Water Resources in the Vicinity of Municipalities On the West-Central Mesabi Iron Range Northeastern Minnesota

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

WATER RESOURCES OF THE MESABI AND VERMILION IRON RANGES

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ABSTRACT

Additional supplies of water are available near the municipalities on the west-central Mesabi Iron Range. The largest sources are the ground-water aquifers in the Biwabik Iron-Formation and the stratified glacial drift. Areas of stratified drift that probably have good water potential have been outlined. Surface-water supplies are negligible in the eastern part of this area but increase toward the west. Flow records from one gaging station, results of discharge measurements at two miscellaneous sites, and data from many wells and test holes are presented.

Most of the ground water is hard and has a high concentration of iron and manganese. The surface water generally has a high concentration of iron and is colored. Analyses of water from many sources are shown.

INTRODUCTION

This report describes existing and potential water supplies on the west-central Mesabi Iron Range.

Increased supplies of water are needed for expansion and diversification of the economy of the iron ranges. Specifically, supplies are needed for taconite processing, wood and peat processing, and municipal expansion. This investigation made in cooperation with the Minnesota Department of Iron Range Resources and Rehabilitation indicates that in some areas large quantities of water are available from both ground and surface sources.

The most productive aquifers are the Biwabik Iron-Formation and the stratified glacial drift. Bodies of stratified drift, believed by the authors to be potential sources for large ground-water supplies, are outlined as numbered areas. Their boundaries are drawn on the basis of topography, geologic mapping, test drilling, and test pumping. The accuracy of the assessment of the ground-water supplies in each numbered area is proportional to the subsurface control.

Where adequate pumpage data is available, specific capacities of wells are noted. Multiplying the specific capacity by the maximum allowable drawdown will give the short-term maximum yield of a well Specific capacities decrease with an increase in time and pumping rate. Specific capacities of wells completed in artesian aquifers should not be compared with those of wells completed in water-table aquifers, because, in otherwise identical aquifers, the value obtained for a well in the artesian aquifer would be much lower.

The geologic sections in this report are based on the indicated test-hole information and open-pit mine exposures. Identification of glacial deposits from drill cuttings and correlation of deposits between test holes is tenuous. However, the sections show the sequence and general lithology that probably would be penetrated in a drill hole along the line of section.

The surface-water supplies that are present on the west central Mesabi Iron Range are negligible in the eastern part, but increase toward the west. Fairly large supplies are available in the streams and lakes in the upper basin of the Swan River. Flow records at one gaging station and discharge measurements at two sites are presented.

The quality of ground and surface water is adequate for many industrial uses. Ground water commonly has a high concentration of iron and manganese and is hard. Surface water commonly has a high concentration of iron and is colored. Analyses of water from many sources are included. Where no analyses have been made, tables 7 and 8 in Cotter and others (1965) can be used to approximate the quality of a potential supply.

NUMBERING SYSTEM

Identification numbers assigned to wells, test holes, or specific locations in this report also serve as location numbers. The system of numbering is based on the U.S. Bureau of Land Management's system of subdivision of the public lands. Figure 1 illustrates the method of numbering. The number 57.18.8ddbl identifies the first well or test hole located in the NW¼SE¼SE¼ sec. 8, T. 57 N., R. 18 W. Where locations are not accurate to within 10 acres, they are identified by using only the first two lowercase letters and no number suffix.

ACKNOWLEDGMENTS

The authors acknowledge the help of municipal officials and well drillers who contributed much of the basic data.

Mining companies in the area furnished maps and drill-hole logs and allowed examination of mine faces. W. A. Cummens, engineer of the Oliver Iron Mining Division of U.S. Steel Corp., was particularly

helpful in the ground-water phase of the investigation by furnishing current information on test drilling and other information on the hydrology of the area.

COOLEY AND NASHWAUK

The villages of Cooley and Nashwauk are about 2 miles southeast of the Giants Range as shown on the Cooley-Nashwauk map (pl. 1). The extreme northwestern corner of the area is drained by the Prairie River; the drainage in the rest of the area is south to the Swan River by way of Swan Lake, which is fed by O'Brien, Oxhide, and Pickerel Creeks.

The bedrock in the area consists of Ely Greenstone, Giants Range Granite, Pokegama Quartzite, Biwabik Iron-Formation, and Virginia Argillite. In the northwestern corner of the area is a 130-foot high ridge of Giants Range Granite. Over much of the northwest flank of the ridge, the granite is exposed or is very thinly covered with

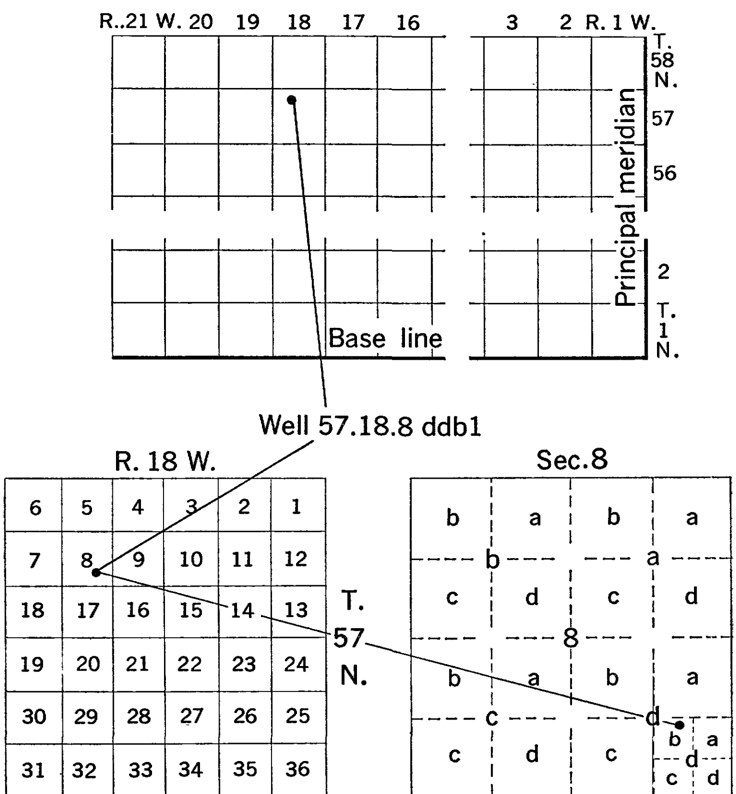

Figure 1.—Sketch showing method of numbering test holes and wells.

glacial drift. Southward from the Giants Range the glacial drift thickens from 25 to 50 feet along the north limit of the Biwabik to 100–150 feet along the south edge. In some areas, it is 200-feet thick.

Cooley obtains its water supply from a well that taps the Virginia Argillite and the Biwabik Iron-Formation. The Nashwauk well is in the Biwabik Iron-Formation.

COOLEY

Population: 87

PRESENT WATER SUPPLY

Source of information: Vic Lager, Butler Brothers master mechanic; Thiel (1947, p. 134).

Ownership of water supply: Butler Brothers, M. A. Hanna Co., Agent.

Number of customers: 36 (1960). Also supplies Nashwauk in emergencies by mutual connection.

Average consumption: 70,000 gpd (gallons per day) (estimated, 1960).

Storage: Elevated steel tank, 50,000 gal.

Treatment: None.

Source of supply: One well.

Well location 56.22.6cccl. At Harrison mine shops; drilled in 1932 and deepened in 1938; 12 inches in diameter; 537 feet deep. Cased to 162 feet; is not screened; has a 600 gpm (gallons per minute) turbine pump set at 310 gpm. Water obtained from Virginia and Biwabik Iron-Formation. Has been pumped at 330 gpm; has 84 feet of drawdown below the static water level of 215 feet.

Quality of water.—The water has a low dissolved-solids content, and the concentration of chemical constituents is far below the maximums of the drinking-water standards (U.S. Public Health Service, 1962). However, the water is hard and moderately siliceous (table 1).

POTENTIAL WATER SUPPLY

PRESENT GROUND-WATER SOURCE

The Cooley municipal well is open in the upper slaty and upper cherty members of the Biwabik Iron-Formation and the lower part of the Virginia Argillite. Most of the water is obtained from the upper cherty member, which was penetrated at 430 feet. A driller's log of the well shows that the material is decomposed taconite. The well has been pumped at 330 gpm and has a specific capacity of 4 gpm per foot of drawdown. A nearby mine-dewatering well, 56.22.6bcbl, about 290 feet deep is reported to draw down to 275 feet when pumped at 850 gpm (Thiel, 1947, p. 135). This well penetrates 75 feet of glacial drift above the Biwabik, is cased to 238 feet, and has 50 feet of screen.

The Virginia Argillite and the upper slaty member of the Biwabik probably act as confining beds that prevent the ground water in the

TABLE 1.—*Chemical analyses, in parts per million, of water in the Cooley vicinity*

[Analyses by U.S. Geol. Survey]

	Present water supply	Potential water supply
	Ground water	Surface water
Water Source	Biwabik Iron-Formation and Virginia Argillite	Pickerel Lake
Location	56.22.6ccc1	
Silica (SiO_2)	13	7.5
Iron (Fe)	.05	0.1
Manganese (Mn)	.00	.09
Calcium (Ca)	38	35
Magnesium (Mg)	11	11
Sodium (Na)	4.3	6.6
Potassium (K)	1.3	2.4
Bicarbonate (HCO_3)	176	139
Sulfate (SO_4)	2.0	26
Chloride (Cl)	1.0	5.0
Fluoride (F)	.2	.4
Nitrate (NO_3)	.4	.0
Boron (B)	.07	.07
Dissolved solids	152	165
Hardness as $CaCO_3$	139	134
Noncarbonate hardness as $CaCO_3$	0	20
Alkalinity as $CaCO_3$	144	114
Specific conductance (micromhos at 25°C)	279	291
pH	7.3	8.1
Color (units)	0	2
Turbidity as SiO_2	.3	
Date of collection	Sept. 26, 1957	Sept. 28, 1962

glacial drift from infiltrating into the upper cherty member in the vicinity of the Cooley well. Much of the potential recharge to the Biwabik west of Nashwauk is diverted by mine dewatering. However, wells in the Biwabik, such as the Cooley well, which pump water from a lower level than adjacent mine pumping can receive sufficient recharge by lateral movement to sustain moderate withdrawals.

Quality of Water.—Mixtures of water from the Virginia Argillite and from the upper parts of the Biwabik contain less dissolved solids, are softer, and have less iron and manganese than the average Biwabik water. (Cotter and others, 1965, table 7).

OTHER WATER SOURCES

GROUND WATER

Area 1 encloses two glacial drainageways that open into the north end of Swan Lake. About 40 feet of glacial drift overlying the iron-formation is exposed in a mine face in a northern extension of area 1, 0.5 mile northwest of Oxhide Lake. The drift in the interval from

10 to 25 feet below the land surface consists of stratified sand and gravel. Geologic section *A–A′* (pl. 1) shows a thick body of stratified sand at the north end of Swan Lake. Coarser stratified drift may occur farther north.

Regional ground-water movement in area 1 is to the south, but local movement is to Oxhide and Pickerel Creeks and Oxhide and Pickerel Lakes. The drift is as much as 200 feet and most of this thickness is saturated (pl. 1). The west "arm," between Swan and Oxhide Lakes, is probably the most favorable part of area 1 for initiial ground-water exploration.

At the southeast end of Swan Lake, 2 miles south of the map area, test hole 55.22.5acal penetrated outwash to 181 feet. The outwash consisted of sand and silt to a depth of 116 feet and from 116 to 181 feet it was a very permeable sand and gravel. The outwash is probably an extension, through the length of Swan Lake, of the glacial drainageway in area 1.

The broad hilly area between Pickerel Lake and the southeast corner of the Cooley-Nashwauk map area (pl. 1) may be an area of ice-contact deposition. No test drilling has been done in the area, however, and an evaluation cannot be made of its ground-water potential. The area is crossed by the valley of O'Brien Creek which is described under Nashwauk in area 2.

SURFACE WATER

With the exception of a small potential supply from Pickerel and Oxhide Lakes, the available surface water supply is the same as for Nashwauk.

Quality of water.—The chemical quality of water from Pickerel Lake is indicated in table 1. The water has a low content of dissolved solids and iron and is only slightly colored, but it is hard and has a manganese content in excess of the recommended limit of 0.05 ppm (U.S. Public Health Service, 1962).

NASHWAUK

Population: 1,712

PRESENT WATER SUPPLY

Source of information: R. A. Loux, water and light superintendent.
Ownership of water supply: Municipal.
Number of customers: Approximately 600 (1960). Also supplies Cooley in emergencies by mutual connection.
Average consumption: 165,000 gpd (1960).
Storage: Elevated steel tank, 100,000 gal.
Treatment: Part-time polyphosphate stabilization; emergency chlorination facilities.

Source of supply: One well.

Well location 57.22.32cda1. At Fern Avenue and Fourth Street; drilled in 1948; 10 inches in diameter; 540 feet deep. Cased to 197 feet; is not screened; has a 450 gpm turbine pump. Water obtained from Biwabik Iron-Formation. Has been pumped at 650 gpm for 24 hours; static water level 127 feet below land surface.

Quality of water.—The water has a low dissolved-solids content; however, it is moderately siliceous, is hard, and contains much iron and manganese (table 2). Except for the iron and manganese content, water from this supply is similar in chemical quality to water from the Cooley supply.

TABLE 2.—*Chemical analyses, in parts per million, of water in the Nashwauk vicinity*

[Analyses by U.S. Geol. Survey]

	Present water supply	Potential water supply			
	Ground water	Surface water			
Water source / Location	Biwabik Iron-Formation (57.22.32 cda1)	O'Brien Lake	Swan Lake	Swan River near Warba [1] (Station 2170) Average	Swan River near Warba [1] (Station 2170) Maximum
Silica (SiO_2)	11	2.3	2.3	8.8	16
Iron (Fe)	.89	.01	.30	.23	.32
Manganese (Mn)	.42	.00	.01	.04	.28
Calcium (Ca)	39	24	26	26	31
Magnesium (Mg)	12	8.3	8.3	8.0	10
Sodium (Na)	4.1	4.9	4.6	4.3	4.7
Potassium (K)	1.8	2.5	2.7	1.5	1.9
Bicarbonate (HCO_3)	185	98	104	109	134
Sulfate (SO_4)	2.0	17	21	17	24
Chloride (Cl)	1.0	4.3	1.2	.7	2.2
Fluoride (F)	.2	.3	.2	.2	.4
Nitrate (NO_3)	.6	2.2	.2	.8	1.3
Boron (B)	.05	.03	.05	.05	.06
Dissolved solids	161	123	135	144	156
Hardness as $CaCO_3$	148	94	99	101	120
Noncarbonate hardness as $CaCO_3$	0	14	14	12	15
Alkalinity as $CaCO_3$	150	80	85	89	110
Specific conductance (micromhos at 25°C)	296	215	211	209	243
pH	7.0	7.7	7.7	--------	7.5
Color (units)	0	3	14	55	95
Turbidity as SiO_2	3	--------	--------	--------	--------
Temperature (°F)	45	--------	--------	--------	--------
Date of collection	Sept. 26, 1957	Sept. 28, 1962	Sept. 28, 1962	9 analyses during 1955–62	

[1] Sampling site is 14 miles southwest of area shown on pl. 1.

POTENTIAL WATER SUPPLY

PRESENT GROUND-WATER SOURCE

The 540-foot village well, 57.22.32cda1, is open in the upper cherty, lower slaty, and lower cherty members of the Biwabik Iron-Formation. The lower slaty here is very thin, but the cherty members are thick and may be oxidized (White, 1954, pl. 1). The well has yielded 650 gpm for 24 hours. Two former village wells, 57.22.32bac1, and 2, were finished in the Biwabik and yielded about 100 gpm. They were 414 and 360 feet deep, respectively, and penetrated about 110 feet of glacial drift. A drainage shaft, 57.22.31da, in the Hawkins mine, is reported to have been pumped at 1,000 gpm. Another well in the Biwabik, 57.22.28caa1, is 215 feet deep and has a specific capacity of 1.3 gpm per foot of drawdown when pumped at 40 gpm. The iron-formation is mainly recharged by precipitation falling on the numerous open-pit mines. All the mines in the Cooley-Nashwauk map area northeast of Nashwauk are inactive and ground-water movement is not diverted by mine dewatering. Immediately west and southwest of the village, the mines are active and relatively deep; thus, some potential recharge to the Biwabik is diverted by mine drainage.

OTHER WATER SOURCES

GROUND WATER

Area 1, described under Cooley, and area 2 are areas of potential ground-water development from the glacial drift. Area 2 outlines a major glacial drainageway that is probably underlain by stratified drift. It is occupied by O'Brien Creek which flows in a deep, narrow valley and by O'Brien and Little O'Brien Lakes. The boundaries of area 2 are based on topography and surficial exposures. On the south side of U.S. Highway 169 at O'Brien Creek, 8 feet of sand and gravel is exposed below 8 feet of brown silty till. Along the west side of the Perry mine (in the extreme northeastern corner of the Cooley-Nashwauk map, pl. 1) there is a pronounced depression in the surface of the Biwabik Iron-Formation which is filled with at least 40 feet of sand and gravel. This coarse stratified drift may be a reflection of deposition along the drainageway. Local ground-water movement is into area 2 and southward parallel to O'Brien Creek.

The flat topography bordering the east side of Swan Lake south of area 2 is underlain by fine outwash (section *A–A′*, pl. 1). This material will probably provide only small quantities of water to individual wells.

West-northwest of Nashwauk, thin glacial drift overlies the bedrock in the area not occupied by open-pit mines. Examination of mine faces and well records indicates that the glacial drift is largely brown silty and gray bouldery tills and is a poor source of large ground-water supplies.

SURFACE WATER

A supply of water probably could be obtained from O'Brien Lake into which O'Brien and Welcome Creeks flow and from Swan Lake, which is headwaters of the Swan River. There are no gaging stations on these streams, the nearest being near Warba on the Swan River.

FLOW DATA

On November 10, 1955, a discharge measurement of 18.9 cfs (cubic feet per second) was made on O'Brien Creek above Swan Lake. At the same time the flow of the Swan River near Warba was 77 cfs, and the flow for the day was nearly constant.

SWAN RIVER NEAR WARBA, MINN.

Location.—Lat 47°06'40", long 93°15'50", in SE¼ sec. 33, T. 54 N., R. 23 W., on left bank 75 feet upstream from highway bridge, 1½ miles south of Warba, 3¾ miles northwest of Swan River, and 22 miles upstream from mouth.

Drainage area.—254 square miles.

Records available.—October 1953 to September 1960.

Average discharge.—7 years, 132 cfs.

Extremes: 1953–60.—Maximum discharge, 1,000 cfs April 13, 1954 (gage height, 9.02 ft, Apr. 13, 1954, backwater from ice); minimum discharge, 34 cfs, August 29, 30, 1956; minimum daily discharge, 34 cfs, August 29, 30, 1956.

Flood in May 1950 reached a stage of about 11.5 feet. This information obtained from local residents.

Flood frequency.—10-year flood, 480 cfs; 20-year flood, 585 cfs; 30-year flood, 690 cfs.

Low-flow frequency.—Annual 7-day minimum discharge: 2-year, 45 cfs; 10-year, 30 cfs; 20-year, 25 cfs.

Quality of water.—Water from O'Brien Lake, Swan Lake, and Swan River has a low content of dissolved solids and manganese and is moderately hard (table 2). Water from Swan Lake and Swan River contains appreciable amounts of iron. The river water is highly colored and, at times, contains appreciable amounts of manganese.

KEEWATIN

Population: 1,651

The village of Keewatin is 2 miles southeast of the crest of the Giants Range (pl. 1). This area includes the divide separating drainage to the Mississippi River and to the St. Lawrence River. The eastern one-third drains to Lake Superior by way of West Swan River and the western two-thirds to the Mississippi River by way of Hay and Welcome Creeks.

The glacial drift that mantles the area ranges in thickness from about 20 feet in the northwest to more than 200 feet in the south and east. The underlying bedrock consists of Giants Range Granite, Pokegama Quartzite, Biwabik Iron-Formation, and Virginia Argillite. The argillite underlies the southeastern two-thirds of the Keewatin map area, and the iron-formation underlies most of the remaining one-third (pl. 1). Keewatin is on the contact of the Biwabik and the Virginia Argillite and obtains its water supply from the Biwabik Iron-Formation.

PRESENT WATER SUPPLY

Source of information: A. J. Boudreau, utilities superintendent; village records.
Ownership of water supply: Municipal.
Number of customers: Approximately 600 (1960).
Average consumption: 190,000 gpd (1960).
Storage: Ground level reservoir, 80,000 gal.; elevated steel tank, 100,000 gal.
Treatment: None.
Source of supply: Two wells.

Well location 57.22.24dcdl. At southeast side of Carlz 2 open-pit mine; drilled in 1951 and deepened in 1958; 10 inches in diameter; 490 feet deep. Cased to 220 feet: bottom 30 feet of casing slotted; has a 300 gpm turbine pump. Water obtained from Biwabik Iron-Formation. Has been pumped at 500 gpm for 24 hours. Static water level 279 feet below land surface.

Well location 57.22.25abdl. At First Avenue and Second Street; this auxiliary well drilled in 1952; 13 inches in diameter; drilled through bottom of a 6- by 6-foot concrete shaft 211 feet deep to a total depth of 600 feet. Cased to 220 feet; is not screened; has a 500 gpm turbine pump. Water obtained from Biwabik Iron-Formation. When pumped at 490 gpm for 4½ hours, water level lowered 55 feet below static water level of 174 feet.

Quality of water.—The water has a low content of dissolved-solids and silica (table 3). It is hard and contains iron and manganese in excess of the recommended maximums for drinking water.

POTENTIAL WATER SUPPLY

PRESENT GROUND-WATER SOURCE

Keewatin's main well, 57.22.24dcdl, is open in the upper cherty, lower slaty, and lower cherty members of the Biwabik Iron-Formation, and auxiliary well 57.22.25abdl is open in all four members. According to White (1954, pl. 1), the upper and lower cherty members at Keewatin are oxidized cherty taconite. Pumping the auxiliary well at 490 gpm for 4½ hours showed a specific capacity of 9 gpm per foot of drawdown. Two 240-foot-deep mine-drainage wells, 57.22.24adal and 2, at the Bennett mine, have been individually pumped at their maximum capacities of 700 and 830 gpm. They produced considerably less, however, when pumped simultaneously. A 215-foot drainage shaft, 57.22.23ddcl, at the Sargent mine has been pumped at 450 gpm.

TABLE 3.—*Chemical analyses, in parts per million, of water in the Keewatin vicinity*

[Analyses for 57.21.22.cbb1 by Great Northern Railway; all others by U.S. Geol. Survey]

	Present water supply		Potential water supply	
	Ground water		Ground water	Surface water
Water source	Biwabik Iron-Formation	Biwabik Iron-Formation	Glacial drift	Welcome Creek
Location	57.22.25 abdl	57.22.24 dcd1	57.21.22 cbb1	
Silica (SiO_2)	10	9.1	18	23
Iron (Fe)	.35	.19	0.4	1.1
Manganese (Mn)	.52	.17	----------	.38
Calcium (Ca)	49	43	----------	37
Magnesium (Mg)	15	14	----------	19
Sodium (Na)	8.1	6.3	(1)	5.6
Potassium (K)	1.7	1.3		2.8
Bicarbonate (HCO_3)	230	205	----------	136
Sulfate (SO_4)	9.0	3.8	74.0	63
Chloride (Cl)	2.0	1.5	13.7	2.2
Fluoride (F)	.2	.2	----------	.0
Nitrate (NO_3)	.3	.6	----------	.0
Boron (B)	.08	.08	----------	.02
Dissolved solids	202	177	250	233
Hardness as $CaCO_3$	186	166	180	169
Noncarbonate hardness as $CaCO_3$	0	0	32	57
Alkalinity as $CaCO_3$	189	168	147	112
Specific conductance (micromhos at 25° C.)	372	328	----------	348
pH	7.4	7.3	----------	7.5
Color (units)	0	0	----------	45
Turbidity as SiO_2	2	5	----------	----------
Temperature (°F)	----------	43	----------	----------
Date of collection	Sept. 26, 1957		----------	Sept. 28, 1962

[1] Alkali salts, 70 ppm.

Northeast from Keewatin the limits of the Biwabik Iron-Formation widen to about 2 miles. Thus, a large area of the iron-formation is in contact with, and receives recharge through, the overlying glacial drift. However, the Biwabik is being mined extensively in this area and is trenched by several large open pits. Dewatering of these pits intercepts part of the ground water moving through the formation and lowers the water table in the immediate vicinity of the mines. Altered parts of the Biwabik can yield large quantities of water in this area, but wells near active mines must be deep to overcome the influence of mine drainage.

OTHER WATER SOURCES

GROUND WATER

Area 1 is probably the best potential source of ground water from the glacial drift within the Keewatin map area (pl. 1). It contains thick glacial outwash deposits, which range in grain size from silt to coarse sand and gravel (section *A–A′*, pl. 1). The principal sand and gravel deposit ranges from about 40 to 110 feet in thickness.

Pumping data on three shallow wells at Kelly Lake indicate this sand and gravel can support wells that have specific capacities of 12–15 gpm per foot of drawdown (see table as follows).

Pumpage data on four Great Northern Railway wells at Kelly Lake

Location	Depth (feet)	Diameter (inches)	Static water level (feet below land surface)	Pumping rate (gpm)	Period of pumping (hours)	Total drawdown (feet)	Specific capacity (gpm per foot of drawdown)
57.21.15ccc1	65	6	10	18	8	1.5	12
15ccc2	139	6	12	20	------	113	0.2
22cba1	65	6	18	15	------	1.1	15
22cbb1	63	12	12	260	1	23	11
				300	1	25	12
				350	4	29	12

Well 57.21.15 ccc2 is cased through the upper sand and gravel and is finished in sand and gravel from 135 to 139 feet. The specific capacity of this deep well is much lower than those of the other three. However, this lower aquifer is artesian owing to a clayey till and silt separating the two aquifers, and the specific capacity cannot be compared to those of the water-table wells.

An estimate shows that the thickness of the saturated part of the sand and gravel layer averages about 40 feet and may be as much as 75 feet (section *A–A′*, pl. 1). Assuming a specific capacity of 12 gpm per foot of drawdown, it is probable that wells yielding more than 500 gpm could be developed in the aquifer.

The regional direction of ground-water flow is to the south; thus, precipitation in and north of area 1 and south of the crest of the Giants range is potential recharge to the drift in area 1. Only one open-pit mine is located northwest of area 1, but to the north and northeast there are several large mines. These pits are active and intercept some lateral ground-water flow from the glacial drift. However, if the upper sand and gravel aquifer extends to the northwest, it will receive substantial recharge from precipitation in that area. For a description of the eastward extension of area 1, see Hibbing, area 2.

Except for the four test holes from 57.21.30cbb2 to 57.21.30add3 (section *B–B′*, pl. 1), the test holes in the southern half of the area that is mapped penetrate much till and very little stratified drift. Area 2 is based on these four test holes, which contain as much as 53 feet of sand and gravel. This stratified drift is probably outwash from glacial drainage through a gap in the Giants Range about 2 miles northeast of the Keewatin map area in sec. 5, T. 57 N., R. 21 W. The boundaries of area 2 are approximate because the drainageway cannot be defined in the topography and few test holes are available. The sand and gravel may extend east of area 2 (section *B–B′*, pl. 1).

The recharge area is bounded on the north by the Giants Range. Most of the open-pit mines northwest of the area are inactive and do not affect ground-water movement southward.

Quality of water.—The analysis for well 57.21.22cbb1 shown in table 3 is for the water in the upper aquifer of area 1. It has an above average content of sulfate and chloride and is hard. See Hibbing, area 2 for additional data on quality of water in the eastward extension of area. 1.

SURFACE WATER

Some surface water is available from Welcome Creek at the east edge of Keewatin. There is no gaging station on this stream, and, as at Nashwauk, the nearest gaging station is on the Swan River near Warba. Shown on the east edge of the Keewatin map is the West Swan River, which rises in Kelly Lake. No flow data are available.

FLOW DATA

From two measurements made on O'Brien Creek on November 10, 1955, one above Welcome Creek and one below (pl. 1), the flow of Welcome Creek was determined to be 17.1 cfs at the entrance to O'Brien Lake. Correlating this flow with the Swan River flow near Warba and allowing for the reduction in drainage area between O'Brien Lake and Keewatin, an estimate of the available flow at Keewatin could be made.

See Nashwauk for Swan River near Warba data.

Quality of water.—The single surface-water analysis given in table 3 represents the quality of the water in Welcome Creek during a period of low flow (2.8 cfs). It indicates that the water is hard, is considerably colored, and contains much iron and manganese. For most streams the chemical quality of the water improves as flow increases; therefore, the average quality of the water in the stream probably is somewhat better than that represented by the analysis.

For data on O'Brien Lake and Swan River near Warba, see table 2.

HIBBING

Population: 17,731

The village of Hibbing is the largest municipality on the Mesabi Iron Range. It is about 4 miles south of the Laurentian Divide. Several small creeks drain the area to the south into the East Swan and West Swan Rivers, through the St. Louis River, the Great Lakes, and into the St. Lawrence River (pl. 1).

Most of the area is underlain by Virginia Argillite; the Biwabik Iron-Formation underlies only the northernmost part. In places the combined thickness of the overlying glacial drift and Cretaceous rocks are as much as 200 feet. The village obtains its water supply from 12 wells completed in the glacial drift and 1 in the iron-formation.

PRESENT WATER SUPPLY

Source of information: A H. Hanson, former public utilities superintendent: Roy Ingels, former public utilities superintendent; A. M. Selvo, public utilities superintendent; W.T. Mattson, public utilities chemist; 1959 annual report of the public utilities commission.

Ownership of water supply: Municipal and private.

Number of customers: 5,362 (1959). Also supplies Kelly Lake, Kerr Location, Leetonia, and Redore.

Average consumption: 1,650,000 gpd (1959).

Storage: Collecting reservoir, 1 million gal; concrete reservoir, 3 million gal. Three elevated steel tanks, two of 300,000 gal and one of 50,000 gal.

Treatment: Chlorination of water from Scranton mine well (57.21.12aba1).

Source of supply: Thirteen wells as described in table 4.

Quality of water.—The chemical quality of the water from the 13 wells differs considerably (table 5). The dissolved-solids content ranged from 145 to 477 ppm. The best quality water is from the Scranton mine well, 57.21.12aba1; the only well that produces from the Biwabik Iron-Formation. Water from this well has a low content of dissolved solids, iron, and manganese, but it is hard and moderately siliceous. The quality of water from well 56.20.7bbb2 is typical of the quality of water from wells that tap glacial drift. It is very hard, siliceous, and generally has much iron and manganese.

TABLE 1.—*Statistics on wells used for the Hibbing municipal water supply (1961)*

[All wells drilled]

Location	Village well	Year drilled [1]	Depth (feet below land surface)	Diameter (inches)	Screen diameter (inches)	Screen setting (feet below land surface)	Aquifer	Static water level (feet below land surface)	Pump type and capacity	Yield	Location
56.20.6bbb1	7	1915 (1959)	122	12	12	Between 93 and 122.	Glacial sand and gravel.	42	Submersible; 400 gpm.	425 gpm	Town Line Road and First Avenue South.
7bbb2	1B	1954 (1961)	116	16	16	Between 88 and 116.	do	30	Turbine; 600 gpm.	600 gpm	1.2 miles south of Town Line Road on First Avenue South.
7bbc1	2A	1926 (1960)	100	14	14	Between 72 and 100.	do	30	do	500 gpm	Do.
56.21.1aab4	3A	1934 (1961)	148	16	16		do	31	Turbine; 1,000 gpm.	750 gpm with a 23-foot drawdown.	Town Line Road and First Avenue South.
1aab7	9A	1944	182	16	16	Between 155 and 182.	do	29	Turbine; 400 gpm.	375 gpm for 24 hours	Do.
57.20.31bba2	8A	1944 (1961)	135	16	16	Between 105 and 185.	do	13	Turbine; 700 gpm.	850 gpm for 8 hours	Lindquist Road and First Avenue South
31bbb5	11B	1956	96	12	10	Between 56 and 96.	Glacial sand	15	Submersible; 400 gpm.	450 gpm for 5 hours with a 68-foot drawdown.	Do.
31dcc1	12	1923 (1959)	137	12	12	Between 99 and 137.	Glacial sand and gravel.	20	do	450 gpm	0.6 mile east of First Avenue South on Town Line Road.
31dcc2	12A	1954	120	16	16	Between 90 and 120.	do	20	Turbine; 200 gpm.	200 gpm	Do.
57.21.12aba1	Scranton	1953	[2] 291	24	16	Between 189 and 291.	Biwabik Iron-Formation.	Varies with mine pumpage.	Turbine; 500 gpm.	450 gpm	In the Scranton open-pit mine.
13dcd2	14	1956	120	12	12	Between 99 and 120.	Glacial sand and gravel.	59	Turbine; 600 gpm.	615 gpm for 9 hours with a 31-foot drawdown.	31st Street and Fifth Avenue West.
Auxiliary wells											
57.20.4bbc2	15	1957	150	16	16	Between 122 and 150.	Glacial sand and gravel.	34	Submersible; 150 gpm.	290 gpm for 5 days with an 86-foot drawdown.	East end of First Street in Kitzville.
7ccc2	13	1956	108	14	14	Between 87 and 108.	do	34	Turbine; 1,000 gpm.	1,000 gpm for 24 hours with a 32-foot drawdown.	First Avenue and 18th Street.

[1] The year in parenthesis is the year in which the well was reconditioned.
[2] The bottom of the well is approximately 540 ft below original land surface.

The water used by Hibbing is a blend of water from many wells. Therefore the quality depends on the proportion of water that comes from each of the wells, and it is between that from the Scranton mine well and that from well 56.20.7bbb2.

POTENTIAL WATER SUPPLY

PRESENT GROUND-WATER SOURCE

The Hibbing supply is obtained from 10 wells completed in glacial drift, 1 in the Biwabik Iron-Formation and 2 auxiliary wells completed in glacial drift. They can be grouped into those in the south well field and those within the village limits.

Many test holes have been drilled in the Hibbing area by the village and by the Geological Survey. These test holes and the topography indicate three areas that have good potential for the development of ground water from a considerable thickness of permeable sand and gravel (pl. 1).

Area 1 includes the south well field, which now supplies most of the water to the village from nine wells. It is divided into 1 and 1A on the basis of quality of water. The shape of the northern part of area 1 is based on test-drilling data. The southwest border of the area is a ridge of ice-contact deposits, and the southeast border is the margin of a glacial lake. The principal aquifer is sand and gravel immediately underlying the gray bouldery till (section *B–B′*, pl. 1). The specific capacities of wells in area 1 range from 4 to 33 gpm per foot of drawdown, but the wells in the south part have the highest specific capacities (table 6).

Regional movement of the water in this area is to the southeast and static water levels range from 5 to 43 feet below the land surface. Area 1 has the best recharge potential of the three areas because it can be recharged from a larger area. Recharge to the stratified drift in area 1 is by infiltration of precipitation through the overlying glacial deposits and by ground-water movement down-gradient from the north. Records of observation well 57.20.31dbc1 show that the water level rises rapidly following periods of heavy rainfall, which indicates that the stratified drift is recharged rapidly.

Area 1 is the best area for the development of ground water from glacial drift in the vicinity of Hibbing. Most of the wells within area 1 are pumped at a rate of more than 400 gpm, and the quality of water is generally good.

Area 2 is drawn to include test holes that penetrate thick sections of sand and gravel (sections *A–A′* and *B–B′*, pl. 1). Of the three municipal wells that lie within the area, two are finished in drift and the other is in the Biwabik Iron-Formation. The drift wells 57.20.7ccc2 and 57.21.13dcd2 have high specific capacities (table 6).

TABLE 5.—*Chemical analyses, in parts per million, of public water supply at Hibbing*

[Analyses of samples: 56.20.6bbb1 by Hibbing Health Dept.; 57.20.7ccc2 by Minnesota Dept. of Health; all others by U.S. Geol. Survey]

Water source	Finished	Glacial drift											Biwabik Iron-Formation	Glacial drift
Location		56.20.6bbb1	56.20.7bbb2	56.20.7bbc1	56.21.1aab4	56.21.1abb7	57.20.4bbc2	57.20.7ccc2	57.20.31bba2	57.20.31bbb5	57.20.31dcc1	57.20.31dcc2	57.21.12aba1	57.21.13dcd2
Silica (SiO_2)	15	----------	25	25	24	25	21	----------	22	18	23	23	13	18
Iron (Fe)	.08	----------	1.4	1.2	1.1	1.1	5.6	10.0	.75	3.3	.14	.33	.17	2.7
Manganese (Mn)	.01	0.15	.21	.37	.09	.10	1.8	4.2	.20	1.7	.20	.13	.00	.25
Calcium (Ca)	28	----------	41	52	40	42	90	----------	58	38	46	46	26	73
Magnesium (Mg)	15	----------	20	23	18	19	48	----------	28	16	21	22	14	28
Sodium (Na)	5.6	----------	5.4	5.6	5.5	5.1	8.5	----------	7.4	4.3	7.2	5.7	4.7	6.8
Potassium (K)	.6	----------	1.4	1.7	1.2	1.6	1.8	----------	1.9	2.0	1.2	1.2	1.0	1.6
Bicarbonate (HCO_3)	140	208	218	234	218	224	413	341	276	158	232	220	128	331
Sulfate (SO_4)	19	10	20	41	7.5	15	79	88	49	35	24	38	23	19
Chloride (Cl)	8.0	2.0	.0	.0	.0	.0	9.5	11	2.0	2.5	.0	.3	7.5	11
Fluoride (F)	.1	----------	.1	.1	.1	.1	.2	.07	.1	.2	.1	.1	.1	.2
Nitrate (NO_3)	.7	----------	.8	1.1	.5	.7	.2	4	.9	.2	.3	.3	.2	.2
Boron (B)	----------	----------	.03	.05	.03	.04	.11	----------	.03	.04	.05	.03	.05	.02
Dissolved solids	168	----------	211	264	196	216	477	----------	306	210	228	244	145	334
Hardness as $CaCO_3$	132	160	186	224	172	185	420	400	259	160	200	206	124	296
Noncarbonate hardness as $CaCO_3$	17	0	7	32	0	1	81	120	33	30	10	26	19	25
Alkalinity as $CaCO_3$	115	170	179	192	179	184	339	280	226	130	190	180	105	271
Specific conductance at 25°C (micromhos at 25°C)	274	----------	361	430	336	360	758	----------	499	327	387	398	258	557
pH	7.0	7.4	7.8	7.6	7.6	7.7	7.4	7.0	7.5	7.2	7.8	7.7	7.4	7.7
Color (units)	2	4.0	2	3	3	2	5	----------	3	10	4	2	2	5
Turbidity as SiO_2	.8	1.0	.7	.7	1	2	30	----------	1	20	.6	.5	.8	9
Temperature (°F)	45	----------	----------	----------	----------	----------	44	----------	----------	45	----------	----------	----------	43
Date of collection	May 3, 1951 [1]	Oct. 1, 1943	Jan. 31, 1957	Jan. 31, 1957	Jan. 31, 1957	Jan. 31, 1957	June 13, 1958	May 7, 1956	Jan. 31, 1957	June 13, 1958	Jan. 31, 1957	Jan. 31, 1957	Dec. 27, 1956	June 12, 1958

[1] Composite sample of water from eight wells.

TABLE 6.—*Specific capacities of test holes and wells in the Hibbing vicinity*

Designation	Location	Pumping rate (gpm)	Period of pumping (hours)	Specific capacity (gpm per foot of drawdown)
Well 7	56.20.6bbb1	425		5
1A [1]	7bbb1	700		16
2A	7bbc1	500		25
3A	56.21.1aab4	750		33
9 [1]	1aab6	546	23	8
9A	1aab7	560	25	8
15	57.20.4bbc2	290	120	3
Emmert well (abandoned Great Northern Railway well).	5dad1	40		.5
Test hole 2	7ccc1	492	16	14
Well 13	7ccc2	1,000	24	31
Test hole 10	20ccc1	80	5	2
Well 8A	31bba2	450	24	7
8 [1]	31bba3	840	23	23
11B	31bbb5	450	5	9
4 [1]	31dbc1	300		6
12	31dcc1	450		4
Test hole 7A	57.21.13aab1	90	3	1
1	13dcd1	100	12	4
Well 14	13dcd2	615	9	20
2	36ddd1	199	2	4

[1] Not in use.

The regional piezometric surface slopes toward the south, but within area 2 the gradient may be reversed. On section *B–B′*, the ground-water divide is between areas 1 and 2, and movement is northward. Locally, near the open-pit mines, the ground-water movement is toward the pits. Therefore, recharge to aquifers within area 2 is only from local precipitation.

Area 2 is within and adjacent to the village; it contains thick sections of permeable sand and gravel. Although wells in area 2 can be pumped at rates at least equal to those in areas 1, the potential recharge is less, and, the quality of water is inferior.

Keewatin, area 1 is the westward continuation of area 2.

Village well 15, 57.20.4bbc2, taps the lower of two sand and gravel sections. (See 4bbcl on section *B–B′* pl. 1.) The logs of this well and of test hole 57.20.4bdb1, one-fourth of a mile to the southeast, show only thin sections of sand and gravel. Because of this lack of permeable drift and low specific capacity of well 15, the northeastern part of the Hibbing map area is not considered a good ground-water source.

Hibbing obtains part of its water from well 57.21.12aba1 in the lower slaty and lower cherty members of the Biwabik Iron-Formation in the Scranton mine. Two other wells penetrating the Biwabik Iron-

Formation in the vicinity of Hibbing yield less than 1 gpm per foot of drawdown. Further, water levels are depressed by mine drainage, and wells in or near pits obtain water only from the lower part of the formation. Recharge is restricted by more than 200 feet of drift overlying the Biwabik. The water level in observation well 57.20.5dad1, which penetrates the Biwabik Iron-Formation, rises very little in response to periods of heavy rainfall as compared to the rise common in glacial drift aquifers.

Quality of water.—The chemical quality of potential supplies is indicated by analyses in tables 5 and 7. Water from area 1 ranges from 196 to 306 ppm in dissolved solids, from 160 to 259 ppm in hardness, from 0.14 to 3.3 ppm in iron, and from 0.09 to 1.7 ppm in manganese. The concentrations of these constituents and the hardness of the water generally are less in area 1A than in the rest of area 1.

The quality of water from wells within area 2 is more variable and is generally more mineralized than that from area 1; dissolved solids range from 171 to 477 ppm; hardness, from 103 to 420 ppm; iron, from 0.0 to 10 ppm; and manganese, from 0.0 to 4.2.

A wide variance in the quality of the water from shallow and deep outwash bodies at the same location is shown by chemical analyses from village well 15. The upper section has a water quality similar to water from area 2, and the lower section, in which the well is completed, has a water quality similar to that of area 1.

Water from Biwabik near Hibbing, as indicated by analyses for wells 57.20.5dad1, 57.21.12aba1, and 13aab1, is better in quality than water from the drift. It is softer and has less iron and manganese. For potential supplies, therefore, the water of best quality is from the drift in area 1A or from the Biwabik.

OTHER WATER SOURCES

GROUND WATER

Test drilling in area 3 penetrated buried sand and gravel deposits that are generally thin or silty and poorly sorted. Test hole 57.20.20ccc1 has a specific capacity of 2 (table 6).

Water levels in wells in area 3 are commonly within 20 feet of the land surface, and ground-water movement is south through the area. The potential for development of large-capacity wells within area 3 is lower than in areas 1 and 2.

Quality of water.—The analysis of water from test hole 57.20.20ccc1 (table 7) indicates that the quality of water from area 3 is similar to that from area 2.

TABLE 7.—*Chemical analyses, in parts per million, of water from test holes and wells in the Hibbing vicinity*

[Analyses of samples: 56.20.7bbb1 and 57.21.24abb3 by U.S. Geol. Survey; 57.20.5dad1 by Great Northern Railway; 57.20.31dbc1 by Minnesota Dept. of Health; all others by Hibbing Health Dept.]

Location	56.20.7bbb1	57.20.4bbc2	57.20.5dad1	57.20.20ccc1	57.20.31dbc1	57.21.13aab1	57.21.24abb3	57.21.36ddd1
Designation	Abandoned well 1A	Village well 15	Abandoned Great Northern Railway well	Test hole 10	Abandoned well 4	Test hole 7A	Unused well 16	Abandoned well 2
Area	1			3	1A	2	2	1
Depth (feet)	101	150	430	247	92	660	150	115
Aquifer	Sand and gravel from 67 to 100 ft.	Sand and gravel from 55 to 75 ft.[1]	Biwabik Iron-Formation from 375 to 430 ft.	Sand and gravel from 70 to 90 ft.	Sand and gravel from 82 to 92 ft.	Biwabik Iron-Formation from 417 to 660 ft.	Sand and gravel from 55 to 93 ft.	Sand and gravel from 60 to 113 ft.
Silica (SiO_2)	25		8.0				18	
Iron (Fe)	1.0	12.0	0	.47	Trace	.34	2.1	0.7
Manganese (Mn)	.25	2.0		.58	.10	.00	.72	1.2
Calcium (Ca)	45		30				74	
Magnesium (Mg)	20		27				27	
Sodium (Na)	7.2						6.5	
Potassium (K)	1.6						1.6	
Bicarbonate (HCO_3)	240						333	
Sulfate (SO_4)	14					12	23	55
Chloride (Cl)	.0		10			1.5	7.5	1.0
Fluoride (F)	.1						.2	
Nitrate (NO_3)	.3						.2	
Boron (B)	.04						.02	
Dissolved solids	230		171				329	
Hardness as $CaCO_3$	194	384	147	226	168	103	294	216
Noncarbonate hardness as $CaCO_3$		104					21	
Alkalinity as $CaCO_3$	197		66		132		273	135
Specific conductance (micromhos at 25° C)	380						549	
pH	7.7	6.68		7.6	7.5		7.6	7.6
Color (units)	2				5.0		5	25
Turbidity as SiO_2	1				.6		.8	6.0
Temperature (°F)							44	
Date of collection	Jan. 31, 1957	Mar. 18, 1957		Mar. 22, 1957	Oct. 1, 1943		June 13, 1958	Oct. 1, 1943

[1] Well not completed in this aquifer. See table 4.

SURFACE WATER

Because Hibbing is close to the Laurentian Divide, the streams in the vicinity have small drainage areas that have corresponding low discharges. There is no record of any stream within a reasonable distance capable of furnishing an adequate water supply for municipal or industrial use.

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WATER RESOURCES IN THE VICINITY OF MUNICIPALITIES ON THE WEST-CENTRAL MESABI IRON RANGE, NORTHEASTERN MINNESOTA

By R. D. Cotter, H. L. Young, L. R. Petri, and C. H. Prior

ABSTRACT

Additional supplies of water are available near the municipalities on the west-central Mesabi Iron Range. The largest sources are the ground-water aquifers in the Biwabik Iron-Formation and the stratified glacial drift. Areas of stratified drift that probably have good water potential have been outlined. Surface-water supplies are negligible in the eastern part of this area but increase toward the west. Flow records from one gaging station, results of discharge measurements at two miscellaneous sites, and data from many wells and test holes are presented.

Most of the ground water is hard and has a high concentration of iron and manganese. The surface water generally has a high concentration of iron and is colored. Analyses of water from many sources are shown.

INTRODUCTION

This report describes existing and potential water supplies on the west-central Mesabi Iron Range.

Increased supplies of water are needed for expansion and diversification of the economy of the iron ranges. Specifically, supplies are needed for taconite processing, wood and peat processing, and municipal expansion. This investigation made in cooperation with the Minnesota Department of Iron Range Resources and Rehabilitation indicates that in some areas large quantities of water are available from both ground and surface sources.

The most productive aquifers are the Biwabik Iron-Formation and the stratified glacial drift. Bodies of stratified drift, believed by the authors to be potential sources for large ground-water supplies, are outlined as numbered areas. Their boundaries are drawn on the basis of topography, geologic mapping, test drilling, and test pumping. The accuracy of the assessment of the ground-water supplies in each numbered area is proportional to the subsurface control.

Where adequate pumpage data is available, specific capacities of wells are noted. Multiplying the specific capacity by the maximum allowable drawdown will give the short-term maximum yield of a well Specific capacities decrease with an increase in time and pumping rate. Specific capacities of wells completed in artesian aquifers should not be compared with those of wells completed in water-table aquifers, because, in otherwise identical aquifers, the value obtained for a well in the artesian aquifer would be much lower.

The geologic sections in this report are based on the indicated test-hole information and open-pit mine exposures. Identification of glacial deposits from drill cuttings and correlation of deposits between test holes is tenuous. However, the sections show the sequence and general lithology that probably would be penetrated in a drill hole along the line of section.

The surface-water supplies that are present on the west central Mesabi Iron Range are negligible in the eastern part, but increase toward the west. Fairly large supplies are available in the streams and lakes in the upper basin of the Swan River. Flow records at one gaging station and discharge measurements at two sites are presented.

The quality of ground and surface water is adequate for many industrial uses. Ground water commonly has a high concentration of iron and manganese and is hard. Surface water commonly has a high concentration of iron and is colored. Analyses of water from many sources are included. Where no analyses have been made, tables 7 and 8 in Cotter and others (1965) can be used to approximate the quality of a potential supply.

NUMBERING SYSTEM

Identification numbers assigned to wells, test holes, or specific locations in this report also serve as location numbers. The system of numbering is based on the U.S. Bureau of Land Management's system of subdivision of the public lands. Figure 1 illustrates the method of numbering. The number 57.18.8ddbl identifies the first well or test hole located in the NW¼SE¼SE¼ sec. 8, T. 57 N., R. 18 W. Where locations are not accurate to within 10 acres, they are identified by using only the first two lowercase letters and no number suffix.

ACKNOWLEDGMENTS

The authors acknowledge the help of municipal officials and well drillers who contributed much of the basic data.

Mining companies in the area furnished maps and drill-hole logs and allowed examination of mine faces. W. A. Cummens, engineer of the Oliver Iron Mining Division of U.S. Steel Corp., was particularly

helpful in the ground-water phase of the investigation by furnishing current information on test drilling and other information on the hydrology of the area.

COOLEY AND NASHWAUK

The villages of Cooley and Nashwauk are about 2 miles southeast of the Giants Range as shown on the Cooley-Nashwauk map (pl. 1). The extreme northwestern corner of the area is drained by the Prairie River; the drainage in the rest of the area is south to the Swan River by way of Swan Lake, which is fed by O'Brien, Oxhide, and Pickerel Creeks.

The bedrock in the area consists of Ely Greenstone, Giants Range Granite, Pokegama Quartzite, Biwabik Iron-Formation, and Virginia Argillite. In the northwestern corner of the area is a 130-foot high ridge of Giants Range Granite. Over much of the northwest flank of the ridge, the granite is exposed or is very thinly covered with

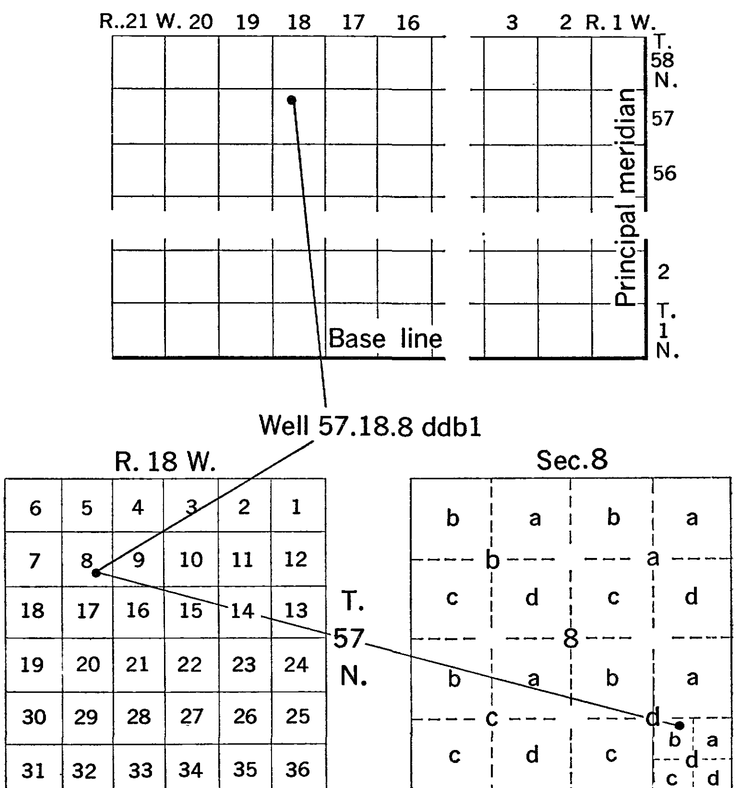

Figure 1.—Sketch showing method of numbering test holes and wells.

glacial drift. Southward from the Giants Range the glacial drift thickens from 25 to 50 feet along the north limit of the Biwabik to 100–150 feet along the south edge. In some areas, it is 200-feet thick.

Cooley obtains its water supply from a well that taps the Virginia Argillite and the Biwabik Iron-Formation. The Nashwauk well is in the Biwabik Iron-Formation.

COOLEY

Population: 87

PRESENT WATER SUPPLY

Source of information: Vic Lager, Butler Brothers master mechanic; Thiel (1947, p. 134).

Ownership of water supply: Butler Brothers, M. A. Hanna Co., Agent.

Number of customers: 36 (1960). Also supplies Nashwauk in emergencies by mutual connection.

Average consumption: 70,000 gpd (gallons per day) (estimated, 1960).

Storage: Elevated steel tank, 50,000 gal.

Treatment: None.

Source of supply: One well.

Well location 56.22.6cccl. At Harrison mine shops; drilled in 1932 and deepened in 1938; 12 inches in diameter; 537 feet deep. Cased to 162 feet; is not screened; has a 600 gpm (gallons per minute) turbine pump set at 310 gpm. Water obtained from Virginia and Biwabik Iron-Formation. Has been pumped at 330 gpm; has 84 feet of drawdown below the static water level of 215 feet.

Quality of water.—The water has a low dissolved-solids content, and the concentration of chemical constituents is far below the maximums of the drinking-water standards (U.S. Public Health Service, 1962). However, the water is hard and moderately siliceous (table 1).

POTENTIAL WATER SUPPLY

PRESENT GROUND-WATER SOURCE

The Cooley municipal well is open in the upper slaty and upper cherty members of the Biwabik Iron-Formation and the lower part of the Virginia Argillite. Most of the water is obtained from the upper cherty member, which was penetrated at 430 feet. A driller's log of the well shows that the material is decomposed taconite. The well has been pumped at 330 gpm and has a specific capacity of 4 gpm per foot of drawdown. A nearby mine-dewatering well, 56.22.6bcbl, about 290 feet deep is reported to draw down to 275 feet when pumped at 850 gpm (Thiel, 1947, p. 135). This well penetrates 75 feet of glacial drift above the Biwabik, is cased to 238 feet, and has 50 feet of screen.

The Virginia Argillite and the upper slaty member of the Biwabik probably act as confining beds that prevent the ground water in the

TABLE 1.—*Chemical analyses, in parts per million, of water in the Cooley vicinity*

[Analyses by U.S. Geol. Survey]

	Present water supply	Potential water supply
	Ground water	Surface water
Water Source	Biwabik Iron-Formation and Virginia Argillite	Pickerel Lake
Location	56.22.6ccc1	
Silica (SiO_2)	13	7.5
Iron (Fe)	.05	0.1
Manganese (Mn)	.00	.09
Calcium (Ca)	38	35
Magnesium (Mg)	11	11
Sodium (Na)	4.3	6.6
Potassium (K)	1.3	2.4
Bicarbonate (HCO_3)	176	139
Sulfate (SO_4)	2.0	26
Chloride (Cl)	1.0	5.0
Fluoride (F)	.2	.4
Nitrate (NO_3)	.4	.0
Boron (B)	.07	.07
Dissolved solids	152	165
Hardness as $CaCO_3$	139	134
Noncarbonate hardness as $CaCO_3$	0	20
Alkalinity as $CaCO_3$	144	114
Specific conductance (micromhos at 25°C)	279	291
pH	7.3	8.1
Color (units)	0	2
Turbidity as SiO_2	.3	
Date of collection	Sept. 26, 1957	Sept. 28, 1962

glacial drift from infiltrating into the upper cherty member in the vicinity of the Cooley well. Much of the potential recharge to the Biwabik west of Nashwauk is diverted by mine dewatering. However, wells in the Biwabik, such as the Cooley well, which pump water from a lower level than adjacent mine pumping can receive sufficient recharge by lateral movement to sustain moderate withdrawals.

Quality of Water.—Mixtures of water from the Virginia Argillite and from the upper parts of the Biwabik contain less dissolved solids, are softer, and have less iron and manganese than the average Biwabik water. (Cotter and others, 1965, table 7).

OTHER WATER SOURCES

GROUND WATER

Area 1 encloses two glacial drainageways that open into the north end of Swan Lake. About 40 feet of glacial drift overlying the iron-formation is exposed in a mine face in a northern extension of area 1, 0.5 mile northwest of Oxhide Lake. The drift in the interval from

773-579—65——2

10 to 25 feet below the land surface consists of stratified sand and gravel. Geologic section $A-A'$ (pl. 1) shows a thick body of stratified sand at the north end of Swan Lake. Coarser stratified drift may occur farther north.

Regional ground-water movement in area 1 is to the south, but local movement is to Oxhide and Pickerel Creeks and Oxhide and Pickerel Lakes. The drift is as much as 200 feet and most of this thickness is saturated (pl. 1). The west "arm," between Swan and Oxhide Lakes, is probably the most favorable part of area 1 for initiial ground-water exploration.

At the southeast end of Swan Lake, 2 miles south of the map area, test hole 55.22.5acal penetrated outwash to 181 feet. The outwash consisted of sand and silt to a depth of 116 feet and from 116 to 181 feet it was a very permeable sand and gravel. The outwash is probably an extension, through the length of Swan Lake, of the glacial drainageway in area 1.

The broad hilly area between Pickerel Lake and the southeast corner of the Cooley-Nashwauk map area (pl. 1) may be an area of ice-contact deposition. No test drilling has been done in the area, however, and an evaluation cannot be made of its ground-water potential. The area is crossed by the valley of O'Brien Creek which is described under Nashwauk in area 2.

SURFACE WATER

With the exception of a small potential supply from Pickerel and Oxhide Lakes, the available surface water supply is the same as for Nashwauk.

Quality of water.—The chemical quality of water from Pickerel Lake is indicated in table 1. The water has a low content of dissolved solids and iron and is only slightly colored, but it is hard and has a manganese content in excess of the recommended limit of 0.05 ppm (U.S. Public Health Service, 1962).

NASHWAUK

Population: 1,712

PRESENT WATER SUPPLY

Source of information: R. A. Loux, water and light superintendent.
Ownership of water supply: Municipal.
Number of customers: Approximately 600 (1960). Also supplies Cooley in emergencies by mutual connection.
Average consumption: 165,000 gpd (1960).
Storage: Elevated steel tank, 100,000 gal.
Treatment: Part-time polyphosphate stabilization; emergency chlorination facilities.

Source of supply: One well.

Well location 57.22.32cda1. At Fern Avenue and Fourth Street; drilled in 1948; 10 inches in diameter; 540 feet deep. Cased to 197 feet; is not screened; has a 450 gpm turbine pump. Water obtained from Biwabik Iron-Formation. Has been pumped at 650 gpm for 24 hours; static water level 127 feet below land surface.

Quality of water.—The water has a low dissolved-solids content; however, it is moderately siliceous, is hard, and contains much iron and manganese (table 2). Except for the iron and manganese content, water from this supply is similar in chemical quality to water from the Cooley supply.

TABLE 2.—*Chemical analyses, in parts per million, of water in the Nashwauk vicinity*

[Analyses by U.S. Geol. Survey]

	Present water supply	Potential water supply			
	Ground water	Surface water			
Water source / Location	Biwabik Iron-Formation (57.22.32 cda1)	O'Brien Lake	Swan Lake	Swan River near Warba[1] (Station 2170)	
				Average	Maximum
Silica (SiO_2)	11	2.3	2.3	8.8	16
Iron (Fe)	.89	.01	.30	.23	.32
Manganese (Mn)	.42	.00	.01	.04	.28
Calcium (Ca)	39	24	26	26	31
Magnesium (Mg)	12	8.3	8.3	8.0	10
Sodium (Na)	4.1	4.9	4.6	4.3	4.7
Potassium (K)	1.8	2.5	2.7	1.5	1.9
Bicarbonate (HCO_3)	185	98	104	109	134
Sulfate (SO_4)	2.0	17	21	17	24
Chloride (Cl)	1.0	4.3	1.2	.7	2.2
Fluoride (F)	.2	.3	.2	.2	.4
Nitrate (NO_3)	.6	2.2	.2	.8	1.3
Boron (B)	.05	.03	.05	.05	.06
Dissolved solids	161	123	135	144	156
Hardness as $CaCO_3$	148	94	99	101	120
Noncarbonate hardness as $CaCO_3$	0	14	14	12	15
Alkalinity as $CaCO_3$	150	80	85	89	110
Specific conductance (micromhos at 25°C)	296	215	211	209	243
pH	7.0	7.7	7.7	-------	7.5
Color (units)	0	3	14	55	95
Turbidity as SiO_2	3	-------	-------	-------	-------
Temperature (°F)	45	-------	-------	-------	-------
Date of collection	Sept. 26, 1957	Sept. 28, 1962	Sept. 28, 1962	9 analyses during 1955–62	

[1] Sampling site is 14 miles southwest of area shown on pl. 1.

POTENTIAL WATER SUPPLY

PRESENT GROUND-WATER SOURCE

The 540-foot village well, 57.22.32cda1, is open in the upper cherty, lower slaty, and lower cherty members of the Biwabik Iron-Formation. The lower slaty here is very thin, but the cherty members are thick and may be oxidized (White, 1954, pl. 1). The well has yielded 650 gpm for 24 hours. Two former village wells, 57.22.32bac1, and 2, were finished in the Biwabik and yielded about 100 gpm. They were 414 and 360 feet deep, respectively, and penetrated about 110 feet of glacial drift. A drainage shaft, 57.22.31da, in the Hawkins mine, is reported to have been pumped at 1,000 gpm. Another well in the Biwabik, 57.22.28caa1, is 215 feet deep and has a specific capacity of 1.3 gpm per foot of drawdown when pumped at 40 gpm. The iron-formation is mainly recharged by precipitation falling on the numerous open-pit mines. All the mines in the Cooley-Nashwauk map area northeast of Nashwauk are inactive and ground-water movement is not diverted by mine dewatering. Immediately west and southwest of the village, the mines are active and relatively deep; thus, some potential recharge to the Biwabik is diverted by mine drainage.

OTHER WATER SOURCES

GROUND WATER

Area 1, described under Cooley, and area 2 are areas of potential ground-water development from the glacial drift. Area 2 outlines a major glacial drainageway that is probably underlain by stratified drift. It is occupied by O'Brien Creek which flows in a deep, narrow valley and by O'Brien and Little O'Brien Lakes. The boundaries of area 2 are based on topography and surficial exposures. On the south side of U.S. Highway 169 at O'Brien Creek, 8 feet of sand and gravel is exposed below 8 feet of brown silty till. Along the west side of the Perry mine (in the extreme northeastern corner of the Cooley-Nashwauk map, pl. 1) there is a pronounced depression in the surface of the Biwabik Iron-Formation which is filled with at least 40 feet of sand and gravel. This coarse stratified drift may be a reflection of deposition along the drainageway. Local ground-water movement is into area 2 and southward parallel to O'Brien Creek.

The flat topography bordering the east side of Swan Lake south of area 2 is underlain by fine outwash (section *A–A′*, pl. 1). This material will probably provide only small quantities of water to individual wells.

West-northwest of Nashwauk, thin glacial drift overlies the bedrock in the area not occupied by open-pit mines. Examination of mine faces and well records indicates that the glacial drift is largely brown silty and gray bouldery tills and is a poor source of large ground-water supplies.

SURFACE WATER

A supply of water probably could be obtained from O'Brien Lake into which O'Brien and Welcome Creeks flow and from Swan Lake, which is headwaters of the Swan River. There are no gaging stations on these streams, the nearest being near Warba on the Swan River.

FLOW DATA

On November 10, 1955, a discharge measurement of 18.9 cfs (cubic feet per second) was made on O'Brien Creek above Swan Lake. At the same time the flow of the Swan River near Warba was 77 cfs, and the flow for the day was nearly constant.

SWAN RIVER NEAR WARBA, MINN.

Location.—Lat 47°06'40", long 93°15'50", in SE¼ sec. 33, T. 54 N., R. 23 W., on left bank 75 feet upstream from highway bridge, 1½ miles south of Warba, 3¾ miles northwest of Swan River, and 22 miles upstream from mouth.

Drainage area.—254 square miles.

Records available.—October 1953 to September 1960.

Average discharge.—7 years, 132 cfs.

Extremes: 1953–60.—Maximum discharge, 1,000 cfs April 13, 1954 (gage height, 9.02 ft, Apr. 13, 1954, backwater from ice); minimum discharge, 34 cfs, August 29, 30, 1956; minimum daily discharge, 34 cfs, August 29, 30, 1956.

Flood in May 1950 reached a stage of about 11.5 feet. This information obtained from local residents.

Flood frequency.—10-year flood, 480 cfs; 20-year flood, 585 cfs; 30-year flood, 690 cfs.

Low-flow frequency.—Annual 7-day minimum discharge: 2-year, 45 cfs; 10-year, 30 cfs; 20-year, 25 cfs.

Quality of water.—Water from O'Brien Lake, Swan Lake, and Swan River has a low content of dissolved solids and manganese and is moderately hard (table 2). Water from Swan Lake and Swan River contains appreciable amounts of iron. The river water is highly colored and, at times, contains appreciable amounts of manganese.

KEEWATIN

Population: 1,651

The village of Keewatin is 2 miles southeast of the crest of the Giants Range (pl. 1). This area includes the divide separating drainage to the Mississippi River and to the St. Lawrence River. The eastern one-third drains to Lake Superior by way of West Swan River and the western two-thirds to the Mississippi River by way of Hay and Welcome Creeks.

The glacial drift that mantles the area ranges in thickness from about 20 feet in the northwest to more than 200 feet in the south and east. The underlying bedrock consists of Giants Range Granite, Pokegama Quartzite, Biwabik Iron-Formation, and Virginia Argillite. The argillite underlies the southeastern two-thirds of the Keewatin map area, and the iron-formation underlies most of the remaining one-third (pl. 1). Keewatin is on the contact of the Biwabik and the Virginia Argillite and obtains its water supply from the Biwabik Iron-Formation.

PRESENT WATER SUPPLY

Source of information: A. J. Boudreau, utilities superintendent; village records.
Ownership of water supply: Municipal.
Number of customers: Approximately 600 (1960).
Average consumption: 190,000 gpd (1960).
Storage: Ground level reservoir, 80,000 gal.; elevated steel tank, 100,000 gal.
Treatment: None.
Source of supply: Two wells.

Well location 57.22.24dcdl. At southeast side of Carlz 2 open-pit mine; drilled in 1951 and deepened in 1958; 10 inches in diameter; 490 feet deep. Cased to 220 feet; bottom 30 feet of casing slotted; has a 300 gpm turbine pump. Water obtained from Biwabik Iron-Formation. Has been pumped at 500 gpm for 24 hours. Static water level 279 feet below land surface.

Well location 57.22.25abdl. At First Avenue and Second Street; this auxiliary well drilled in 1952; 13 inches in diameter; drilled through bottom of a 6- by 6-foot concrete shaft 211 feet deep to a total depth of 600 feet. Cased to 220 feet; is not screened; has a 500 gpm turbine pump. Water obtained from Biwabik Iron-Formation. When pumped at 490 gpm for 4½ hours, water level lowered 55 feet below static water level of 174 feet.

Quality of water.—The water has a low content of dissolved-solids and silica (table 3). It is hard and contains iron and manganese in excess of the recommended maximums for drinking water.

POTENTIAL WATER SUPPLY

PRESENT GROUND-WATER SOURCE

Keewatin's main well, 57.22.24dcdl, is open in the upper cherty, lower slaty, and lower cherty members of the Biwabik Iron-Formation, and auxiliary well 57.22.25abd1 is open in all four members. According to White (1954, pl. 1), the upper and lower cherty members at Keewatin are oxidized cherty taconite. Pumping the auxiliary well at 490 gpm for 4½ hours showed a specific capacity of 9 gpm per foot of drawdown. Two 240-foot-deep mine-drainage wells, 57.22.24adal and 2, at the Bennett mine, have been individually pumped at their maximum capacities of 700 and 830 gpm. They produced considerably less, however, when pumped simultaneously. A 215-foot drainage shaft, 57.22.23ddc1, at the Sargent mine has been pumped at 450 gpm.

TABLE 3.—*Chemical analyses, in parts per million, of water in the Keewatin vicinity*

[Analyses for 57.21.22.cbb1 by Great Northern Railway; all others by U.S. Geol. Survey]

	Present water supply		Potential water supply	
	Ground water		Ground water	Surface water
Water source	Biwabik Iron-Formation	Biwabik Iron-Formation	Glacial drift	Welcome Creek
Location	57.22.25 abd1	57.22.24 dcd1	57.21.22 cbb1	
Silica (SiO_2)	10	9.1	18	23
Iron (Fe)	.35	.19	0.4	1.1
Manganese (Mn)	.52	.17	----------	.38
Calcium (Ca)	49	43	----------	37
Magnesium (Mg)	15	14	----------	19
Sodium (Na)	8.1	6.3	(1)	5.6
Potassium (K)	1.7	1.3		2.8
Bicarbonate (HCO_3)	230	205	----------	136
Sulfate (SO_4)	9.0	3.8	74.0	63
Chloride (Cl)	2.0	1.5	13.7	2.2
Fluoride (F)	.2	.2	----------	.0
Nitrate (NO_3)	.3	.6	----------	.0
Boron (B)	.08	.08	----------	.02
Dissolved solids	202	177	250	233
Hardness as $CaCO_3$	186	166	180	169
Noncarbonate hardness as $CaCO_3$	0	0	32	57
Alkalinity as $CaCO_3$	189	168	147	112
Specific conductance (micromhos at 25° C.)	372	328	----------	348
pH	7.4	7.3	----------	7.5
Color (units)	0	0	----------	45
Turbidity as SiO_2	2	5	----------	----------
Temperature (°F)	----------	43	----------	----------
Date of collection	Sept. 26, 1957		----------	Sept. 28, 1962

[1] Alkali salts, 70 ppm.

Northeast from Keewatin the limits of the Biwabik Iron-Formation widen to about 2 miles. Thus, a large area of the iron-formation is in contact with, and receives recharge through, the overlying glacial drift. However, the Biwabik is being mined extensively in this area and is trenched by several large open pits. Dewatering of these pits intercepts part of the ground water moving through the formation and lowers the water table in the immediate vicinity of the mines. Altered parts of the Biwabik can yield large quantities of water in this area, but wells near active mines must be deep to overcome the influence of mine drainage.

OTHER WATER SOURCES

GROUND WATER

Area 1 is probably the best potential source of ground water from the glacial drift within the Keewatin map area (pl. 1). It contains thick glacial outwash deposits, which range in grain size from silt to coarse sand and gravel (section *A–A′*, pl. 1). The principal sand and gravel deposit ranges from about 40 to 110 feet in thickness.

Pumping data on three shallow wells at Kelly Lake indicate this sand and gravel can support wells that have specific capacities of 12–15 gpm per foot of drawdown (see table as follows).

Pumpage data on four Great Northern Railway wells at Kelly Lake

Location	Depth (feet)	Diameter (inches)	Static water level (feet below land surface)	Pumping rate (gpm)	Period of pumping (hours)	Total drawdown (feet)	Specific capacity (gpm per foot of drawdown)
57.21.15ccc1	65	6	10	18	8	1.5	12
15ccc2	139	6	12	20	------	113	0.2
22cba1	65	6	18	15	------	1.1	15
22cbb1	63	12	12	260	1	23	11
				300	1	25	12
				350	4	29	12

Well 57.21.15 ccc2 is cased through the upper sand and gravel and is finished in sand and gravel from 135 to 139 feet. The specific capacity of this deep well is much lower than those of the other three. However, this lower aquifer is artesian owing to a clayey till and silt separating the two aquifers, and the specific capacity cannot be compared to those of the water-table wells.

An estimate shows that the thickness of the saturated part of the sand and gravel layer averages about 40 feet and may be as much as 75 feet (section *A–A′*, pl. 1). Assuming a specific capacity of 12 gpm per foot of drawdown, it is probable that wells yielding more than 500 gpm could be developed in the aquifer.

The regional direction of ground-water flow is to the south; thus, precipitation in and north of area 1 and south of the crest of the Giants range is potential recharge to the drift in area 1. Only one open-pit mine is located northwest of area 1, but to the north and northeast there are several large mines. These pits are active and intercept some lateral ground-water flow from the glacial drift. However, if the upper sand and gravel aquifer extends to the northwest, it will receive substantial recharge from precipitation in that area. For a description of the eastward extension of area 1, see Hibbing, area 2.

Except for the four test holes from 57.21.30cbb2 to 57.21.30add3 (section *B–B′*, pl. 1), the test holes in the southern half of the area that is mapped penetrate much till and very little stratified drift. Area 2 is based on these four test holes, which contain as much as 53 feet of sand and gravel. This stratified drift is probably outwash from glacial drainage through a gap in the Giants Range about 2 miles northeast of the Keewatin map area in sec. 5, T. 57 N., R. 21 W. The boundaries of area 2 are approximate because the drainageway cannot be defined in the topography and few test holes are available. The sand and gravel may extend east of area 2 (section *B–B′*, pl. 1).

The recharge area is bounded on the north by the Giants Range. Most of the open-pit mines northwest of the area are inactive and do not affect ground-water movement southward.

Quality of water.—The analysis for well 57.21.22cbb1 shown in table 3 is for the water in the upper aquifer of area 1. It has an above average content of sulfate and chloride and is hard. See Hibbing, area 2 for additional data on quality of water in the eastward extension of area. 1.

SURFACE WATER

Some surface water is available from Welcome Creek at the east edge of Keewatin. There is no gaging station on this stream, and, as at Nashwauk, the nearest gaging station is on the Swan River near Warba. Shown on the east edge of the Keewatin map is the West Swan River, which rises in Kelly Lake. No flow data are available.

FLOW DATA

From two measurements made on O'Brien Creek on November 10, 1955, one above Welcome Creek and one below (pl. 1), the flow of Welcome Creek was determined to be 17.1 cfs at the entrance to O'Brien Lake. Correlating this flow with the Swan River flow near Warba and allowing for the reduction in drainage area between O'Brien Lake and Keewatin, an estimate of the available flow at Keewatin could be made.

See Nashwauk for Swan River near Warba data.

Quality of water.—The single surface-water analysis given in table 3 represents the quality of the water in Welcome Creek during a period of low flow (2.8 cfs). It indicates that the water is hard, is considerably colored, and contains much iron and manganese. For most streams the chemical quality of the water improves as flow increases; therefore, the average quality of the water in the stream probably is somewhat better than that represented by the analysis.

For data on O'Brien Lake and Swan River near Warba, see table 2.

HIBBING

Population: 17,731

The village of Hibbing is the largest municipality on the Mesabi Iron Range. It is about 4 miles south of the Laurentian Divide. Several small creeks drain the area to the south into the East Swan and West Swan Rivers, through the St. Louis River, the Great Lakes, and into the St. Lawrence River (pl. 1).

Most of the area is underlain by Virginia Argillite; the Biwabik Iron-Formation underlies only the northernmost part. In places the combined thickness of the overlying glacial drift and Cretaceous rocks are as much as 200 feet. The village obtains its water supply from 12 wells completed in the glacial drift and 1 in the iron-formation.

PRESENT WATER SUPPLY

Source of information: A H. Hanson, former public utilities superintendent: Roy Ingels, former public utilities superintendent; A. M. Selvo, public utilities superintendent; W.T. Mattson, public utilities chemist; 1959 annual report of the public utilities commission.

Ownership of water supply: Municipal and private.

Number of customers: 5,362 (1959). Also supplies Kelly Lake, Kerr Location, Leetonia, and Redore.

Average consumption: 1,650,000 gpd (1959).

Storage: Collecting reservoir, 1 million gal; concrete reservoir, 3 million gal. Three elevated steel tanks, two of 300,000 gal and one of 50,000 gal.

Treatment: Chlorination of water from Scranton mine well (57.21.12aba1).

Source of supply: Thirteen wells as described in table 4.

Quality of water.—The chemical quality of the water from the 13 wells differs considerably (table 5). The dissolved-solids content ranged from 145 to 477 ppm. The best quality water is from the Scranton mine well, 57.21.12aba1; the only well that produces from the Biwabik Iron-Formation. Water from this well has a low content of dissolved solids, iron, and manganese, but it is hard and moderately siliceous. The quality of water from well 56.20.7bbb2 is typical of the quality of water from wells that tap glacial drift. It is very hard, siliceous, and generally has much iron and manganese.

TABLE 1.—*Statistics on wells used for the Hibbing municipal water supply (1961)*

[All wells drilled]

Location	Village well	Year drilled[1]	Depth (feet below land surface)	Diameter (inches)	Screen diameter (inches)	Screen setting (feet below land surface)	Aquifer	Static water level (feet below land surface)	Pump type and capacity	Yield	Location
56.20.6bbb1	7	1915 (1959)	122	12	12	Between 93 and 122.	Glacial sand and gravel.	42	Submersible; 400 gpm.	425 gpm	Town Line Road and First Avenue South.
7bbb2	1B	1954 (1961)	116	16	16	Between 88 and 116.	do	30	Turbine; 600 gpm.	600 gpm	1.2 miles south of Town Line Road on First Avenue South.
7bbc1	2A	1926 (1960)	100	14	14	Between 72 and 100.	do	30	do	500 gpm	Do.
56.21.1aab4	3A	1934 (1961)	148	16	16		do	31	Turbine; 1,000 gpm.	750 gpm with a 23-foot drawdown.	Town Line Road and First Avenue South.
1aab7	9A	1944	182	16	16	Between 155 and 182.	do	29	Turbine; 400 gpm.	375 gpm for 24 hours	Do.
57.20.31bba2	8A	1944 (1961)	135	16	16	Between 105 and 185.	do	13	Turbine; 700 gpm.	850 gpm for 8 hours	Lindquist Road and First Avenue South
31bbb5	11B	1956	96	12	10	Between 56 and 96.	Glacial sand	15	Submersible; 400 gpm.	450 gpm for 5 hours with a 68-foot drawdown.	Do.
31dcc1	12	1923 (1959)	137	12	12	Between 99 and 137.	Glacial sand and gravel.	20	do	450 gpm	0.6 mile east of First Avenue South on Town Line Road.
31dcc2	12A	1954	120	16	16	Between 90 and 120.	do	20	Turbine; 200 gpm.	200 gpm	Do.
57.21.12aba1	Scranton	1953	[2] 291	24	16	Between 189 and 291.	Biwabik Iron-Formation.	Varies with mine pumpage.	Turbine; 500 gpm.	450 gpm	In the Scranton open-pit mine.
13dcd2	14	1956	120	12	12	Between 99 and 120.	Glacial sand and gravel.	59	Turbine; 600 gpm.	615 gpm for 9 hours with a 31-foot drawdown.	31st Street and Fifth Avenue West.
Auxiliary wells											
57.20.4bbc2	15	1957	150	16	16	Between 122 and 150.	Glacial sand and gravel.	34	Submersible; 150 gpm.	290 gpm for 5 days with an 86-foot drawdown.	East end of First Street in Kitzville.
7ccc2	13	1956	108	14	14	Between 87 and 108.	do	34	Turbine; 1,000 gpm.	1,000 gpm for 24 hours with a 32-foot drawdown.	First Avenue and 18th Street.

[1] The year in parenthesis is the year in which the well was reconditioned.
[2] The bottom of the well is approximately 540 ft below original land surface.

The water used by Hibbing is a blend of water from many wells. Therefore the quality depends on the proportion of water that comes from each of the wells, and it is between that from the Scranton mine well and that from well 56.20.7bbb2.

POTENTIAL WATER SUPPLY

PRESENT GROUND-WATER SOURCE

The Hibbing supply is obtained from 10 wells completed in glacial drift, 1 in the Biwabik Iron-Formation and 2 auxiliary wells completed in glacial drift. They can be grouped into those in the south well field and those within the village limits.

Many test holes have been drilled in the Hibbing area by the village and by the Geological Survey. These test holes and the topography indicate three areas that have good potential for the development of ground water from a considerable thickness of permeable sand and gravel (pl. 1).

Area 1 includes the south well field, which now supplies most of the water to the village from nine wells. It is divided into 1 and 1A on the basis of quality of water. The shape of the northern part of area 1 is based on test-drilling data. The southwest border of the area is a ridge of ice-contact deposits, and the southeast border is the margin of a glacial lake. The principal aquifer is sand and gravel immediately underlying the gray bouldery till (section *B–B′*, pl. 1). The specific capacities of wells in area 1 range from 4 to 33 gpm per foot of drawdown, but the wells in the south part have the highest specific capacities (table 6).

Regional movement of the water in this area is to the southeast and static water levels range from 5 to 43 feet below the land surface. Area 1 has the best recharge potential of the three areas because it can be recharged from a larger area. Recharge to the stratified drift in area 1 is by infiltration of precipitation through the overlying glacial deposits and by ground-water movement down-gradient from the north. Records of observation well 57.20.31dbc1 show that the water level rises rapidly following periods of heavy rainfall, which indicates that the stratified drift is recharged rapidly.

Area 1 is the best area for the development of ground water from glacial drift in the vicinity of Hibbing. Most of the wells within area 1 are pumped at a rate of more than 400 gpm, and the quality of water is generally good.

Area 2 is drawn to include test holes that penetrate thick sections of sand and gravel (sections *A–A′* and *B–B′*, pl. 1). Of the three municipal wells that lie within the area, two are finished in drift and the other is in the Biwabik Iron-Formation. The drift wells 57.20.7ccc2 and 57.21.13dcd2 have high specific capacities (table 6).

TABLE 5.—*Chemical analyses, in parts per million, of public water supply at Hibbing*

[Analyses of samples: 56.20.6bbb1 by Hibbing Health Dept.; 57.20.7ccc2 by Minnesota Dept. of Health; all others by U.S. Geol. Survey]

Water source	Finished	Glacial drift										Biwabik Iron-Formation	Glacial drift
Location		56.20. 6bbb1	56.20. 7bbb2	56.20. 7bbc1	56.21. 1aab4	56.21. 1abb7	57.20. 4bbc2	57.20. 7ccc2	57.20. 31bba2	57.20. 31bbb5	57.20. 31dcc1	57.20. 31dcc2	57.21. 12aba1	57.21. 13dcd2
Silica (SiO_2)	15	--------	25	25	24	25	21	--------	22	18	23	23	13	18
Iron (Fe)	.08	--------	1.4	1.2	1.1	1.1	5.6	10.0	.75	3.3	.14	.33	.17	2.7
Manganese (Mn)	.01	0.15	.21	.37	.09	.10	1.8	4.2	.20	1.7	.20	.13	.00	.25
Calcium (Ca)	28	--------	41	52	40	42	90	--------	58	38	46	46	26	73
Magnesium (Mg)	15	--------	20	23	18	19	48	--------	28	16	21	22	14	28
Sodium (Na)	5.6	--------	5.4	5.6	5.5	5.1	8.5	--------	7.4	4.3	7.2	5.7	4.7	6.8
Potassium (K)	.6	--------	1.4	1.7	1.2	1.6	1.8	--------	1.9	2.0	1.2	1.2	1.0	1.6
Bicarbonate (HCO_3)	140	208	218	234	218	224	413	341	276	158	232	220	128	331
Sulfate (SO_4)	19	10	20	41	7.5	15	79	88	49	35	24	38	23	19
Chloride (Cl)	8.0	2.0	.0	.0	.0	.0	9.5	11	2.0	2.5	.0	.3	7.5	11
Fluoride (F)	.1	--------	.1	.1	.1	.1	.2	.07	.1	.2	.1	.1	.1	.2
Nitrate (NO_3)	.7	--------	.8	1.1	.5	.7	.2	4	.9	.2	.3	.3	.2	.2
Boron (B)	--------	--------	.03	.05	.03	.04	.11	--------	.03	.04	.05	.03	.05	.02
Dissolved solids	168	--------	211	264	196	216	477	--------	306	210	228	244	145	334
Hardness as $CaCO_3$	132	160	186	224	172	185	420	400	259	160	200	206	124	296
Noncarbonate hardness as $CaCO_3$	17	0	7	32	0	1	81	120	33	30	10	26	19	25
Alkalinity as $CaCO_3$	115	170	179	192	179	184	339	280	226	130	190	180	105	271
Specific conductance at 25°C (micromhos at 25°C)	274	--------	361	430	336	360	758	--------	499	327	387	398	258	557
pH	7.0	7.4	7.8	7.6	7.6	7.7	7.4	7.0	7.5	7.2	7.8	7.7	7.4	7.7
Color (units)	2	4.0	2	3	3	2	5	--------	3	10	4	2	2	5
Turbidity as SiO_2	.8	1.0	.7	.7	1	2	30	--------	1	20	.6	.5	.8	9
Temperature (°F)	45	--------	--------	--------	--------	--------	44		--------	45	--------	--------	--------	43
Date of collection	May 3, 1951[1]	Oct. 1, 1943	Jan. 31, 1957	Jan. 31, 1957	Jan. 31, 1957	Jan. 31, 1957	June 13, 1958	May 7, 1956	Jan. 31, 1957	June 13, 1958	Jan. 31, 1957	Jan. 31, 1957	Dec. 27, 1956	June 12, 1958

[1] Composite sample of water from eight wells.

TABLE 6.—*Specific capacities of test holes and wells in the Hibbing vicinity*

Designation	Location	Pumping rate (gpm)	Period of pumping (hours)	Specific capacity (gpm per foot of drawdown)
Well 7	56.20.6bbb1	425		5
1A [1]	7bbb1	700		16
2A	7bbc1	500		25
3A	56.21.1aab4	750		33
9 [1]	1aab6	546	23	8
9A	1aab7	560	25	8
15	57.20.4bbc2	290	120	3
Emmert well (abandoned Great Northern Railway well).	5dad1	40		.5
Test hole 2	7ccc1	492	16	14
Well 13	7ccc2	1,000	24	31
Test hole 10	20ccc1	80	5	2
Well 8A	31bba2	450	24	7
8 [1]	31bba3	840	23	23
11B	31bbb5	450	5	9
4 [1]	31dbc1	300		6
12	31dcc1	450		4
Test hole 7A	57.21.13aab1	90	3	1
1	13dcd1	100	12	4
Well 14	13dcd2	615	9	20
2	36ddd1	199	2	4

[1] Not in use.

The regional piezometric surface slopes toward the south, but within area 2 the gradient may be reversed. On section *B–B′*, the ground-water divide is between areas 1 and 2, and movement is northward. Locally, near the open-pit mines, the ground-water movement is toward the pits. Therefore, recharge to aquifers within area 2 is only from local precipitation.

Area 2 is within and adjacent to the village; it contains thick sections of permeable sand and gravel. Although wells in area 2 can be pumped at rates at least equal to those in areas 1, the potential recharge is less, and, the quality of water is inferior.

Keewatin, area 1 is the westward continuation of area 2.

Village well 15, 57.20.4bbc2, taps the lower of two sand and gravel sections. (See 4bbcl on section *B–B′* pl. 1.) The logs of this well and of test hole 57.20.4bdb1, one-fourth of a mile to the southeast, show only thin sections of sand and gravel. Because of this lack of permeable drift and low specific capacity of well 15, the northeastern part of the Hibbing map area is not considered a good ground-water source.

Hibbing obtains part of its water from well 57.21.12aba1 in the lower slaty and lower cherty members of the Biwabik Iron-Formation in the Scranton mine. Two other wells penetrating the Biwabik Iron-

Formation in the vicinity of Hibbing yield less than 1 gpm per foot of drawdown. Further, water levels are depressed by mine drainage, and wells in or near pits obtain water only from the lower part of the formation. Recharge is restricted by more than 200 feet of drift overlying the Biwabik. The water level in observation well 57.20.5dad1, which penetrates the Biwabik Iron-Formation, rises very little in response to periods of heavy rainfall as compared to the rise common in glacial drift aquifers.

Quality of water.—The chemical quality of potential supplies is indicated by analyses in tables 5 and 7. Water from area 1 ranges from 196 to 306 ppm in dissolved solids, from 160 to 259 ppm in hardness, from 0.14 to 3.3 ppm in iron, and from 0.09 to 1.7 ppm in margnese. The concentrations of these constituents and the hardness of the water generally are less in area 1A than in the rest of area 1.

The quality of water from wells within area 2 is more variable and is generally more mineralized than that from area 1; dissolved solids range from 171 to 477 ppm; hardness, from 103 to 420 ppm; iron, from 0.0 to 10 ppm; and manganese, from 0.0 to 4.2.

A wide variance in the quality of the water from shallow and deep outwash bodies at the same location is shown by chemical analyses from village well 15. The upper section has a water quality similar to water from area 2, and the lower section, in which the well is completed, has a water quality similar to that of area 1.

Water from Biwabik near Hibbing, as indicated by analyses for wells 57.20.5dad1, 57.21.12aba1, and 13aab1, is better in quality than water from the drift. It is softer and has less iron and manganese. For potential supplies, therefore, the water of best quality is from the drift in area 1A or from the Biwabik.

OTHER WATER SOURCES

GROUND WATER

Test drilling in area 3 penetrated buried sand and gravel deposits that are generally thin or silty and poorly sorted. Test hole 57.20.20ccc1 has a specific capacity of 2 (table 6).

Water levels in wells in area 3 are commonly within 20 feet of the land surface, and ground-water movement is south through the area. The potential for development of large-capacity wells within area 3 is lower than in areas 1 and 2.

Quality of water.—The analysis of water from test hole 57.20.20ccc1 (table 7) indicates that the quality of water from area 3 is similar to that from area 2.

TABLE 7.—*Chemical analyses, in parts per million, of water from test holes and wells in the Hibbing vicinity*

[Analyses of samples: 56.20.7bbb1 and 57.21.24abb3 by U.S. Geol. Survey; 57.20.5dad1 by Great Northern Railway; 57.20.31dbc1 by Minnesota Dept. of Health; all others by Hibbing Health Dept.]

Location	56.20.7bbb1	57.20.4bbc2	57.20.5dad1	57.20.20ccc1	57.20.31dbc1	57.21.13aab1	57.21.24abb3	57.21.36ddd1
Designation	Abandoned well 1A	Village well 15	Abandoned Great Northern Railway well	Test hole 10	Abandoned well 4	Test hole 7A	Unused well 16	Abandoned well 2
Area	1			3	1A	2	2	1
Depth (feet)	101	150	430	247	92	660	150	115
Aquifer	Sand and gravel from 67 to 100 ft.	Sand and gravel from 55 to 75 ft.[1]	Biwabik Iron-Formation from 375 to 430 ft.	Sand and gravel from 70 to 90 ft.	Sand and gravel from 82 to 92 ft.	Biwabik Iron-Formation from 417 to 660 ft.	Sand and gravel from 55 to 93 ft.	Sand and gravel from 60 to 113 ft.
Silica (SiO_2)	25		8.0				18	
Iron (Fe)	1.0	12.0	0	.47	Trace	.34	2.1	0.7
Manganese (Mn)	.25	2.0		.58	.10	.00	.72	1.2
Calcium (Ca)	45		30				74	
Magnesium (Mg)	20		27				27	
Sodium (Na)	7.2						6.5	
Potassium (K)	1.6						1.6	
Bicarbonate (HCO_3)	240						333	
Sulfate (SO_4)	14					12	23	55
Chloride (Cl)	.0		10			1.5	7.5	1.0
Fluoride (F)	.1						.2	
Nitrate (NO_3)	.3						.2	
Boron (B)	.04						.02	
Dissolved solids	230		171				329	
Hardness as $CaCO_3$	194	384	147	226	168	103	294	216
Noncarbonate hardness as $CaCO_3$		104					21	
Alkalinity as $CaCO_3$	197		66		132		273	135
Specific conductance (micromhos at 25° C)	380						549	
pH	7.7	6.68		7.6	7.5		7.6	7.6
Color (units)	2				5.0		5	25
Turbidity as SiO_2	1				.6		.8	6.0
Temperature (°F)							44	
Date of collection	Jan. 31, 1957	Mar. 18, 1957		Mar. 22, 1957	Oct. 1, 1943		June 13, 1958	Oct. 1, 1943

[1] Well not completed in this aquifer. See table 4.

SURFACE WATER

Because Hibbing is close to the Laurentian Divide, the streams in the vicinity have small drainage areas that have corresponding low discharges. There is no record of any stream within a reasonable distance capable of furnishing an adequate water supply for municipal or industrial use.

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