Water Resources of the Mesabi and Vermilion Iron Ranges

By R. D. COTTER, H. L. YOUNG, L. R. PETRI, *and* C. H. PRIOR

This volume was published as separate chapters A–F

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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By R. D. COTTER, H. L. YOUNG, L. R. PETRI, and C. H. PRIOR

ABSTRACT

Within the Mesabi-Vermilion Iron Range area, water of good quality is available from the Biwabik Iron-Formation, from stratified drift, and from lakes and streams. About 700 bgy (billion gallons a year) leaves the area as surface water, of which about one-third comes from ground water.

Leached, oxidized, and fractured parts of the Biwabik Iron-Formation yield as much as 1,000 gpm (gallons per minute) to wells. Much of the permeable stratified drift within the area underlies the Ice-Contact region and the Morainal and Ice-Contact region, and several wells drilled in drift have been pumped at rates of more than 1,000 gpm.

Parts of three major drainage basins lie within the area, and lakes compose about 5 percent of the area. Low-flow and flood-frequency data have been compiled for many of the streams. Large quantities of surface water are available from the Border-Lakes region and the Morainal and Ice-Contact region.

The quality of ground water from the Biwabik Iron-Formation and from the drift is similar. The water is generally moderately siliceous, hard or very hard, and contains much iron and manganese. Surface water is generally soft, contains much iron, and is highly colored.

Large uses of water in the area include: taconite processing (50 bgy), wash-ore processing (19 bgy), power plants (63 bgy), municipal water supplies (3 bgy) and paper processing (1 bgy). Optimum development of the water resources might be achieved by using streamflow in the spring and summer and ground-water and surface-water storage in the fall and winter.

INTRODUCTION

The Mesabi and Vermilion Iron Range area (pl. 1) has a population of about 125,000, which is largely dependent on industrial employment. The industries and population are concentrated in two narrow bands paralleling the deposits of iron ore. The precipitation of 26 inches a year is nearly the lowest in the Eastern United States. Surface runoff is equivalent to only about 9 inches a year, although the

numerous lakes function as reservoirs and increase the total water available during periods of low flow. The area lies on a 3-way continental divide, and the only surface inflow is to the extreme southwest and northeast corners (pl. 1). The remainder of the area is dependent on local precipitation.

The quantity of water available is critical to industrial expansion. Taconite processing requires about 6,000 gallons per ton of finished product; a paper mill about 40,000 gallons per ton of finished product.

Large supplies of ground and surface water of good quality are available within the report area. The major problem is economic development of these sources.

PURPOSE OF INVESTIGATION

This report describes the occurrence and quality of water in the Mesabi and Vermilion Iron Range area, describes its present development, and considers its potential development.

HISTORY OF INVESTIGATION

The earliest water-resources investigations in the Mesabi and Vermilion Iron Range area were related to streamflow. The U.S. Army Corps of Engineers has recorded flow data on the Mississippi River at Grand Rapids since 1884. As early as 1911 the U.S. Geological Survey, on behalf of the U.S. Department of State, measured flows of streams tributary to or forming the international boundary water system. In 1942, five additional gaging stations were established in northeastern Minnesota in cooperation with the Minnesota Department of Iron Range Resources and Rehabilitation. The Lake Superior Industrial Bureau entered into a cooperative program with the U.S. Geological Survey in 1952 and furnished data for assembling a bedrock topographic map to aid in future ground-water studies on the Mesabi Iron Range. In 1953 a cooperative agreement was made between the U.S. Geological Survey and the Minnesota Department of Iron Range Resources and Rehabilitation for an expanded study of the water resources of the Mesabi Iron Range. Work with this agency has continued to the present with only a short break during 1959. The area of study was expanded in 1959 to include the Vermilion Iron Range. This report is a result of this cooperative study.

PREVIOUS INVESTIGATIONS

Because of the economic importance of the iron-bearing formations in this area, the bedrock geology has been extensively studied. Van Hise and Leith (1911) discussed all of the major iron-mining districts in the Lake Superior region. The principal reports on the Vermilion Iron Range are by Clements (1903) and Van Hise and Leith (1911).

Leith (1903, p. 29–62) summarized the early literature in a comprehensive report on the Mesabi Iron Range. Grout and Broderick (1919) gave a detailed account of the Precambrian stratigraphy and structure of the eastern Mesabi Range. Leith, Lund, and Leith (1935) reviewed the geology of the Lake Superior region, and Gruner (1946) reported on the mineralogy and geology of the Mesabi district. The most recent comprehensive report on this district is by White (1954). Goldich and others (1961) used radioactive age determinations to revise the geologic column for this area.

Prior to 1932, geologists concentrated on the bedrock geology, and the principal references to glacial geology were in reports of the Minnesota Geological Survey by H. V. Winchell, Warren Upham, and U.S. Grant, and by Lawrence Martin (in Van Hise and Leith, 1911, p. 427–459). The only major work on the Pleistocene geology of the area is by Leverett (1932). Wright (1955, 1956) made some modifications of Leverett's interpretations. A map showing geomorphology and surficial geology (Cotter and others, 1964) covers the two iron ranges.

The water resources of the area have been described only briefly. Thiel (1947) summarized the geology and ground-water conditions in northeastern Minnesota. A report on test drilling in the Mountain Iron-Virginia area (Cotter and Rogers, 1961) and a mimeographed basic-data report on municipal water supplies (Cotter and Young, 1960) refer specifically to the Mesabi and Vermilion Iron Ranges.

Minnesota Department of Conservation, Division of Waters Bulletin 5 (1951), tabulated all available flow records of streams in the Mesabi Range. Through the 1960 water year, basic data for gaging stations were published by the Geological Survey in an annual series of water-supply papers, "Surface Water Supply of the United States." Records for this area are found in part 4, St. Lawrence River basin, and part 5, Hudson Bay and Upper Mississippi River basins. The latest of this series are Water-Supply Papers 1707 (U.S. Geol. Survey, 1961) and 1708 (U.S. Geol. Survey, 1962a). Beginning with the 1961 water year, streamflow records and related data are published by the Geological Survey in annual reports by State. "Surface Water Records of Minnesota, 1961" (U.S. Geol. Survey, 1962b) contains the latest published data for this area. The bar chart (fig. 1) shows periods of gaging-station records used in this report. Records from stations affected by extensive artificial regulation are not included.

Records of the chemical quality of surface waters in the area of this report are published annually in the series of water-supply papers entitled "Quality of Surface Waters in the United States," parts 4

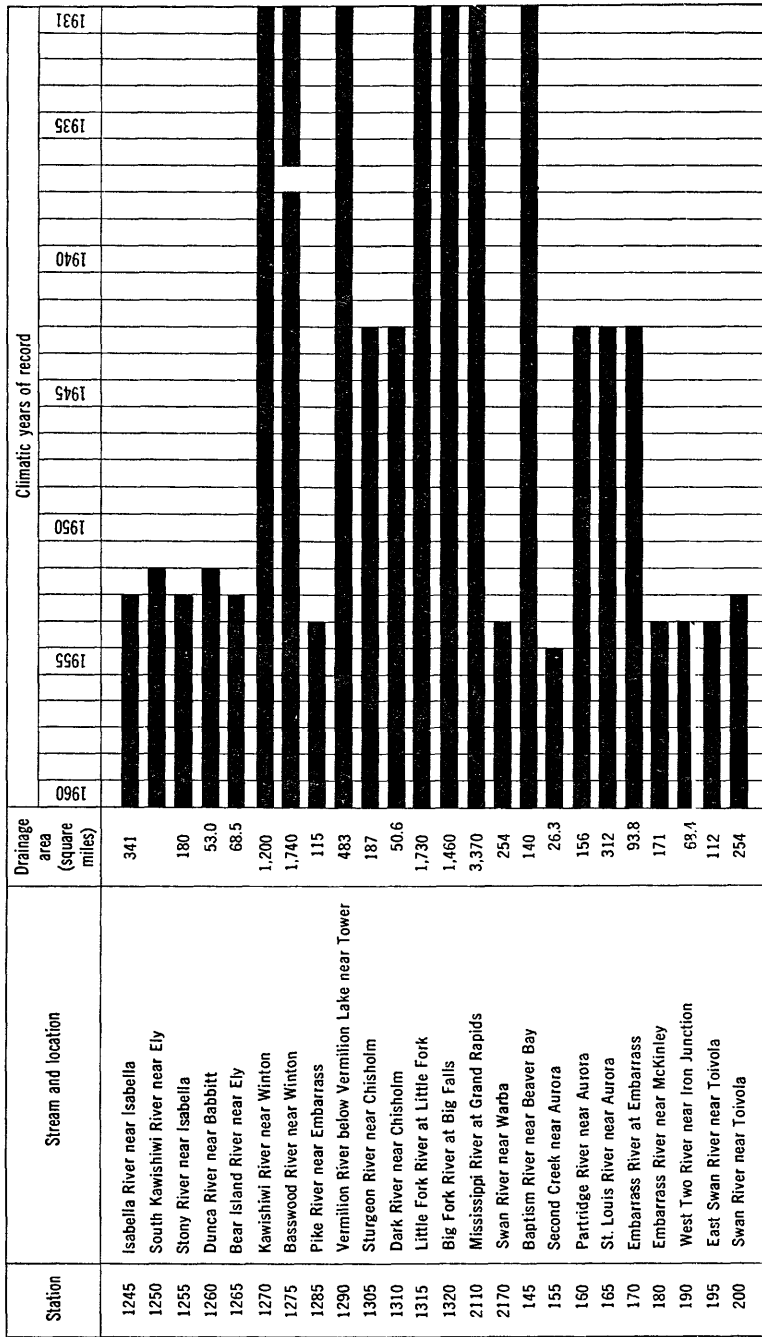| Station	Stream and location	Drainage area (square miles)
1245	Isabella River near Isabella	341
1250	South Kawishiwi River near Ely	180
1255	Stony River near Isabella	53.0
1260	Dunca River near Babbitt	68.5
1265	Bear Island River near Ely	1,200
1270	Kawishiwi River near Winton	1,740
1275	Basswood River near Winton	115
1285	Pike River near Embarrass	483
1290	Vermilion River below Vermilion Lake near Tower	187
1305	Sturgeon River near Chisholm	50.6
1310	Dark River near Chisholm	1,730
1315	Little Fork River at Little Fork	1,460
1320	Big Fork River at Big Falls	3,370
2110	Mississippi River at Grand Rapids	254
2170	Swan River near Warba	140
145	Baptism River near Beaver Bay	26.3
155	Second Creek near Aurora	156
150	Partridge River near Aurora	312
165	St. Louis River near Aurora	93.8
170	Embarrass River at Embarrass	171
180	Embarrass River near McKinley	68.4
190	West Two River near Iron Junction	112
195	East Swan River near Toivola	254
200	Swan River near Toivola	

Climatic years of record

FIGURE 1.—Records available for gaging stations for the period 1931–60.

and 5. Lohr and Love (1954, p. 230, 239) listed chemical analyses of the Hibbing and Virginia municipal supplies.

ACKNOWLEDGMENTS

Municipal officials furnished data on water supplies near municipalities. Mining companies operating in the area furnished maps and well records and allowed examination of mine faces.

DESCRIPTION OF AREA

The area of this report is shown on plate 1. Most of its 5,000 square miles lie in Itasca and St. Louis Counties, and it includes the economically important parts of the Mesabi and Vermilion Iron Ranges.

White (1954, p. 1) designated the Mesabi Range as " * * * the preglacial outcrop area * * * of the Biwabik iron-bearing formation * * * ." As used in this report the Mesabi Range refers to the area of economic importance along the Biwabik suboutcrop and includes the municipalities whose economy is at least partly dependent on the iron resources. The Mesabi Range is about 90 miles in length and extends from Grand Rapids which is shown in the southwest part of plate 1 to Babbitt in the northeast.

The Vermilion Iron Range was described by Clements (1903, p. 32) as having an area of approximately 1,000 square miles within " * * * a narrow belt extending east-northeast from near the west end of Vermilion Lake * * * to the vicinity of Gunflint Lake, on the international boundary * * *." For the purposes of this report, it is restricted to the area of present economic importance near Tower-Soudan and Ely.

GEOLOGY

Geology controls the water resources in the area. The shape of the land surface and the character of the rocks determine stream patterns, the position of lakes, and the occurrence of ground water. The quality of water is affected by soluble rock materials with which the water comes in contact.

The rocks of the Mesabi-Vermilion Range area are of two basic types: bedrock and unconsolidated glacial drift. The bedrock is predominantly Precambrian basement rock but includes some Cretaceous sedimentary rocks. Pleistocene drift overlies the bedrock and forms the land surface.

For a description of the Precambrian basement rocks the reader is referred to those publications cited under "Previous investigations" and specifically to Goldich (1961), Schwartz (1956), and White (1954). The general relations of these rocks are shown in figure 2.
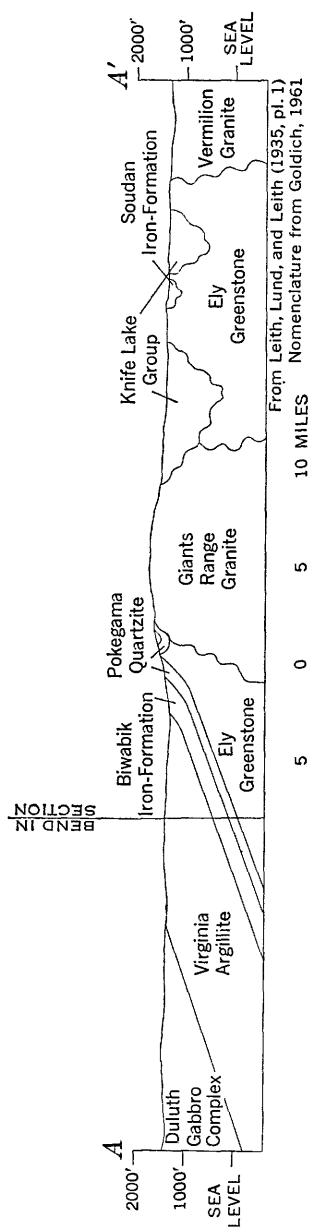
FIGURE 2.—Geologic section through Mesabi and Vermilion Iron Range area showing relations of bedrock units (pl. 1).

TABLE 1.—*Lithology, thickness, and water-bearing characteristics of bedrock units*

Formation or group	Maximum thickness (feet)	General lithology	Water-bearing characteristics
Coleraine Formation of Stauffer (1933)	50	Basal conglomerate, sandstone, siltstone and shale.	Is not known to yield water to wells in the area.
Duluth Gabbro Complex	(?)	Coarse-grained olivine gabbro.	May yield 5–15 gpm from fractured zones near its upper surfaces.
Virginia Argillite	2,000	Thinly bedded gray to black argillite.	Yields up to 30 gpm from fractured zones near its upper surface. Utilized for numerous domestic supplies and for Iron Junction municipal supply.
Biwabik Iron-Formation	800	Taconite—dark-colored hard dense iron-bearing silicic rock. Ore—black, yellow, or red, soft iron-bearing porous rock.	Yields up to 1,000 gpm to wells in highly fractured taconite and ore. Utilized for numerous municipal and industrial supplies. See text.
Pokegama Quartzite	350	Varicolored vitreous quartzite.	May yield 5–15 gpm from fractured zones near its upper surface. A well at the former community of Mahoning reportedly obtained 80 gpm from this formation.
Giants Range Granite	(?)	Hornblende granite and biotite granite.	Yields 5–15 gpm from fractured zones near its upper surface.
Vermilion Granite	(?)	Granites and gneissic rocks.	May yield 5–15 gpm from fractured zones near its upper surface.
Knife Lake Group	22,000	21 members including: slates, graywackes, tuffs, conglomerates, and breccias.	
Soudan Iron-Formation	Hundreds	Dark-colored dense iron-bearing rocks.	
Ely Greenstone	Thousands	Schist, altered basaltic lavas, and clastics.	

Conglomerate, sandstone, and shale exposed in the open-pit mines on the Mesabi Iron Range have been identified as Cretaceous by their fossil content (Bergquist, 1944, p. 2).

During the last million years the Mesabi and Vermilion Iron Ranges were overridden by many Pleistocene continental glaciers. These massive ice bodies incorporated rock fragments from, and deposited sediments on, the terrain over which they passed. The sediments deposited by the glaciers may be made up of locally derived material or of material from an area much farther north, toward the source of the glacier. In the Mesabi and Vermilion Iron Range area, glacial deposits cover most of the underlying bedrock. Bedrock is exposed along the Giants Range and the Vermilion Iron Range and locally in the intermediate area.

The glacial deposits that occur within the area of this report are tabulated on table 1. Although their color, lithology, and known areal extent are given in this table, their detailed stratigraphy is not discussed. The reader is referred to the section on "Previous investigations" for a list of reports dealing with the stratigraphy of some of these units. For principles of glacial geology, see texts by Flint (1957) and Thwaites (1950).

DEFINITION OF GEOLOGIC TERMS

The following geologic terms are used in discussions of ground-water sources and are defined as follows to aid in understanding ground-water availability.

Drift. All deposits resulting from glacial activity.

Drumlin. A linear teardrop-shaped hill that is formed either by erosion of the country rock and (or) older surficial drift, or by deposition of till.

End moraine. A ridgelike deposit formed at the glacier front when the ice front is stationary.

Esker. A sinuous generally discontinuous ridge of washed sediments deposited by melt-water streams flowing on, in, or under the glacier.

Glacial lake. A lake formed by blocking of drainage by ice.

Ice-contact stratified drift. Stratified drift deposited by melt water adjacent to the ice.

Ice-contact topography. Irregular terrain characterized by kettles, eskers, and kames.

Kame. A mound of poorly sorted ice-contact stratified drift deposited as a fan or delta against the edge of the ice, or as a filling in an opening in the ice.

Kettle. A depression in drift, made by the wasting away of a detached mass of glacier ice that had been either wholly or partly buried in the drift.

Outwash. Stratified drift deposited beyond the ice front by meltwater streams.

Pitted outwash plain. A plain composed of outwash and characterized by kettles.

Stratified drift. Sorted and layered drift, deposited from glacial melt water.

Suboutcrop. What would be the outcrop if the overlying unconformable formation were removed.

Till. An unsorted mass of rock fragments ranging in size from clay to boulders deposited directly by the ice.

DRAINAGE

Parts of three major drainage basins are shown on plate 1. The Laurentian Divide, following in part the crest of the Giants Range, separates waters flowing north to Hudson Bay from those flowing south to the Mississippi River and Lake Superior. A divide that extends south of the Laurentian Divide from a point north of Hibbing separates the southward-flowing waters into those flowing southwest to the Mississippi River and the Gulf of Mexico and those flowing southeast to Lake Superior and the St. Lawrence River. The main streams in the Hudson Bay basin are the Basswood, Vermilion, and Little Fork Rivers and their tributaries; in the St. Lawrence River basin, the St. Louis River and its tributaries; and in the Mississippi River basin, the Mississippi River and its tributaries.

CLIMATE

"Owing to its midcontinental location, Minnesota has a marked continental climate, characterized by wide variations in temperature, scanty winter precipitation, normally ample summer rainfall, and a general tendency towards extremes in all climatic features" (U.S. Dept. Agriculture, 1941, p. 933). The area shown on plate 1 is in the northeast and north-central divisions of the State as established by the U.S. Weather Bureau. Averaging the long-term means of these two divisions gives a mean spring and summer (April–September) temperature of 56.8°F, and a mean fall and winter (October–March) temperature of 21.6°F. The mean temperature for January is 8.4°F and for July is 57.0°F. The average growing season is 90–110 days; the average date of the first fall frost is September 9. The following table shows the temperature ranges at the Virginia meteorological station.

TABLE 2.—*Maximum, minimum, and mean monthly temperatures at Virginia for 1931–60*

Month	Maximum	Minimum	Mean
January	53	−42	8. 3
February	53	−41	11. 9
March	81	−29	23. 5
April	91	−08	39. 9
May	96	18	53. 0
June	102	27	62. 5
July	103	36	68. 1
August	97	31	65. 4
September	99	21	55. 7
October	88	01	44. 9
November	68	−19	26. 8
December	54	−41	13. 1

The average annual precipitation, based on averaging the long-term means of the two divisions, is 25.92 inches. The spring and summer average is 19.05 inches, and the fall and winter average is 6.87 inches. During the growing season, most of the precipitation occurs in the form of thunderstorms. Table 3 shows average monthly precipitation at Virginia.

TABLE 3.—*Mean monthly precipitation, in inches, at Virginia for 1931–60*

January	1. 00
February	. 75
March	1. 40
April	2. 14
May	2. 85
June	3. 79
July	3. 63
August	3. 76
September	3. 09
October	2. 05
November	1. 74
December	. 93

CULTURE

The economy of the iron range area is largely determined by activity of the mining industry, which employs or is served by a large percentage of the population. The population of the area shown on plate 1 is estimated to be 126,000, of which about 84,000 are concentrated in municipalities.

The tourist industry is of major importance in the northeastern part of the State, where many lakes make the area particularly popular for recreation.

Farming is a minor part of the economy. In 1954, one-third of the 5,269 farms in Itasca and St. Louis Counties were dairy farms and more than half the value of products sold was in dairy products (U.S. Bureau Census, 1956, p. 60–68). More than half of the farm operators in Itasca and St. Louis Counties had other income exceeding the value of farm products sold.

Other industries in the area include a paper company in Grand Rapids, wood-processing plants in Grand Rapids and Virginia, public utility powerplants in Cohasset and Hoyt Lakes, sand and gravel operations, and logging operations.

HYDROLOGY

The hydrologic cycle (fig. 3) shows the movement of water from the time it falls as precipitation until its return to the atmosphere. Water is constantly in motion, whether it is ground water, whose rate of movement may be in the order of inches per year through openings in rock, or whether it is surface water flowing in streams, whose rate of movement is measured in feet per second. Water for man's use is commonly obtained from lakes or streams (surface water) or from permeable earth materials that yield water to wells and springs (ground water).
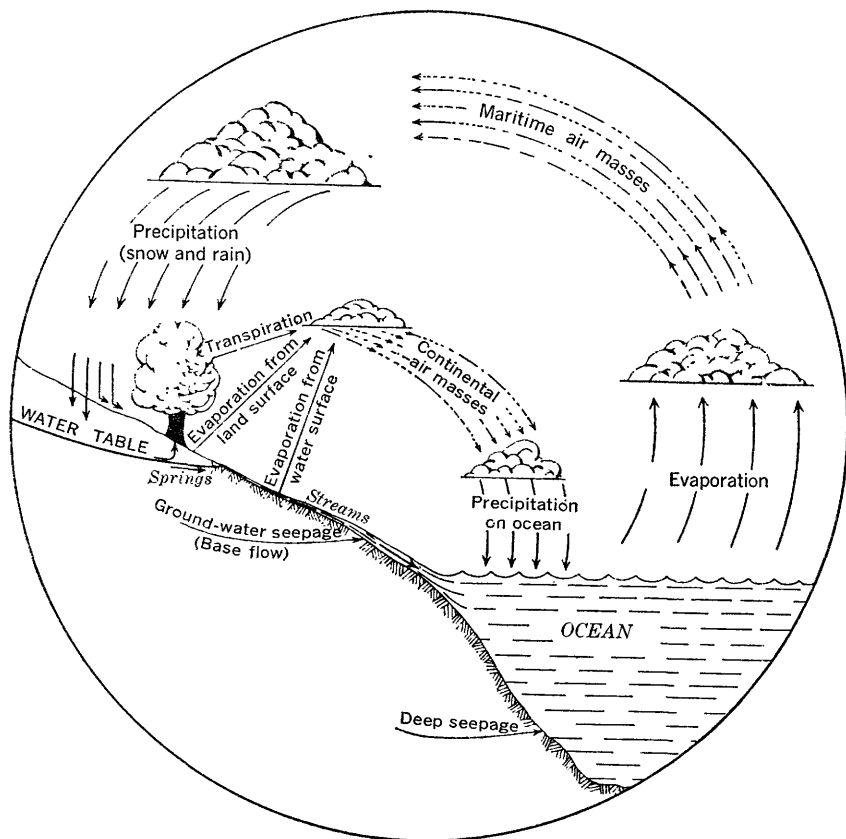
FIGURE 3.—Schematic representation of the hydrologic cycle.

HYDROLOGIC DEFINITIONS

The following terms are used in this report in describing the occurrence of water.

Aquifer. A formation, group of formations, or part of a formation that yields water.

Artesian aquifer. An aquifer overlain by a confining bed of lower permeability. Water in the aquifer is under sufficient pressure to rise above the base of the confining bed in a well.

Base flow. That part of streamflow composed largely of ground-water effluent.

Discharge, ground-water. Release of ground water to the land surface, a surface-water body, or the atmosphere.

Discharge, surface-water. Streamflow measured in cubic feet per second.

Drainage basin. A surface area occupied by a surface stream or body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

Drainage divide. The rim of a drainage basin.

Gaging station. A particular site on a stream where systematic observations of discharge are obtained.

Ground water. That part of the subsurface water that is in the zone of saturation.

Mean annual flood. The average of the maximum floods of each year of record.

Permeability. The capacity of a material to transmit water.

Porosity. The ratio of the total volume of interstices in a material to its mass.

Recharge, ground-water. Addition of water to an aquifer by infiltration of precipitation through the soil, by flow from streams or other bodies of surface water, or by flow of ground water from another aquifer.

Recharge area. An area where water is absorbed which eventually reaches the zone of saturation.

Recurrence interval. The average period of time within which a flood or low flow of specific quantity will occur.

Regulation. The artificial manipulation of the flow of a stream.

Runoff. That part of precipitation that appears in surface streams.

Static water level. The level to which water will rise in a well under its full pressure head.

Surface water. Water on the surface of the earth.

Water table. The upper surface of a zone of saturation except where that surface is formed by an impermeable body, in which case no water table exists.

Zone of saturation. Zone below the ground surface whose rock interstices are filled with water under atmospheric, or greater, pressure.

GROUND WATER

Ground water occurs in primary pore spaces in unconsolidated and consolidated rocks and in secondary solution and fracture openings in consolidated rocks. Porosity controls the quantity of water that can be held in an aquifer and permeability controls the rate of yield to wells. For a comprehensive discussion of the principles of occurrence of ground water, the reader is referred to Ferris and others (1962) and Meinzer (1923a and b).

Two rock types in the Mesabi-Vermilion Iron Range area are known to yield large quantities of water to wells. They are the permeable altered parts of the Biwabik Iron-Formation and the stratified deposits of the glacial drift. Most of the wells completed in the Biwabik are artesian; glacial drift wells may be either artesian or water table.

BEDROCK AQUIFERS

Except for the altered parts of the Biwabik Iron-Formation, the bedrock in the report area yields little water to wells (table 1).

The Biwabik Iron-Formation is divided into four members. They are, from oldest to youngest: lower cherty member, lower slaty member, upper cherty member, and upper slaty member. Following common usage (Gruner, 1946, p. 5), all rocks in this formation except the ores proper are called taconite in this report. The altered zones where the taconite has been oxidized, hydrated, and leached are mainly in areas where the taconite was previously broken by folding and faulting, thus exposing it to these processes.

As described by Gruner (1946, p. 94–102), the end product of these processes depends upon the processes involved and the type of taconite altered. The slaty taconites found mainly in the upper and lower slaty members commonly alter to "paint rock," a sticky, clayey rock of low permeability. The cherty members may alter to a more permeable rock.

The following description of textures is adapted from Gruner (1946, p. 101–102). Oxidation and hydration of taconite minerals with no subsequent leaching, produces a "* * * highly fractured, crumbly, almost silt-like material in some parts of the taconite, and porous though cemented layers in others." Where extensive leaching has taken place, porosity may exceed 50 percent. Following the collapse of the rock due to the large percentage of void space, porosity of as high as 40 percent may remain. "Even pieces which look relatively

massive and solid, almost like the original oxide bands of unaltered taconite are full of minute pores."

Oxidation of the taconite on the west end of the Mesabi Range is extensive, but leaching is incomplete (White, 1954, p. 81). Although this has resulted in a lower grade ore or a noncommercial deposit, it has increased the permeability of the formation. White (1954, p. 81) described the altered cherty members of the western Mesabi Range as consisting mainly of "* * * goethite-martite bands alternating with partly decomposed, friable, powdery chert bands."

On the central and eastern Mesabi Range, oxidation is less widespread, but leaching is more complete where oxidation has taken place (F. L. Klinger, oral commun.).

The Biwabik Iron-Formation has been test drilled extensively for mining exploration, but, except for the present municipal wells, few water-well test holes have been drilled. Pumpage data from these wells indicate that locally the formation is highly permeable. Wells drilled in the vicinity of mines may penetrate permeable horizons. If an ore body is not completely mined out, wells adjacent to the pit may penetrate permeable water-bearing ore. Locally, the iron formation may be an aquifer beyond the limits of the ore body prǝper. The transition between an ore body and the surrounding taconite may be a marginal mass of oxidized but poorly leached taconite (Gruner, 1956, p. 207) or it may change abruptly from unaltered taconite to an oxidized and highly leached ore body (Gruner 1956, p. 210).

The yield of wells in the Biwabik Iron-Formation is limited by the available recharge. Over much of the Mesabi Range the Biwabik laps against the south flank of the Giants Range, and the recharge area is limited to that zone south of the crest of the Giants Range and north of the southern limit of the Biwabik suboutcrop. Further, where open-pit mines have been drained, the water level in the vicinity of the mines is lowered and wells finished in the Biwabik must obtain water from a level lower than the dewatered zone. Where mining has stopped, many of the pits have filled with water. Wells drilled in permeable sections adjacent to the water-filled pits would induce recharge from the pits.

DRIFT AQUIFERS

The best aquifer in the drift is coarse stratified sand and gravel (table 4). It is widespread and generally highly permeable. The size, shape, and permeability of the stratified drift bodies differ greatly depending on the conditions of deposition. Some have a distinct topographic expression, whereas others have none and must be located by test drilling.

TABLE 4.—*Lithology, areal extent, and water-bearing characteristics of glacial units*

Drift type	Lithology	Known areal distribution within the area of this report	Water-bearing characteristics
Till_____	Till, clayey, reddish-brown to brownish-gray.	South of the Giants Range between Kelly Lake and Hoyt Lakes.	Is not known to yield water to wells in the area; may furnish recharge to wells in adjacent more permeable drift.
	Till, clayey, silty, brown to gray, calcareous.	Western half of figure; as far east as Tower north of the Giants Range.	Do.
	Till, sandy, gravelly bouldery, gray to brown.	Entire area_____	May yield up to 50 gpm to wells.
	Till, sandy, clayey, silty, brown to brownish-red.	South of Giants Range west of Kinney.	Is not known to yield water to wells in the area; may furnish recharge to wells in adjacent, more permeable drift.
	Till, clayey, silty, sandy, yellowish-brown to gray.	South of Giants Range west of Hibbing.	Do.
	Till, clayey, silty, sandy, medium- to dark-gray, calcareous.	_____do_____	Do.
Stratified drift	Clay, silty to sandy clay____	Discontinuous throughout entire area.	Do.
	Silt; clayey to sandy silt____	_____do_____	Do.
	Sand; clayey to silty sand___	_____do_____	May yield up to several hundred gpm to wells.
	Sand and gravel; silty sand and gravel	_____do_____	Yield several hundred gpm to wells; well 5⁰ 18.12ccc3, near Virginia was pumped at 2,000 gpm.

On the Vermilion Iron Range, glacial deposits are thin or absent, and the principal aquifers are coarse outwash deposits in narrow glacial drainageways. Isolated kames are potential aquifers, but they are topographic highs underlain by bedrock and, consequently, have slight saturated thickness.

On the Mesabi Iron Range the drift thickens south from the Giants Range. From Chisholm east, most of the stratified drift is of ice-contact origin and lies beneath a surficial reddish-brown clayey till and above a gray bouldery till. West of Hibbing the drift is thicker, and stratified drift is common above and below the gray bouldery till.

In the vicinity of municipalities where considerable test drilling has been done, more is known about the distribution of the glacial units. Although the tills are not assigned ages in this report, they have been grouped into units on the basis of their lithology. Table 3 gives the areal distribution and water-bearing characteristics of glacial units within the report area.

The maximum yield available from a stratified drift aquifer is principally dependent on the permeability and saturated thickness of the stratified drift and of adjacent sediments, and on proximity to drainage divides, open-pit mines, and surface-water bodies.

SURFACE WATER

Surface water is that part of precipitation that is observed as lakes or streams. It is the part remaining after ground percolation, evaporation, and transpiration have occurred. The part of streamflow that is the result of ground-water movement into the channel is the base flow.

Surface-water flow, being mostly from overland runoff, is subject to wide variations in volume owing to seasonal changes and to storm runoff. Figure 4 shows the annual precipitation at Virginia and the discharge per square mile at four gaging stations in the area. Some of the indicated variations between rainfall and runoff are due to the Virginia rainfall station not being representative of the whole area.

LOW-FLOW FREQUENCY

For any water supply the question of adequacy is the first to be considered. Will there be enough to meet the minimum requirement? Will the deficient periods, if any, be of such short duration that they may be neglected? Will the intervals between periods of low flow be great enough to warrant the development of the supply?

To obtain at least partial answers to these questions, low-flow frequency studies based on the annual 7-day minimum discharges were made, and curves were developed for 19 gaging stations unaffected by regulation. The period of record used was the standard 1931–60 period, and the climatic year April 1 to March 31 was used as the basis for the annual computations. Records for gaging stations in the area did not cover this entire period, and it was necessary to make extensions by correlation with long-term records of nearby stations. The best correlation was obtained with the Little Fork, Big Fork, Baptism, and Basswood Rivers, and the records were extended by averaging combinations of records from these streams. A typical frequency curve for the annual 7-day minimum flows is that for the Dark River near Chisholm (fig. 5). Table 5 lists the data for all the stations. The recurrences were determined for intervals as great as the curve definition would allow. This meant that some were determined for the 30-year intervals and others for shorter intervals.

For those not familiar with the use of frequency curves, whether for floods or low flows, it should be emphasized that frequency curves are not exact determinations of a fixed time interval; a 10-year flood or low flow will not occur once each 10 years. A 10-year flow means that a discharge of this magnitude will recur about 100 times each 1,000 years.
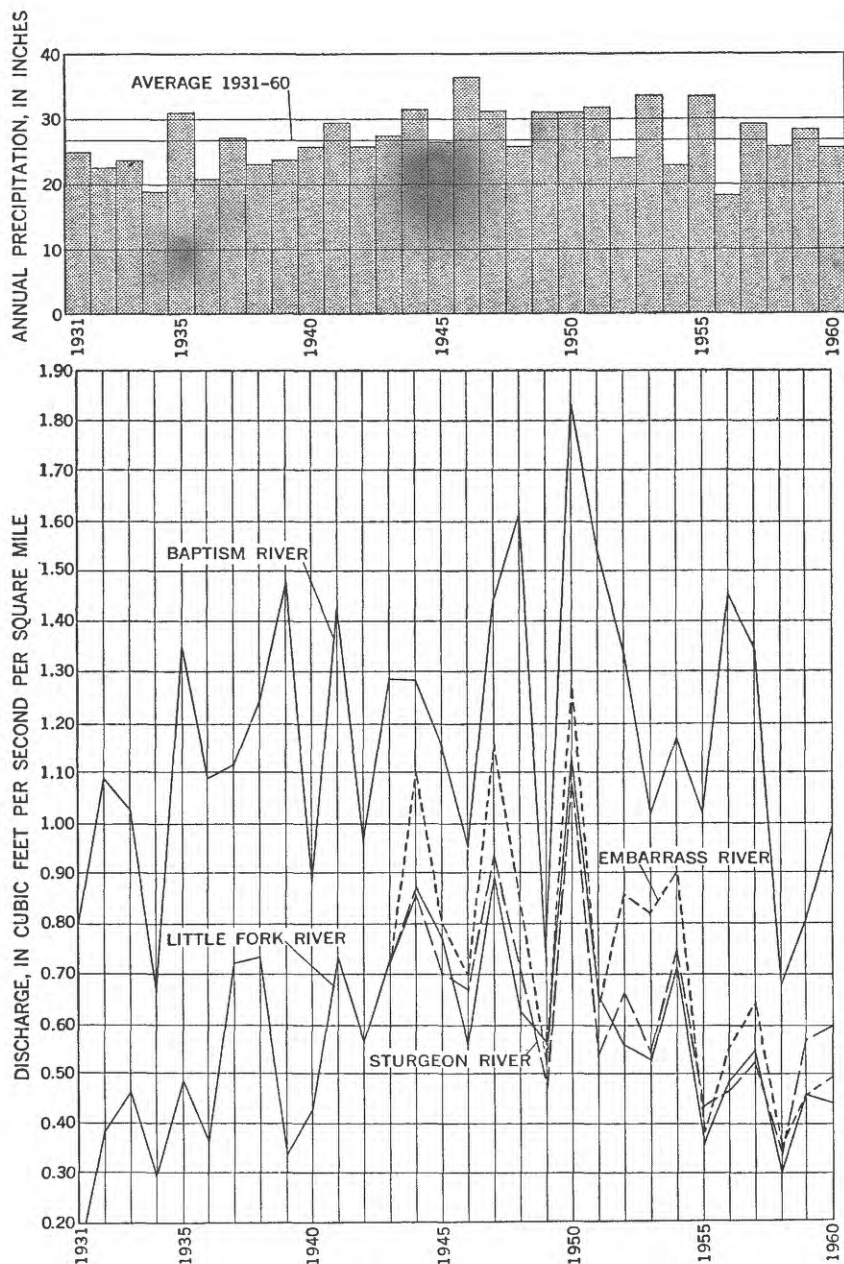
FIGURE 4.—Annual precipitation at Virginia, Minn., and discharges per square mile at selected gaging stations.
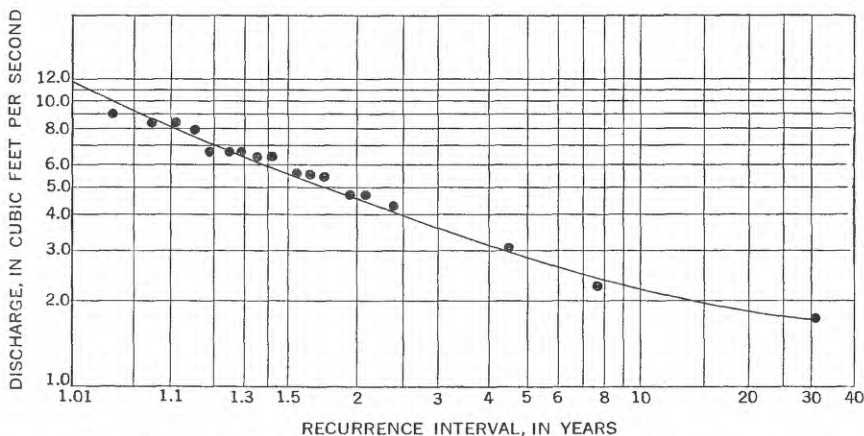
FIGURE 5.—Annual 7-day minimum frequency curve for station 1310, Dark River near Chisholm, Minn.

TABLE 5.—*Discharges at gaging stations not materially affected by regulation of annual 7-day minimums for selected recurrence intervals*

Station	Station name	Drainage area (sq mi)	Runoff for 2-year recurrence interval (cfs per sq mi)	Discharge, in cfs, for recurrence intervals, in years shown			
				2 years	10 years	20 years	30 years
1245	Isabella River near Isabella	341	0.158	54	29		
1250	South Kawishiwi River near Ely			110	58	34	30
1255	Stony River near Isabella	180	.094	17	9.0	6.7	5.7
1260	Dunka River near Babbitt	53.0	.043	2.3	1.1	.8	.7
1265	Bear Island River near Ely	68.5	.058	4.0	1.2	.7	.5
1275	Basswood River near Winton	1,740	.218	380	192	130	96
1285	Pike River near Embarrass	115	.049	5.6	2.9		
1290	Vermilion River below Vermilion Lake near Tower.	483	.166	80	20	9.6	6.0
1305	Sturgeon River near Chisholm	187	.053	10	5.2	4.2	
1310	Dark River near Chisholm	50.6	.089	4.5	2.2	1.9	1.7
1315	Little Fork River at Little Fork	1,730	.039	67	37	31	27
1320	Big Fork River at Big Falls	1,460	.048	70	25	20	18
2170	Swan River near Warba	254	.157	40	25		
145	Baptism River near Beaver Bay	140	.079	11	2.7	1.4	.9
170	Embarrass River at Embarrass	93.8	.034	3.2	1.4	1.1	
180	Embarrass River near McKinley	171	.117	20	12		
190	West Two River near Iron Junction	68.4	.083	5.7	2.7		
195	East Swan River near Toivola	112	.161	18	11		
200	Swan River near Toivola	254	.114	29	13		

FLOODS

FREQUENCY CURVES

In order to determine the frequency and magnitude of flooding that might be expected in a given area, curves can be constructed using the methods described by Dalrymple (1960). A frequency curve for northeastern Minnesota (region A of Prior and Hess, 1961, pl. 1), shows the relation between recurrence interval and ratio of a probable flood to the mean annual flood for the report area (fig. 6). Curves also show the relation between mean annual floods, drainage area, and percentage of lake area (fig. 7).
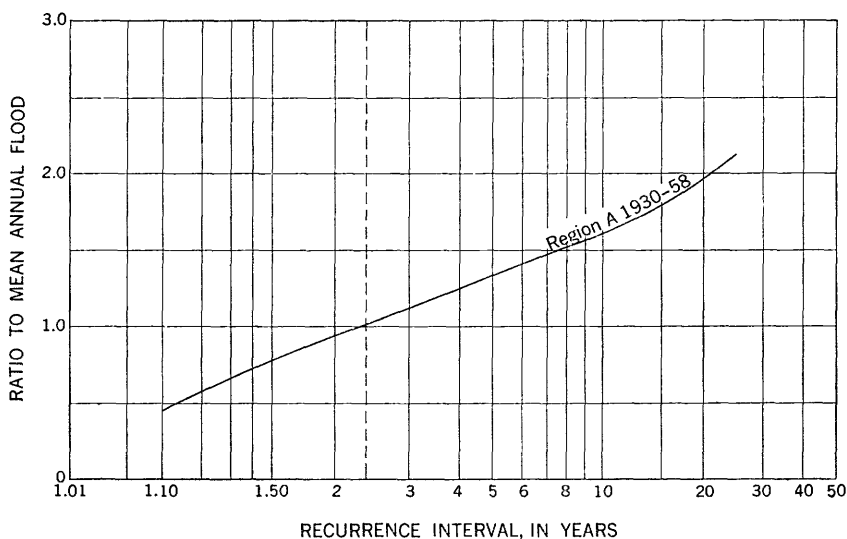
FIGURE 6.—Composite frequency curve of annual floods within region A, northeastern Minnesota.

APPLICATION OF CURVES

From the preceding curves, the recurrence interval of a flood of any magnitude can be approximated if the drainage area and percentage of lake area are known.

If, for example, a site on a stream having a drainage area of 200 square miles is under consideration, and an investigation indicates that 3 percent of this area is covered by lakes, the mean annual flood can be determined from figure 7 as 1,500 cfs (cubic feet per second).

To determine the recurrence interval of a flood of 3,000 cfs, the ratio is obtained by dividing this value by 1,500 cfs which equals 2.00. Using figure 6 and entering the curve at 2.00, it is found that the curve is intercepted at a recurrence interval of about 21 years.

Table 6 gives the values of the 10, 20, and 30 year floods computed on the basis of figures 6 and 7. The 30-year values are obtained from an extension of the ratio-recurrence curve and are therefore of a more speculative nature than are the 10- and 20-year values.

In order to compare the yield during periods of low flow of the various drainage basins in the area, the runoff per square mile for the annual 7-day minimums that have a recurrence interval of 2 years was computed for the gaging stations not affected by extensive regulations.

There is no definite pattern related to the geographic location of the drainage areas. The most dominant factor seems to be the per-

centage of lake area in the basins, as the natural storage therein tends to sustain the yield during periods of deficient precipitation.

The data and interpretations regarding surface water will aid those planning utilization of available water and planning installations that need protection from flooding by eliminating some of the unknowns always present in ungaged areas. A knowledge of deficient flow will indicate the necessity of utilizing storage to bridge the low periods; or such knowledge might reveal a site to be impractical.

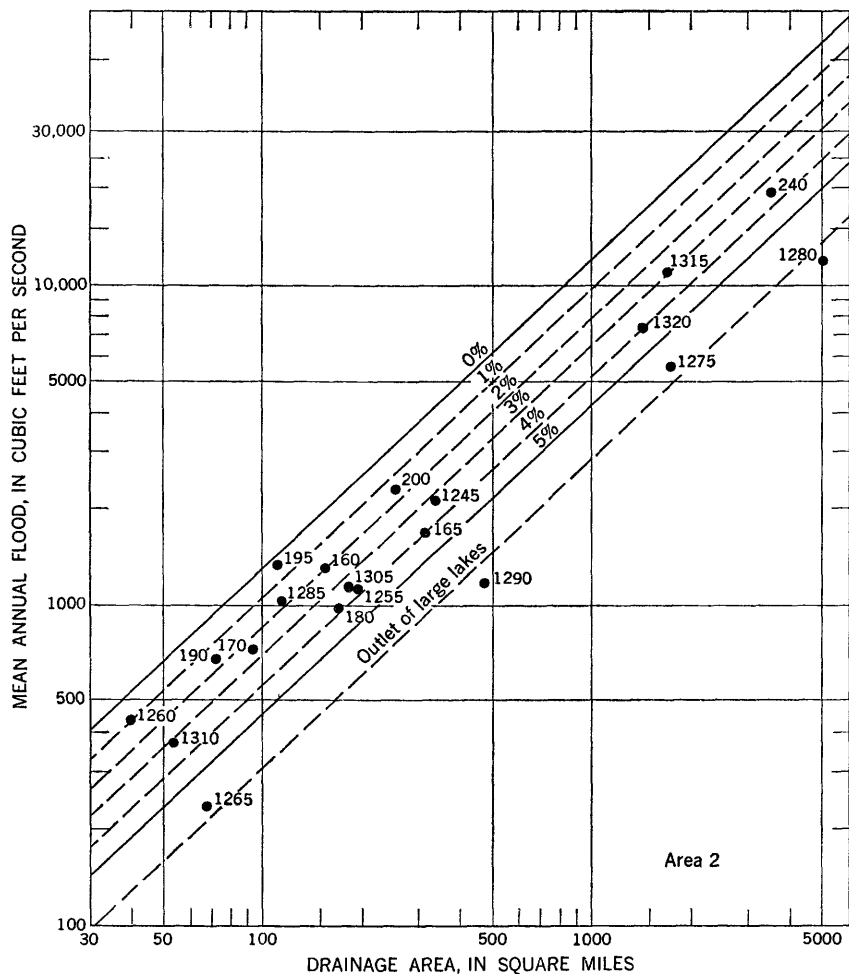FIGURE 7.—Relation curves between mean annual flood, drainage area, and percentage of lakes.

TABLE 6.—*Flood frequency at gaging stations in and near the area of this report*

Station	Station name	Drainage area (sq mi)	Flood, in cfs, for recurrence interval, in years, shown		
			10 years	20 years	30 years
1245_____	Isabella River near Isabella_____	341	3,470	4,230	4,990
1255_____	Stony River near Isabella_____	180	1,790	2,180	2,580
1260_____	Dunka River near Babbitt_____	53.0	694	846	998
1265_____	Bear Island River near Ely_____	68.5	384	468	552
1275_____	Basswood River near Winton_____	1,740	8,900	10,800	12,800
1285_____	Pike River near Embarrass_____	115	1,630	1,990	2,350
1290_____	Vermilion River below Vermilion Lake near Tower.	483	1,900	2,320	2,740
1305_____	Sturgeon River near Chisholm_____	187	1,810	2,200	2,600
1310_____	Dark River near Chisholm_____	50.6	592	722	851
1315_____	Little Fork River at Little Fork_____	1,730	17,300	21,100	24,800
1320_____	Big Fork River at Big Falls_____	1,460	11,600	14,200	16,700
2170_____	Swan River near Warba_____	254	480	585	690
145_____	Baptism River near Beaver Bay_____	140	4,830	5,890	6,950
155_____	Second Creek near Aurora_____	26.3	48	58	69
160_____	Partridge River near Aurora_____	156	2,050	2,500	2,940
165_____	St. Louis River near Aurora_____	312	2,700	3,300	3,890
170_____	Embarrass River at Embarrass_____	93.8	1,150	1,400	1,650
180_____	Embarrass River near McKinley_____	171	1,570	1,910	2,260
190_____	West Two River near Iron Junction_____	68.4	1,060	1,290	1,520
195_____	East Swan River near Toivola_____	112	2,140	2,610	3,080
200_____	Swan River near Toivola_____	254	3,680	4,480	5,290

A consideration of the number of high flows that may be expected can be balanced against the economic considerations of how far the design should go in preventing flooding. A typical example is the question of whether to build a highway fill with bypass structures so as to withstand all flooding, or to build at much less cost with the expectation of loss at predetermined average intervals.

DISTRIBUTION OF GROUND WATER AND SURFACE WATER BY PHYSIOGRAPHIC REGIONS

The distribution of water resources within the area of this report is discussed by physiographic region (pl. 1). Each region has a unique physiography that broadly determines water occurrence. The names of the regions as used in this report are generally as Wright (1956, p. 10–15) designated them, but some are extended and slightly modified, and two additional regions (Morainal and Ice-Contact region and Ice-Contact region) are added.

Physiography relates landforms to geology. The composition, mode of deposition, and extent of weathering of the rocks control the shape of the land surface. This shape controls the pattern of surface-water flow and the distribution of lakes.

Individual rock types can be inferred from their characteristic landforms. Both near-surface ice-contact deposits and outwash plains, which are major aquifers in the area, can be identified by their characteristic topography. These and other glacial landforms have been delineated on a glacial map that covers most of the area of this report. (Cotter, Young, and Winter, 1964.)

GIANTS RANGE

The most prominent topographic feature in the area of this report is the Giants Range, a long ridge trending northeast parallel to the Mesabi Iron Range (pl. 1). At the longitude of Virginia and Eveleth the ridge is Z shaped. This flexure is known as the Virginia Horn.

The Giants Range generally stands 100–480 feet above the surrounding land surface and is highest on the east and central Mesabi Range. Toward the west the Giants Range decreases in altitude and merges into the surrounding land surface. It reaches a maximum altitude of about 1,950 feet above mean sea level at Pike Mountain, north of McKinley. North of Coleraine its altitude is 1,560 feet. West of Coleraine it is not a discernible topographic feature, and its trend is obscured by transverse glacial landforms.

Except for a few very small streams and the southward-flowing Embarrass River, whose drainage basin extends 25 miles north of the Giants Range, the crest of this ridge forms the drainage divide for waters flowing north and south. This region contains only a few small lakes and streamflows are very low. Its surface-water potential is poor.

The Giants Range is formed by the southernmost exposures of the Giants Range Granite. The drift cover is very thin or absent, and the only stratified drift is in the form of boulder pavements restricted to notches in the crest. Neither the drift nor the bedrock is a reliable source of water and the ground-water potential is poor.

COOK-EMBARRASS REGION

The Cook-Embarrass region lies between the Giants Range and the Vermilion moraine (pl. 1). From the south shore of Birch Lake past the south shore of Lake Vermilion, the moraine is the north limit of the region and is discernible on plate 1 as a line of discontinuous ridges. Although the region is largely low and swampy, it is crossed by two east-west morainal ridges. The underlying bedrock surface is very irregular and crops out in many parts of this region. Glacial drift has filled bedrock lows lessening irregularity of the terrane.

Drainage is sluggish, and swamps are large. The major streams draining the region include the Dark, Embarrass, Little Fork, Pike, Prairie, and Sturgeon Rivers. Several lakes are associated with the moraines. Surface-water potential of the region is fair.

The stratified drift includes lake sediments, spotty occurrences of ice-contact drift, and scarce occurrences of outwash. Babbitt obtains its water supply from a pitted outwash plain, Chisholm from buried outwash, and Tower-Soudan from a narrow channel fill. Ground-

water potential of the region is fair, but locally it is good in areas of outwash and ice-contact drift.

The border-lakes region is north of the Vermilion Moraine and contains the Vermilion Iron Range (pl. 1). The region consists of low irregularly shaped bedrock hills and ridges separated by numerous lakes. The drift cover is thin or absent in this area, and the topography is controlled by the underlying bedrock. The east-northeast trend of the bedrock structure is reflected by the shape of the lakes and the stream patterns.

The region contains several large lakes including Birch, Burntside, Trout, Vermilion, and White Iron, and the Kawishiwi, Stony, and Vermilion Rivers. Ely obtains its water supply from Burntside Lake. The surface-water potential is very good.

Some stratified drift occurs in the region as thin isolated ice-contact deposits and outwash in narrow glacial drainageways. Although the ground-water potential is fair in these deposits, the potential of the region, as a whole, is poor.

The Ice-Contact region parallels the central southern flank of the Giants Range. It is a belt of irregular glacial topography that averages about 5 miles in width (pl. 1). Eskers, kettles, and kames are common, and many of the kettle holes are occupied by lakes. Because of these diagnostic landforms, the deposits within this area are referred to as ice contact. However, the sediments are, in part, outwash deposited by melt-water drainage through notches in the Giants Range. East and West Two Rivers, East Swan River, and numerous other small streams head in the Giants Range immediately north of the region and have relatively low flows. The Embarrass and Partridge Rivers have large drainage areas and greater flows. Large lakes in the region are Embarrass, Whitewater, Colby, Ely, and St. Marys of which the latter three are the respective water supplies for Hoyt Lakes, Gilbert, and Eveleth. Surface-water potential is fair.

The Biwabik Iron-Formation underlies the northern part of the region and is locally an important aquifer. Biwabik, Buhl, and McKinley obtain their water from this formation.

Stratified drift is widespread throughout the region but thins near the Giants Range. Test drilling and test pumping have shown this drift will yield large quantities of ground water. Mountain Iron and Kinney obtain their water supplies from drift, and Aurora, Hibbing, and Virginia from both drift and the Biwabik. The ground-water potential of the region is very good.

GLACIAL LAKE AITKIN-UPHAM REGION

Southwest of the Ice-Contact region is the Glacial Lake Aitkin-Upham region (pl. 1), a low flat-lying area, formerly occupied by glacial Lakes Aitkin and Upham. Surficial deposits of peat, clay, silt, and sand obscure the shape of the underlying drift surface. Within the northeastern part of the lake basin, numerous "islands" of ice-contact stratified drift are exposed above the level of the surrounding lake sediments.

Drainage is sluggish and most of the region is covered by swamp. A few lakes are associated with ice-contact deposits near the margin of the region, and the Mississippi and St. Louis Rivers and their tributaries flow southward through the region. The surface-water potential is good for the areas near rivers, but only fair for the region as a whole.

The ground-water potential for the stratified drift in the northeastern part of the region is good. The remainder of the region is probably underlain by fine-grained lake sediments and till, and the potential for the region as a whole is poor.

MORAINAL AND ICE-CONTACT REGION

The Morainal and Ice-Contact region is west of the Glacial Lake Aitkin-Upham region and extends north across the Giants Range (pl. 1). It is an area of very irregular hummocky glacial topography containing numerous lakes. The principal "grain" of the land surface, as shown by the lakes, ridges, and eskers, is south-southeast, but some smaller features trend southwest or west. The region is a morainal complex containing associated ice-contact deposits.

The Big Fork and Little Fork Rivers drain the region north of the Laurention Divide. The Mississippi and its tributary the Prairie River drain the region south of the divide. There are numerous large lakes within the region, the largest being Pokegama Lake. The surface-water potential for the region is very good.

The Biwabik Iron-Formation flanks the south side of the Giants Range and extends southwestward beyond Grand Rapids. Permeable parts of this formation can support large withdrawals of ground-water. Calumet, Cooley, Keewatin, Marble, Nashwauk, and Taconite obtain their water from the iron-formation.

Ice-Contact stratified drift and outwash aquifers are widespread throughout the region. Bovey and Coleraine obtain their water from stratified drift, and Grand Rapids obtains its water from drift and the Biwabik Iron-Formation. The ground-water potential of the region is good.

TOIMI DRUMLIN FIELD

The Toimi drumlin field is a belt of southwestward-trending drumlins extending from the east end of the Giant Range (pl. 1). These ridges control the drainage within the region, and the valleys between them are occupied by lakes, streams, and swamps. The ridges that were examined in the field were composed of a gray to brown bouldery till.

The Dunka River drains the region north of the Laurentian Divide. The St. Louis River and its tributaries, which include the Partridge and Whiteface Rivers, drain the region to the southwest. The region contains several lakes and the Whiteface reservoir. The surface-water potential of the region is fair.

Some ground water can be obtained from isolated deposits of ice-contact stratified drift, which are scattered throughout the region. The Biwabik Iron-Formation flanks the south side of the Giants Range in this region, but it is mainly dense taconite here and not a good source of ground water. The ground-water potential of the region is poor.

QUALITY OF WATER

In selecting a source of water, quality is an important consideration. Quality requirements vary widely depending on the particular use for which the water is intended. Although water is commonly treated to make it acceptable for the intended use, the cost of this treatment depends on the quality of the "raw" water. In many areas alternative sources are available, and quality is the determining factor in the final selection of a supply.

Records on the chemical quality of surface water in the Mesabi and Vermilion Iron Ranges have been obtained since 1955. The records include daily observations for several years at 4 stream sites— Embarrass River at Embarrass, Second Creek near Aurora, Partridge River near Aurora, and West Two River near Iron Junction; monthly or semiannual observations for several years at 13 other stream sites; and single observations for numerous lakes. Records of the chemical quality of ground water were obtained about 1957, mostly for municipal supplies or for test holes in the vicinity of municipalities.

Chemical analyses by the U.S. Geological Survey were made by using methods described by Rainwater and Thatcher (1960). Analytical results are given mostly in parts per million, which is a unit weight of a constituent in a million unit weights of water. Specific conductance is given in micromhos per centimeter at 25°C; this is a measure of the capacity of the water to conduct an electrical current and is closely related to the dissolved-solids content (residue on

evaporation at 180°C) of the water. The degree of acidity or alkalinity is indicated in pH units, which are the negative logarithms of the hydrogen ion concentration in moles per liter. Color is given in units of the platinum-cobalt scale (Hazen, 1892).

CRITERIA FOR EVALUATING THE QUALITY OF WATER

The quality of water for municipal use can be evaluated by comparing the chemical characteristics of the water with the drinking-water standards of the U.S. Public Health Service (1962), given in part below:

Constituent or property		Maximum concentration
Iron (Fe)	ppm	0.3
Manganese (Mn)	do	.05
Sulfate (SO₄)	do	250
Chloride (Cl)	do	250
Fluoride (F)	do	[1] 0.8–1.7
Nitrate (NO₃)	do	45
Dissolved solids	do	500
Color	units	15
Turbidity	do	5

[1] Varies depending on annual average of maximum daily air temperature.

The significance of the chemical constituents or properties of drinking water is described in detail by Welsh and Thomas (1960). The significance of these and other constituents in relation to industry and irrigation is described by Lohr and Love (1954), the U.S. Salinity Laboratory Staff (1954), and Hem (1959).

No specific standards for hardness have been established, but the following ratings, recognized by the U.S. Geological Survey, are used in this report.

Hardness (ppm)	Rating	Suitability
0–60	Soft	Suitable for many uses without further softening.
61–120	Moderately hard	Usable except in some industrial applications.
121–180	Hard	Softening required by laundries and some other industries.
181+	Very hard	Requires softening for many uses.

No generally accepted standards for silica have been established, although maximum concentrations have been recommended for certain industrial applications. For this report and for closely related reports (Cotter and others, 1965, a, b, c, d, and e), water having more than 20 ppm is considered to be siliceous and 10–20 ppm is moderately siliceous.

GROUND WATER

The chemical composition of ground water from municip·l wells shows an average dissolved-solids content of about 230 ppm (table 7). The principal constituents of well waters are calcium, magnesium, and bicarbonate. Sulfate is present in significant concentrations in most well waters. The water generally is moderately siliceous, is hard or very hard, and contains much iron and manganese. Other dissolved constituents, such as sodium, potassium, chloride, fluoride, nitrate, and boron, occur in such low concentrations that they have little effect on the use of the water. The color of water from most wells is 5 units or less and for some is nearly zero. The turbidity in water from most wells is less than 2 units, but for a few it is between 20 and 30.

TABLE 7.—*Chemical composition of untreated ground water used for municipal supply (1960)*

[Results in parts per million except as indicated]

Constituent or property	Glacial drift (24 wells)				Biwabik Iron-Formation (15 wells)			
	Maxi-mum	Mini-mum	Aver-age	Per-cent [1]	Maxi-mum	Mini-mum	Aver-age	Per-cent [1]
Silica (SiO₂)	33	13	21	9.0	26	4.1	14	6.4
Iron (Fe)	10	.04	1.9	.9	4.9	.05	.82	.4
Manganese (Mn)	5.5	.00	.83	.3	1.8	.00	.35	.2
Calcium (Ca)	90	20	52	20.3	76	18	45	20.6
Magnesium (Mg)	48	8.9	19	7.7	36	6.6	18	8.2
Sodium (Na)	9.1	2.5	5.8	2.4	12	4.1	7.1	3.3
Potassium (K)	3.3	.6	1.8	.7	5.8	.9	2.1	1.0
Bicarbonate (HCO₃)	413	102	220	43.5	333	94	219	48.6
Sulfate (SO₄)	88	3.8	34	13.4	88	2.0	23	10.1
Chloride (Cl)	12	.0	3.5	1.5	12	.0	3.0	1.1
Fluoride (F)	.3	.0	.2	.1	.2	.0	.1	.0
Nitrate (NO₃)	1.6	.0	.5	.2	7.1	.0	.9	.2
Boron (B)	.11	.00	.04	.0	.09	.01	.06	.0
Dissolved solids	477	127	253	--------	396	104	213	--------
Hardness as CaCO₃	420	87	212	--------	339	72	191	--------
Noncarbonate hardness as CaCO₃	--------	--------	32	--------	--------	--------	11	--------
Alkalinity as CaCO₃	339	84	180	--------	273	77	180	--------
Percent sodium	--------	--------	6	--------	--------	--------	8	--------
Specific conductance (micromhos at 25° C.)	758	178	408	--------	648	162	372	--------
pH	7.8	6.5	7.4	--------	7.8	6.8	7.4	--------
Color (units)	130	0	10	--------	5	0	2	--------
Temperature (°F)	49	42	45	--------	50	43	45	--------

[1] By weight of dissolved solids.

Most of the wells for which chemical analyses of water were made produce water from drift or from the Biwabik Iron-Formation. Differences in most chemical characteristics of water from the drift and from the Biwabik are relatively slight (table 7). On the average, water from the Biwabik has a slightly lower dissolved-solids content and much lower silica, iron, and manganese content than water from the drift. Water from the drift is more likely to have significant amounts of sulfate and is more likely to be colored. The average of 10 units of color for water from the drift, however, may be misleading

because the analysis of water from one municipal supply showed 130 units, which significantly affected the average. Had this high result been omitted, the average would have been only four units.

For most chemical characteristics, water from the drift and water from the Biwabik have similar percentages by weight and similar maximums and minimums of dissolved solids as shown in table 7. The similarity in water from the two types of deposits results partly because much of the water in the Biwabik was previously in contact with the overlying drift. In some parts of the Biwabik, most of the soluble mineral matter was leached when the ore bodies were being formed; consequently, after percolating into the Biwabik, the water changes little in chemical composition.

Much of the drift contains a relatively large number of limestone and shale fragments that are sources of the calcium and bicarbonate in the ground water.

Complex iron silicates, iron oxides, carbonates, and quartz are the predominant minerals in the rocks of the Biwabik Iron-Formation. Several of these minerals contribute calcium and bicarbonate to the water. Gruner (1946, p. 21) reported that calcite, calcium carbonate, is recognizable with the unaided eye in drill cores in the top 10–20 feet of the Biwabik in the eastern half of the range, and that it may be observed microscopically as well-formed white or colorless rhombohedrons in many samples from all parts of the formation. He also reported amphiboles and pyroxenes, complex silicates containing calcium, in the eastern Mesabi Range. White (1954, p. 24 and 29) indicated that the lower cherty member of the Biwabik contains calcite, that limestone beds occur at the contact of the Biwabik and the Virginia, and that the limestone in both the Biwabik and the Virginia is continuous along nearly all of the main Mesabi Range.

SURFACE WATER

Records of water quality indicate that the dissolved-solids content is less than 200 ppm (parts per million) and averages less than 100 ppm for most streams in the Mesabi and Vermilion Ranges. Like the ground water, the surface water contains principally calcium, magnesium, and bicarbonate. Iron is present in concentrations from a few tenths to about 1 ppm, manganese is generally absent, and the water is relatively soft.

The only surface water that is being used for municipal supply is from lakes. The dissolved-solids content of the water from the four lakes (Burntside, Colby, Elby, and St. Marys) was less than 100 ppm, and the average hardness of the water was 46 ppm. Except for Colby Lake, the water had little silica or iron and was only slightly

colored.   The chemical quality of the water undoubtedly varies some-
what with changes in lake altitudes.

The frequency distributions in table 8 provide an estimate of the
ranges in concentration of chemical constituents likely to be present
in streamflow, and they provide a convenient means for comparing
the quality of the water from one stream to another.   Data in the
table indicate, for example, that dissolved solids did not exceed 100
ppm in water from Bear Island and South Kawishiwi Rivers, where-
as it did exceed 100 ppm in a significant percentage of samples from
all other streams.   Also, the dissolved-solids content in water from
East Two River and Swan River is generally much higher than that
from other streams.   Water from most of the streams is colored.
All samples from five of the streams indicate that the water is soft.

PRESENT WATER DEVELOPMENT

The quantity of available water leaving the area shown in figure 1
has been estimated at 700 bgy (billion gallons a year).   This esti-
mate is based on available surface-water data and a precipitation of 27
inches for the water year 1959 (October 1958–September 1959).   Sur-
face water entering the area was subtracted from outflow, and ground
water entering the area by subsurface flow has not been included in
the total.   This 700 bgy is about 26 percent of the precipitation.   A
part of the flow of surface streams is from ground water that dis-
charges to the stream as seeps and springs.   During periods of little
precipitation almost all the surface flow of a stream is from ground-
water discharge.   Using the minimum streamflow for the year as the
increment of flow from ground water, at least 200 bgy, or about one-
third of the annual surface-water flow, is contributed from ground
water.   This is equal to a flow of about 400,000 gpm (gallons per
minute).   In addition to this, a large quantity of water leaves the area
as ground-water underflow.

Major industrial and municipal water users on the Mesabi and
Vermilion Iron Ranges utilize about 135 bgy.   Only about 5 percent
of this water is "consumed" or is not available for reuse within
the area.

INDUSTRIAL USE

The largest single water user in the area is the largest industry,
mining.   Although the "shovel" ores of the Mesabi and the "lump
grade" ores of the Vermilion are "direct shipping" and require no
beneficiation, the lower grade ores must be concentrated.   The latter
are the magnetic taconite ores and the "wash" ores.   Most of the
water used to process these ores is surface water from lakes, rivers,
and manmade catchment basins.

TABLE 8.—*Frequency distribution of chemical constituents and properties of water from streams*

[Results are given in parts per million except as indicated]

Station	Stream site	Period of record	Silica (SiO2)		Iron (Fe)		Manganese (Mn)		Calcium (Ca)		Magnesium (Mg)		Sodium (Na)		Potassium (K)		Bicarbonate (HCO3)	
			Percentage of samples in which concentrations exceeded—															
			10	20	0.3	1.0	0.05	0.3	20	40	10	20	10	20	1	2	50	100
5-1265	Bear Island River near Ely	1955-62	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0
5-1310	Dark River near Chisholm	1955-61	25	0	100	12	17	0	0	0	0	0	0	0	43	0	0	0
5-1260	Dunka River near Babbitt	1955-60	56	0	100	22	14	0	0	0	0	0	0	0	25	0	0	0
4-0195	East Swan River near Toivola	1955-60	38	0	62	0	29	0	50	0	38	0	12	0	71	29	87	37
4-0189	East Two River near Iron Junction	1957-60	11	0	0	0	20	0	100	46	93	43	83	7	100	93	100	83
4-0187.7	Elbow Creek near Iron Junction	1959-60	50	0	0	0	33	0	75	0	67	0	17	0	100	67	100	33
4-0170	Embarrass River at Embarrass	1955-62	67	2	81	19	0	0	3	0	0	0	0	0	24	2	34	1
4-0180	Embarrass River near McKinley	1955-60	38	0	32	0	11	0	4	0	0	0	0	0	57	0	71	0
4-0160	Partridge River near Aurora	1955-59	49	0	45	3	0	0	7	0	2	0	1	0	53	13	41	0
5-1285	Pike River near Embarrass	1955-60	33	0	100	22	0	0	0	0	0	0	0	0	0	0	0	0
4-0165	St. Louis River near Aurora	1955-59	44	0	100	0	9	0	2	0	0	0	3	0	47	2	42	0
4-0155	Second Creek near Aurora	1957-59	77	8	29	0	—	—	55	0	52	3	11	0	92	45	88	29
5-1250	South Kawishiwi River near Ely	1955-60	0	0	62	0	17	0	0	0	0	0	0	0	0	0	0	0
5-1255	Stony River near Isabella	1955-60	20	0	78	0	14	0	0	0	0	0	0	0	11	0	0	0
5-1305	Sturgeon River near Chisholm	1955-60	26	0	95	5	20	0	0	0	0	0	0	0	61	3	38	0
4-0200	Swan River near Toivola	1955-60	41	0	38	0	25	0	77	23	60	10	37	0	93	50	97	66
4-0190	West Two River near Iron Junction	1956-57	27	0	20	0	0	0	57	3	37	1	3	0	94	30	91	53

TABLE 8.—Frequency distribution of chemical constituents and properties of water from streams—Continued

Station	Stream site	Period of record	Sulfate (SO4)		Chloride (Cl)		Fluoride (F)		Nitrate (NO3)		Boron (B)		Dissolved solids (residue on evaporation at 180°C)			Hardness as CaCO3		Color [1]		
			20	40	10	20	0.1	0.4	20	45	0.05	0.2	100	200	300	60	120	50	100	200
			Percentage of samples in which concentrations exceeded—																
5-1265	Bear Island River near Ely	1955-62	0	0	0	0	38	0	0	0	0	0	0	0	0	0	0	100	0	0
5-1310	Dark River near Chisholm	1955-61	0	0	0	0	71	0	0	0	50	0	13	0	0	0	0	100	75	12
5-1260	Dunka River near Babbitt	1955-60	0	0	0	0	88	0	22	11	60	0	67	11	0	11	0	100	89	44
5-0195	East Swan River near Toivola	1955-60	75	0	12	0	100	0	0	0	25	0	100	0	0	88	25	71	29	0
4-0189	East Two River near Iron Junction	1957-60	100	89	89	39	89	0	0	0	50	0	100	82	21	100	83	24	0	0
4-0187.7	Elbow Creek near Iron Junction	1959-60	100	42	0	0	100	0	0	0	33	0	100	8	0	100	33	25	0	0
4-0170	Embarrass River at Embarrass	1955-62	1	0	0	0	71	5	0	0	77	0	46	0	0	14	0	85	59	6
4-0180	Embarrass River near McKinley	1955-60	6	0	0	0	73	0	0	0	78	0	56	0	0	45	0	78	14	0
4-0160	Partridge River near Aurora	1955-59	33	1	11	2	83	6	0	0	88	0	69	0	0	38	0	87	48	5
5-1285	Pike River near Embarrass	1955-60	0	0	0	0	75	0	0	0	60	0	33	0	0	0	0	100	78	33
4-0165	St. Louis River near Aurora	1955-59	11	0	1	0	78	2	0	0	76	3	50	0	0	30	0	91	47	2
4-0155	Second Creek near Aurora	1957-59	73	23	61	15	91	17	1	0	89	3	91	26	0	90	28	23	0	0
5-1250	South Kawishiwi River near Ely	1955-60	0	0	0	0	43	0	0	0	0	0	0	0	0	0	0	88	12	0
5-1255	Stony River near Isabella	1955-60	0	0	0	0	67	0	0	0	50	0	10	0	0	0	0	100	70	10
5-1305	Sturgeon River near Chisholm	1955-60	0	0	0	0	64	0	0	0	25	0	28	0	0	12	0	63	24	0
4-0200	Swan River near Toivola	1955-60	66	12	38	0	97	0	0	0	64	0	97	42	3	84	50	50	22	3
4-0190	West Two River near Iron Junction	1956-57	24	0	4	0	86	2	0	0	29	0	85	9	0	84	24	35	1	0

[1] Color is given in units.

The Erie Mining Co. plant at Hoyt Lakes and the Oliver Iron Mining Division plant at Mountain Iron have an average use of more than 6,000 gallons of water per ton of taconite concentrate. Of this, nearly 700 gallons is not available for reuse. This water is either lost in ponding, evaporated, or contained in the final product.

Data from 13 "wash" ore plants show an average use of 1,200 gallons of water per ton of concentrate of which about 125 gallons is not available for reuse.

In 1961, 7.6 million tons of taconite concentrate were shipped. Of the nearly 50 billion gallons of water used in processing, more than 5 billion gallons were not available for reuse. The same year, 16.7 million tons of "wash" ore concentrate were shipped from both iron ranges. Based on averages from the 13 plants, about 20 billion gallons of water were used in processing, of which about 2 billion gallons were not available for reuse.

Two steam-powered electric generator plants owned by the Minnesota Power and Light Co. use large volumes of water. The plant near Cohassett used 3 million gallons of ground water and 17.4 billion gallons of surface water in 1959, and their plant near Hoyt Lakes used 1 million gallons of ground water and 45.5 billion gallons of surface water during the same year. Very little water used in either plant is consumed.

The Blandin Paper Co. at Grand Rapids uses about 1.3 billion gallons of surface water per year (1957) in wood processing. Other minor industrial water uses include gravel washing operations, dairies, and wood and vegetable processing. Many of the open-pit mines on the Mesabi Range have wells for drinking and sanitation water.

MUNICIPAL USE

About two-thirds of the population within the area shown on plate 1 is concentrated in 26 municipalities, of which 4 use surface water (lakes) and 22 use ground water for municipal supplies. Virginia obtains most of its water by pumping a flooded mine shaft at the bottom of an open-pit mine. Although drifts run from the shaft beneath a lake in the pit bottom, most of the water is from the Biwabik Iron-Formation. Of the 22 municipal ground-water supplies, 8 are from drift, 8 from the Biwabik Iron-Formation, 2 from a combination of these aquifers, 2 from the Biwabik Iron-Formation and the Virginia Argillite, 1 from the 3 aquifers, and 1 from the Virginia Argillite, above.

Treatment facilities are varied. Ten municipalities using ground water do not treat their supplies. The surface-water sources all include prechlorination, coagulation, sedimentation, filtration, and postchlorination. Of the municipalities that do treat ground water, six

either aerate and filter the water to remove iron, or hold the iron in solution by polyphosphate stabilization, or both. Kinney has a serious manganese problem and uses coke and pyrolusite beds to remove it. Babbitt, Chisholm, and Virginia have more complete treatment facilities including coagulation, chlorination, and filtration.

The total water consumption of the 26 municipalities is about 8 million gpd (gallons per day) or 2.8 bgy. This is an average per capital consumption of about 92 gpd.

CONSIDERATIONS FOR FUTURE DEVELOPMENT

Obviously, it would not be desirable or economical to capture and utilize all the water moving through the area. Where maximum development of the water resources is required, streamflow can be used during periods of sustained high flow and lakes and ground water used during periods of sustained low flow. Aquifers and lakes are storage reservoirs, and can supply water during the fall and winter, during periods of low streamflow.

When heavily pumped, the water level in an aquifer lowers as the aquifer is emptied. During spring and summer rains, the aquifer is refilled. The periodic lowering of the water table is beneficial as it reduces the evapotranspiration losses.

Water stored in lakes and in the surrounding shallow aquifers can be obtained from either source. Lowering the water table near the edge of a lake by pumping a well induces water to flow from the lake to the well. As the lake level is lowered the entire lake basin functions as a tremendous well, inducing ground-water inflow from the surrounding area. Water induced to flow from a lake to a well is commonly of better quality than lake water; specifically, it is less turbid and more uniform in temperature.

In all areas the total supply is limited first by the total precipitation falling in the area and second by the quantity available from storage during prolonged periods of no precipitation. Other things being equal, the area with the largest surface- or ground-water reservoirs will yield the greatest quantity of water. Economical utilization of ground water requires that wells be completed in permeable deposits so that each well can draw large quantities of water from an extensive aquifer. Because physiography controls the distribution of the water resources in the Mesabi and Vermilion Iron Ranges, the physiography of the region in which the water occurs must be considered in order to achieve optimum development.

The best surface-water potential is in the Border-Lakes region and Morainal and Ice-Contact region, and the best ground-water potential is in the Ice-Contact region and the Morainal and Ice-Contact region.

In order to provide more detailed information for future water use and management, a series of reports has been prepared. These reports (Cotter and others, 1965a, b, c, d, and e) contain descriptions of the hydrology in the vicinity of 26 municipalities, 22 of which obtain their water supplies from the 3 previously mentioned regions. Also of assistance is the surficial geologic map (Cotter, Young, and Winter, 1964) that outlines glacial landforms indicating the presence of potential aquifers in most of the report area.

The water quality at a potential site must be considered. The dissolved-solids content of the ground water averages about 220 ppm, and that of most streams averages less than 100 ppm. Both ground and surface waters contain principally calcium, magnesium, and bicarbonate and generally contain high concentrations of iron. Most of the ground water also contains high concentrations of manganese and is hard or very hard. Most of the surface water is highly colored, but it is soft or only moderately hard. Generally the ground water is of good quality for most uses if it is softened and if it is treated to remove iron and manganese, and surface water is of good quality for most uses if it is treated to remove color and iron.

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