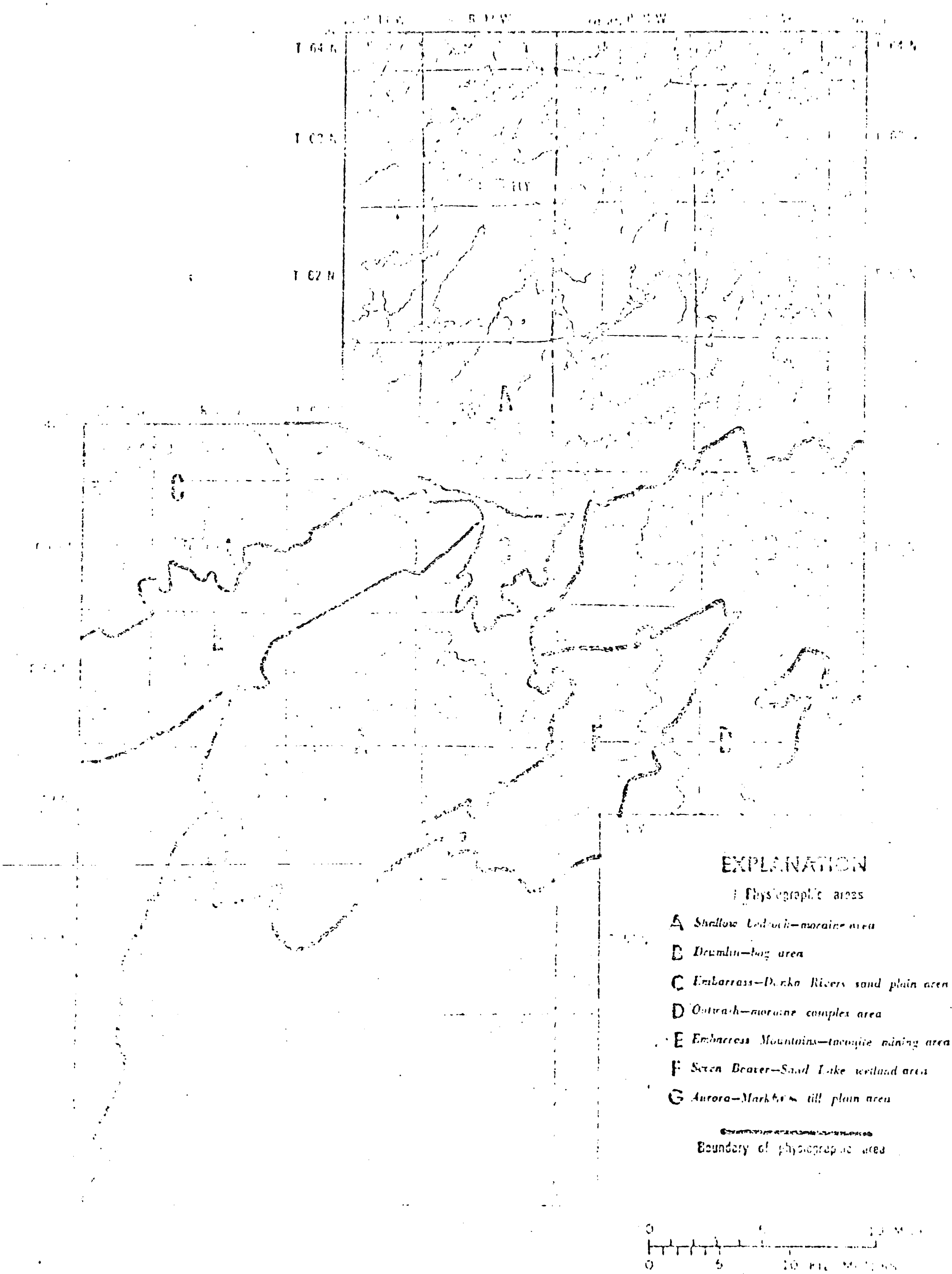


Figure 8.—Physiographic areas of the Copper-
... (from White ?)

Table 5.--Ground-Water Availability by Physiographic Area

Physiographic area	Water-bearing units	General aquifer thickness (in feet)	Estimated potential yields to well (in gallons per minute)
Shallow bedrock-moraine area	till upon fractured bedrock	10 feet of till; 100 feet of bedrock	5
Drumlin-bog area	till, discontinuous lenses of sand and gravel within till	50	5
Embarrass-Dunka Rivers sand plain area	sand and gravel	50 to 200	5 to 1,000
Outwash-moraine complex area	till, sand and gravel lenses	15	5 to 25
Seven Beaver-Sand Lake wetland area	till, sand and gravel lenses	15	5 to 25
Aurora-Markham till plain area	sand and gravel	50 to 150	10 to 300
Embarrass Mountains taconite mining area	Biwabik Iron-Formation	800±	100 to 1,000

The Aurora-Markham Till Plain Area roughly coincides with the area covered by red clayey till of the Des Moines Lobe. The red clayey till was deposited on an older, bouldery till that overlies the bedrock. Several broad channels in the older bouldery till are filled with as much as 150 feet of outwash sand and gravel (Maclay, 1966). The channels are confined by the overlying red clayey till.

Outwash deposits occur between Aurora and the Partridge River and may extend southward along the map boundary to Loon Lake (Olcott and Siegel, 1978, pls. 1 and 3). Yields of wells should be about 100 gal/min where the aquifer is thickest. Aquifers in the shallow unconfined sand and gravel deposits near the Partridge River and Second Creek and the low terraces (secs. 14, 21, and 22, T.58 N., R.15 W.) along the St. Louis and Partridge Rivers may yield 100 to 200 gal/min to wells (Maclay, 1966). Similar yields should be available from sand and gravel deposits between Whitewater and Colby Lakes and north and northeast of Colby Lake.

Wells in the red clayey and bouldery tills northeast of Aurora yield less than 5 gal/min. Deep wells in fracture zones in the Biwabik Iron-Formation near Aurora may yield as much as 300 gal/min.

The Drumlin-Bog and Seven Beaver-Sand Lake Areas include the northern most extent of the Toimi Drumlin Field and the extensive wetlands around Seven Beaver Lake. The drumlins consist of 30 to 75 feet of compacted clayey till that rests on bedrock. Logs of test holes indicate that the bog areas are typically underlain by 1 to 3 feet of clay resting on bedrock, 2 to 6 feet of sand, and 10 to 15 feet of peat.

Thick buried sand and gravel lenses, which locally may be present beneath bogs, could yield as much as 25 gal/min to wells for short periods. However, development of wells for sustained yields may be limited by the amount of recharge that can occur through relatively impermeable till and peat.

Except for small isolated eskers that consist of sand and gravel, estimated maximum yields from wells in till and bedrock are less than 5 gal/min. The esker deposits where saturated may have sustained yields of up to 25 gal/min.

Ground water availability in the Outwash-Moraine Complex Area is confined to the numerous small areas of sand and gravel which are generally less than 15 feet thick. Thick morainal deposits in the area may contain lenses of sand and gravel. Where these lenses are confined by low permeable till, recharge is decreased and the sustained yield is limited. Except for a few areas, yields to wells in these deposits are estimated to be between 5 and 25 gal/min.

In the Embarrass Mountains-Taconite Mining Area, relatively small amounts of water are available from wells in the drift, Pokegama Quartzite, Virginia Argillite, Duluth Complex, and Giants Range Granite. Yields are generally less than 5 gal/min and are only useful for domestic supplies. In the Biwabik Iron-Formation, ground-water availability is dependent upon local variations in porosity and permeability. Where the taconite beds are fractured and leached, porosity is as much as 50 percent and yields greater than 1,000 gal/min from wells are possible. Prediction of potential yields at a particular location in the Biwabik Iron-Formation is not possible because of the wide variations in secondary permeability such as fractures and leached zones.

Sand and gravel deposits in the Embarrass-Dunka Rivers Sand Plain Area have the greatest potential for future ground-water development of any aquifer in the study area. West of Babbitt, thicknesses in the Embarrass River Sand Plain range from less than 50 to more than 200 feet. Yields as high as 1,000 gal/min are possible from coarse gravel deposits. Yields of 100 gal/min to wells are available from the thin silt and sand deposits underlying the Dunka River basin.

WATER USE

Water-use data compiled for the study were obtained from state, municipal, and private sources. Appropriation permits provided by the Minnesota Department of Natural Resources were the main data source for 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.

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 territories. Water use by tourism was estimated by visitor days per resort. Water use by hydroelectric generation was obtained from U.S. Geological Survey 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 170 billion gallons per year. Data summarizing water use between 1971-76 is given in plate . Locations of major water use are shown in figure 9.

Figure 9.--Near here

From 1971-75, between 69 and 75 percent of water used was related to hydroelectric power generation at Winton (fig. 10). Another 17 to 30 percent was for thermoelectric

---

Figure 10.--Near here

---

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 of total water used. Less than 3 percent of total water used during 1971-76 was for municipal, rural, and irrigation needs, while mine dewatering accounted for between 2 and 6 percent.

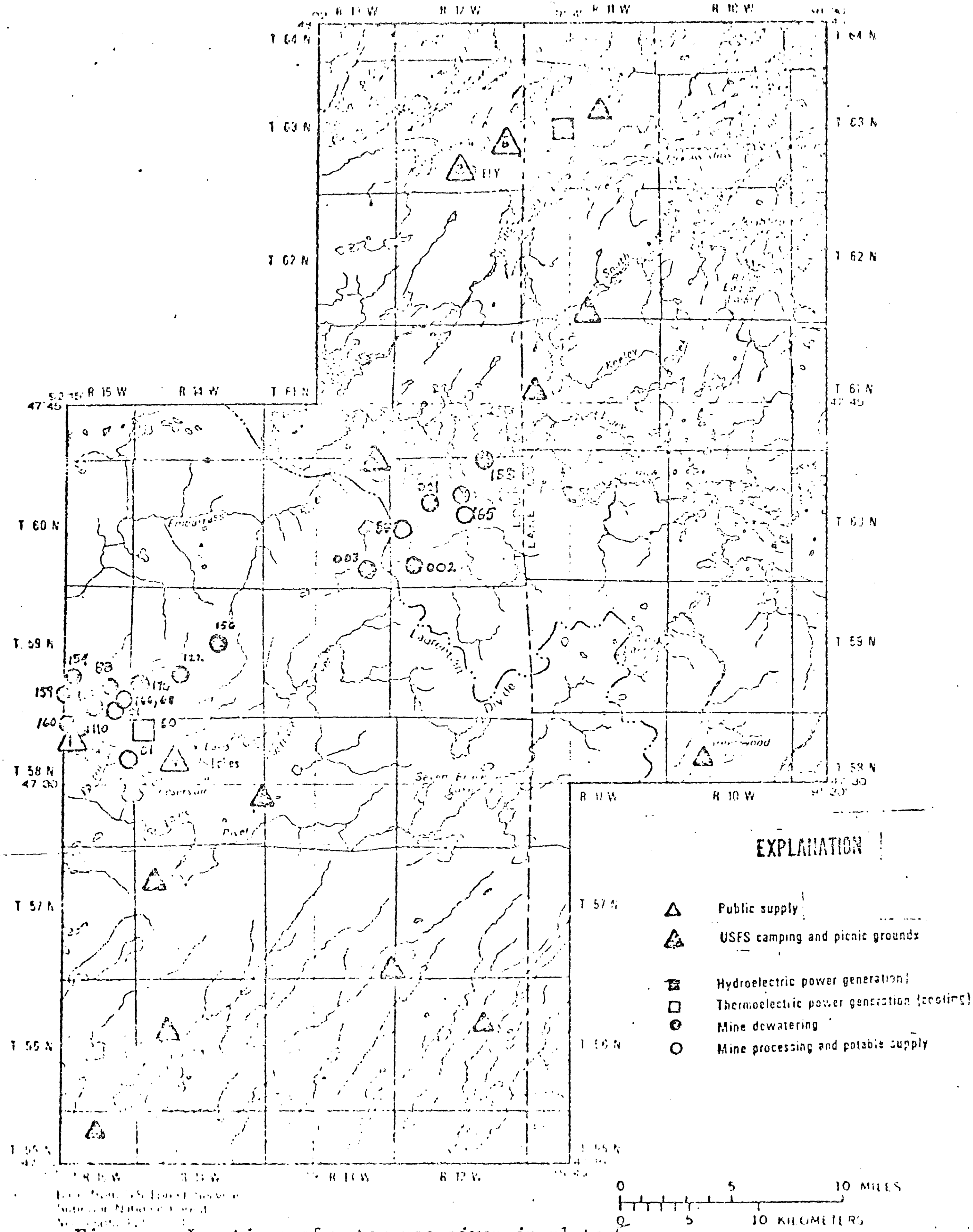
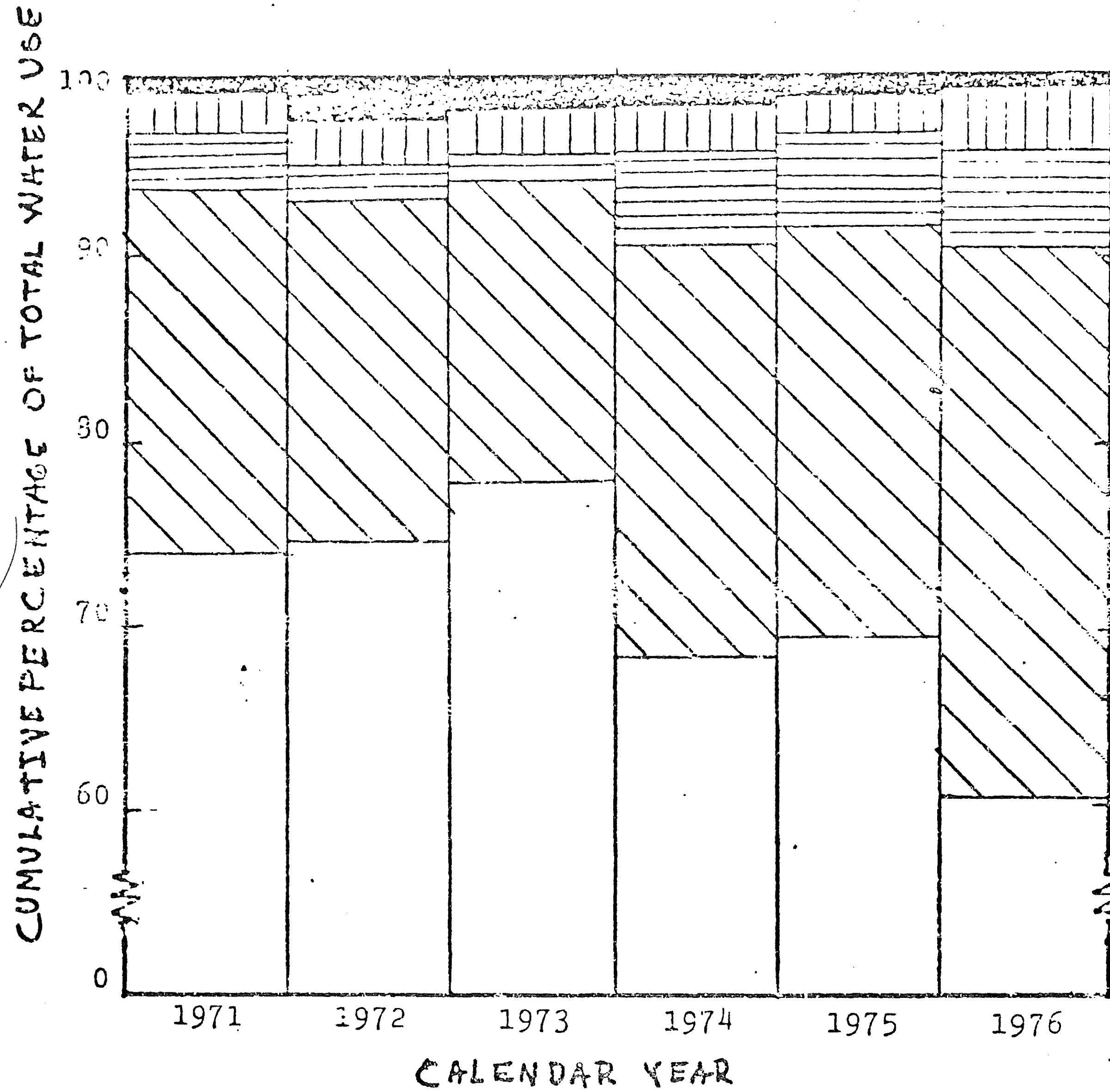
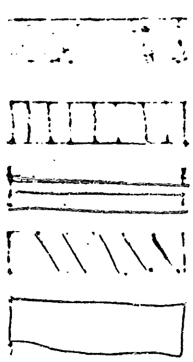


Figure 9. Locations of water use given in plate 5 .



EXPLANATION



Municipal, rural and irrigation

Mine processing

Mine dewatering

Thermoelect

Hydroelectric power production

Figure 10. Total Water Use expressed as cumulative percentage.

Surface-water Use

Almost all use of surface water usage is nonconsumptive, mainly the generation of power (fig. 11). Between 1971-76

Figure 11.--Near here

---

approximately 97 percent of surface-water use was by combined hydroelectric and thermoelectric power generation at Winton and at Colby Lake. Mine operations used 3 percent, and less than 1 percent was used by the City of Ely for municipal supply.

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

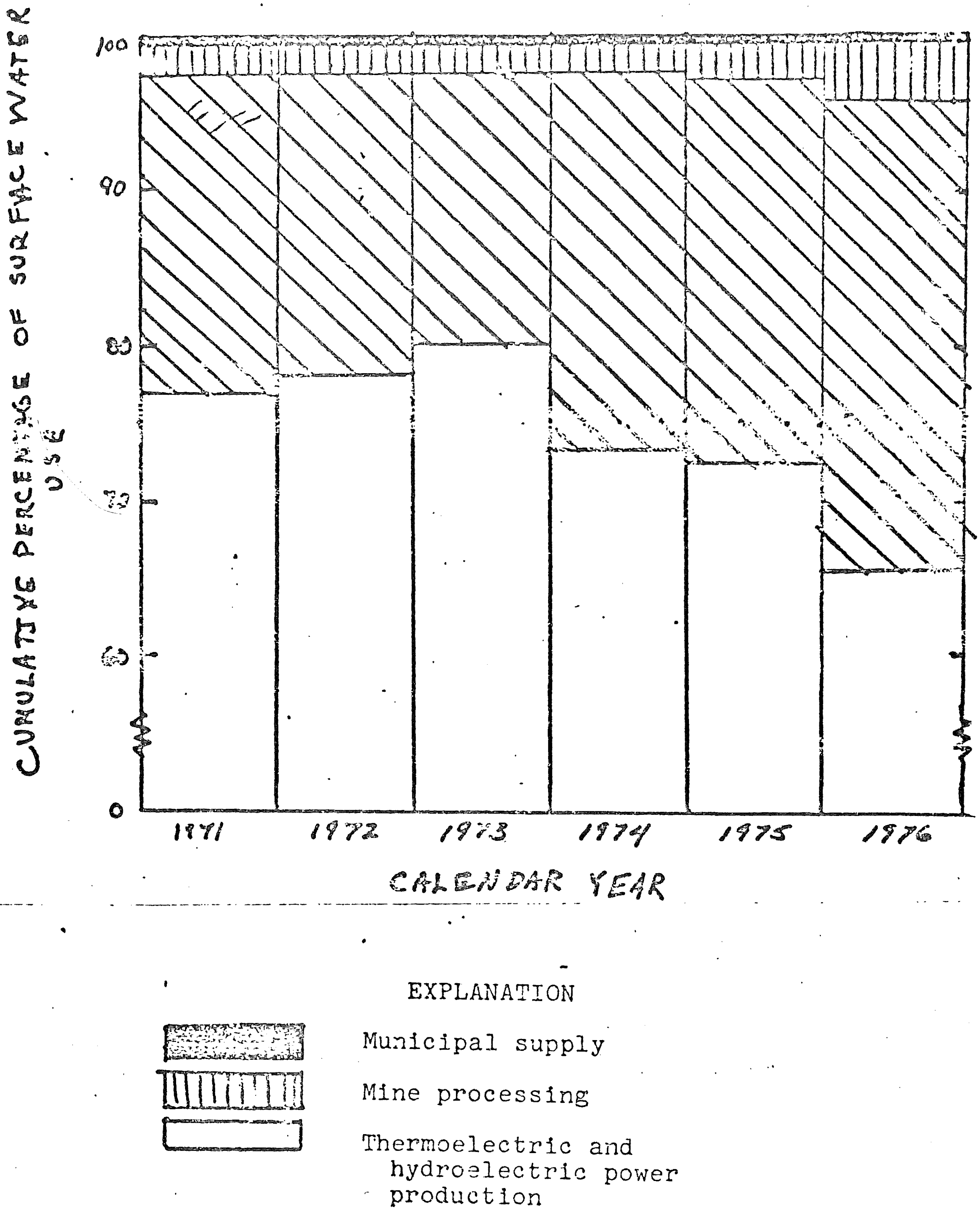


Figure 11.—Surface water use expressed as cumulative percentage

Ground-water Use

Between 1971-76, mine dewatering accounted for about 95 percent of the total ground water used in the region (fig. 12), or between 5 and 12 billion gallons per year.

Figure 12.--Near here

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.

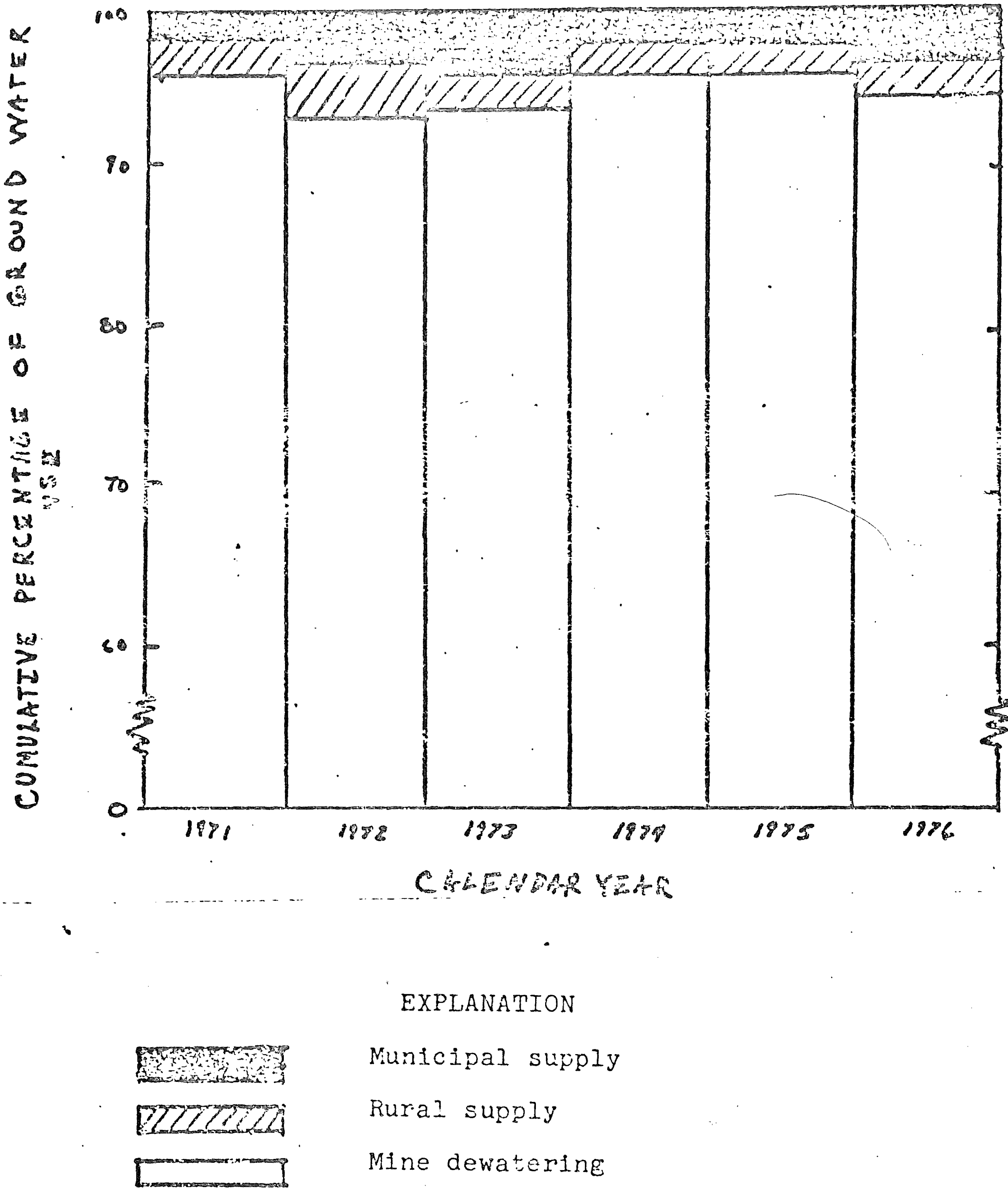


Figure 12.--Ground water use expressed as cumulative percentage

Ground-water use remained fairly constant during 1971-76 (fig. 13). With additional mining operations and asso-

---

Figure 13.--Near here

---

ciated development, it is likely that ground-water use will increase. However, it should be noted that although 8 new taconite areas were opened by Erie Mining Co. in 1974, total long-term ground-water use did not appreciably increase although total use in 1974 nearly doubled as a temporary effect of the new mine operations (fig. 13). Additional mining operations associated with copper and nickel exploration and development may increase withdrawals 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. These withdrawals, mainly for dewatering, would be nonconsumptive use.

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.

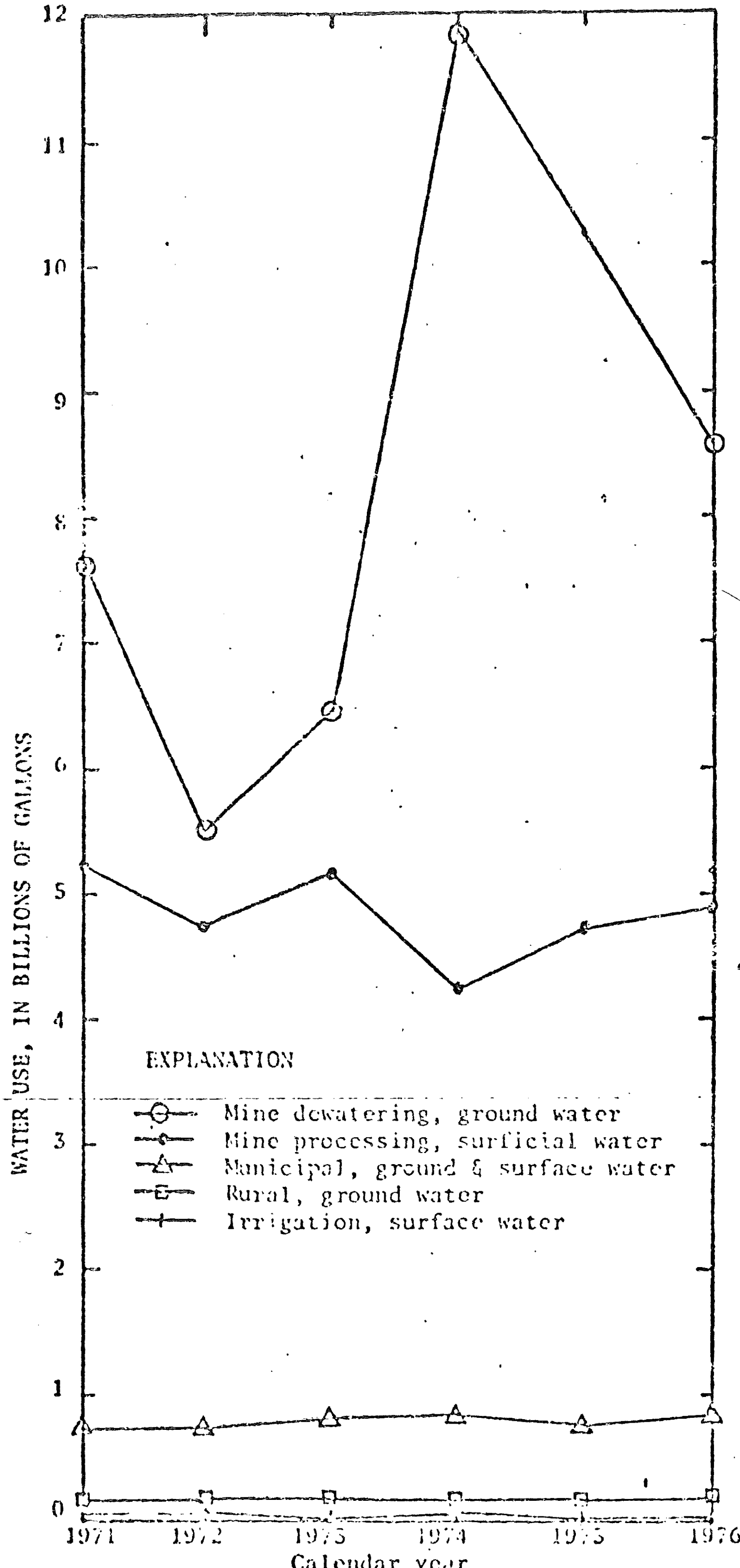


Figure 13.–Total water use, 1971-76 (excluding use for hydroelectric & thermoelectric power generation)

QUALITY OF GROUND WATER

Water samples were collected for chemical analysis quarterly during 1976-77 from 12 observation wells finished in glaciofluvial sand and gravel, 11 wells finished in the Rainy Lobe till, and 2 wells finished in peaty material. An additional single sampling of the U.S. Forest Service campground wells was added during a drought period in October 1976 when ground-water levels were extremely low. This sampling included 3 wells finished in sand and gravel, 5 wells finished in Rainy Lobe till, and 3 wells in the Duluth Complex. Three other wells in the Duluth Complex were sampled during 1975. Locations of sampled wells are given in figure 14.

Figure 14.--Near here

In order to relate geochemical variations with known hydrologic conditions in the study region, interpretations of ground-water quality generally were made using only the U.S. Geological Survey analyses as published in the annual report "Water Resources Data for Minnesota, Water Year 1976." Not all wells could be sampled an equal number of times and not all analyses were complete. Interpretations of ground-water quality were made using seasonal subsets of the data.

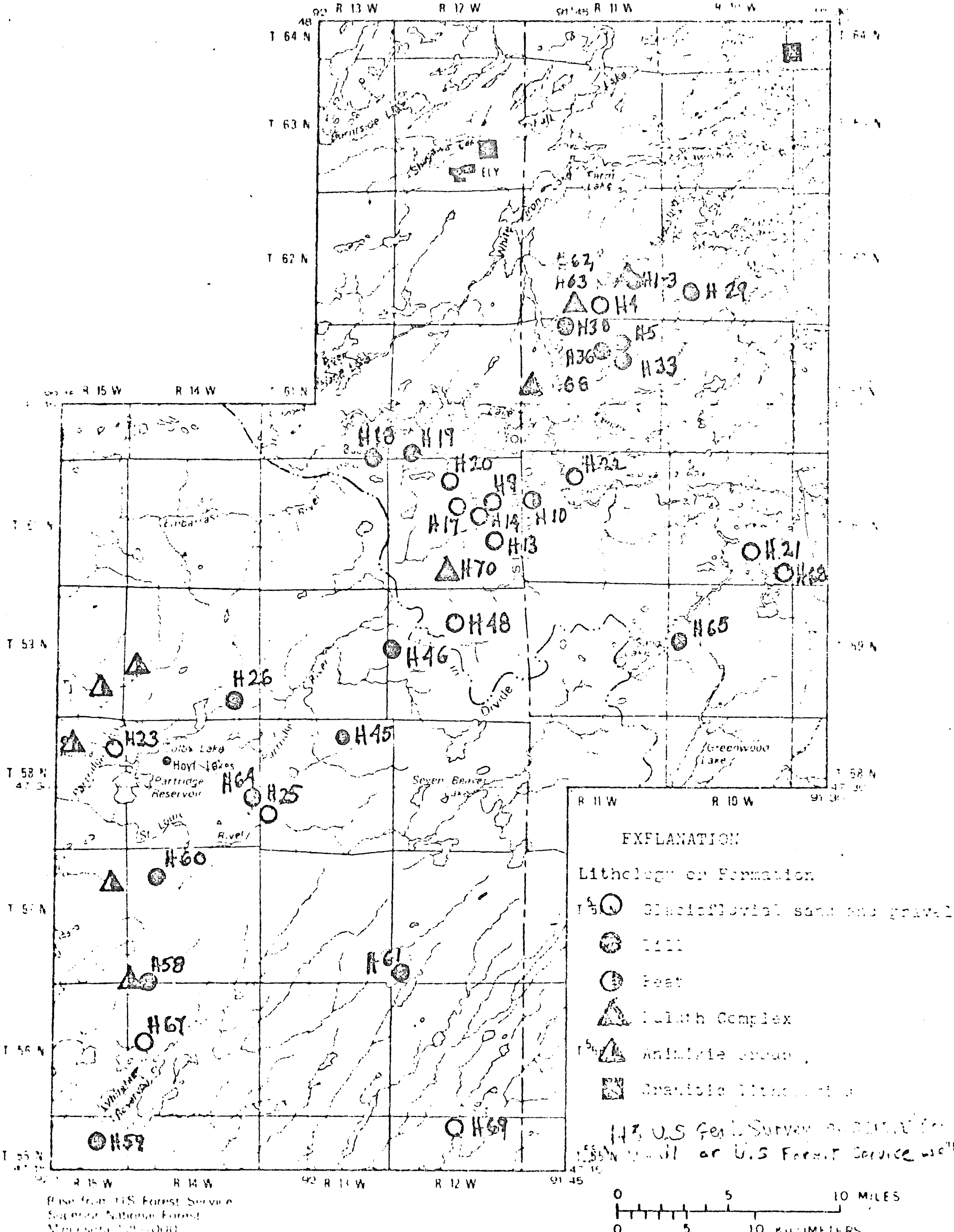


Figure14. Wells sampled for chemical analysis

All samples collected during the study were analyzed by U.S. Geological Survey laboratories in Denver, Colo. and Salt Lake City, Utah. Sampling procedures and analytical methodology followed U.S. Geological Survey standards, as outlined by Brown, Skougstad, and Fishman (1970), with modifications to current technological precision and accuracy for trace metals.

The chemical data were studied by standard graphic and statistical procedures. In the graphs that follow, the straight-line relationships were computed by the least-squares method. The correlation between variables, for which a line of best fit (regression line) is presented, was tested statistically by the correlation coefficient.

The significance of differences between mean values for sample populations from surficial lithologies was evaluated using the t-test at 0.05 level of significance. The t-test was not applied to bedrock ground-water data because the sample populations were deemed too small. Different water types were identified by use of Piper and semilogarithmic graphs (Hem, 1970).

Water collected from well H2, which is finished in till near the base of an ore-sample site in T.62 N., R. 11 W., sec.25, had trace-metal concentrations considerably greater than general background levels. These anomalously high concentrations are the result of the weathering and oxidation of sulfide minerals. Consequently, the analyses from this well have been excluded from the regional characterization of ground water and will be treated separately in the section on potential environmental impacts.

SURFICIAL AQUIFERS

Summary statistics for major dissolved constituents and other properties for samples collected by the U.S. Geological Survey during winter 1976-77 are presented in table 6. These samples were collected when ground-water

---

Table 6.--Near here

---

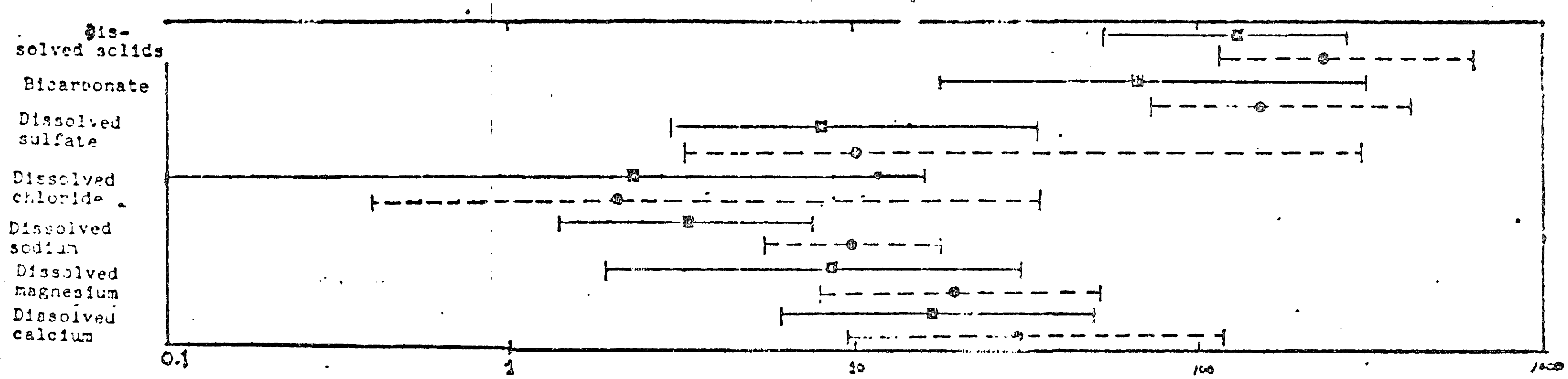
levels were declining and were least affected by dilution from recharge. The concentration range of the major dissolved constituents that characterize ground water is presented in figure 15 for all samples collected during 1976-77.

Figure 15.--Near here

T-test results indicate that with the exception of bicarbonate, mean values of major dissolved constituents are significantly higher for ground water from Rainy Lobe till than in ground water from outwash sand and gravel aquifers. Mean and median concentrations of the major ions, specific conductivity, and hardness in water from till aquifers are about twice that found in water from sand and gravel aquifers.

Table 6.--Summary statistics for ground-water quality from surficial materials, sampled during winter 1976. Concentrations in milligrams per liter except when designated otherwise.

Constituent or Property	Samples from till aquifers					Samples from sand and gravel aquifers				
	Number samples	Maxi-mum	Mini-mum	Mean	Median	Number samples	Maxi-mum	Mini-mum	Mean	Median
Specific conductance (mmhos)	13	1250	144	435	285	15	487	55	200	172
pH---(unitless)-------------	12	8.0	6.20	6.1	6.9	14	7.1	5.6	6.4	6.5
Chemical Oxygen Demand------	4	870	40.0	435	115.0	5	310.0	0	123.4	63.0
Hardness (Ca,Mg)------------	13	637	60.5	204	127.4	16	252.1	26.4	101.9	70.3
Dissolved Calcium-----------	13	150	4.6	47.0	26.0	16	58.0	6.1	20.7	15.1
Dissolved Magnesium---------	13	64	7.3	21.5	15.0	16	31.0	1.9	12.7	7.6
Dissolved Sodium------------	13	18	2.1	9.0	7.40	16	7.3	1.4	3.5	3.3
Dissolved Potassium---------	13	9.3	0.1	3.1	2.4	16	2.8	0.4	1.4	1.3
Bicarbonate-----------------	12	423	74	163	120.5	14	310.0	15	91	65.5
Dissolved Sulfide-----------	5	12.0	0.0	2.6	.34	5	.30	0	.12	.10
Sulfate---------------------	13	450	3.3	79.6	11.0	15	35.0	3.0	11.8	8.2
Chloride--------------------	13	35.0	0.6	5.6	1.5	15	18.0	.30	5.1	2.3
Silica----------------------	6	27.0	14.0	20.8	18.5	8	28.0	11.0	19.7	19.5
Solids (Residue at 180°)----	13	938	97	293	187	12	284	55	145	130.0
Nitrate plus nitrite--------	13	11.0	.31	3.6	1.4	13	7.4	.74	4.0	3.1
Total phosphorous-----------	6	.07	0	.01	0.0	0	---	---	---	---
Dissolved organic carbon----	10	41.0	2.1	20.5	17.6	12	26.0	.7	9.2	5.4



Concentration, in milligrams per liter (logarithmic scale)

EXPLANATION

Range, for sand and gravel aquifers

Range, for till aquifers

Median concentrations for sand and gravel aquifers

Median concentrations for till aquifers

(February 1976 sampling)

Figure 15. Diagram illustrating concentration ranges and medians for major dissolved constituents in ground water

Median concentrations are for the single sampling during February, 1976.

Concentrations of many chemical constituents are greater in till than in sand and gravel aquifers. Silt and finer-sized particles found in the till have large surface area to volume ratios, which places large areas of minerals in contact with the ground water and enhances chemical reactions. In addition, till has a much lower hydraulic conductivity than sand and gravel and the time available for chemical reactions is at least an order of magnitude greater because of the slow ground-water movement.

Water in till is classified (Hem, 1972) as moderately hard to very hard, while water in sand and gravel aquifers is classified as moderately hard to hard.

During winter 1976, the pH of water from sand and gravel aquifers ranges from 5.8 to 7.1. The pH of water from Rainy Lobe till ranges from 6.2 to 8.0. The lower range of pH in water in sand and gravel reflects rapid recharge to the aquifer from precipitation and a shorter time available for chemical reactions.

The pH of water from observation wells H10 and H33, which are finished in reed-sedge peat, ranged from 5.9 to 6.2.

The Piper diagram (fig. 16) shows that the samples

Figure 16.--Near here

---

collected from sand and gravel and from peat are a mixed calcium-magnesium bicarbonate type, based on predominant ions. This type of water is typical of ground waters in contact with calcic igneous minerals, as are found in the proposed mining area, and which have either a short residence time or have been collected in a recharge area. Analyses plotted are of samples collected during summer 1976, when ground-water levels were declining in response to drought conditions. Normal seasonal differences generally are not great enough to significantly alter the plots if other analyses from the same wells were plotted.

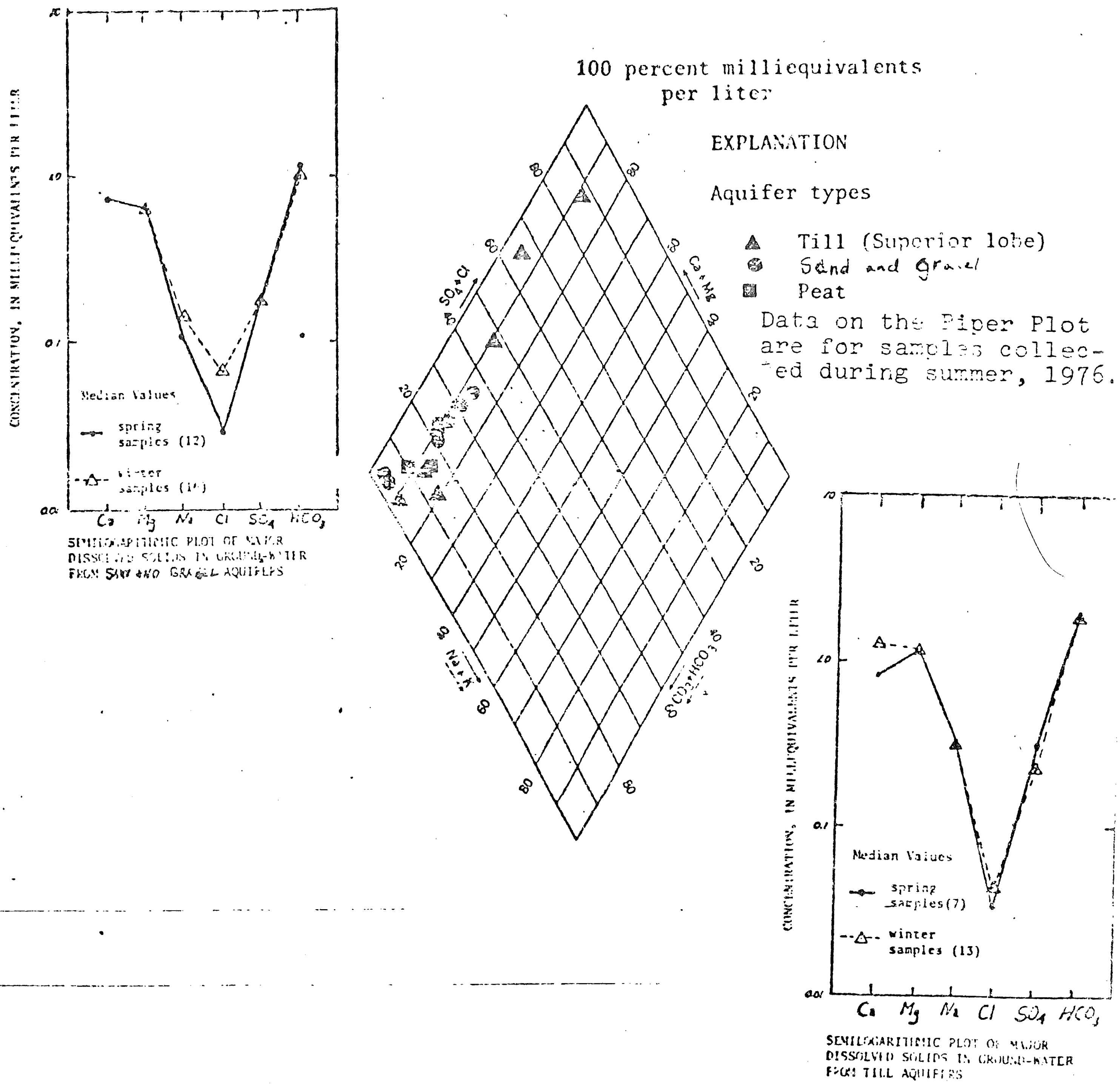


Fig 16.-- Piper Plot and individual semi-logarithmic plots of ground-water chemistry for major surficial aquifer types.

Water collected from wells in till can be classified as either a calcium magnesium bicarbonate or calcium magnesium sulfate type, based on predominant ions. 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 accounts for the increase in sulfate concentration found in this water.

The curves connecting the median values for dissolved solids on the semilogarithmic graphs (fig.) illustrate the overall chemical similarity between water from the sand and gravel and till aquifers. Median concentrations were chosen so that the plots would not be biased with extreme values. The parallelism of the curves suggests that chemical reactions between surficial sediments and the ground water are generally the same. The slight separation between the curves indicates longer residence time for water moving through till. Consequently, water-quality differences in surficial aquifers are more a matter of relative concentrations than of differences in specific ions.

Mean values of the principal constituents in ground water from till and from sand and gravel aquifers do not vary significantly between seasons. The semilogarithmic plots illustrate the nearly identical concentrations between the median values for the major parameters sampled during both winter and spring.

Mean concentrations of nitrate, total phosphorous, total organic carbon, silica and chemical oxygen demand in water from sand and gravel, peat, and till are not significantly different. Summary statistics for all samples collected from drift materials (table 7), however, give order-of-

---

Table 7.--Near here

---

magnitude ranges in the data, which reflect the diversity of local hydrochemical conditions and seasonal hydrologic conditions.

Table 7.--Summary statistics for ground-water quality from surficial materials, sampled during 1976. Concentrations in milligrams per liter except when designated otherwise.

Constituent or Property	Samples from till aquifers: Number samples	Maxi-mum	Mini-mum	Mean	Median	Samples from sand and gravel aquifers: Number samples	Maxi-mum	Mini-mum	Mean	Median
Specific conductance (mmhos)	32	1250	120	368	251	40	577	5.5	193	166
pH (unitless)---------------	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	600	0	93	18.5
Hardness (Ca,Mg)------------	30	637	37	173	104	40	284	26	93	71
Dissolved Calcium-----------	31	150	6.5	38.9	22.3	40	76	6.0	20	16
Dissolved Magnesium---------	31	64	5.1	18.0	14.0	41	31	1.1	10.2	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	.1	2.7	2.1	41	3.0	0.2	1.3	1.1
Bicarbonate-----------------	30	423	45	145	120	39	392	15	95	69
Dissolved Sulfide-----------	11	12	0	1.5	.4	17	4	0	.9	.6
Sulfate---------------------	31	450	1.8	61	11	40	35	0.7	11	6
Chloride--------------------	31	35	.4	4	1.4	40	18	0.1	4	2.2
Silica----------------------	13	37	13	20.5	18.3	21	28	10	18.6	18
Solids (Residue at 180°)----	13	938	97	293	187	14	284	55	148	130
Nitrate plus nitrite--------	11	12	0	1.5	0.4	37	10	.01	2.2	.62
Total phosphorous-----------	13	.07	0	.006	0.001	21	.04	0	---	---
Dissolved organic carbon----	22	46	2.1	18	13	33	52	0.7	11.3	6.4

Summary statistics for selected minor and trace metals for all samples collected from wells in till and in sand and gravel are give in table 8.

Table 8.--Near here

Concentrations of copper, cobalt, and nickel generally are less than 30 micrograms per liter but can exceed 100 micrograms per liter in surficial material directly over the mineralized contact zone between the Duluth Complex and older rocks. These metals are probably related to oxidation of sulfide ores found at the contact zone and in the nearby glacial deposits. Concentrations of chromium, cadmium, and lead are less, generally ranging from 0 to 15 micrograms per liter. Iron is occasionally found in anomalously high concentrations ranging up to 67 milligrams per liter. These concentrations of iron are difficult to explain with the limited data base, but probably reflect local chemical conditions related to the reduction of iron in the system.

Trace and minor metal concentrations from water in two wells in peat are within the same range as found for that in the other surficial materials.

Table ____ Summary statistics for selected trace and minor metals in surficial aquifers, (concentration, in micrograms per liter)

Constituent	Till aquifers					Sand and gravel aquifers				
	No. of samples	Maximum	Minimum	Mean	Median	No. of samples	Maximum	Minimum	Mean	Median
Cadmium--------	29	8.4	0.00	0.8	0.3	30	1.2	0.0	0.3	0.3
Cobalt---------	30	28.0	0.3	3.5	1.4	30	46.0	0.1	6.3	0.7
Chromium-------	30	5.5	0.00	0.9	0.6	31	[illegible].2	0.0	0.6	0.5
Copper---------	30	190.0	0.6	11.7	3.8	30	45.0	0.2	7.2	4.2
Lead-----------	30	6.4	0.1	1.8	1.3	31	18.0	0.0	1.9	1.1
Nickel---------	27	120.0	1.0	15.2	9.0	29	40.0	0.7	7.5	5.0
Aluminum-------	24	200.0	0.0	20.0	20.0	30	280.0	0.0	32.0	29.0
Zinc-----------	30	170.0	3.9	27.6	8.9	30	620.0	0.7	56.1	14.1
Iron-----------	30	3100.0	0.0	221.0	25.0	38	67000.0	0.0	5152.0	45.0
Manganese------	31	7190.0	10.0	1268.0	330.0	38	26000.0	0.0	2140.0	45.0

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. 17 and 18). Anomolous concentrations

---

Figures 17 and 18.--Near here

---

of both copper and nickel occur in zones about 5 to 10 miles wide centered on the contact. Ground water within these zones generally contains other trace metals as well, as a result of the oxidation of sulfide minerals found in the surficial deposits.

BEDROCK AQUIFERS

Representative analyses of water samples collected from wells in the major bedrock units in the study region are given in table 9.

Table 9.--Near here

Although the number of samples collected was not large enough to adequately perform statistical tests of significance, the analyses do show apparent differences.

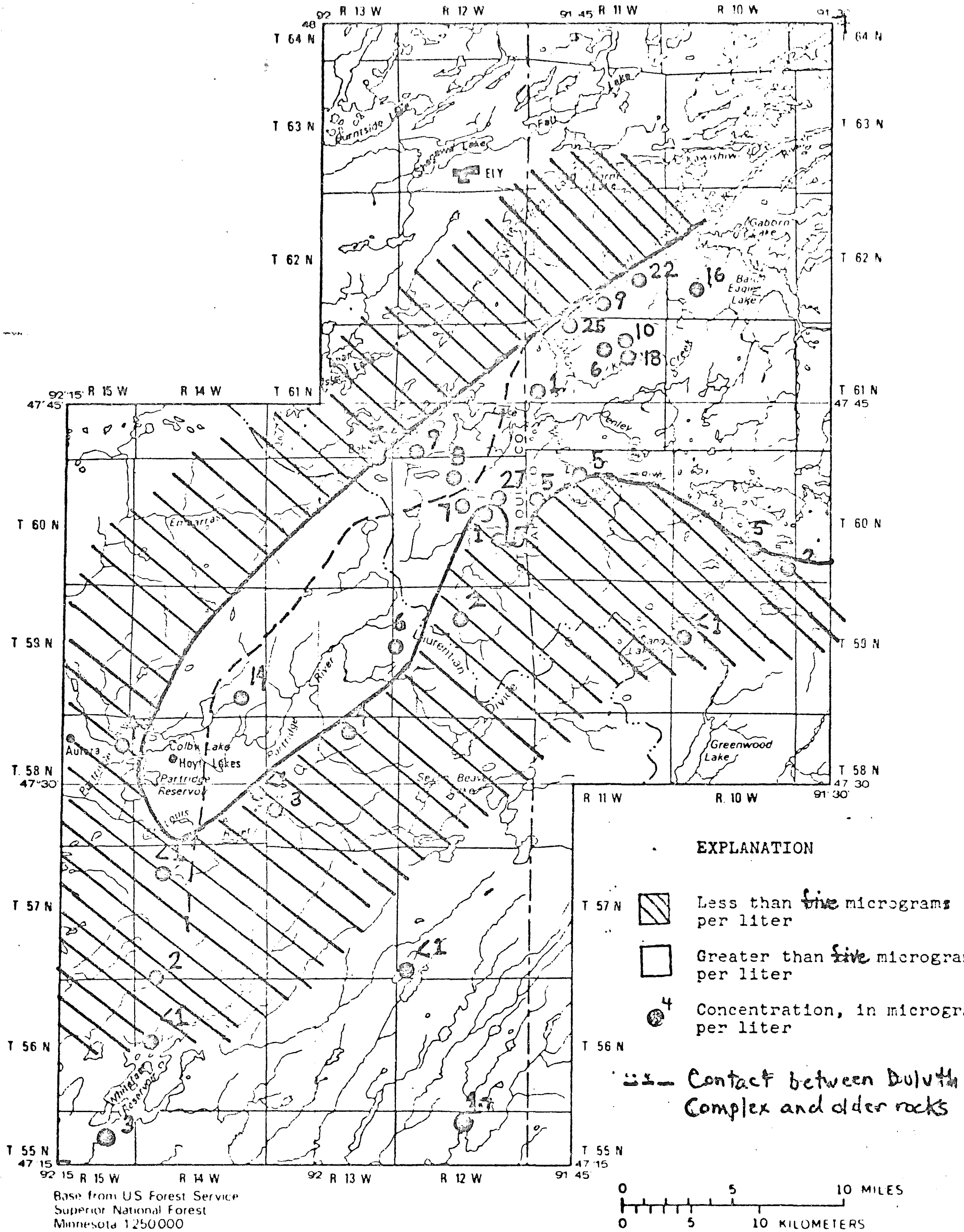


Figure 17 Generalized Nickel distribution in surficial aquifers (data from 10-76 or 4-76 sampling)

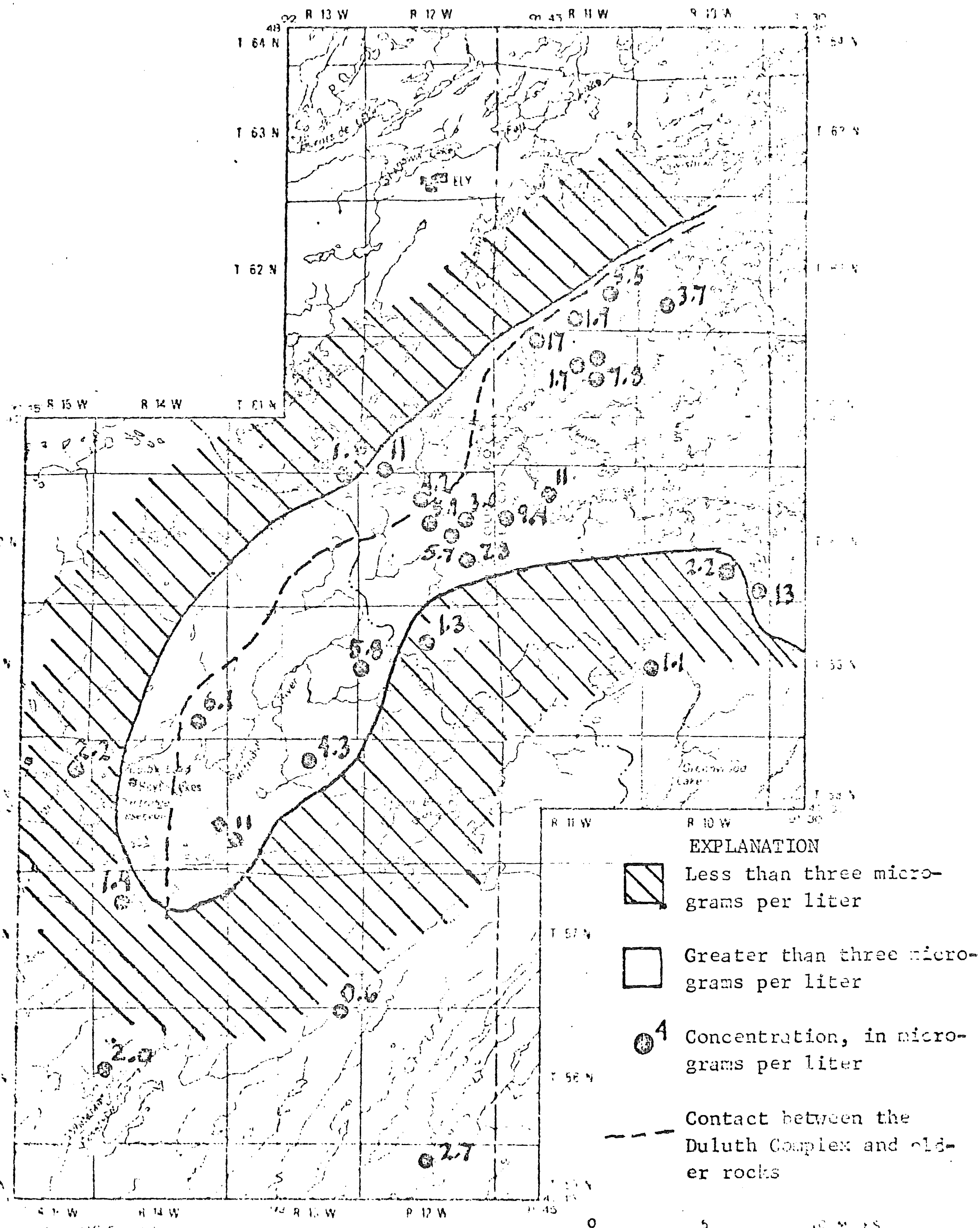


Figure 18 Generalized copper distribution in surficial aquifers (data from 10-76 or 4-76 sampling)

LOCAL IDENTIFIER	Source of Analysis	GEOLOGIC UNIT	TOTAL DEPTH OF WELL (FT)	DATE OF SAMPLE	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	HARDNESS (CA,MG) (MG/L)	DISSOLVED CALCIUM (CA) (MG/L) (00915)	DISSOLVED MAGNESIUM (MG) (MG/L) (00925)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L) (00935)	BICARBONATE (HCO3) (MG/L) (00440)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED SILICA (SIO2) (MG/L)	DISSOLVED SOLIDS (SUM OF CONSTITUENTS) (MG/L)
62·11·33 da	USGS	DCPX	225	10/21/76	320	8.5	7	2.7	[illegible]	7.[illegible]	0.1	167	3.8	5.3	—	—
62·11·33 ac	U.S.G.S.	DCPX	1000	10/20/76	1300	7.4	150	44	9.1	220	3.3	155	45	310	—	—
61·11·19 bd	U.S.G.S.	DCPX	125	10/19/76	220	7.7	9	3.1	.3	48	0.3	115	9.6	4.3	—	—
60·12·32 aa	X MAX	DCPX	1096	2/15/77	4620	8.1L	1100	420	2.0	470	2.0	94	3.6	1500	—	—
59·15·26 1-6	US GS	BBKF	398	[illegible]/74	380	7.4	200	[illegible]	[illegible]	[illegible]	2.3	[illegible]	41	9	[illegible]	---
62·12·14 dbd	USGS.	BBKF	197	9/8/72	298	7.1	110	19	6	[illegible]	0.6	71	17	12	17	---
58·15·3 bcc 2	MS BOH	BBKF	180	10-65	---	---	130	58	---	---	---	99	47	1.4	---	---
58·15·3 caa	MS BOH	BBKF	---	10-70	---	8.9	94	42	---	20	7	32	88	7.8	---	180
59·14·2 ad	MDH	GRNT	197	8/8/75	240	8.2	---	93	5.3	7.3	0.8	207	17	1.0	---	---
60·13·7 abc	USGS	GRNT	425	12/5/74	143	8.3	63	31	9.1	15.0	1.9	140	7.3	1.3	14	---
62·12·14 dbd	USGS	GRNT	147	9/8/72	572	7.5	193	19	6.0	4.6	0.9	71	65	7.5	13	323
63·11·17 ccc	USGS	GRNT	121	9/12/72	237	---	---	110	10	26	2.6	204	13.8	1.5	---	---
56·14·6 bba	USGS	VRGN	90	12/3/74	745	7.8	390	46	66	19	4.2	523	22	1.3	19	436

Table 9. Representative ground water analyses from major bedrock types in the Copper-Nickel study region.

Concentrations of major constituents in water from the Duluth Complex are highly variable. Specific conductance, a measure of total dissolved solids, ranges from 220 to 4,620 micromhos per centimeter at 25°C, while chloride concentrations range from 1.3 to 1,500 milligrams per liter. Available data from six wells suggests that concentrations increase with depth, but, since water in the Duluth Complex occurs in isolated fractures and joints, the chemical composition is probably a function of local hydrogeochemical conditions rather than indicative of a trend with depth. Field pH in water from the Duluth Complex ranges from 7.0 to 8.5, generally one pH unit more basic than water from surficial lithologies in the study area.

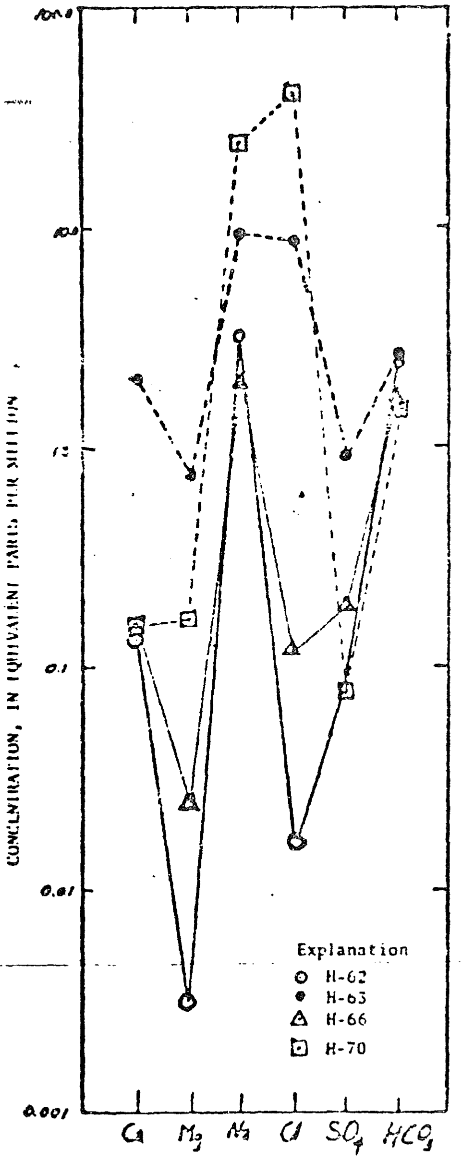
Water from the Duluth Complex plotted on both Piper and semilogarithmic diagrams (fig. 18), ranges from sodium

---

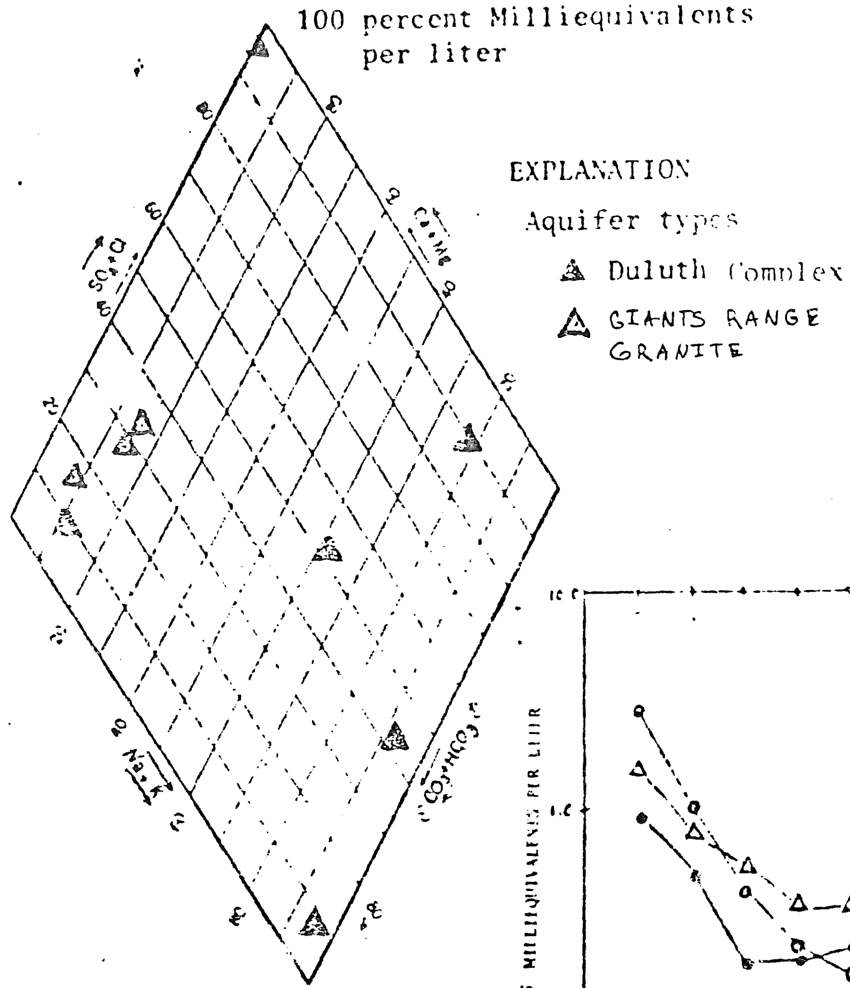
Figure 18.--Near here

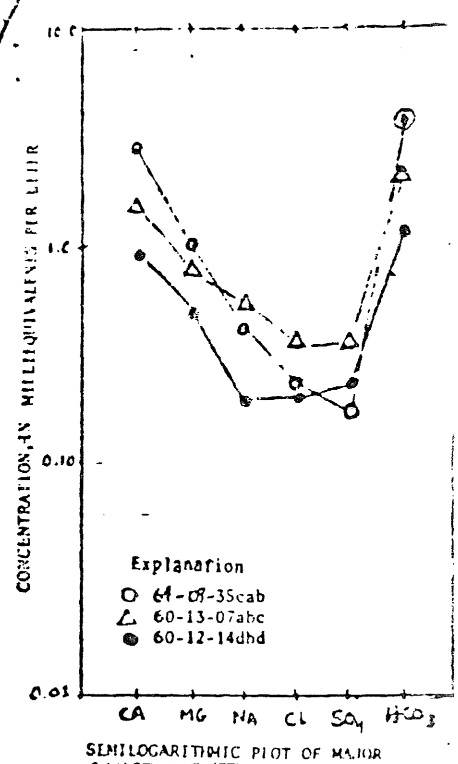
---

chloride to sodium bicarbonate types.



SEMILOGARITHMIC PLOT OF MAJOR CONSTITUENTS IN GROUND WATER FROM THE DULUTH COMPLEX





SEMILOGARITHMIC PLOT OF MAJOR CONSTITUENTS IN GROUND WATER FROM THE GIANTS RANGE GRANITE

Figure Piper Plot and semilogarithmic plots of major constituents of ground water from the Duluth Complex and Giants Range Granite

Waters from granite, Biwabik Iron-formation, and other non-troctolitic lithologies (fig. 19) are a mixed calcium-

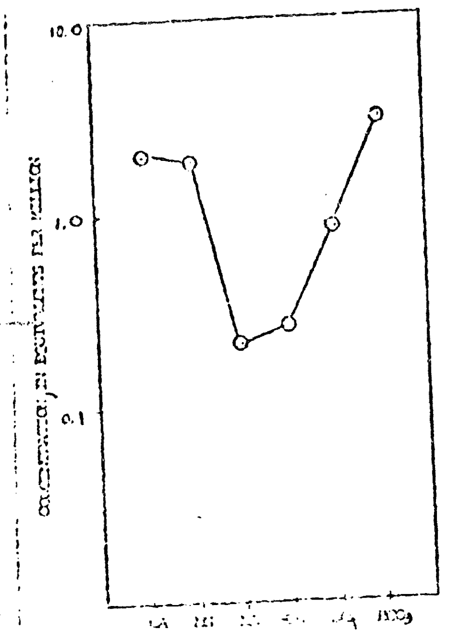
---

Figure 19.--Near here

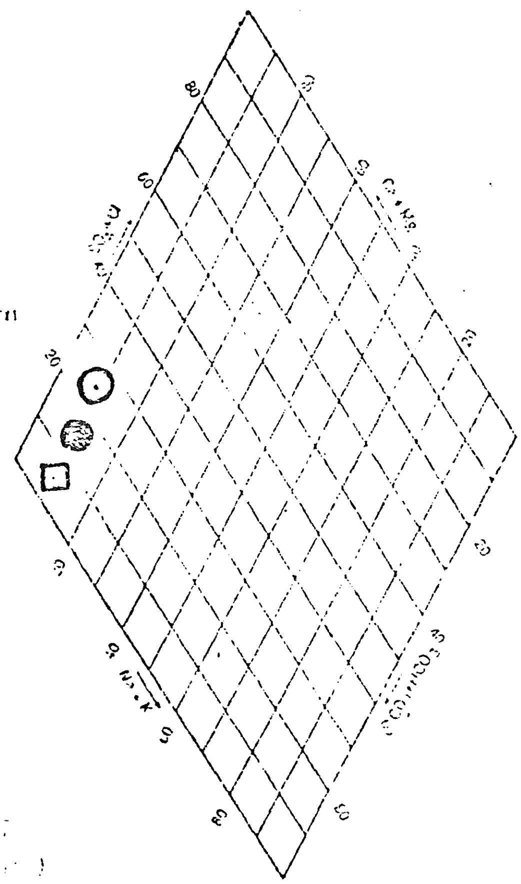
---

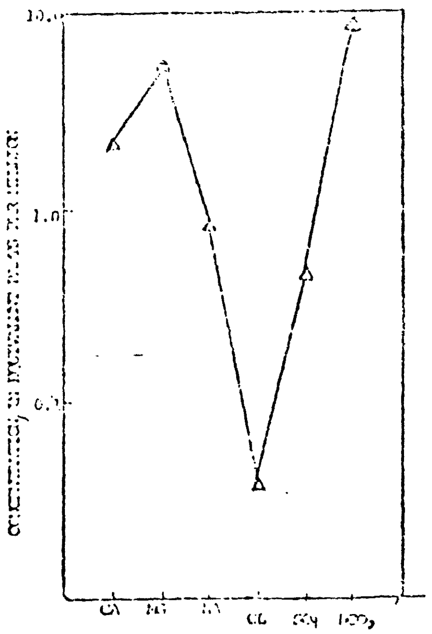
magnesium bicarbonate type, comparable to water from surficial materials. Water in these lithologies mainly occurs in an upper fracture zone that is in hydrologic continuity with overlying surficial sediments. As a result, wells finished near the upper surface of the granite or in fractures within the Animikie Group produce water having a chemical compositon similar to that of water in surficial materials but modified by reactions with the bedrock surfaces.

Except for iron and manganese, few reliable trace and minor-metal analyses exist for water from bedrock aquifers in the study region. The small number of analyses available suggest that dissolved copper, nickel, cadmium, silver, mercury, and lead concentrations are less than a few micrograms per liter in water from most bedrock.



100 percent milliequivalents per liter





EXPLANATION

Virginia Argillite
([illegible] R.14 [illegible])

Biwabik Iron-formation
(T. [illegible] R.15 Sec. [illegible])

Mean value of 15 municipal wells in Biwabik Iron-formation (Cotter,)

Figure - Piper Plot and individual semilogarithmic plots of major constituents of ground water from the Biwabik Iron-formation and the Virginia Argillite

Iron and manganese concentrations in water from the Duluth Complex range from 0 to 150 and 0 to 60 micrograms per liter, respectively. Concentrations of these metals are higher in water from the Biwabik Iron-formation, ranging from 50 to about 5,000 micrograms per liter for iron and from 0 to 1,800 micrograms per liter for manganese. Data from 4 wells indicate iron and manganese concentraions for water in the Giants Range Granite can be as high as 500 micrograms per liter.

Evaluation of trends in bedrock ground water chemistry cannot be made with the present data base. Most variations likely reflect local complexities in the hydrogeochemical and hydrologic environment.

Fair to good correlations exist between specific conductance in surficial and bedrock aquifers and dissolved calcium, hardness (Ca + Mg), and dissolved solids for all analyses performed for this study (fig. 20).

Figure 20.--Near here

Because of this relationship, easily obtained specific conductance measurements can be used to roughly predict these constituents.

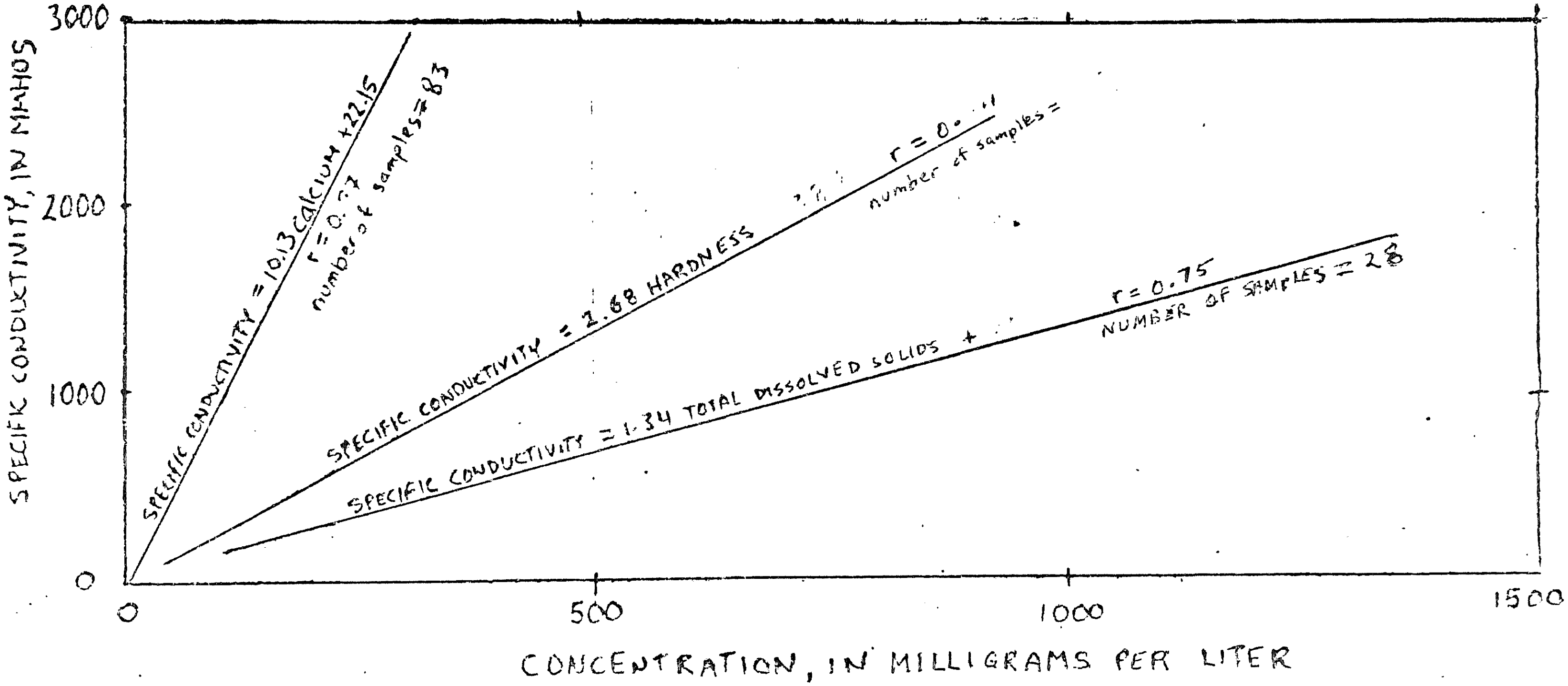


FIGURE Graph showing relation between specific conductivity and selected constituents in ground water collected from the Copper-Nickel Study Area.

No significant correlation coefficients (greater than 0.5) were obtained between trace metals and sulfate as might be expected from oxidation of sulfide minerals included within drift and bedrock, or between dissolved organic carbon and trace metals as might be expected from chelation of metals by humic or fulvic acids. The lack of these correlations highlights the complexity of local hydrogeochemical conditions. Concentrations of trace metals are controlled by inorganic and organic mechanisms that operate non-uniformly over the region. An evaluation of local trace-metal concentrations requires a site-specific understanding of the local ground-water flow system and the mineral and organic constituents in the glacial drift.

POTENTIAL IMPACTS OF MINING ON THE HYDROLOGIC SYSTEM

The potential impacts on the hydrologic system of future copper and nickel mining and associated development include: aquifer dewatering and surface-water diversions by open-pit activities, increased use of surface and ground water by new and expanded cities, and water-quality changes in surface- and ground-water systems by mine discharge. The data gathered for this study were for regional evaluation. Additional studies will 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 in the region. The bedrock and overlying surficial materials along the contact zone between the Duluth Complex and older bedrock generally have very low permeability. Dewatering of 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 Biwabic Iron-formation underlying the Duluth Complex. Potentially, water under confined conditions could seep upward to mines in the Duluth Complex if the mine penetrated near or into the Biwabik Iron-formation. Such discharge would increase the amount of water required to dewater the mine.

Mine dewatering may be required from open-pit operations that intersect buried sand and gravel filled channels, especially, 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 wall.

Table 10 presents calculated ground-water discharges

Table 10.--Near here

---

from surficial materials to hypothetical open-pit mines illustrated in figure 21. The discharges were calcu-

---

Figure 21.--Near here

---

lated using 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 . 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.

Subj... Table ...—Ground-water discharges to hypothetical open-pit mines.

702 POST OFFICE BUILDING
ST. PAUL, MINNESOTA 55101

Map key ~~Area~~	Approximate location	Estimated range in 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	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

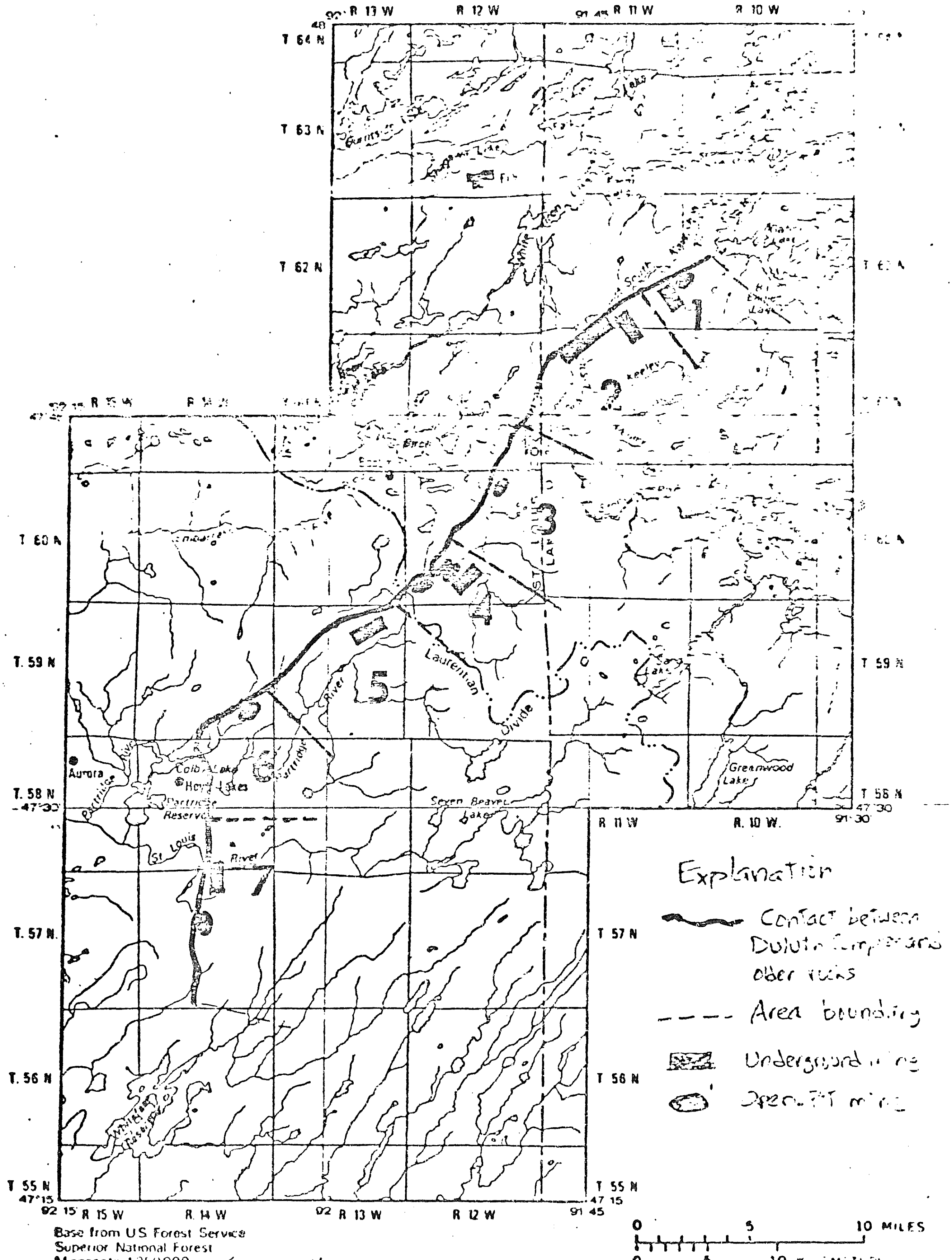


Fig — Hypothetical Mining Areas and Mine Sites (from data supplied by the Regional Copper-Nickel

Ground-water discharge to hypothetical mines in areas 1, 4, 5, and 6 should be minimal owing to the relative impermeability and small saturated thickness of the material in the drift. Ground-water discharge to an open pit mine located in area 3 potentially could have long term and significant 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 50 feet thick, which are in hydraulic communication with the aquifer underlying the Dunka River basin. Discharge to the mine from these deposits could be as much as 2,000 gallons per minute. Such continuous discharge would 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 gallons per minute to the Erie Dunka Mine Pit. The source of the springs is buried sand and gravel that is exposed on the mine wall. This diversion caused a loss of about 0.7 cubic foot per second of flow from the Dunka River during low-flow conditions in August 1976, and may be more at high flow.

Additional Water Use

Increased ground-water withdrawals for municipal or other needs from surficial aquifers will depress the water table around pumping wells. Sand and gravel deposits underlying the Embarrass, Dunka, and Lower Partridge Rivers are the only viable aquifers for any extensive future development. Of these, the surficial aquifer underlying the Embarrass River offers the best potential for ground-water development. 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 possible to continuously pump 2,000 gallons per minute from a well in the aquifer underlying the Embarrass River Valley for a year before the engineering limit is reached (fig. 22). The City of Babbitt, with a current population of about

---

Figure 22.--Near here

2,900 people, used about 130 million gallons of ground water in 1976. This would be equivalent to only 45 days of pumping at the given rate. Projections of increased population by the year 2000 in the region as a result of both copper and nickel mining and expanded taconite production range up to 15,000 additional people. (Bauman, 1978, written communication). Assuming a worst case, that all 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. Since some of the additional population will be dispersed throughout the region, impacts on the major ground-water resource will be even less.

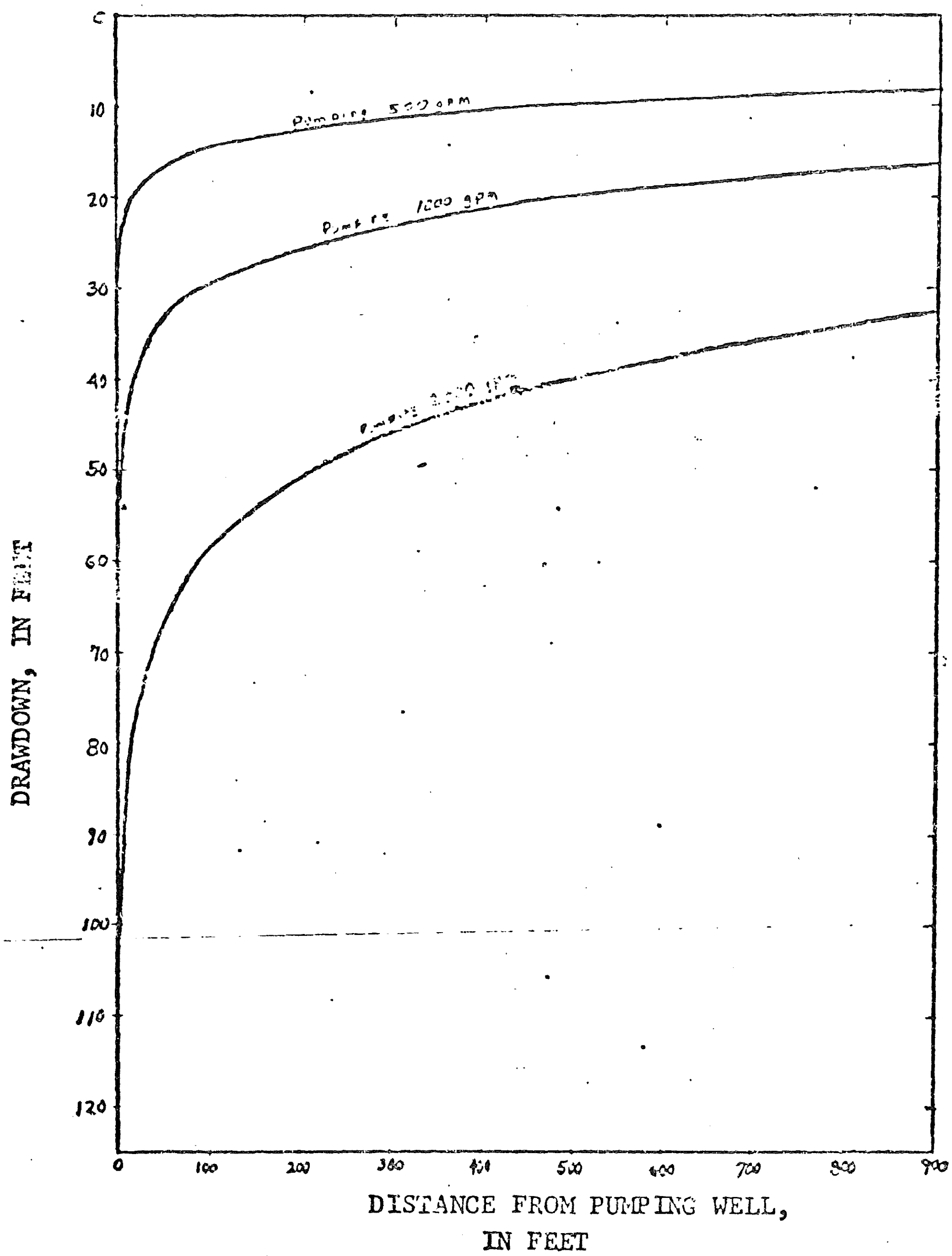


Figure Distqnce-drawdown cufves for a well pumping from the aquifer underlying the Embarrass River

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 background concentrations. For example, copper and nickel concentrations from ground-water discharging from a bulk-ore sample site (T.62 N., R.11 W., sec.) near Filson Creek are as great as 700 micrograms per liter. Nearby background values are less than 25 micrograms per liter. Water from observation well H-2, finished at the base of the sample site, had copper and nickel concentrations of 370 and 3,800 micrograms per liter in April 1976. Cobalt concentration was 440 micrograms per liter, an order of magnitude greater than general background levels. Consequently, the location of sites for tailings basins, stockpiles, and other similar facilities should take advantage of natural hydrogeological controls to minimize contamination of ground-water or surface-water by trace metals or other chemicals.

The potential for contamination of ground-water is reduced where natural barriers to vertical ground water flow exist. To guide discussion of possible impacts on the natural environment, the Regional Copper-Nickel Study Staff has delineated hypothetical mine development sites (fig. , page) located adjacent to the contact between the Duluth Complex and older rocks. With the exceptions of areas 3 and 4 near the Dunka River basin, 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 generally is less than 10 feet thick along and east of the contact, and is underlain by bedrock of very 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 upon small wetland basins, contamination to both surface-water and underlying ground-water systems may be further limited by the natural removal of some potentially toxic metals by organic compounds.

In the Dunka River basin, (areas 3 and 4) water bearing sand and gravel deposits are greater than 50 feet thick (pl. 3, part 1). Contamination to 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.

REFERENCES

Brown, Skougstad and Fishman, 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: Techniques of Water-Resources Investigation of the U.S. Geological Survey, Book 5, chap. A1, 160 p.

Cooper, Roger W., 1978, Lineament and structural analysis of the Duluth Complex, Hoyt Lakes--Kawishiwi area, northeastern Minnesota: unpublished PhD thesis, University of Minnesota, Minneapolis.

Cotter and others, 1965, Water-resources in the vicinity of municipalities on the western Mesabi Iron Range northeastern Minnesota: U.S. Geological Survey Water Supply-Paper, 36 p.

Erskine, C. F., 1975, Report on glacial drift pumping tests performed at the Minnamox Project, February 22 to 26, 1975, 32 p.

Hem, John D., 1970, 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 Metall. Eng. Trans. 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 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.

Malcolm, J. B., 1976, written communication

Olcott, P. G., Felsheim, P. E., and Ericson, D. W., 1978, Water resources of the Lake Superior watershed northeastern Minnesota: U.S. Geological Survey Hydrologic Atlas HA-582.

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

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

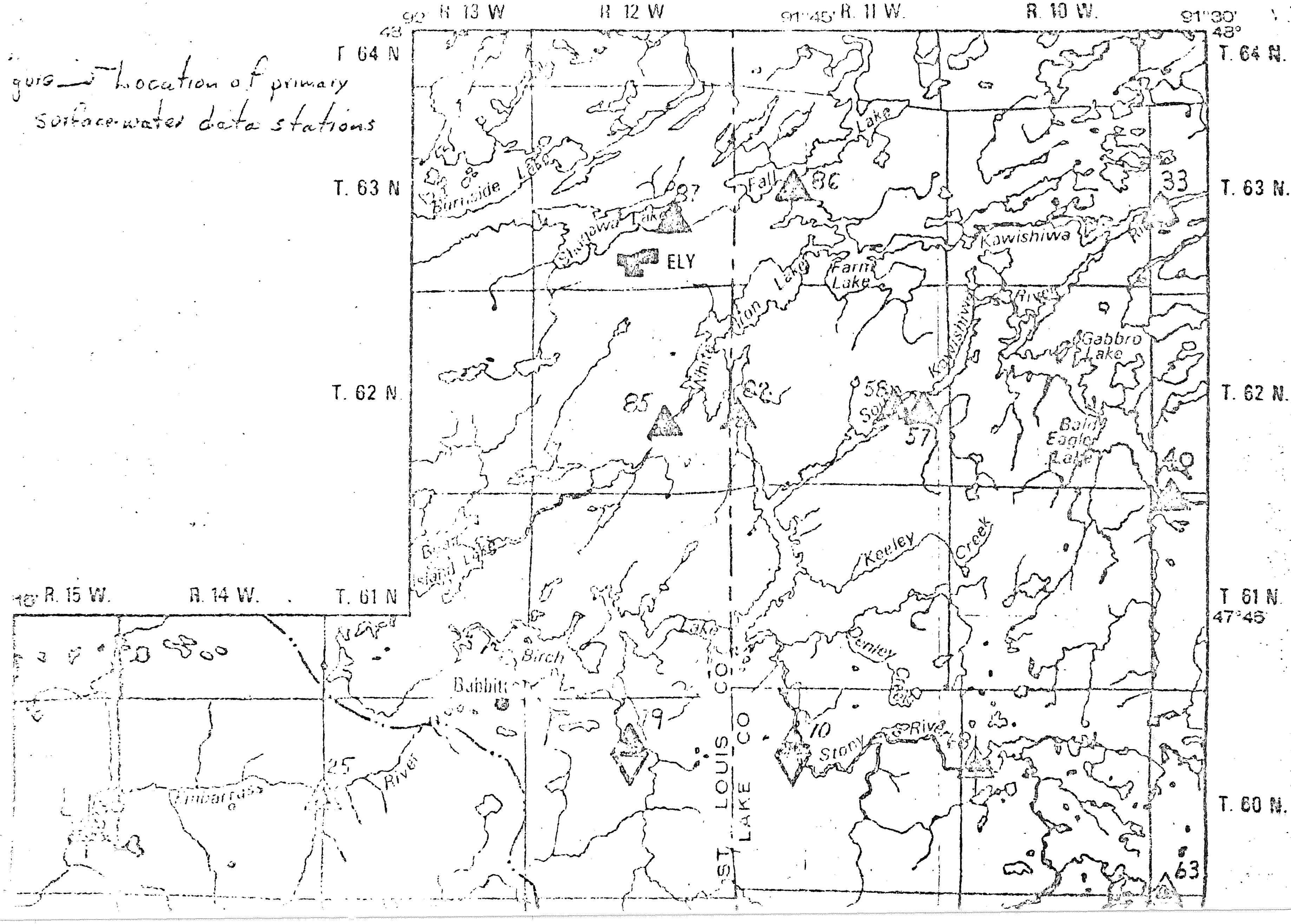
U.S. Geological Survey, Water resources data for Minnesota, water year 1976: U.S. Geological Survey Water-Data Report MN-76-1, 896 p.

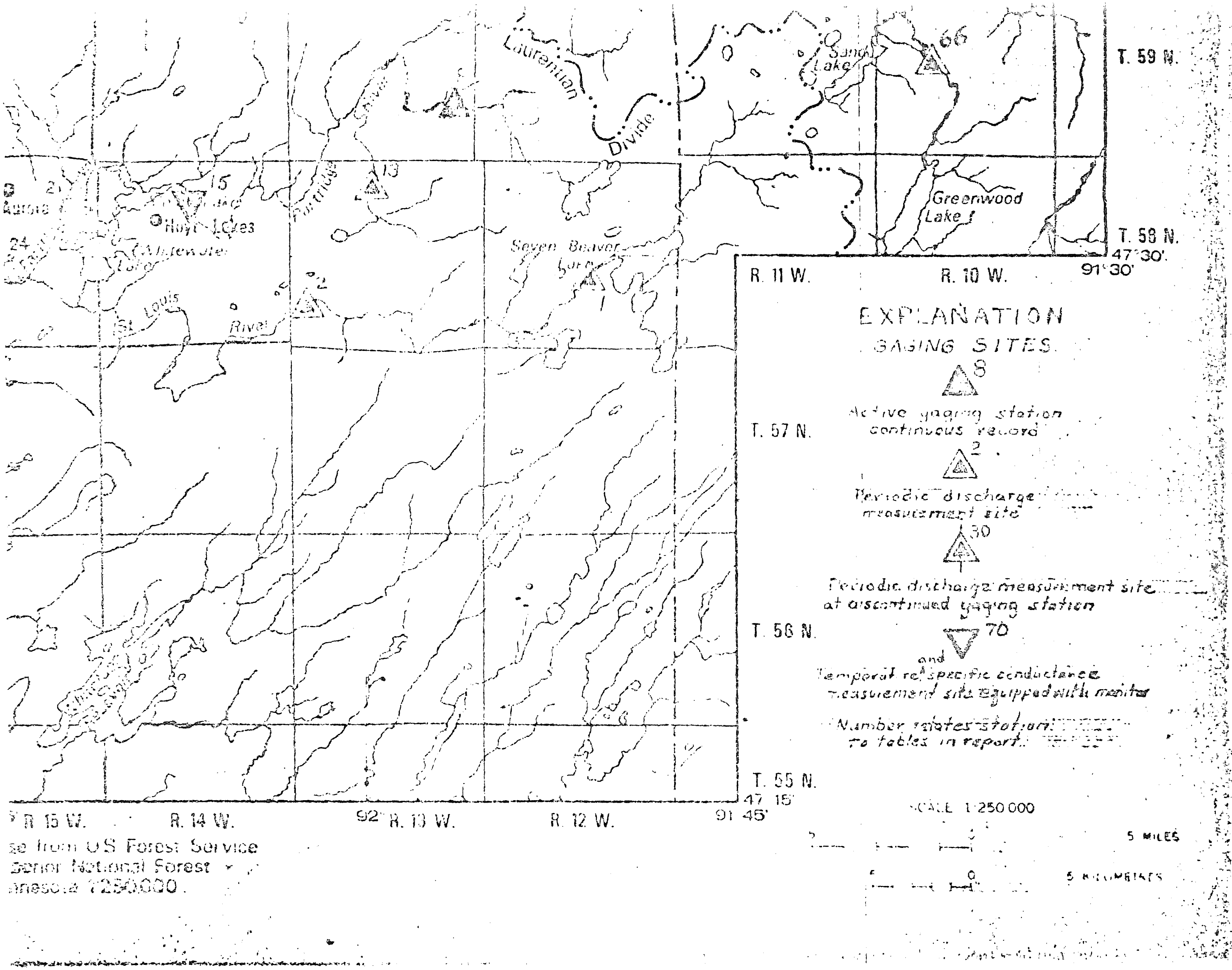
U.S. Geological Survey, Water resources data for Minnesota, water year 1977: U.S. Geological Survey Water-Data Report MN-77-1, in press.

Plate 5 Water use in the study area, 1971–76

Category & User	1971 Surface	1971 Ground	1971 Total	1972 Surface	1972 Ground	1972 Total	1973 Surface	1973 Ground	1973 Total	1974 Surface	1974 Ground	1974 Total	1975 Surface	1975 Ground	1975 Total	1976 Surface	1976 Ground	1976 Total	Remarks
[illegible] supply system																			
[illegible] of [illegible]	---	102,000	102,000	---	120,[illegible]	12[illegible]	---	178,6[illegible]	[illegible]	---	205,[illegible]	205,500	---	132,500	132,500	---	[illegible]	[illegible]	Treatment plant: [illegible]
[illegible]	---	110,[illegible]	110,[illegible]	---	[illegible]	[illegible]	---	98,6[illegible]	[illegible]	---	[illegible]	1[illegible],100	---	107,200	107,200	---	128,[illegible]	[illegible]	Treatment plant: [illegible]
[illegible] of Ely	402,700	---	402,700	387,800	---	[illegible],800	398,000	---	39[illegible]	[illegible],300	---	402,300	409,400	---	409,400	409,400	---	409,[illegible]	Treatment plant: [illegible]
[illegible] of [illegible] Lakes	117,400	---	117,400	126,[illegible]	---	1[illegible]	123,[illegible]	---	12[illegible]	12[illegible]	---	123,200	120,100	---	120,100	147,500	---	[illegible]	
[illegible]	3,100	---	3,100	2,000	---	1,[illegible]	1,400	---	1,400	1,[illegible]	---	1,800	1,600	---	1,600	1,700	---	1,7[illegible]	Treatment plant: [illegible]
[illegible] of Winton	7,500	---	7,500	9,700	---	9,700	7,100	---	7,100	7,[illegible]	---	7,500	7,400	---	7,400	8,[illegible]	---	[illegible]	Treatment plant: [illegible]
[illegible]	530,700	212,000	742,700	524,800	224,700	749,500	530,000	277,200	807,200	53[illegible]	311,600	848,600	538,500	239,700	778,200	5[illegible]	269,[illegible]	[illegible]	
[illegible] supply, self supplied																			
[illegible]																			
[illegible] and [illegible] unorganized [illegible]																			
Part of [illegible] Township	---	500	500	---	500	500	---	500	500	---	500	500	---	500	500	---	500	500	Mainly returned to [illegible] systems. A treatment [illegible] Campgrounds include [illegible]
[illegible] of [illegible]	---	13,000	13,000	---	13,000	13,000	---	13,000	13,000	---	13,000	13,000	---	13,000	13,000	---	13,[illegible]	13,[illegible]	
[illegible] Township	---	1,100	1,100	---	1,100	1,100	---	1,100	1,100	---	1,100	1,100	---	1,100	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	---	16,400	16,400	---	16,400	16,400	---	16,[illegible]	16,4[illegible]	
Part of [illegible] Township	---	6,600	6,600	---	6,600	6,600	---	6,600	6,600	---	6,600	6,600	---	6,600	6,600	---	6,[illegible]	6,600	
Part of [illegible] Township	---	21,900	21,900	---	21,900	21,900	---	21,900	21,900	---	21,900	21,900	---	21,900	21,900	---	21,[illegible]	21,900	
[illegible]	---	2,[illegible]	2,[illegible]	---	2,200	2,200	---	2,200	2,200	---	2,200	2,200	---	2,200	2,200	---	[illegible]	[illegible]	
[illegible] Township	---	5,500	5,500	---	5,500	5,500	---	5,500	5,500	---	5,500	5,500	---	5,500	5,500	---	[illegible]	[illegible]	
[illegible]	---	300	300	---	300	300	---	300	300	---	300	300	---	300	300	---	[illegible]	300	
[illegible] Township	---	2,500	2,500	---	2,500	2,500	---	2,500	2,500	---	2,500	2,500	---	2,500	2,500	---	2,[illegible]	2,500	
[illegible] territory [illegible] St. Louis	---	13,[illegible]	13,[illegible]	---	13,100	13,100	---	13,100	13,100	---	13,100	13,100	---	13,100	13,100	---	13,[illegible]	13,100	
[illegible] Township	---	30,100	30,100	---	30,100	30,100	---	30,100	30,100	---	30,100	30,100	---	30,100	30,100	---	30,[illegible]	30,100	
[illegible]	---	12,000	12,000	---	12,000	12,000	---	12,000	12,000	---	12,000	12,000	---	12,000	12,000	---	12,[illegible]	12,[illegible]	
[illegible] unorganized territory [illegible]	---	13,700	13,700	---	13,700	13,700	---	13,700	13,700	---	13,700	13,700	---	13,700	13,700	---	13,[illegible]	13,[illegible]	
[illegible] Township	---	35,600	35,600	---	35,600	35,600	---	35,600	35,600	---	35,600	35,600	---	35,600	35,600	---	35,[illegible]	35,600	
[illegible] territory of [illegible]	---	1,100	1,100	---	1,100	1,100	---	1,100	1,100	---	1,100	1,100	---	1,100	1,100	---	1,[illegible]	1,100	
Stock Watering	---	13,000	13,000	---	18,000	18,000	---	18,000	18,000	---	17,000	17,000	---	15,500	15,500	---	14,[illegible]	14,000	
[illegible]																			
[illegible]	100	200	300	300	200	500	200	200	400	200	300	500	200	300	500	200	400	600	
[illegible] (est.)	100	200	200	100	200	300	100	200	300	100	200	300	100	200	300	100	[illegible]	300	
[illegible] (est.)	---	5,000	5,000	---	5,000	5,000	---	5,000	5,000	---	5,000	5,000	---	5,000	5,000	---	5,[illegible]	5,000	
[illegible]	2[illegible]0	19[illegible]	199,2[illegible]	400	199,000	199,400	300	199,000	199,300	300	199,100	199,400	300	196,600	196,9[illegible]	300	19[illegible]	19[illegible]	
Irrigation																			
[illegible]	---	---	---	3,100	---	3,100	3,400	---	3,400	5,000	---	5,000	2,300	---	2,300	9,900	---	9,[illegible]	[illegible]
[illegible]	100	---	100	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
[illegible]	[illegible],200	---	53,[illegible]	55,100	---	55,100	9,800	---	9,800	34,[illegible]	---	34,600	---	---	---	---	---	---	
[illegible]	53,[illegible]	---	53,[illegible]	58,200	---	58,200	13,200	---	13,200	39,[illegible]	---	39,600	2,300	---	2,300	9,9[illegible]	---	9,9[illegible]	
[illegible] Power & Light Co. [illegible]	174,942,300	---	174,942,300	139,974,300	---	139,974,300	196,454,400	---	196,454,400	138,180,100	---	138,220,100	149,082,000	---	149,082,000	104,163,700	---	10[illegible]	[illegible]
[illegible] Power & Light Co.	44,174,700	---	44,174,700	43,798,200	---	43,798,200	42,800,100	---	42,800,100	44,200,200	---	44,200,200	49,289,900	---	49,289,900	50,237,000	---	50,23[illegible]	[illegible] Lake & [illegible]
[illegible]																			
[illegible]	---	762,400	762,400	---	371,200	371,200	---	454,200	464,200	---	579,600	579,600	---	431,300	431,300	---	[illegible]	[illegible]	[illegible]
[illegible] 127)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	[illegible]	[illegible]	
[illegible] Pacific [illegible] Mine)	---	231,700	231,700	---	274,400	274,400	---	251,500	251,500	---	241,500	241,500	---	---	---	---	[illegible]	[illegible]	[illegible]
[illegible]	---	---	---	---	---	---	---	---	---	---	---	---	---	1,374,[illegible]	1,3[illegible]	---	[illegible]	[illegible]	[illegible]
[illegible] Co. – Area 1	---	---	---	---	---	---	---	---	---	---	2,309,100	2,309,100	---	1,212,700	1,2[illegible]	---	[illegible]	[illegible]	
Area 2	---	---	---	---	---	---	---	---	---	---	---	---	---	[illegible]	[illegible]	---	[illegible]	[illegible]	[illegible]
Area 3	---	---	---	---	---	---	---	---	---	---	333,000	333,000	---	257,[illegible]	[illegible]	---	[illegible]	[illegible]	[illegible]
Area 5	---	---	---	---	---	---	---	---	---	---	846,200	846,200	---	1[illegible]	1[illegible]	---	[illegible]	[illegible]	[illegible]
Area 8	---	---	---	---	---	---	---	---	---	---	835,700	835,700	---	766,[illegible]	76[illegible]	---	[illegible]	[illegible]	[illegible]
Area 9	---	---	---	---	---	---	---	---	---	---	294,800	294,800	---	132,500	1[illegible]	---	[illegible]	[illegible]	[illegible]
Area 9 So.	---	---	---	---	---	---	---	---	---	---	322,300	322,300	---	352,400	352,4[illegible]	---	[illegible]	[illegible]	Fleet Creek
[illegible] North	---	433,300	433,300	---	587,800	587,800	---	720,400	720,400	---	635,300	635,200	---	574,[illegible]	574,3[illegible]	---	[illegible]	[illegible]	[illegible]
[illegible] 25 & 17	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	[illegible]	[illegible]	[illegible]
Reserve Mining Co. [illegible] 001	---	1,700,900	1,700,900	---	942,800	942,800	---	1,053,900	1,053,900	---	937,900	937,500	---	1,363,700	1,363,700	---	[illegible]	[illegible]	[illegible]
002	---	383,000	382,000	---	1,003,100	1,003,100	---	862,500	862,500	---	1,541,800	1,541,800	---	877,200	872,700	---	[illegible]	[illegible]	[illegible]
003	---	4,119,200	4,119,200	---	2,323,[illegible]	2,323,800	---	3,143,900	3,143,400	---	2,949,600	2,949,600	---	2,318,200	2,31[illegible]	---	1,[illegible]	[illegible]	
Totals	---	7,636,500	7,636,500	---	5,503,100	5,503,100	---	6,496,400	6,496,400	---	11,316,800	11,816,800	---	10,267,300	10,267,300	---	8,55[illegible]	[illegible]	
[illegible] PROCESSING AND [illegible] SUPPLY																			
[illegible] Mine Well	---	200	200	---	100	100	---	100	100	---	100	100	---	[illegible]00	6[illegible]	---	200	[illegible]	S[illegible] Creek
[illegible] Pacific Co.	---	---	---	---	---	---	---	---	---	---	---	---	71,000	---	[illegible]	15,300	---	15,3[illegible]	[illegible] Creek
[illegible] Co. – 01	[illegible],230,300	---	5,230,300	4,741,000	---	4,741,000	5,135,000	---	5,135,000	4,207,400	---	4,207,400	4,637,200	---	4,637,200	5,83[illegible]	---	5,835,[illegible]	[illegible]
[illegible] – (59-0056)	29,000	[illegible]	29,000	28,000	---	28,000	26,000	---	26,000	32,100	---	32,100	11,900	---	11,900	2,[illegible]	---	2,[illegible]	[illegible]
(59-0215)	---	---	---	---	---	---	---	---	---	---	---	---	23,500	---	23,500	25,[illegible]	---	25,7[illegible]	[illegible]
4-21	---	---	---	---	---	---	---	---	---	---	---	---	---	[illegible]00	[illegible]	---	---	---	[illegible]
AMAX (59-0177)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	2,[illegible]	---	2,[illegible]	[illegible]
Totals	[illegible]	2[illegible]	5,[illegible]0,100	4,769,000	100	4,769,100	5,161,000	100	5,161,100	4,239,[illegible]	100	4,233,600	4,743,600	1,[illegible]00	4,7[illegible]	5,[illegible]	[illegible]	5,[illegible]	
[illegible] = OTHER [illegible] classified	---	---	---	---	---	---	---	---	---	---	400	400	---	1,[illegible]00	1,[illegible]00	---	---	---	Industr[illegible]
TOTAL [illegible] USE	[illegible]	8,0[illegible]	2[illegible]	230,121,900	5,926,[illegible]	2[illegible]	244,959,000	6,972,7[illegible]	251,931,7[illegible]	87,234,700	12,230,[illegible]	199,[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

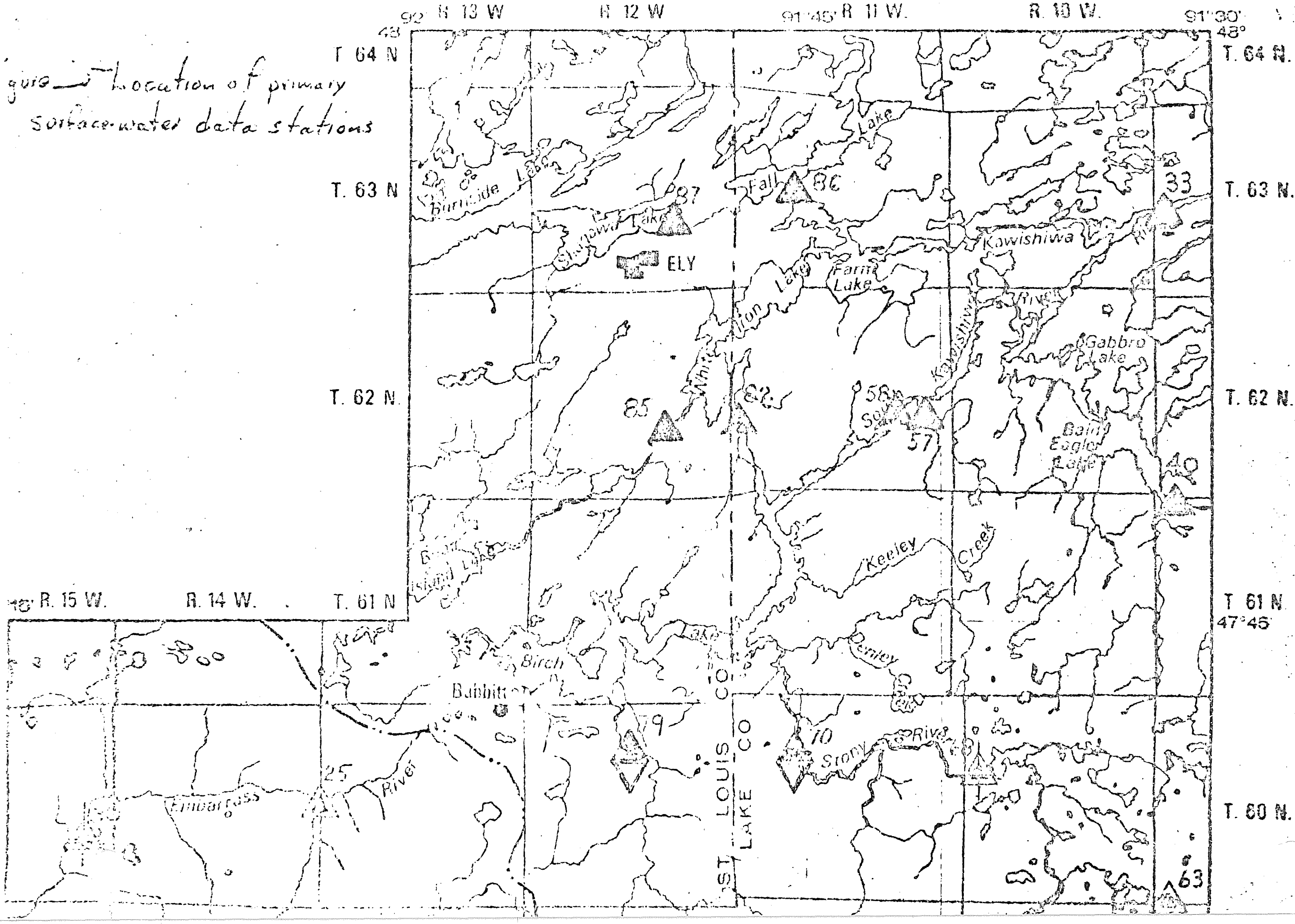
gure — Location of primary surface-water data stations





Laurentian Divide
Sand Lake
66
T. 59 N.
13
15
Partridge
Aurora
Hoyt Lakes
24
St. Louis River
Seven Beaver Lake
Greenwood Lake
T. 58 N.
47°30'
91°30'
R. 11 W.
R. 10 W.
EXPLANATION
GAGING SITES
8
Active gaging station continuous record
2
Periodic discharge measurement site
30
Periodic discharge measurement site at discontinued gaging station
70
and
Temperature and specific conductance measurement site equipped with monitor
Number relates station to tables in report.
T. 57 N.
T. 56 N.
T. 55 N.
47°15'
R. 15 W.
R. 14 W.
92° R. 13 W.
R. 12 W.
91°45'
SCALE 1:250 000
5 MILES
5 KILOMETERS
se from U.S. Forest Service
perior National Forest
nnesota 1:250,000

...gure — Location of primary surface-water data stations



High-flow Characteristics

Flow characteristics of rivers and streams should be considered in planning and design of any development utilizing or affecting streamflow. Some flow characteristics can be defined by frequency curves that relate magnitude of flow to recurrance interval. Low-flow frequency curves are useful in determining adequacy of flow when streams are used for water supply for public, industrial, or agricultural development. Indexes are sometimes selected from low-flow frequency curves to be used for water permit systems and pollution control. Some of the uses of high-flow frequency curves are storage analysis, planning and design of reservoir systems, and any construction within the floodplain of a stream.

A computer program was used in the analysis of high-flow frequency relationships for streams in the area. Gaging station records were processed to give for each water year beginning October 1, the highest mean discharges for the indicated number of consecutive days of flow. These values were arrayed in order of magnitude and assigned order numbers beginning with the largest as number 1. Recurrence intervals were then determined using the formula RI = n + 1/m, where n is the number of years of record and m is the order number. Recurrence intervals, given in years are reciprocals of probability of exceedence in one year so an event having a 20-year recurrence interval will have a 1/20 or 5 percent chance of occurring in any one year.

The computer output for this method is a plot of each input value and its corresponding recurrence interval on a graph having a log scale on the ordinate for discharges and a normal probability scale on the obscissa for recurrence interval. A graphical interpretation is then made fitting a curve to the plotted points.

The computer program gives a second solution fitting the frequency curves mathematically to a log Pearson Type III probability distribution. One of the advantages of mathematical fitting is that if the same theoretical distribution is used, the results will always be the same for a given set of data. The high-flow frequency curves resulting from the graphical interpretation and the Pearson Type III distribution analysis are nearly the same, so mathematically fitted curves were used.

The high-flow frequency curves are given in tabular form in table ____. Extrapolation of the curves beyond the

---

Place table ___ near here.

---

maximum recurrence intervals given is not recommended. Discharge values listed to 3 and 4 significant figures in the table are from computer printouts. Frequency curves for these stations are not that well defined, so discharges should generally be rounded to two significant figures.

Table - High-flow characteristics, value of discharge for given number of consecutive days at various recurrence intervals.

U. S. GOVERNMENT PRINTING OFFICE [illegible]

Table — High-flow characteristics, value of discharge for given number of consecutive days at various recurrence intervals

	Figure Plotting Number	Station I.D. Number	Station Name	Period of Record (climatic years)	Recurrence Interval (years)	1 day	3 days	7 days	15 days	30 days	60 days	90 days	120 days	[illegible] days	[illegible] days
SC-1	21	04015500	Second Creek near Aurora	1956-77	2	106	96.7	84.3	71.4	58.7	46.4	40.7	35.7	29.6	[illegible]
					5	146	133	114	92.6	73.2	57.6	49.8	43.7	36.9	27.5
					10	177	161	134	105	81.0	63.6	54.7	48.[illegible]	41.4	32.2
					25	223	203	161	119	89.4	70.0	59.8	53.7	46.6	38.5
	22	04016000	Partridge River near Aurora	1943-77	2	986	955	842	654	482	346	279	230	172	[illegible]
					5	1643	1576	1307	1033	741	516	406	330	241	[illegible]
					10	2080	1779	1699	1265	902	617	484	389	281	[illegible]
					25	2613	2400	2087	1532	1093	732	572	438	[illegible]	[illegible]
					50	2992	2795	2352	1720	1225	808	632	504	336	[illegible]
SL-1	24	04016500	St. Louis River near Aurora	1943-77	2	1482	1451	1334	1123	902	678	554	461	348	220
					5	2306	2150	2063	1718	1335	900	766	600	458	293
					10	2942	2652	2598	2141	1630	1155	904	724	528	333
					25	3852	3694	3332	2703	2029	1391	1077	856	613	[illegible]
					50	4609	4381	3917	3139	2331	1565	1205	95[illegible]	675	425
E-1	30	04017000	Embarrass River at Embarrass	1943-64	2	563	529	452	358	282	205	166	139	[illegible]	[illegible]
					5	963	896	750	579	441	302	235	194	[illegible]	[illegible].9
					10	1268	1174	971	734	548	363	260	228	165	[illegible]
					25	1692	1559	1275	934	680	437	336	270	193	[illegible]
					50	2034	1867	1516	1086	777	490	377	300	212	[illegible]
K-6	33	05124480	Kawishiwi River near Ely	1967-77	2	1287	1192	1157	1084	915	691	539	438	334	[illegible]
					5	1497	1483	1437	1319	1113	873	691	557	410	[illegible]
					10	1654	1642	1589	1440	1213	969	764	630	448	[illegible]
					25	1823	1814	1753	1563	1315	1069	895	715	486	[illegible]
I-1	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	639	[illegible]
					25	4178	4064	3684	3030	2306	1575	1223	953	686	412
K-2	58	05125000	South Kawishiwi River near Ely	1952-61 1977	2	2127	2063	1905	1726	1511	1143	939	808	616	[illegible]
					5	3497	3407	3186	2844	2334	1699	1364	1136	834	[illegible]
					10	4470	4362	4152	3666	2879	2032	1619	1320	964	625
					25	5746	5687	5492	4781	3556	2411	1911	1518	1116	725
SR-2	68	05125500	Stony River near Isabella	1953-64	2	796	783	731	[illegible]28	513	382	314	260	200	125
					5	1295	1266	1161	979	757	541	442	[illegible]	263	[illegible]
					10	1679	1636	1485	1235	933	648	528	421	303	[illegible]
					25	2224	2159	1936	1580	1170	785	640	505	352	[illegible]
D-1	79	05126000	Dunka River near Babbitt	1952-62 1976-77	2	315	297	254	202	158	108	88.1	75.3	57.7	[illegible]
					5	457	429	367	287	219	148	122	102	73.7	43.7
					10	558	523	446	343	267	178	148	121	85.7	[illegible]
					25	695	647	549	414	335	219	185	147	103	57.3
BI-1	85	05126500	Bear Island River near Ely	1953-62 1976-77	2	234	230	221	206	179	129	107	90.8	68.0	[illegible]
					5	329	324	311	293	250	180	147	123	90.5	52.5
					10	368	363	349	345	281	205	167	139	102	[illegible]
					25	450	445	410	400	335	252	186	155	112	67.6
K-3	86	05127000	Kawishiwi River near Winton	1906, 1916,-17, 1919, 1924-77	2	5059	4921	4763	4445	3779	2843	2327	1943	1431	[illegible]
					5	7509	7388	7186	6661	5507	4065	3254	2659	1986	[illegible]
					10	9009	8924	8696	7986	6506	4738	3753	3057	2250	[illegible]
					25	11200	11100	10500	9650	7610	5451	4273	3486	2520	[illegible]
					50	12900	12700	12400	11000	8329	5897	4594	3759	2685	[illegible]
					100	14800	14700	14200	12200	8970	6281	4068	4000	2824	1693
Sh-1	87	05127230	Shagawa River at Ely	1968-77	2	333	331	323	310	273	217	165	161	126	87.5
					5	436	432	415	382	342	282	243	205	156	112
					10	508	501	476	422	382	323	279	232	173	[illegible]
					25	603	592	553	466	430	372	324	265	190	[illegible]

[illegible]h-flow frequency curves for Partridge River near Aurora have been constructed from data in table ___ and are presented in figure ___. The family of curves with

---

Place figure ___ near here.

---

similar shapes in this example are typical for most stations in the area.

Figure - High-flow frequency curves, Partridge River near Aurora.

9-179b
Extreme log data plot
(Rev. 7-67)

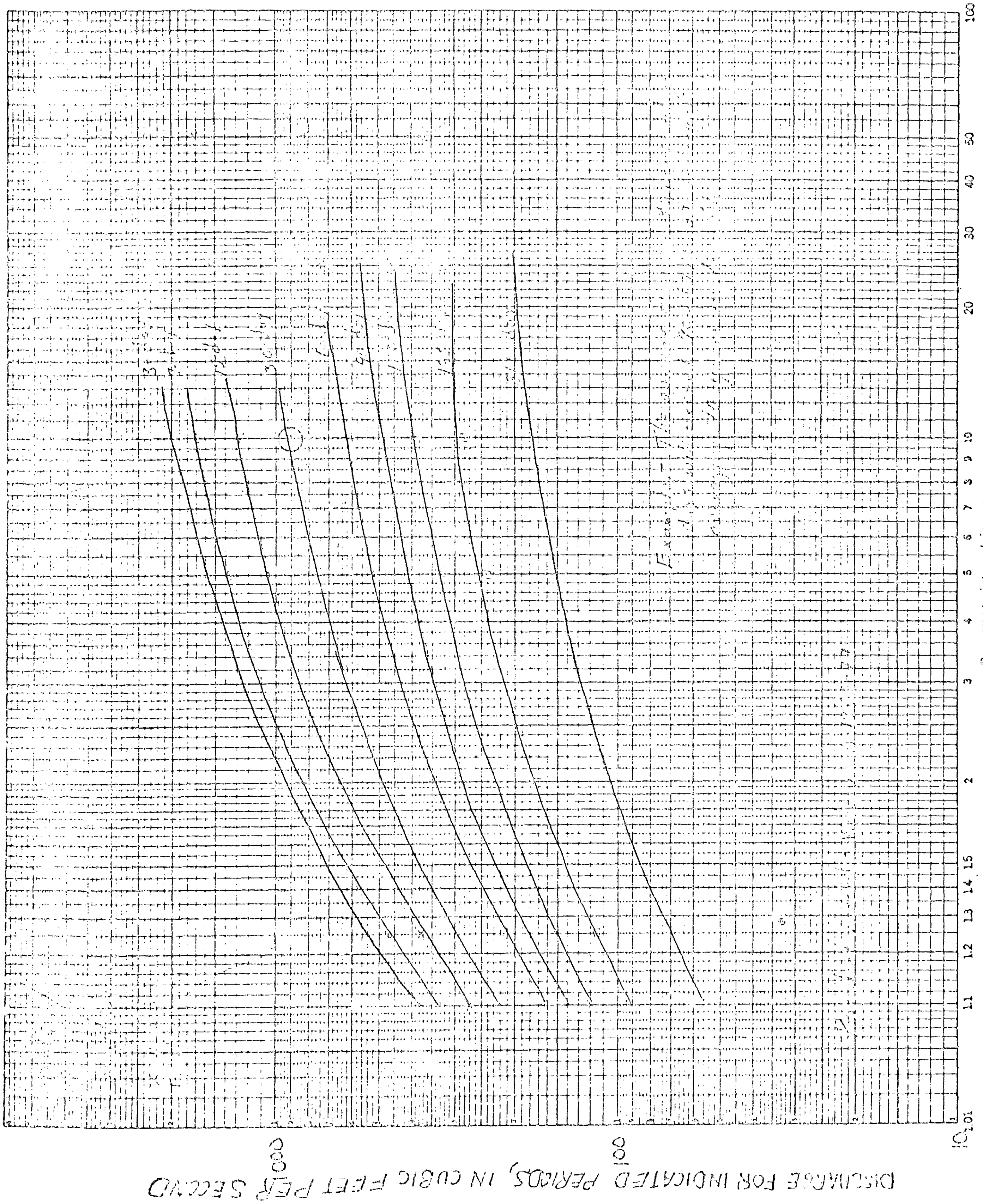
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

B-6

Sta. No. ....

Magnitude and frequency of High Flow on Partridge River at Aurora

Drainage area .... sq. mi. Period 1940-73



Sheet No. _____ of _____ Sheets. Prepared by _______________ Date __________ Checked by __________ Date

Data Network

The U.S. Geological Survey assigns eight-digit numbers to all sites where there are systematic collections of surface-water resources data. The first two digits of the number refer to the part or major drainage basin involved. The study area is located in two major drainage basins, St. Lawrence River basin which is designated 04, and Hudson Bay and upper Mississippi River basin which is 05. The remaining six digits is the downstream order number for the site. Numbers increase for sites located farther downstream. The station identification numbers are not consecutive to allow for new stations in future years.

The eight-digit station numbers are listed in all tables, but because of their length and the number of sites involved, they are not used for most map illustrations. Instead, a single or two-digit downstream order number was assigned to each site and used for location purposes on the maps.

The water year, rather than the calendar year, is used for surface-water records. The water year is the 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends. For example, the year ending September 30, 1977, is called the "1977 water year".

Location of sites, where surface-water resources data have or are being collected in the study area, is shown in figure ___. (Place fig — nearby, "Location of primary surface-water data stations") There are 16 continuous-record gaging stations in the data network. At twelve stations, 10 or more years of streamflow records are available and these records were the basis for determining flow characteristics for streams in the area. Pertinent information for the gaging stations is listed in table ___.

(Place table — "Stream gaging stations")

Table — Stream gaging stations

Figure Plotting Number	Station I.D. Number	Station Name	Drainage Area (mi²)	Period of Record	Maximum Discharge (Date)	Maximum Discharge (ft³/s)	Minimum Discharge (Date)	Minimum Discharge (ft³/s)	Years of Record	Average Discharge (ft³/s)	Mean Annual Runoff (inches)
8	04015455	So Br Partridge River near Babbitt	18.5	June 1977-	Sept.26 1977	a/ 82	---	No flow at times	<1	---	---
21	04015500	Second Creek near Aurora	29.0 nc 6.6	Mar. 1955	Apr.22, 1961	254	Oct. 17, 1976	1.2	22	22.4	---
22	04016000	Partridge River near Aurora	161 nc 13	Aug. 1942-	May 10, 1950	3,230	Jan. 30, 31, 1961	2.2	35	*126	*10.83
24	04016500	St. Louis River near Aurora a	290 nc 13 277	Aug. 1942-	May 14, 1950	5,380	Oct. 1, 1940 and Jan. 29-Feb. 10, 1977	4.0	35	*244	*11.51
30	04017000	Embarrass River at Embarrass	88.3	Aug. 1942-Dec. 1964	May 8, 9, 1950	1,740	Jan. 28-Feb. 5, 1963	.90	22	64.4	9.90
33	05124480	Kawishiwi River near Ely	253	June 1966-	Apr. 24, 1976	1,720	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	Apr. 19, 1976	3,900	Aug. 21, 22, 1961 and Sept. 11-13, 1976	24	10	272	10.83
57	05124990	Filson Creek near Ely	9.66	Oct. 1974-	Apr. 25, 1975	129	---	No flow at times	3	6.17	8.67
58	05125000	So. Kawishiwi River near Ely	---	Oct. 1951-Sept.1961 Apr. 1976-	May 4, 1954	5,130	Oct. 12, 1960	25	11	419	---
68	05125500	Stony River near Isabella	180	Oct. 1952-Dec. 1964	Apr. 27,b/ 1957	2,040	Aug. 22, 1961	5.6	12	127	9.58
70	05125550	Stony River near Babbitt	219	Aug. 1975-	Apr. 19, 1976	2,490	Nov. 29, 1976	6.4	2	136	8.43
79	05126000	Dunka River near Babbitt b	53.4 nc 4 +4	Oct. 1951-Sept.1962 Feb. 1975-	Apr. 16, 1954	691	---	No flow at times	13	36.6	9.29
82	05126210	So. Kawishiwi River above White Iron Lake near Ely	---	Aug. 1975-	Apr. 22, 1976	8,080	Mar. 22, 1977	19	2	608	---
85	05126500	Bear Island River near Ely	68.5	Oct. 1952-Sept.1962 Mar. 1975-Sept.1977	May 3, 1954	423	---	No flow at times	12	41.2	8.17
86	05127000	Kawishiwi River near Winton c	1,229 +5	June 1905-June 1907 Oct. 1912-Sept.1919 Sept. 1923-	May 18, 1950	16,000	---	No flow at times	58	1,019	11.25
87	05127200	Shagawa River at Ely	99.0	May 1967-	June 12, 1970	640	Nov. 11, 1976	0.17	10	86.6	11.88

a - 148 cfs measured Apr. 12, 1976.
b - 2,260 cfs measured Apr. 20, 1976.
* - Adjusted for storage and diversion from Colby Lake.
nc - noncontributing drainage area with respect to surface runoff (included in total drainage area)

a 291.1 1/3/78
b 49.4 1/3/78
c 1229 2/3/78

There are eight periodic measurement sites in the data network. Discharge measurements were made at six-week intervals at these sites to develop stage-discharge relationships so discharges could be determined whenever water-quality samples were taken. Information at these sites is listed in table ___. (Place table — "Periodic discharge measurement sites") Two periodic-measurement sites, 30 and 68, are located at discontinued gaging stations, so additional information is given in table ___. Periodic measurements were made at site 8 from December 1975 to June 1977, when it was converted to a continuous-record gaging station.

In addition to streamflow data, continuous records of water temperature and specific conductance were collected at sites 70, 79, and 15 and periodic sediment samples were taken at sites 70, 79, and 85.

Table - Periodic discharge measurement sites.

U. S. GOVERNMENT PRINTING OFFICE

Table - Periodic discharge measurement sites

Figure plotting number	Station I.D. number	Station name	Drainage (area mi²)	Period of discharge measurements	Range of discharge measured (ft³/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	94.0	July 1976-	328	0.22
8	04015455	So. Br. Partridge River near Babbitt	18.5	Dec. 1975-June 1977 /a	148	0
13	04015461	Colvin Creek near Hoyt Lakes	18.3	Dec. 1975-	136	0.25
25	04016900	Embarrass River near Babbitt	17.6	Dec. 1975-	124	0
30	04017000	Embarrass River at Embarrass	88.3	Aug. 1975- /b	449	1.39
63	05125400	Stony River near Murphy City	62.0	Dec. 1975-	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 /b	2260	4.93

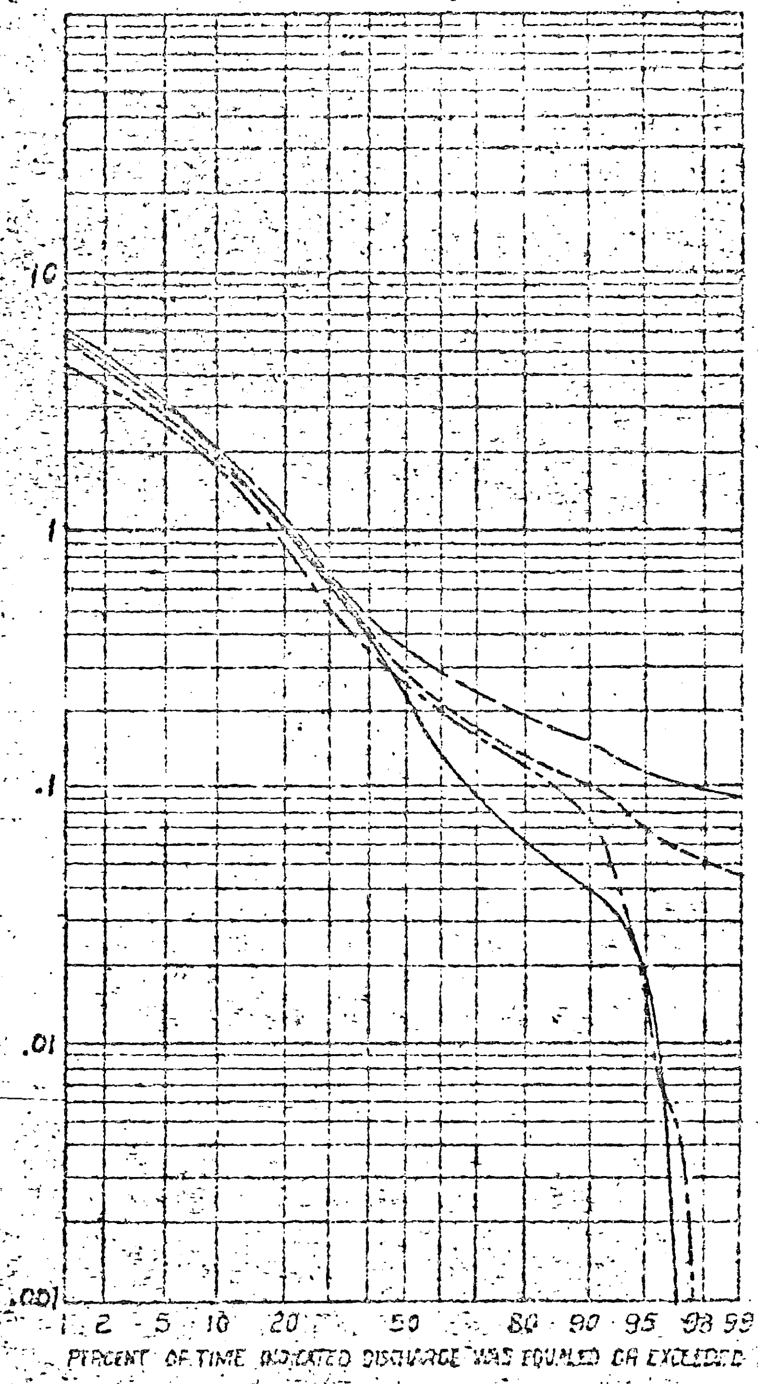
/a Converted to continuous record gaging station June 1977.

/b At discontinued gaging station. See table __.

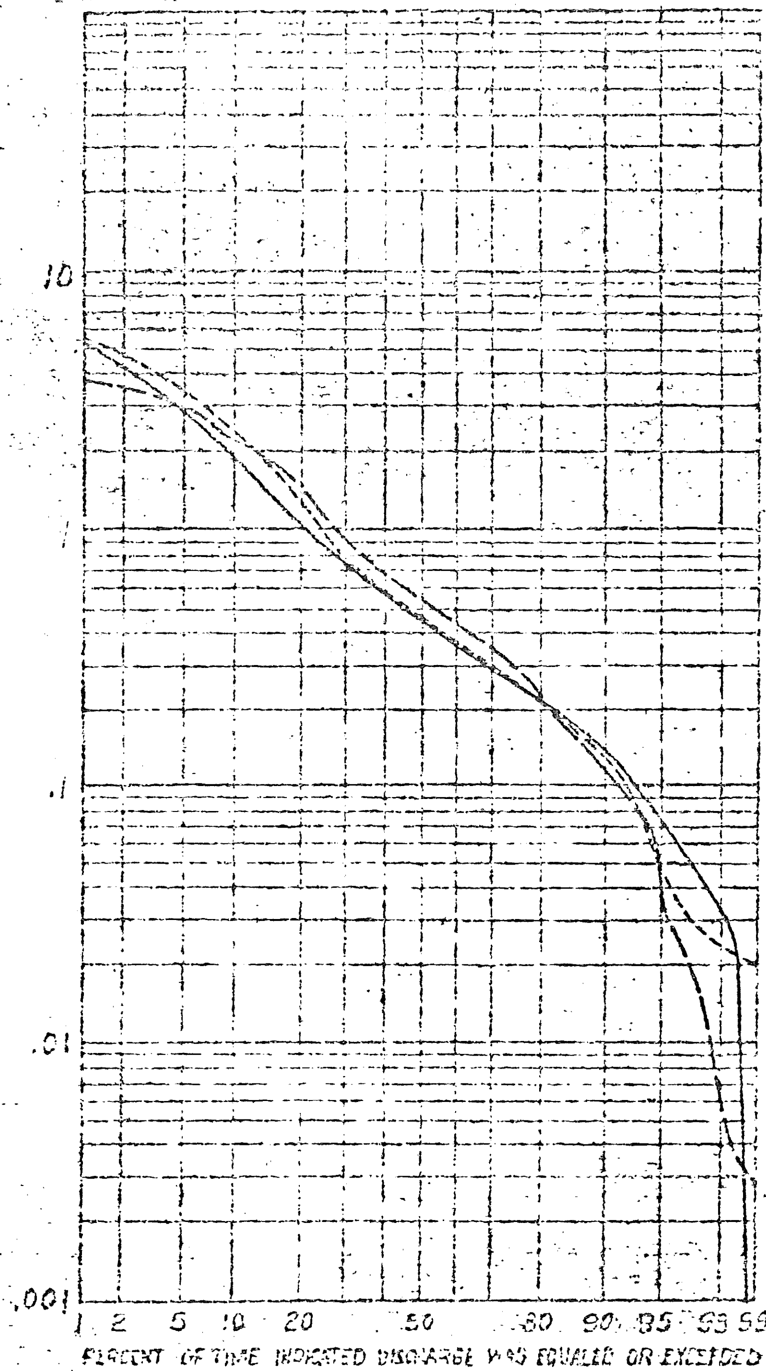
Flow-duration curves

Flow-duration curves are cumulative frequency curves that shows the percentage of time specified discharges are equalled or exceeded during a given time perod without regard to thier sequence of occurrence. Mean discharges of time intervals of flow, such as daily, weekly, monthly, or annual, may be used to construct duration curves. When longer time intervals are selected, however, the range of discharge values decreases and there are fewer values to define the cures. All flow-duration curves presented in this section are based on daily mean discharges. Flow duration curves for streams at the 12 gaging stations having 10 or more years of record are shown in figures __ and __.

Flow characteristics of streams are reflected in their flow-duration curves. A comparison of flow-duration curves for the same period of time for two or more streams indicate differences in basin and flow characteristics of the streams. The slope of a duration curve indicates the vaiability of flow. Flashy streams normally have large ranges in discharge and duration curves that have steep slopes. Conversely, streams that have considerable storage available and therefore less variability of flow have much flatter duration cures.

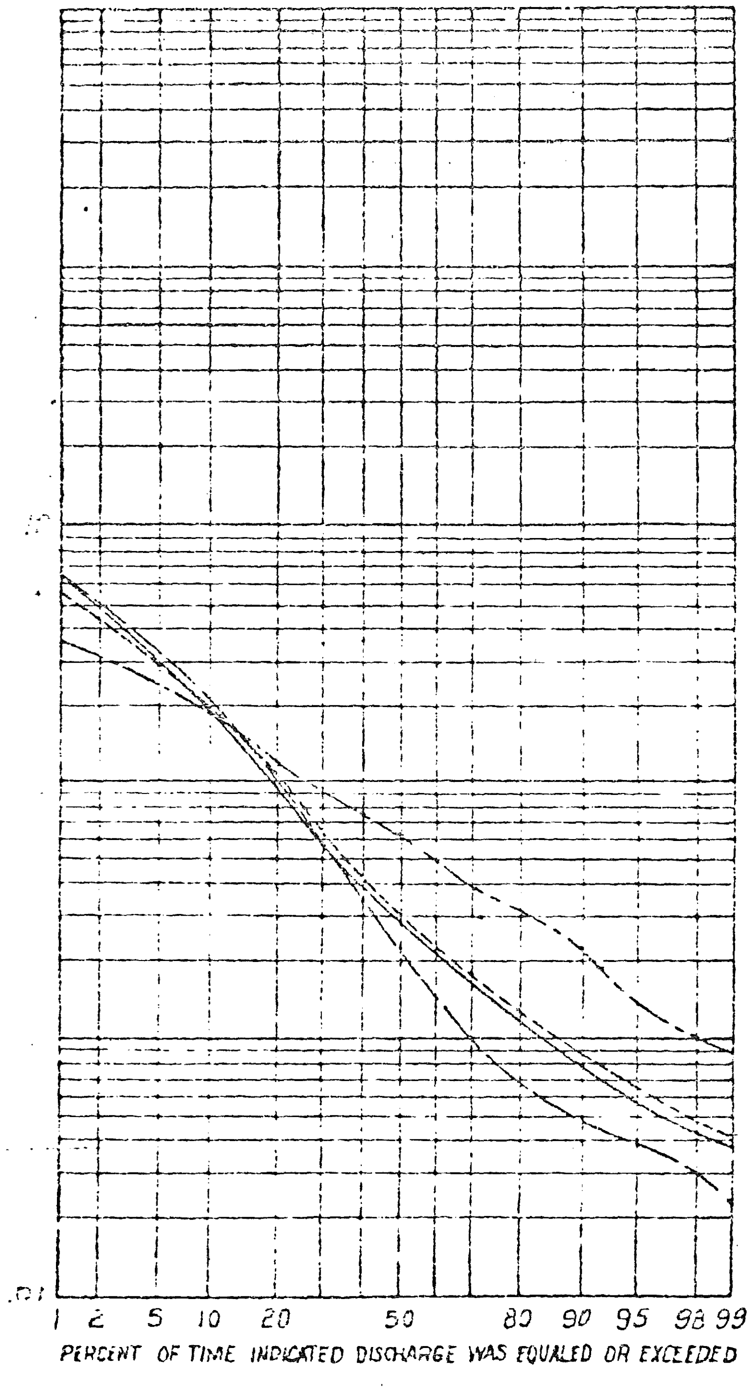


Donka ———
Stacy – – –
Bear Island —·—·—
Isabella —— —— ——



Winton

Saganaga



Partridge
Stoner
Embarrass
Scenic

The shape of duration curves at the extremes is also indicative of basin and flow characteristics. For example, relatively flat slope at the lower end of the curve indicates that the streamflow is being sustained from storage from either surface water or ground water, or a combination of the two. Whereas, streams that drain basins where flood runoff is held in storage will have slopes that flatten near the upper end of the curve.

The flow-duration curve for Second Creek near Aurora has the least slope of all the curves for streams in the St. Louis River basin. This indicates that rather stable flow conditions prevail throughout the entire range of flow in the basin. Flow at this station is significantly affected by several types of vegetation. The amount of vegetation has varied considerably during the 22 years of record; therefore, the curve should not be used for comparison with flow characteristics of other streams or to provide reliable estimates of future flow. For example, from 1956 to 1963, there were 494 days when the daily flow was less than 4.6 ft^3/s, but from 1964 to 1977, there have been only 13 days when the daily flow was this low. The increase in magnitude of low flows since 1964 is caused by water from mine-pit dewatering being discharged into Second Creek and its tributaries.

The shape of the duration curves for Partridge River near Aurora, and St. Louis River near Aurora, are effected by regualtion, particularly at the two extremes. Storage of flood runoff in the off-channel Partridge Reservoir near Colby Lake reduces flood-flow at both stations. Largest diversions are generally made on the rising limb of high water. Low flows at the St. Louis River gage are supplemented by seepage losses from Partridge Reservoir which are related to stage in the reservoir. Three discharge measurements made in the 3-mile reach above the mouth of the Partridge River, which is adjacent to the reservoir, during a high reservoir stage ranged from 6 to 10 ft^3/s increase in flow. Similar discharge measurements made during a low reservoir stage (August 1976) indicated a 0.9 ft^3/s loss in flow. Low flows at the Partridge and St. Louis River gaging stations also are augmented by the above normal flows from Second Creek.

The slope of the flow-duration curve for Kawishiwi River near Winton in figure __ is relatively straight except near the lower end where a sharp break downward shows regulation by the Winton Hydroelectric powerplant. The daily mean discharge was zero for 276 days out of 21,185 days of record, which is 1.3 percent of the time. Of the 276 days of zero flow, 208 were during 1924-28.

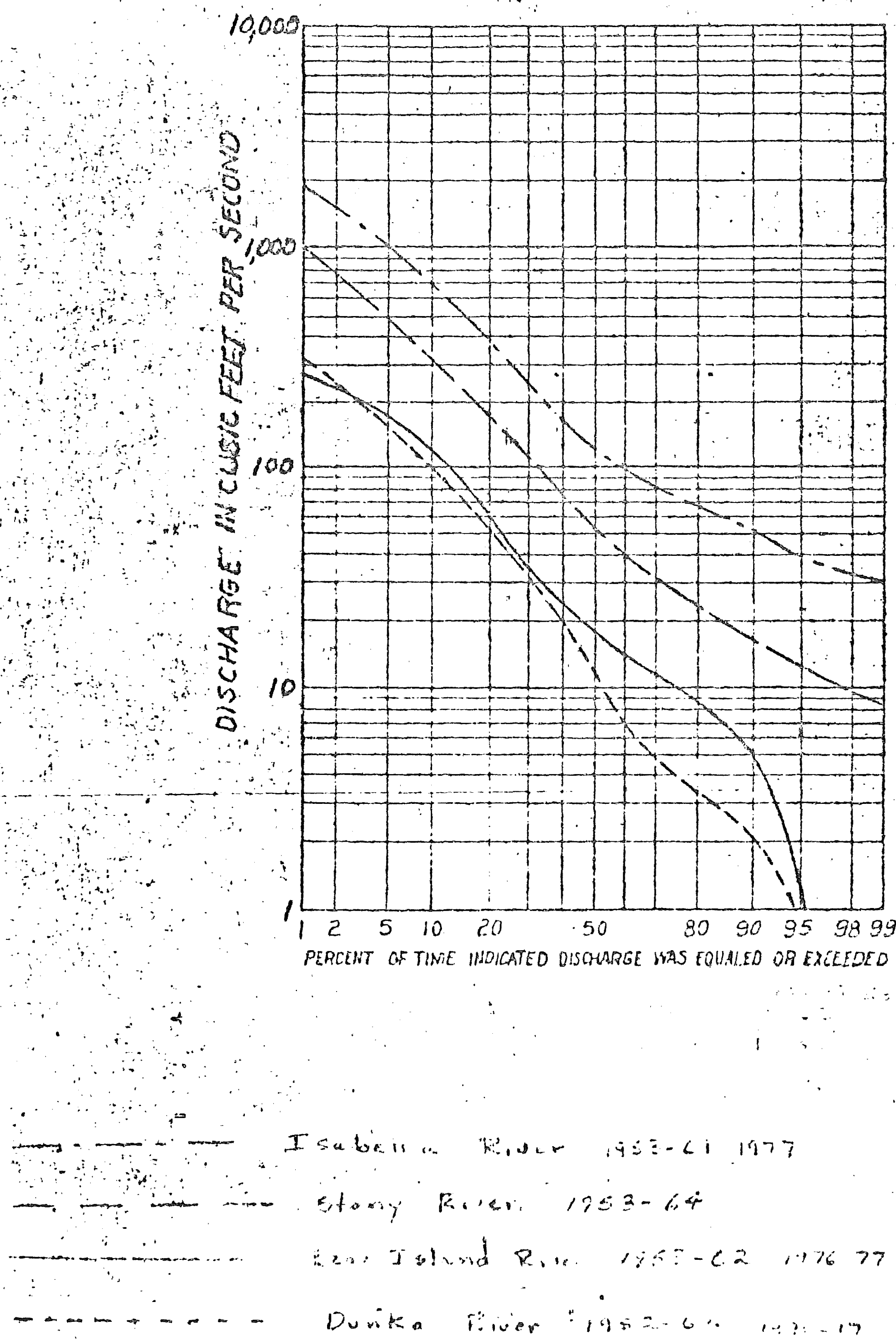
The 10 to 13 years of streamflow records available at several of the gaging stations is a rather short period of time for determining long-term flow characteristics for future years. To compare the hydrology during the short periods of record with that for the long periods of time, flow-duration curves were constructed for Kawishiwi River near Winton for 1952-63 and 1967-77. From the comparison, streamflow of the Kawishiwi River near Winton during 1952-63 was very similar to flows during its 56 years of record. Discharge values between 90 and 99 percent of the time were higher for 1952-63 probably because the Kawishiwi River is 100 percent regulated at the powerplant during low-flow periods.

A similar comparison of duration curves for 1967-77 and long-term record indicated Kawishiwi River streamflow was 5 to 10 percent above normal for 1967-77. Flow-duration curves for Kawishiwi River near Ely and Shagawa River at Ely were not adjusted on the basis of this comparison, because the adjustment varied throughout the curve. Also a comparison of short-term and long-term flow-duration curves for St. Louis River near Aurora indicated streamflow during 1967-77, and 1943-77, were nearly the same.

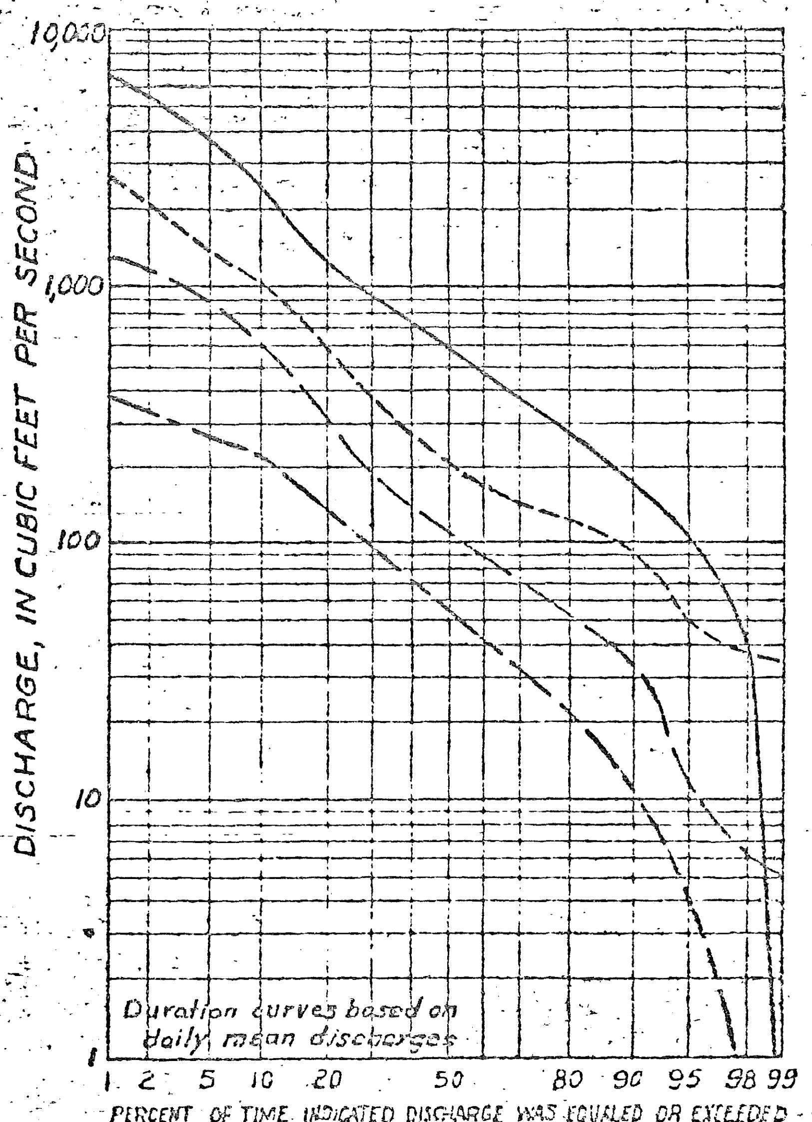
The duration curves for Kawishiwi River near Ely and South Kawishiwi River near Ely are similar except near the lower end. Ther is no man-made regulation affecting flow at either of these stations, however, flows are sustained for extended periods of time by the release of flood-runoff in surface storage. The dip in the slope at the lower end of the curves were caused by extremely low flows during the 1976-77 drought. The curve for South Kawishiwi River near Ely was also effected by the drought in the late fifties and early sixties.

The duration curve for the Shagawa River at Ely flattens at the upper end because storage in Burntside and Shagawa Laeks reduces flood flows. At the lower end, the curve breaks downward indicating that the flow is not well sustained by either lake storage or discharge from the ground-water system.

Flow-duration curves can be compared more readily when unit flow is used instead of total flow. In figures __ and __, the ordinate scale of the flow duration curves at the gaging stations have been converted to discharge per square mile.



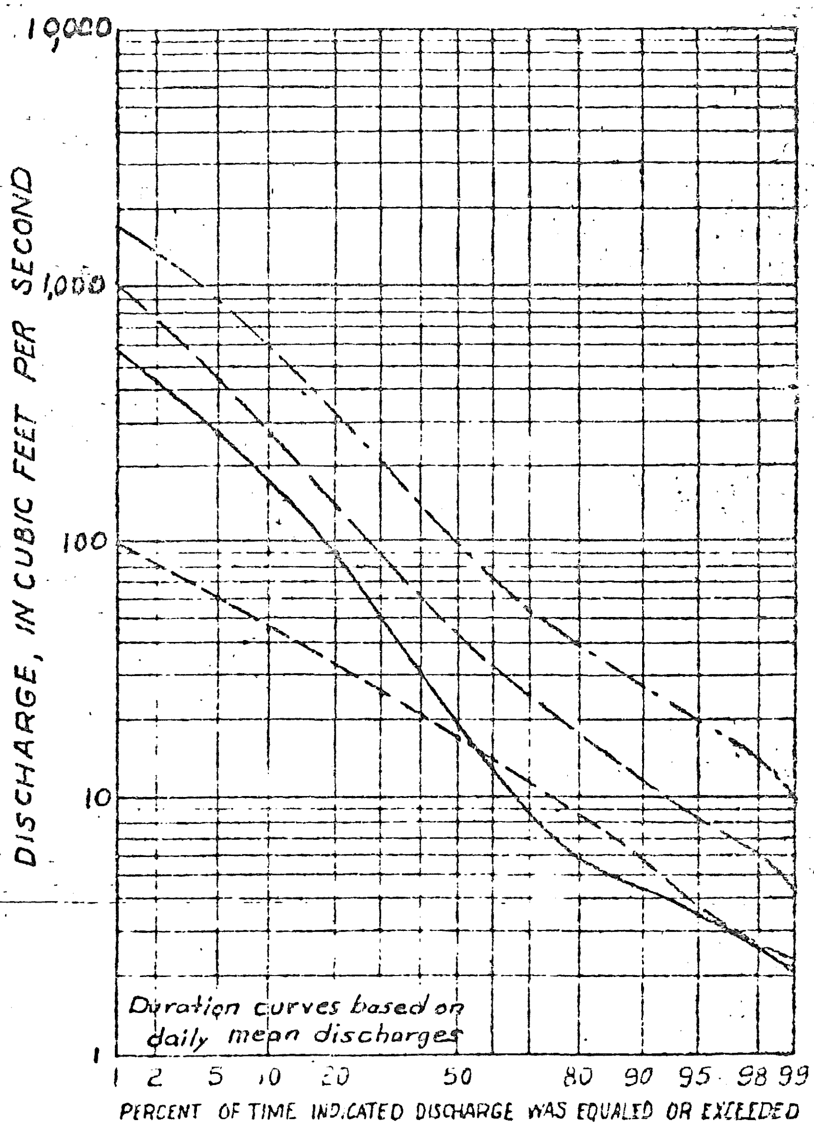
10,000
1,000
100
10
1
DISCHARGE IN CUBIC FEET PER SECOND
1 2 5 10 20 50 80 90 95 98 99
PERCENT OF TIME INDICATED DISCHARGE WAS EQUALED OR EXCEEDED
Isabella River 1953-61 1977
Stony River 1953-64
Island R 1957-62 1976 77
Dunka River 1952-64



———— Kawich... nr Lund 1915, 1916, 1917, 1919, 1924-77

- - - - - - - So. Kawich... nr Ely 1952-6, 1977

—— —— —— Kawich... nr Ely 1962-77



[illegible] 194[illegible]-77

Partridge 194[illegible]-77

[illegible]

[illegible]

Most of the curves are similar in shape and position between 1 and 20 percent on the duration scale. The two major exceptions are the curves for Second Creek near Aurora, which is regulated, and Shagawa River at Ely, which is located at the outlet of a large lake. Between 20 and 80 percent on the duration scale, the curves diverge gradually. Highest unit flows for the segment of the curves are at Second Creek near Aurora and lowest unit flows are at Embarrass River at Embarrass and Dunka River near Babbitt. As the duration exceeds 80 percent of the time, there is a large variation in position and shape of the curves. For this segment of the curves, Dunka River near Babbitt has the lowest unit flows. This part of the flow-duration curve for Dunka River is not representative of basin, because there are significant losses of flow in the channel reach upstream from the gage during periods of base flow. This flow loss is caused by mining activities and is discussed in greater detail in the section ______________.

Excluding Dunka River, the lowest unit flows for durations exceeding 90 percent are at Bear Island River near Ely and Shagawa River at Ely. These two gaging stations are located near outlets of large lakes. Considering only the unregulated streams, highest unit flows for this part of the curves are Isabella River near Isabella and Stony River near Isabella.

Annual hydrographs of daily flows

Flow patterns for five streams are shown by hydrographs in figures __ and __. The hydrographs are constructed from daily mean discharges for the indicated water years. For four of the stations, records were selected for water years when annual runoff was below, near, and above normal. These hydrographs are designated A, B, and C, respectively. The hydrograph for Filson Creek near Ely (fig.) shows runoff from a basin of only 9.9 square miles.

Runoff values for the water year are given for all hydrographs except South Kawishiwi River near Ely, which cannot be determined because of the channel split located upstream from the station. Annual runoff in inches is the depth to which the drainage basin would be covered if all the runoff for the year were uniformly distributed over the basin.

Streamflow generally recedes slowly in late fall and through the winter, rises sharply during spring snowmelt, ~~and~~ recedes during the summer, and rising occasionally during periods of heaby precipitation. This pattern of flow is evident in all the hydrographs except for Filson Creek near Ely.

Streamflow is affected by size and shape of the drainage basin, topography, surface storage, drainage network, geology, soils, and vegetal cover. Additional factors which influence streamflow are the amount and areal distribution of precipitation, humidity, wind velocity, and temperature. Certain factors have a pronounced effect on streamflow and are evident on the stream hydrograph.

The effect that large amounts of surface storage have on streamflow is shown in the South Kawishiwi River near Ely hydrograph. The drainage network for this station has numerous lakes that store water during high-flow periods and then release it slowly, sustaining flow at relatively high rates for several months. Streamflow at Stony River near Isabella is also effected by surface storage, but to a lesser degree than South Kawishiwi River.

Discharge from the ground-water system is slight in the study area. In most basins, aquifers are small and discontinuous. One of the larger aquifers is located in the Embarrass River basin, but hydrographs for this stream (fig.) show that the discharge (even in wet years) is not sustained at a very high rate.

As noted in the section on regulation, flow in the Partridge River is supplemented by discharge from mine-pit dewatering. Even though streamflow was low during the fall, in the 1975 and 1976 water years, flow in Partridge River was sustained during the winter by water from mine-pit dewatering. Above normal flow in the winter of the 1969 water year is attributed to increased runoff from the basin because of excessive precipitation shortly before freeze up.

725-784

Drainage area

Drainage area size is one of the most important characteristics of the basin. Flow characteristics for various basin sizes can be compared when they are converted to unit values (generally per square mile). In multiple correlation studies, drainage area is generally the most significant basin characteristic for describing flow characteristics. In many areas, drainage area is the only basin characteristic necessary to adequately define certain flow characteristics.

A complete drainage area analysis was made for this study. Topographic divides for all gaging stations and miscellaneous water data sites were delineated on the most recently issued U.S. Geological Survey 7 1/2- and 15-minute topographic maps. The area in each basin was then planimetered and the resulting drainage areas are tabulated in table ___ on page ___. Areas that are non-contributing with respect to surface runoff were determined for affected sites, and are listed in the table as "N.C." for non-contributing drainage area.

Previously published drainage areas for gaging stations and partial-record sites in the study area are superseded by values given in table ___.

U. S. GOVERNMENT PRINTING OFFICE : 1959 O - 511171
867-100

River channel profiles

The slope parameter has been found significant in many multiple correlation studies that relate flow characteristics to basin characteristics of a stream. Flood-frequency relationships have been developed for many areas, including Minnesota (Guetzkow, 1977), using regressions based on drainage area, channel slope, and area of surface storage.

Channel profiles for the major streams in the area were constructed from river-mile distances of river crossing contours determined from U.S. Geological Survey 7 1/2- and 15-minute topographic maps. The same scales were used for all profiles except Kawishiwi River, to assist in comparing shapes and gradients of the streams.

U. S. GOVERNMENT PRINTING OFFICE : 1959 O - 511171
847-100

River channel profiles for streams in the upper St. Louis River basin are shown in figure ___. The St. Louis River

Place figure ___, "Channel profiles for streams in the upper St. Louis River basin" nearby.

decends 325 feet in the 41.2 miles (7.9 ft/mi) from the basin divide to 04016500, St. Louis River near Aurora gaging station. The headwaters are located in an area of lakes, marshes, and swamps, where there is little relief as evidenced by the channel gradient of only 2.6 ft/mi in the upper 17 miles of the profile. Immediately downstream from this flat reach, is a 6.4-mile reach that has a gradient of 20.3 ft/mi.

The Partridge River channel is 35.7 miles long and has an average gradient of 6.4 ft/mi. Except for the steps in the profile up and downstream from Colby Lake and near the headwaters, the channel gradient is relatively uniform.

U. S. GOVERNMENT PRINTING OFFICE : 1959 O - 511171
867-100

Figure ___, "Channel profiles for streams in the upper St. Louis River basin".

U. S. GOVERNMENT PRINTING OFFICE : 1959 O - 511171
867-100

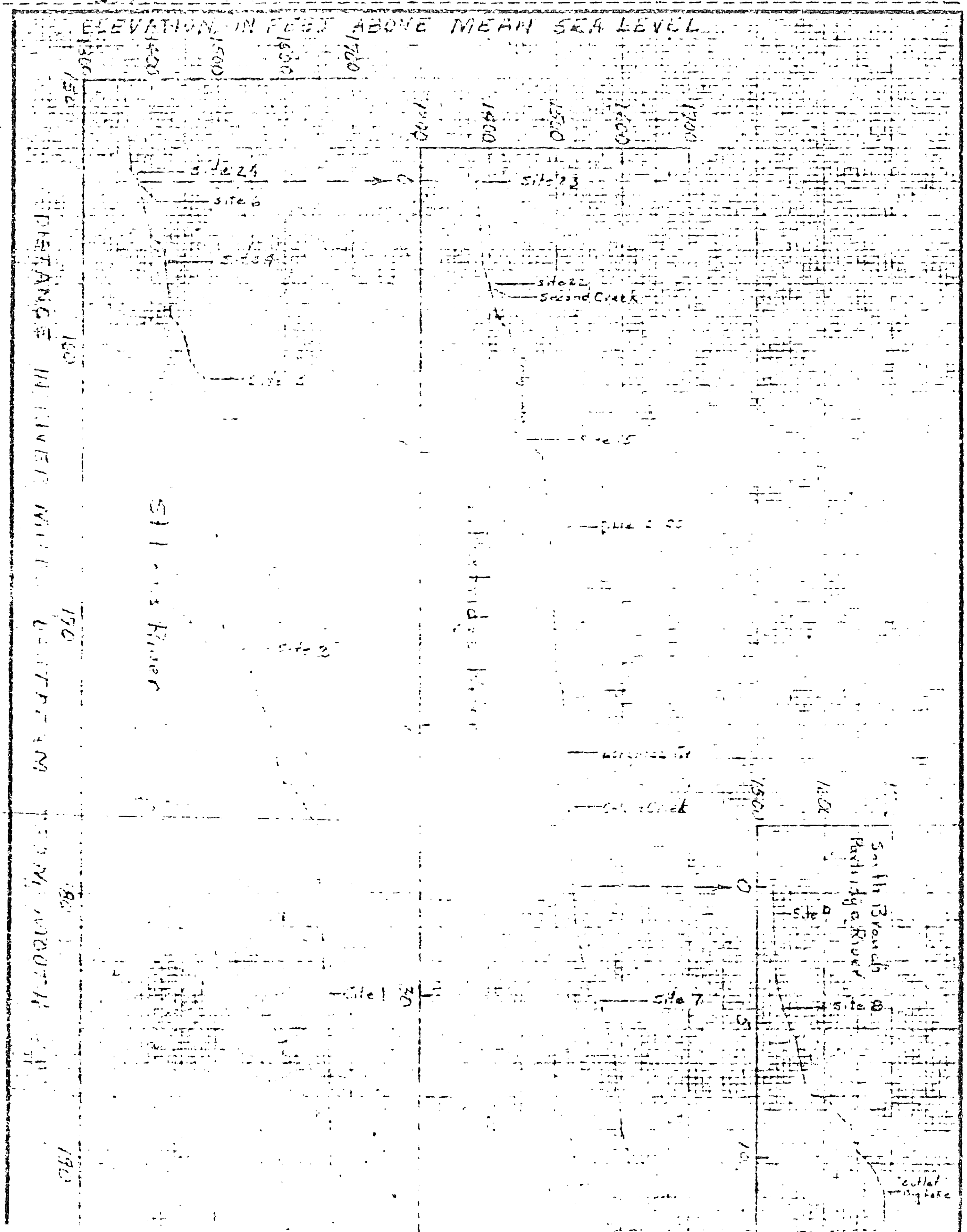


Figure —— Channel

The channel profile for the mainstem of the Kawishiwi River is shown in figure ___. The Kawishiwi River profile

---

Place figure ___, "Channel profile for mainstem of Kawishiwi River" nearby.

---

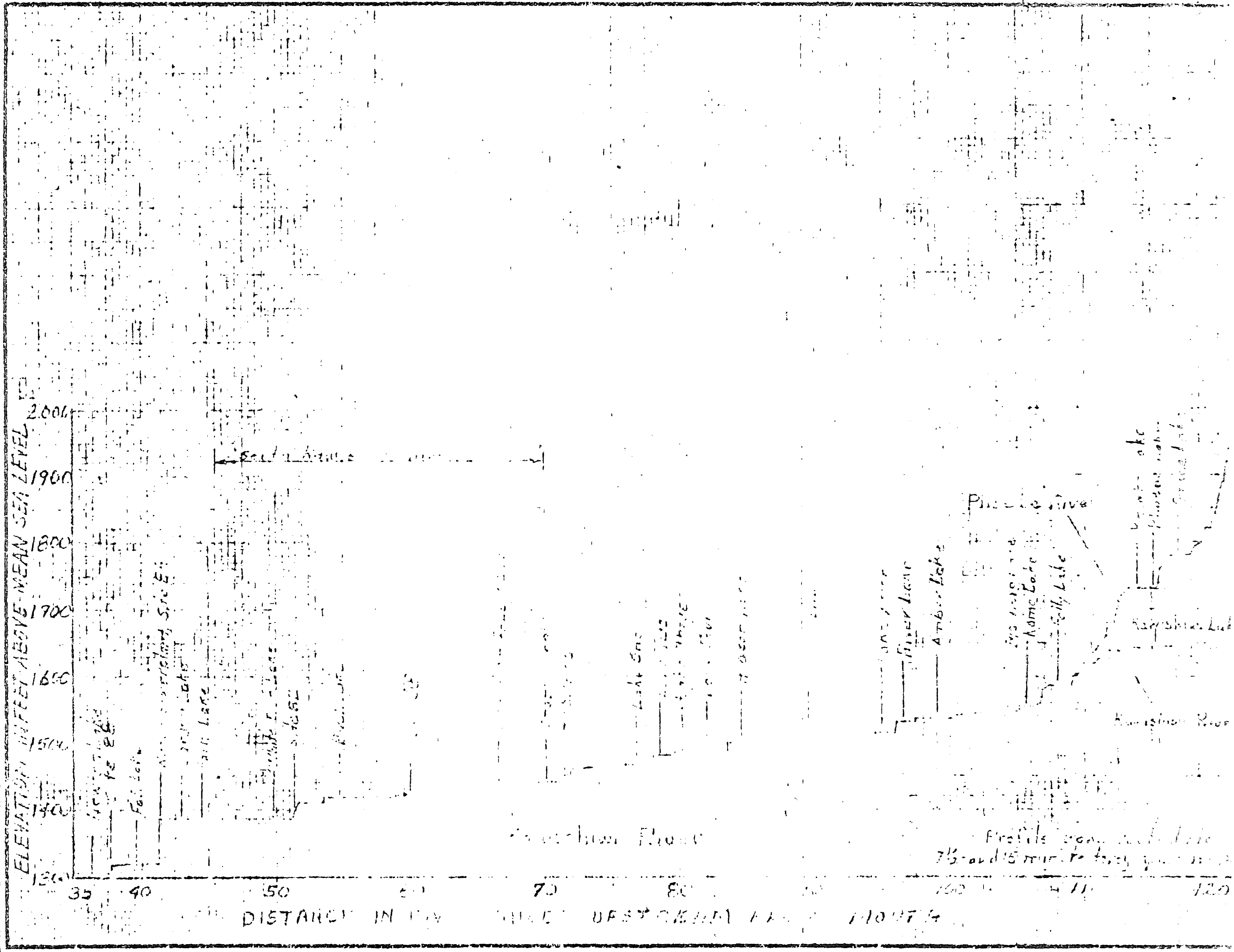
was constructed using the South Kawishiwi River as the main channel between river miles 44 and 70. Near the headwaters, the profile for Phoebe River was included for its channel length is longer and the basin divide is at a higher elevation than the mainstem of the Kawishiwi River upstream from river mile 109.5. The gradient of the Phoebe River is 33.1 ft/mi.

The average gradient of the Kawishiwi River from its source in Kawishiwi Lake to the mouth at Fall Lake is 4.3 ft/mi. The central part of the profile from mile 58 to mile 105 has a gradient of only 2.8 ft/mi. The channel has a uniform drop through this reach except for minor stepping at most lakes. Some of the lakes on the Kawishiwi River are not identified because of the small scale.

U. S. GOVERNMENT PRINTING OFFICE : 1959 O - 511171
867-100

Figure ___, "Channel profile for mainstem of Kawishiwi River."

U. S. GOVERNMENT PRINTING OFFICE : 1959 O - 511171
867-100


ELEVATION IN FEET ABOVE MEAN SEA LEVEL
2000
1900
1800
1700
1600
1500
1400
1300
35
40
50
70
80
DISTANCE IN
Pickle River
Amber Lake
Kawishiwi Lake
Kawishiwi River
Profile

Figure

The channel profiles in figure ___ are for Stony and

Place figure ___, "Channel profiles for Isabella and Stony Rivers" nearby.

Isabella Rivers. The two rivers have channel lengths that are nearly the same, and both rivers descend over 400 feet from basin divide to their mouth. Average gradients are 11.4 ft/mi for Stony River and 10.1 ft/mi for Isabella River.

Channel profiles for smaller tributaries to St. Louis and Kawishiwi Rivers are shown in figure ___. The segment of

---

Place figure ___ "Channel profiles for tributary streams" nearby.

Embarrass River located in the study area has a flat profile. From the basin divide to the gaging station at Embarrass (site 30), the channel drops 80 feet in 21.5 miles for an average gradient of 3.7 ft/mi. In the 14.6-mile reach upstream from site 30, the gradient is only 1.4 ft/mi. The river channel meanders in this reach, which is typical for many low gradient streams.

Figure ___,"Channel profiles for Isabella and Stony Rivers".

U. S. GOVERNMENT PRINTING OFFICE : 1959 O - 511171
667-100

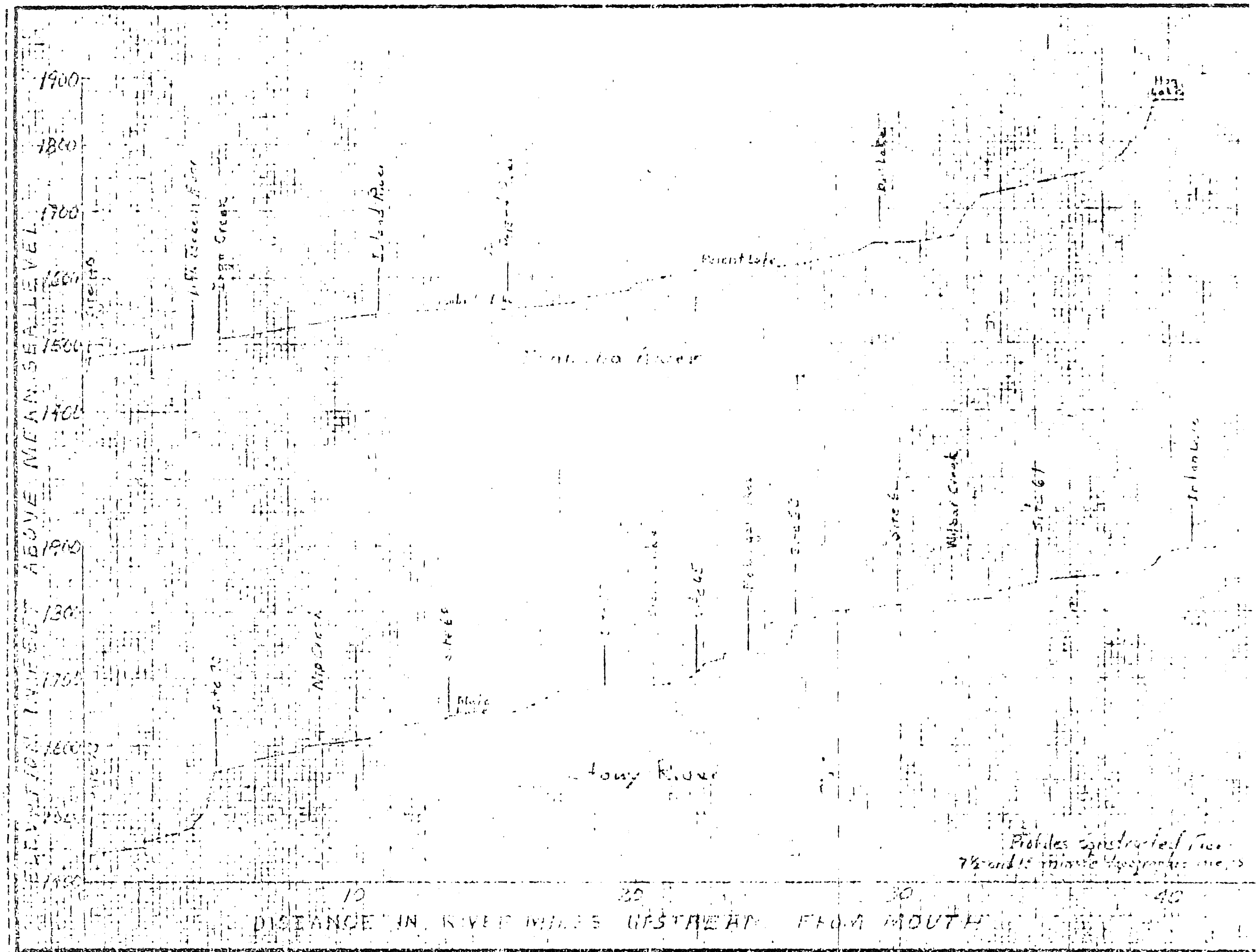
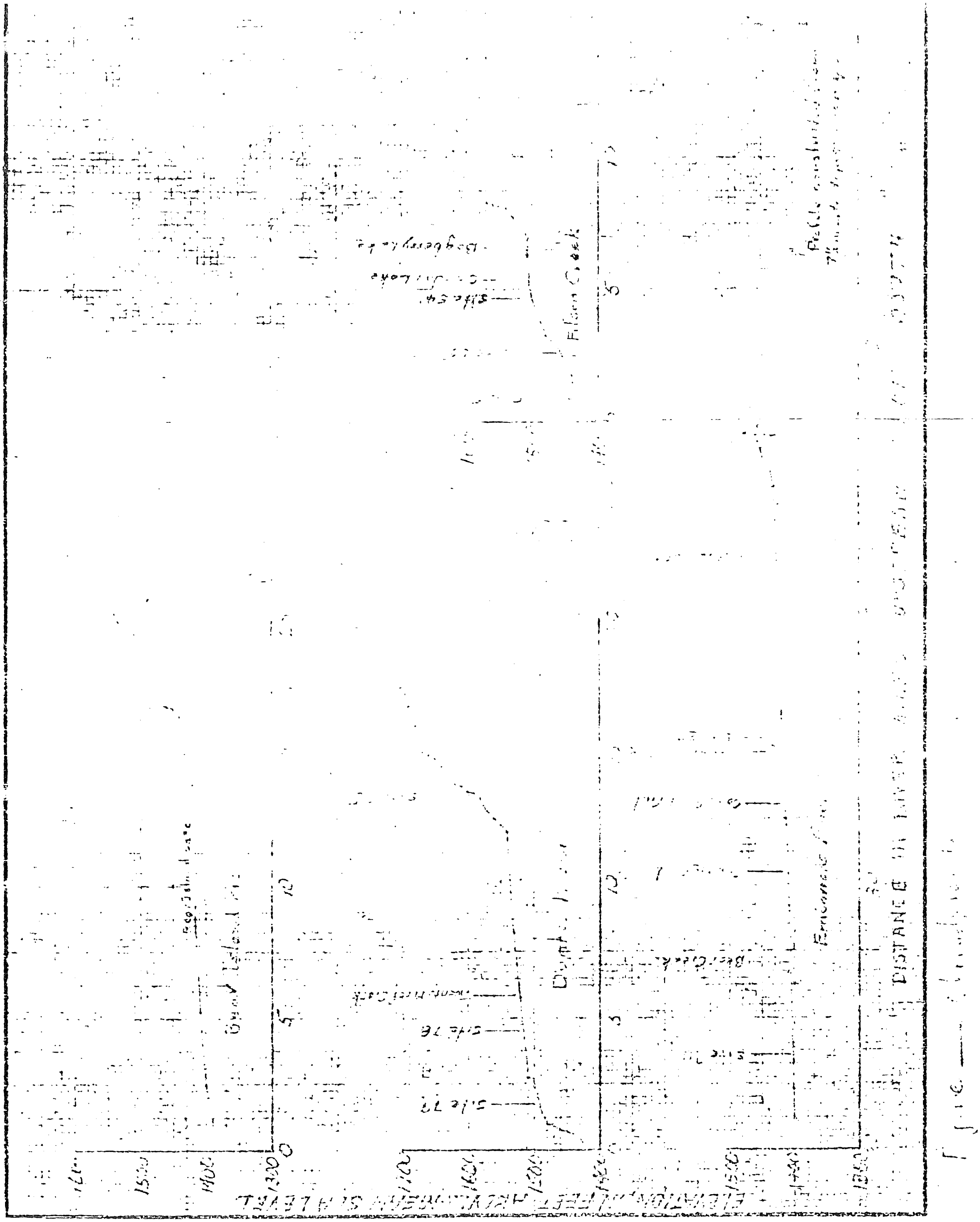


Figure ---- Channel p...

Figure ____, "Channel profiles for tributary streams".

U. S. GOVERNMENT PRINTING OFFICE : 1959 O - 511171
867-100



Sheet No. ...... of .... Sheets. Prepared by Date Checked by Date

The remaining profiles in figure ___ are for tributaries to Kawishiwi River. Filson Creek, which drains an area less than 10 square miles, has a gradient of 16.2 ft/mi. The drainage area for Dunka River exceeds 50 square miles and its channel gradient is 15.9 ft/mi. The lowest channel gradient for these three tributaries is 7.4 ft/mi for Bear Island River. In the lower 12.5-mile reach of this stream, the gradient is only 2.4 ft/mi.

U. S. GOVERNMENT PRINTING OFFICE : 1975 O - 511171
867-190

add discussion re: why we are interested

Surface-Water Resources

Surface-water resources for over 1,700 square miles are analyzed in this section of the report. Twenty-two percent of the area [in study area?] is in the St. Louis River basin and the remaining 78 percent is in the Kawishiwi River and Shagawa River basins. The common drainage divide between St. Louis and Kawishiwi Rivers in the study area is the Laurentian Divide. North of the divide, water in the Kawishiwi River flows through Rainy Lake and Lake of the Woods before turning north to Hudson Bay. South of the Laurentian Divide, water in the St. Louis River flows to the Atlantic Ocean via the Great Lakes and the St. Lawrence River.

The Kawishiwi River has a drainage area of 1,229 square miles at its mouth at Fall Lake. Shagawa River, which also empties into Fall Lake, drains an area exceeding 100 square miles. Both river basins have a high density of lakes and wetlands. Many of the lakes are interconnected by river channels that form the surface-water drainage network. The drainage pattern is partly rectangular as evidenced by nearly right-angle bends in streams which follow lines of structural weakness (joints and faults) in the bedrock. Some lakes are similarly controlled having been formed where glaciers scoured depressions along lines of weakness on the bedrock surface.

From its source at Kawishiwi Lake, the Kawishiwi River flows through 18 lakes before reaching Fall Lake. The on-channel lakes comprise more than 33 miles of the total river length of 75 miles.

Six miles downstream from the outlet of Lake One, the Kawishiwi River channel divides with one channel running west for six miles to Farm Lake. The other channel continues in a southwesterly direction to Birch Lake, then in a northerly direction through White Iron Lake and into Farm Lake. The north or short channel is designated as the Kawishiwi River and the longer channel (26.4 miles) that dips to the south is the South Kawishiwi River.

There are 378 square miles of the St. Louis River basin in the study area. Eighty-eight square ~~miles~~ kilometers of this area are in the Embarrass River basin which is tributary to St. Louis River downstream from the study area. The remaining 290 square miles are drainage for St. Louis River upstream from Aurora.

Whiteface ?

The St. Louis River basin has a high density of wetlands which range in size from very small to large areas covering several square miles. In contrast to the Kawishiwi River basin, there are only a few lakes in the St. Louis River basin and they are concentrated primarily near the headwater of the St. Louis River main stem.

Partridge River is a major tributary to the St. Louis River in the study area. At the mouth of Partridge River, the drainage area is 164 square miles compared to 129 square miles for the St. Louis River above Partridge River.

U. S. GOVERNMENT PRINTING OFFICE

Estimates of monthly and annual discharges at periodic measurement sites

Water-quality samples were obtained at the periodic measurement sites during the 1976-77 water years, so there is an interest in monthly and annual discharges at these locations (Figure ___). River stages were read 20 to 30 times annually at the periodic measurement sites and from stage-discharge rating curves, discharge was determined for each stage reading. At Embarrass River at Embarrass and Stony River near Isabella, which are discontinued gaging stations, recorders were installed and a continuous record of stage was obtained.

Hydrographic comparison techniques were used to estimate flow between known discharges. For most sites, the comparisons were generally good. Poorest relationships were at sites located near outlets of large lakes. To verify the results obtained from the hydrographic comparisons, monthly average flows were estimated by another method using the chronological relationship between known discharges at a periodic site and streamflow records from nearby gaging stations. There was fair to good agreement between results from the two methods. Largest differences were for periods when there was considerable fluctuation in streamflow.

U. S. GOVERNMENT PRINTING OFFICE 1972 O - 457-084

9-1267

11-K

The monthly and annual average discharges estimated by hydrographic comparison for the periodic measurement sites are considered the more reliable of the two methods and are listed in table ___. The user is cautioned there could be considerable error in values for some months.

Place Table ___, "Estimated average monthly and annual discharges at periodic measurement sites for 1976-77 water years" nearby.

9-1257

12-K

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

U. S. GOVERNMENT PRINTING OFFICE 1972 O - 457-094

Table — Estimated average monthly and annual 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	[illegible]
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	So. Br. 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	[illegible]
			1977	0	0	0	0	0	0.2	3.2	5.3	15	7.98	5.99	6.8	[illegible]
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	[illegible]
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	.02	[illegible]
			1977	.05	.11	.05	0	0	1.4	2.8	3.9	10	4.9	3.7	27	[illegible]
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	41
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	36	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.

Hydrographs of monthly mean flow

Long-term flow patterns are shown in hydrographs for selected streams in figure __. The hydrographs were constructed from monthly mean flow data. Except for Kawishiwi River near Winton, the hydrographs were constructed using complete water years of record available for these gaging stations.

The effects of supplementing streamflow by water discharged from mine-pit dewatering are apparent in the hydrograph for Second Creek near Aurora. Since 1964, there has been a large increase in mine-pit dewatering activities, and streamflow in Second Creek has been sustained several cubic feet per second above normal. This is evident on the hydrograph during periods of low flow. The quantity of water Second Creek receives from mine-pit dewatering is not constant from year to year, but variations tend to be small.

Streamflow at station Partridge River near Aurora, also reflects the discharge from mine-pit dewatering measured at Second Creek which flows into Partridge River about 1,000 feet upstream from the station. From 1955 to 1963, a monthly mean flow of less than 5 ft^3/s occurred in 6 of 9 years, but from 1964 to 1977 as min-pit dewatering increased, monthly mean flows have not been less than 5 ft^3/s.

The flow at Kawishiwi River near Winton, is regulated for generation of hydroelectric power throughout period shown on the hydrograph. Flood runoff is stored in the reservoir system and released when natural flow is not adequate for generating electricity at the Winton powerplant. Natural distribution of runoff from the basin is therefore altered within each water year. There is sufficient storage capacity in the reservoir system to carry over water from one year to the next and also effect the distribution of annual runoff. Most years, however, the carryover storage is similar and annual runoff is not altered significantly.

Embarrass River at Embarrass and Partridge River near Aurora, prior to mine-pit dewatering (1964 water year), generally have the largest variation in monthly mean flows each year. The large variability of flow at these two streams can be attributed to the lack of surface storage that reduces flood flows, and limited discharge from ground water to sustain streamflow in the winter and during periods of little or no precipitation.

Visual compariosons between extreme flow events can also be made from the hydrographs. For example, the Kawishiwi River near Winton hydrograph shows streamflow was very low in 1949, 1961, and 1977. Comparing these three low-flow events, it is apparent monthly mean discharges were less than 100 ft^3/s for a longer period of time in 1977. The severity of the drought during the 1976 and 1977 water years is also evident in the hydrographs for the other streams.

During the spring break up in 1950, all active gaging stations in the study area recorded maximum instantaneous discharges of record. It is apparent from the hydrographs that monthly mean discharges were also at record high levels at that time.

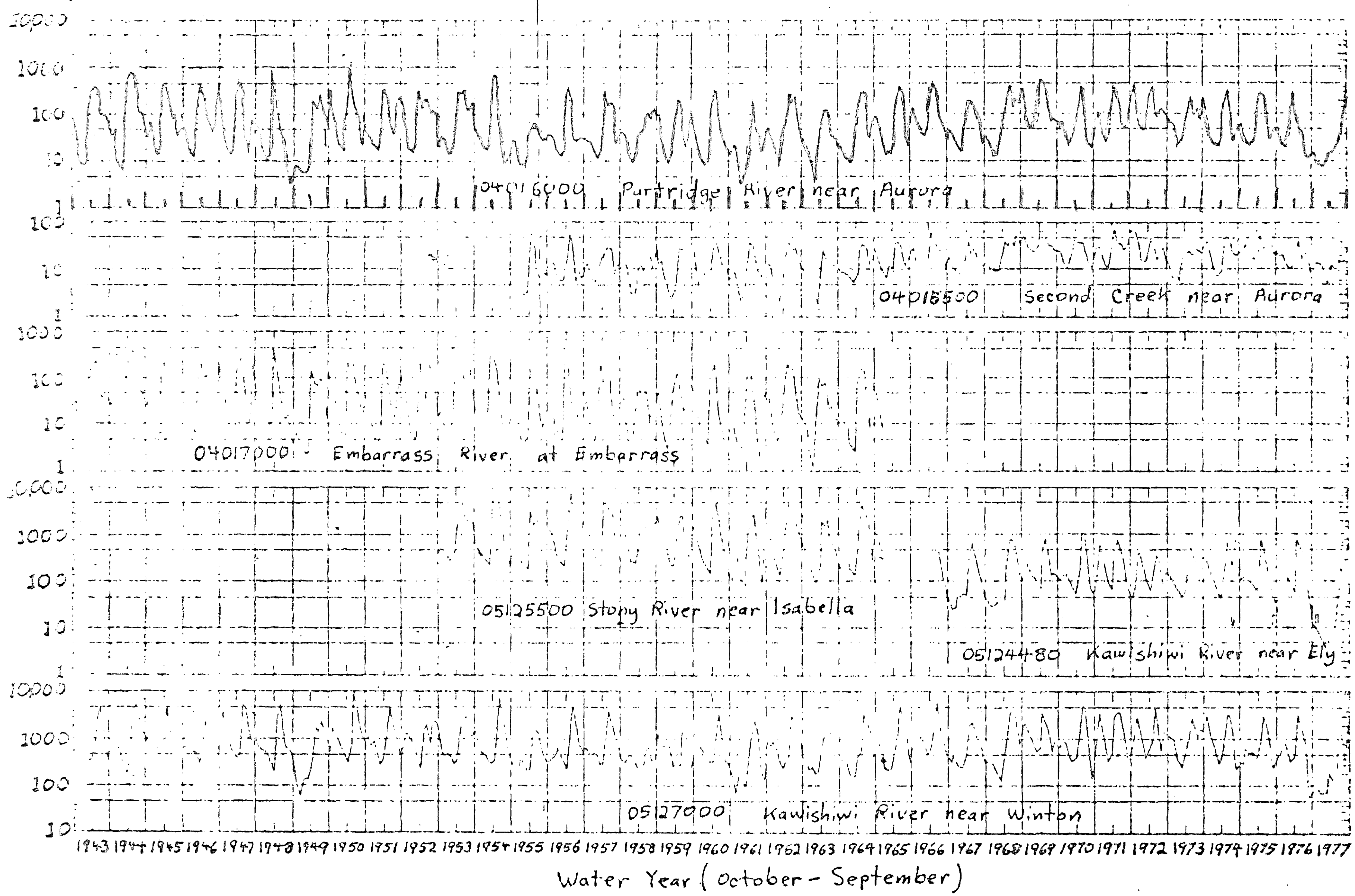


Figure — Hydrographs of monthly mean flow for selected streams

Flood Frequency Characteristics

Encroachment on flood plains of rivers and streams in the study area has been minimal, so most years flooding is not a serious problem. Some secondary roads are subject to flooding and may be impassable for several days during the snowmelt periods in the spring and following intense rainfall. Larger floods can 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 occasionally affected by high water stages.

Most of the area consists of forests and wetlands so flood damage to agriculture is limited. Crops on cleared land are primarily hay and some small grain. In recent years, several paddies for cultivating wild rice have been developed in the southwestern part of the study area.

U. S. GOVERNMENT PRINTING OFFICE

Over sixty percent of the annual maximum floods occurred in the spring when snow accumulated during the winter melts. Magnitude of flood peaks furing the snowmelt period are dependent on water content of the snow pack, soil conditions, weather conditions, and type and amount of additional precipitation. Commonly during the snowmelt period, daytime temperatures range in the thirties to low fifties and night time temperatures are below freezing. Depth of snow in the spring is generally sufficient to require many days at above freezing temperatures before the snow pack releases water and overland runoff begins.

Much of the study area has heavy timber cover that partially shades the snow and reduces wind velocity in contact with the snow pack. The snowmelt is thus delayed and spring runoff occurs later than in most other areas of the State.

The flood in May 1950 was the maximum of record at all four gaging stations in operation at that time. The record flood resulted from a combination of factors including antecedent conditions, above normal snowfall, a late spring with sudden increases in temperature, and precipitation during the high runoff period. In 63 years there have been three annual peaks at Kawishiwi River near Winton that exceeded 10,000 ft^3/s and all occurred in May during the snowmelt period.

~~Flood Frequency Characteristics~~

The expected frequency of recurrence of a particular magnitude of flow can most reliably be estimated from long-term records obtained at gaging stations. The individual estimates are applicable directly only at the gage site for which they were determined. When there are several gaging stations within an area of similar topography and drainage characteristics, however, the results of frequency analyses can be combined to develop general relationships applicable to that area. Relationships may also be developed for transferring flood discharge estimates upstream or downstream along a stream based on discharge to drainage area ratios.

A flood frequency curve has been developed for each gaging station within the study area for which 10 or more years of flow records are available. The Log Pearson Type III method of analysis recommended by the Water Resources Council (U.S. Water Resources Council, 1977, 26 p.) was followed using the generalized skew coefficient of -0.10 applicable in the study area. For some stations the curve resulting from the Log Pearson III method required slight graphical adjustments to accurately represent the data. For two stations the curve resulting from the Log Pearson III method deviated considerably from the data plot and a graphical interpretation was used. ~~About 3 years ago~~ 1975(?), flood frequency curves were developed for all gaging stations on unregulated streams throughout Minnesota for which 10 or more years of record were available. This was done in preparation for the flood frequency report by Guetzkow, L. C., 1977, 33 p. For several stations in this study, the additional data obtained since previous analysis was made and use of one value, -0.10, for the skew coefficient, gives results not significantly different from the values given in that report for most stations. In the earlier analysis, skew values in the range of 0.00-0.20 were assigned in the Log Pearson III method. Results from the ~~several~~ analysis made for this study are used herein because there were additional flood data available and results from the two analyses differ significantly for two gaging stations. Several stations in the study area had not been in operation for 10 years at the time of the earlier analysis and others are affected by man's regulation of streamflow and were not included at that time, but they are included in this study.

Flood-flow frequency data resulting from the analysis are listed in table ___ and the corresponding frequency curves are shown in figure __. For gage locations where the

---

Table __ and Figure __ near here.

---

period of record is only 10 to 14 years, it is not realistic to estimate floods beyond the 25-year recurrence interval and values for more rare events are not given.

U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 457-[illegible]

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

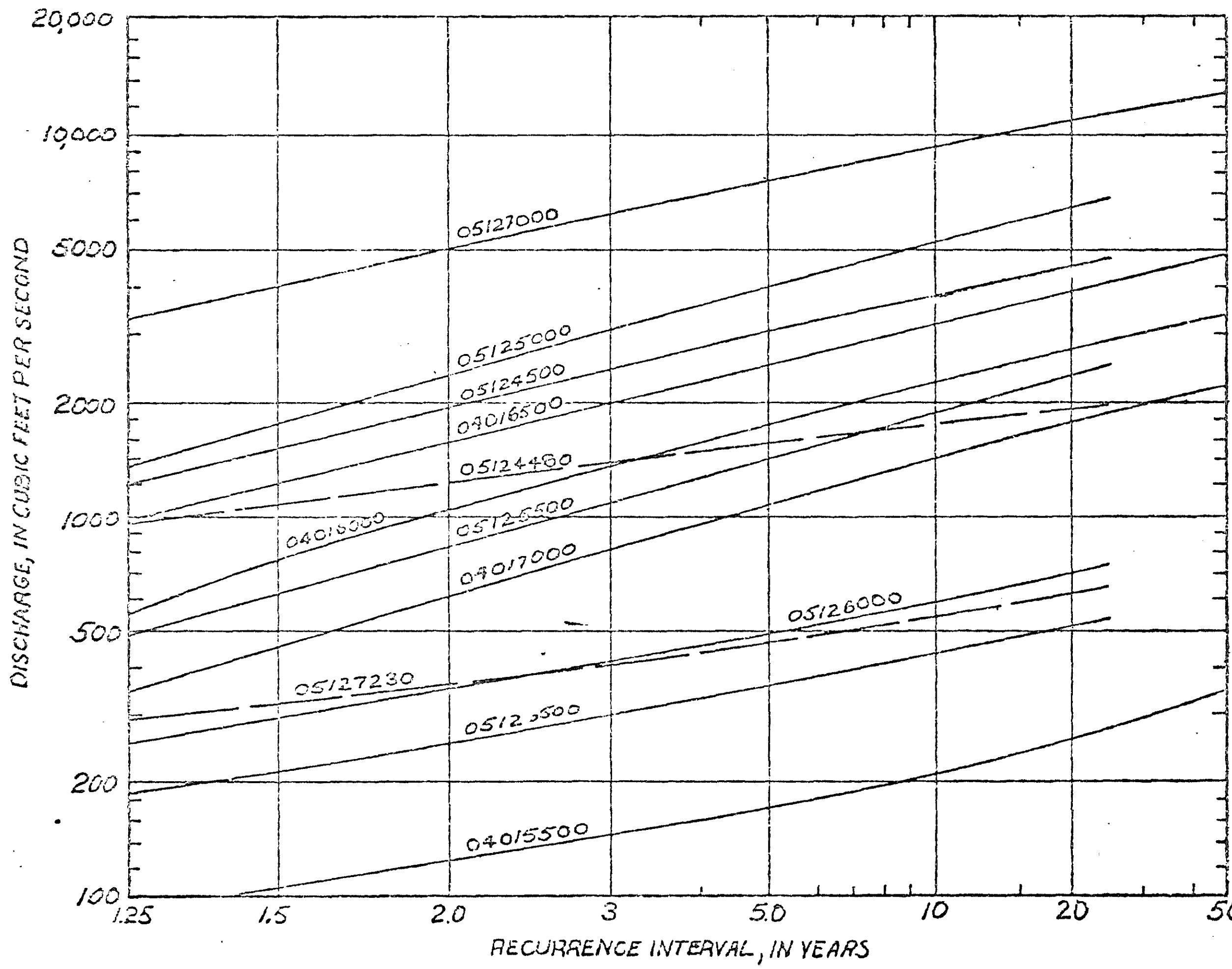


Figure — Flood frequency curves at gaging stations having 10 or more years of record available.

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

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

Figure plotting number	Station I.D. number	Station name	Drainage area (mi^2)	Years of record	Discharge in ft^3/s for indicated recurrence interval, in years Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}
21	04015500	Second Creek near Aurora	29.0 nc 6.59	23	123	168	214	278	344
22	04016000	Partridge River near Aurora	161 nc 13.3	35	1020	1690	2220	2960	3550
24	04016500	St. Louis River near Aurora	290 nc 13.3	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 nc 4.0	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	99.0	10	360	470	542	635	--

Records for gaging stations and periodic measurement sites in operation only a few years are inadequate to indicate expected flood magnitudes and other basis for flood flow estimates must be used. From data presented in table ___ for the long-term stations, a plot of flood discharge versus contributing drainage area was made on full logarithmetic paper for each recurrence interval included in the table. A general relationship between discharge and drainage area was apparent from those plots. By removing data for stations locationed downstream from the outlet of large lakes, a well defined curve of relation could be drawn. From these curves, estimates of flood discharges for stations with short records and for periodic measurement sites were made. Data for gage locations downstream from large lakes were used as a basis to estimate flood discharges on the St. Louis River below Seven Beaver Lake near Fairbanks. Estimates of peak flood flows for periodic measurement sites and stations of short record are listed in Table ___.

Table ___ near here.

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

U. S. GOVERNMENT PRINTING OFFICE

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

Flood frequency data at a gaged site can be transferred up or down stream by a relationship derived from ratio of drainage areas as follows:

$$Q_v = Q_g \, (A_v/A_g)^{0.6}$$

where: Q_v is flood frequency estimate for ungaged site

Q_g is flood frequency value of gaged site

A_v is drainage area for ungaged site

A_g is drainage area for gaged site

Use of the transfer relation should be limited to sites which differ in drainage area size by no more than 40 per cent from the gaged site. Care must be exercised in transferring data so that results are reasonable. Peak flow data should not be simply transferred upstream or downstream across a lake or reservoir, for example.

U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 457-084

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

Figure plotting number	Station I.D. number	Station name	Drainage area (mi^2)	Discharge in ft^3/s 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	94.0	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	62.0	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

J-13

Effects of regulation also have to be considered when using flood frequency data for regulated streams. For locations of limited regulation, smaller flood peaks may be affected significantly, but larger peaks may be unaffected. Partridge River near Aurora and Kawishiwi River near Winton are in that category. When storage in Partridge Reservoir is available, water from Partridge River is diverted to the reservoir as river stage increases during floods. For the more significant high-water periods, the reservoir is filled before the peak flow occurs and the maximum discharge is not affected by the regulation. On the Kawishiwi River, time to peak and duration of flood flows are relatively long. Again, controlled storage is generally filled before peak flows reach the Winton powerplant.

Unit runoff for instantaneous flood peaks is low in the study area. Comparing 25-year flood flows at the gaging station for example, unit runoff ranges from 8.4 to 22 cubic feet per second per square mile in the St. Louis River basin and 6.4 to 15 cubic feet per second per square mile in the Kawishiwi River basin. The two lowest peak unit runoff figures for 25 year floods were at Shagawa River at Ely and Bear Island River near Ely, which are located near outlets of large lakes.