Water Resources in the Vicinity of Municipalities on the East-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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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 east-central Mesabi Iron Range. Both ground water and surface water offer good potential supplies. For the ground-water supplies, the most productive aquifers are the Biwabik Iron Formation and the stratified glacial drift. Surface-water supplies are variable. Streams in the western part of the report area are too small to yield supplies of importance, but lakes are a good potential supply. Eveleth and Gilbert are the only towns presently utilizing this source. In the eastern part of the area of this report, the Pike and Embarrass Rivers offer good potential supplies. Flow records from two gaging stations are presented as are data from many wells and test holes.

Surface water generally has a high concentration of iron and is colored. Most ground water has a high concentration of iron and manganese and is hard. Analyses of water from many sources are presented.

INTRODUCTION

This report describes existing and potential water supplies on the east-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 are 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.

Surface-water supplies in the east-central Mesabi Iron Range are variable. In the western part, drainage areas are too small to yield supplies of any importance. The city of Eveleth obtains water from St. Marys Lake and has good potential supplies from other lakes. Gilbert, the only other town in the area of this report using a surface-water supply, obtains water from Ely Lake. Lakes afford potential supplies to other towns in the region. Near the eastern edge of the area of this report, the Pike and Embarrass Rivers offer a good potential supply. Flow records of two stations in the area are presented.

The quality of ground water 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 6 and 7 in Cotter and others (1965a) 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 57.18.8ddb1 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.

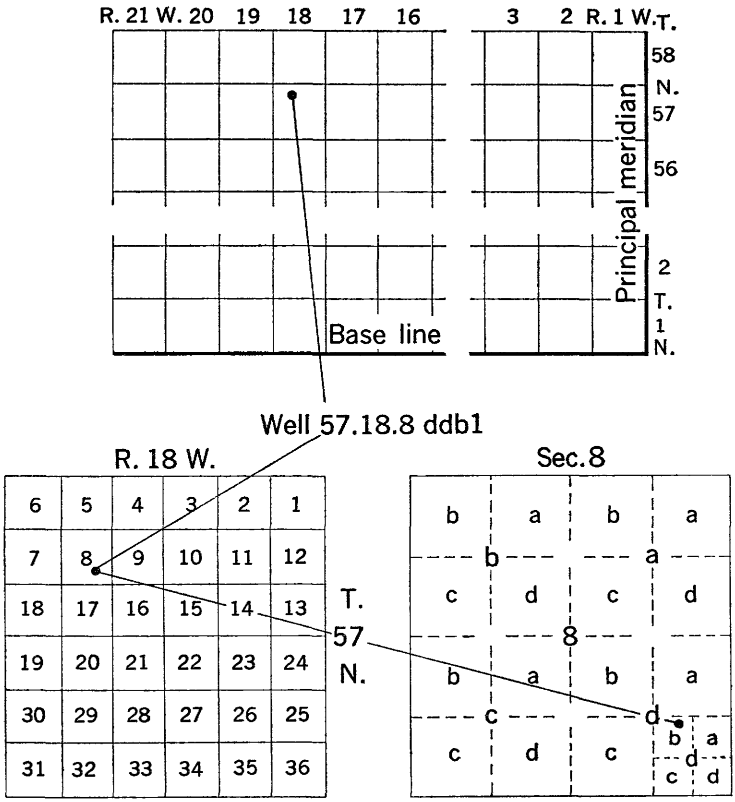

FIGURE 1.—Sketch showing method of numbering test holes and wells

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.

VIRGINIA

Population: 14,034

Virginia is the second largest city on the Mesabi Range. It lies inside the north bend of the "Virginia Horn" about 2 miles west and south of the Laurentian Divide. Drainage is to the north and southwest, away from the divide. The southwestward-flowing drainage reaches the St. Louis River by way of East Two and West Two Rivers.

Near Virginia the Giants Range is composed of Ely Greenstone and the Knife Lake Group, which are intruded by Giants Range Granite (pl. 1). Flanking these rocks on the south and on the west are the Pokegama Quartzite and Biwabik Iron-Formation. In the southwestern part of the area, the bedrock is Virginia Argillite.

The city obtains its water supply from the Biwabik Iron-Formation and the glacial drift.

PRESENT WATER SUPPLY

Source of information: Ed Kozan, assistant superintendent, water and light commission; Forty-sixth annual report of the Water and Light Commission, 1960.

Ownership of water supply: Municipal (pumpage is controlled to some extent by Pacific Isle Mining Co. for the purpose of facilitating mining operations).

Number of customers: 4,217 (1959–60). Also supplies Parkville and West Virginia.

Average consumption: 1,238,000 gpd (gallons per day) (1960).

Storage: Concrete reservoir, 1 million gal.; elevated steel tank, 1 million gal.

Treatment: Coagulation with sodium aluminate, lime and bentonite; chlorination; sedimentation; polyphosphate stabilization; rapid sand filtration.

Source of supply: Missabe Mountain mine and two wells. Most of city's water obtained from Missabe Mountain open-pit mine, not presently active; a small lake has formed in bottom of pit. Pumping station (58.17.8aca) at top of a 12- by 14-foot shaft, 157 feet deep; 2 horizontal shafts at 142 feet extend laterally into lake bottom. Shaft contains 3 turbine pumps, having capacities of 1,000, 2,000, and 2,000 gpm (gallons per minute). The 2,000 gpm units are auxiliary pumps. Water obtained principally from Biwabik Iron-Formation.

Well location 58.17.8cbb1. At Sixth Avenue West and First Street South. This is an auxiliary drilled well; 14 inches in diameter; 450 feet deep. Not screened; has a 500 gpm turbine pump. Water obtained from Biwabik Iron-Formation between 118 and 450 feet; static water level 75 feet below land surface.

Well location 58.18.12ccc3. At McInnis Road and Virginia Road, 0.5 mile west of West Virginia. This is an auxiliary well drilled in 1958; 16 inches in diameter; 94 feet deep. Finished between 69 and 94 feet with 16-inch stainless steel screen; has a turbine pump. Water obtained from glacial sand and gravel. When pumped at 1,400 gpm for 3 days, water level lowered 30 feet below static level of 21 feet.

Quality of water.—The raw water has a moderate dissolved-solids content and is very hard. (Table 1.) The water from the Missabe Mountain open-pit mine is moderately siliceous but is better in quality than that from auxiliary well 58.17.8cbb1 because it contains less iron and manganese. Exposure of the water to air in the open pit probably causes precipitation of much of the iron and manganese. The water quality from auxiliary well 58.18.12ccc3 is represented by the analysis for 12ccc2. It has a high concentration of iron and manganese but not as high as water from 58.17.8cbb1. The finished water meets cur-

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

[Analyses for 58.18.23cbb6 by Oliver Mining Div., U.S. Steel Corp.; all others by the U.S. Geol. Survey]

	Present water supply				Potential water supply								
	Ground water				Ground water						Surface water		
Water source	Biwabik Iron-Formation		Glacial drift		Glacial drift						Manganika Lake outlet		Mashkenode Lake outlet
Location	58.17.8		58.17.8	58.17.8	58.17.18	58.17.18	58.18.12	58.18.14	58.18.14	58.18.23			
	aca		aca	cbb1	bdd3	cca3	ccc2	daa1	dca1	cbb6			
Silica (SiO_2)	14	14	16	4.1	21	19	20	24	22		12	9.9	4.4
Iron (Fe)	.08	.04	.07	4.9	.06	.10	.32	1.7	2.1	0.8	.05	.01	.14
Manganese (Mn)	.00	.00	.05	1.8	1.7	.71	.66	1.6	2.7	1.2	1.2	.06	.60
Calcium (Ca)	47	30	52	76	91	83	64	64	100		59	49	31
Magnesium (Mg)	19	.1	21	36	40	38	26	24	33		32	21	9.6
Sodium (Na)	7.9	20	9.0	12	14	12	6.8	4.9	5.1		22	25	7.3
Potassium (K)	1.4	1.3	2.6	3.9	3.8	3.5	2.5	3.3	3.0		4.8	4.5	2.9
Bicarbonate (HCO_3)	203	[1]0	225	332	400	340	283	294	385		190	200	120
Sulfate (SO_4)	35	35	44	88	87	103	47	30	73		112	52	29
Chloride (Cl)	10	12	8.0	4.8	.4	2.2	2.5	1.5	3.1		33	31	4.7
Fluoride (F)	.1	.1	.1	.2	.2	.3	.3	.2	.2		.3	.0	.2
Nitrate (NO_3)	3.4	2.2	.5	.0	.2	.0	.1	.0	.1		11	3.1	2.3
Boron (B)			.03	.04	.06	.02	.04	.04	.02		.08	.11	.04
Dissolved solids	248	148	264	396	452	431	309	299	434		428	311	159
Hardness as $CaCO_3$	197	75	217	339	391	365	266	258	384	197	278	210	117
Noncarbonate hardness as $CaCO_3$	31	41	32	67	63	86	34	17	68		122	46	19
Alkalinity as $CaCO_3$	166	34	185	272	328	279	232	241	316	197	156	164	98
Specific conductance (micromhos at 25°C)	400	272	443	648	737	687	510	497	693		625	511	262
pH	7.6	10.6	7.8	7.6	7.2	7.4	7.5	7.3	7.5	7.0	7.3	7.6	7.2
Color (units)	2	1	3	4				4			10	13	13
Turbidity as SiO_2	5	5	3	.3									
Temperature (°F.)		43	55	44	43	43	43	43	42				
Date of collection	May 3, 1951		Sept. 26, 1957	Dec. 13, 1960	Sept. 26, 1958	Oct. 24, 1958	Oct. 6, 1954	Oct. 12, 1955	Sept. 1, 1959	Nov. 16, 1960	April 17, 1958	Sept. 27, 1962	April 17, 1958

[1] Hydroxide (OH), 10 ppm; carbonate (CO_3), 20 ppm.

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rent drinking-water standards (U.S. Public Health Service, 1962). It has a low dissolved-solids content, is moderately hard, and has little iron or manganese.

POTENTIAL WATER SUPPLY

PRESENT SOURCE

The Virginia water supply from the Missabe Mountain mine is a combination of ground water and surface water. Although some surface water runoff enters the manmade lake, most of the water pumped is from ground water discharged from the lower cherty member of the Biwabik Iron-Formation. Two mine shafts "feeding" the pumps increase the area of exposure to the aquifer tremendously and allow rapid inflow of ground water. Because the pumping is from an open body of water and the level of this water surface is affected by adjacent mine pumpage, drawdown data are meaningless.

Locally, ground-water movement is toward the open pits where the water level is depressed by mine drainage. When drainage of adjacent sections of the pit are discontinued, recharge to the lake in the Missabe Mountain mine should be ample to supply the city.

Auxiliary city well 58.17.8cbb1 penetrates the Virginia Argillite and is finished in the upper slaty and upper cherty members of the iron-formation, which are fractured taconite at this location. This well has been pumped at a rate of 450 gpm, but a higher rate reportedly caused excessive drawdown. The static water level in an observation well about 500 feet southwest of this well is about 45 feet below the land surface. The water level in this well is lowered when city well 58.17.8cbb1 is pumped, but it shows no response to periods of heavy rainfall. The low permeability of the overlying glacial drift and Virginia Argillite near the observation well prevents infiltration to the aquifer.

Recharge to the iron-formation in the vicinity of Virginia is greater than in other areas bounded by the Laurentian Divide because of the funneling effect produced by the arcuate shape of the "Virginia Horn."

Auxiliary well 58.18.12ccc3 is finished in a thick section of permeable sand and gravel (pl. 1). It is within area 1, one of two numbered areas known to contain permeable stratified drift aquifers.

Area 1 delineates ice-contact sediments overlain by reddish-brown clayey till. The texture and thickness of the water-laid sediments are variable, but some of the material is very permeable as indicated by the specific capacities of wells 3–7. (See table 2.)

TABLE 2.—*Specific capacities of test wells in the Virginia vicinity*

Well	Location	Pumping rate (gpm)	Period of pumping (hours)	Specific capacity (gpm per foot of drawdown)
1	58.17.18bdd3	260	24	137
2	18cca3	455	24	38
3	58.18.12ccc2	142	24	51
4	12ccc3	1,400	72	47
5	14daa1	325	½	168
6	14dca1	192	24	34
7	23cbb6 [1]	210	24	40?

[1] This site is 100 ft west of the area shown on pl. 1 along *B–B′*.

The most permeable deposits are alined in a southwest trend along the trace of geologic section *B–B′* (pl. 1) from 23cbb6 to 12ccc2 and 3. Testing indicates that wells along this trend can supply a large volume of ground water. The character of the deposits in the southeast part of Area 1 is inferred from topography, and the location of this boundary is approximate.

Recharge to the stratified drift in Area 1 is derived from precipitation falling south of the Laurentian Divide within the Virginia map area (pl. 1). Ground-water movement is to the south through Area 1 and some recharge can undoubtedly be induced from the lakes and streams. The principal deterrent to recharge of the stratified drift by infiltration is the overlying reddish-brown clayey till. Observation wells 58.18.12ccc1 and 13aba1 are finished in sand and gravel beneath 10–30 feet of surficial clayey till. However, the till pinches out less than half a mile north of well 58.18.12ccc1. Both observation wells show a rapid rise in water level following periods of heavy rainfall. It is not known whether these rises in water level represent recharge to the aquifer or loading of the surface.

Area 1 has a very good potential for the development of groundwater from glacial drift.

OTHER WATER SOURCES

GROUND WATER

Area 2 outlines outwash deposits in a buried channel which has no surficial expression. The outwash aquifer in Area 2 underlies a thick section of reddish-brown clayey till (section *A–A′*, pl. 1). (See Cotter and Rogers, 1961, pl. 2 for a more detailed section.) Table 2 (wells 1 and 2) lists the test pumping of outwash in Area 2.

The test pumping of 58.17.18bdd3 was from a thin permeable section of outwash. The test indicated that water was drawn from a small part of the aquifer that was receiving little or no recharge during the period of pumping. The outwash penetrated in well 58.17.18cca3 was thicker and a pumping test showed a greater volume of water in storage. However, recharge to Area 2 from the north and west is limited by the nearness of the Laurentian Divide, the open-pit mines, and the city of Virginia. Within the city much of the potential recharge from precipitation is diverted through storm sewers. A permanent well at 58.17.18bdd3 probably would soon deplete the aquifer. The pumping rate of a well-field development at 58.17.18caa3 would have to be controlled to avoid dewatering the aquifer.

The southern extent of this channel deposit has not been determined, but it may extend into the area of ice-contact deposits outlined under Iron Junction in area 1 (Cotter and others, 1965b). The northern part of the area is in a bedrock low (Oakes, 1964, map 2), which appears to extend north into the vicinity of Virginia Lake.

Quality of water.—The quality of the potential supply of water from the glacial drift is indicated by analyses in table 1. Water for potential supplies from the Biwabik and the drift is not likely to be as good as the water from the open pit now in use because of higher dissolved solids, hardness, iron, and manganese.

SURFACE WATER

Virginia and Silver Lakes lie within the city limits of Virginia. A tributary of East Two River flows through these lakes. Because it heads at the nearby Laurentian Divide, the stream is small. No flow records on this creek are available, but it is doubtful if the flow would be great enough to sustain the lake levels if water were withdrawn for use by the city. The East Two River drainage and Mashkenode and Manganika Lakes southwest of Virginia form small potential supplies.

Quality of water.—According to the two analyses of lake outflow given in table 1, water from Manganika Lake is poorer in quality than water from the present supply; it has a much higher dissolved-solids content and is much harder. At times, the manganese content of the water is also very high. Discharge from the Virginia sewage-disposal plant into Manganika Lake alters the chemical and bacterial quality of the water. Comparison of the two analyses indicates significant fluctuations in sulfate, nitrate, and fluoride content of the water.

Water from Mashkenode Lake, less than a mile west of Manganika Lake, seems from the one analysis available to be of much better quality than water from Manganika Lake but not as good as the present supply.

EVELETH

Population: 5,721

The city of Eveleth is on the south flank of a large flexure in the Giants Range known as the "Virginia Horn." Drainage in this area is away from the Laurentian Divide, to the south into the St. Louis River.

As shown on plate 1, the Biwabik Iron-Formation and the Pokegama Quartzite parallel the Laurentian Divide, which follows the curvature of the "Horn." The Virginia Argillite underlies the area to the south and west. The Giants Range is composed of Ely Greenstone and the Knife Lake Group and has a thin mantle of glacial drift. South and west of the Giants Range within the Eveleth map area (pl. 1), the glacial drift has an average thickness of about 100 feet. Eveleth's water supply is obtained from St. Marys Lake.

PRESENT WATER SUPPLY

Source of information: J. V. Anderson, public utilities superintendent; city records.

Ownership of water supply: Municipal.

Number of customers: Approximately 1,750 (1960). Also supplies village of Leonidas.

Average consumption: 700,000 gpd (estimated, 1960).

Storage: Clear well, 100,000 gal.; elevated steel tank, 310,000 gal.

Treatment: Prechlorination; coagulation with alum; sedimentation; rapid sand filtration; postchlorination.

Source of supply: St. Marys Lake. Pumping station at north end of St. Marys Lake (57.17.9cac) equipped with three pumps having capacities of 1,150 gpm each. Two of these are auxiliary units. A 16-inch intake pipe extends 100 feet into the lake and the point intake is 20 feet below lake level.

Quality of water.—Water from St. Marys Lake has a low dissolved-solids content but is moderately hard (table 3). The chemical constituents except for iron and manganese meet the drinking-water standards. The saturation index of about −1.4 determined for September 26, 1957, indicates that the water has a tendency to be corrosive. The municipal treatment reduces the color and turbidity; the chemical composition of the finished water is probably similar to that of the raw water.

POTENTIAL WATER SUPPLY

PRESENT SURFACE-WATER SOURCE

The city of Eveleth obtains its water from St. Marys Lake. The pumping capacity is 3,450 gpm of which 2,300 gpm are auxiliary units. With no apparent inlet or outlet, St. Marys Lake is evidently dependent on ground water to maintain its supply. No data is available regarding the maximum pumpage that might be developed.

TABLE 3.—*Chemical analyses, in parts per million, of the public water supply at Eveleth*

[Analyses of finished water by the Minnesota Dept. of Health; analyses of 57.17.9 cac by U.S. Geol. Survey]

Water source	Finished	St. Marys Lake [1] 57.17.9 cac
Silica (SiO_2)		0.9
Iron (Fe)	0.26	.17
Manganese (Mn)	.09	.06
Calcium (Ca)		16
Magnesium (Mg)		6.6
Sodium (Na)		3.3
Potassium (K)		1.9
Bicarbonate (HCO_3)		71
Sulfate (SO_4)	10	13
Chloride (Cl)		3.2
Fluoride (F)	.14	.1
Nitrate (NO_3)		.7
Boron (B)		.01
Dissolved solids		93
Hardness as $CaCO_3$	79	67
Noncarbonate hardness as $CaCO_3$		9
Alkalinity as $CaCO_3$	65	58
Specific conductance (micromhos at 25°C)		150
pH	7.7	6.9
Color (units)		7
Turbidity as SiO_2		1
Date of collection	Dec. 8, 1949	Sept. 26, 1957

[1] Location of well.

OTHER WATER SOURCES

SURFACE WATER

Northwest of Eveleth lies Manganika Lake (pl. 1), which is near the headwaters of East Two River. Adjacent to St. Marys Lake are Ely and Horseshoe Lakes, and to the south are Long and Pleasant Lakes. These lakes have potential supplies as great as St. Marys Lake.

Quality of water.—The water from Manganika Lake is discussed on page E8 and in table 1. An analysis of the water from Ely Lake is given in table 4. No chemical quality data are available for Long, Horseshoe, and Pleasant Lakes.

GROUND WATER

The rich ore from the mines in this area indicates the extensive leaching and oxidation which has taken place in the Biwabik Iron-Formation near Eveleth. Bodies of permeable low grade ore probably occur adjacent to mined-out areas. However, these mines are high on the flank of the Giants Range, and recharge to wells near the mines would be extremely limited. The inactive pits in the area are either dry or contain little water, indicating that the glacial drift and at least 100 feet of the Biwabik is unsaturated.

Test holes west and south of the Giants Range penetrated permeable sand and gravel deposits in the Eveleth map area (pl. 1). (See also Cotter and Rogers, 1961, pls. 1 and 2.) On the basis of test drilling and a study of the topography, three areas have been outlined that are favorable for the development of ground water from glacial drift.

Although its limits are poorly controlled, area 1 is probably an extension of the bedrock channel in Virginia, area 2. Reported logs of test holes 58.18.25acb1 and 25abb1, 0.2 mile north of the Eveleth map area, show 41 feet of sand and 88 feet of sand and gravel, respectively. Test hole 58.18.25cab1 penetrated outwash consisting of 88 feet of silt underlain by 5 feet of sand and gravel. The depth at which bedrock was found in these three holes (106–157 ft) was 15–55 feet below the altitude at which it was found in 58.18.26add1, and this indicates a bedrock low in area 1.

The recharge area is bounded on the east by the Laurentian Drainage Divide, and ground-water movement down gradient from the north would be the principal source of recharge to a well in area 1.

Area 2 is a small part of the ice-contact area that is described under Iron Junction, area 2 (Cotter and others, 1965b). Test hole 57.18.25 bbc2 penetrated sand and gravel from 26 feet to the bottom of the hole at 66 feet (pl. 1). Both areas 1 and 2 have better potential for ground-water development in their extensions described under Iron Junction and Virginia than they do within the Eveleth map area.

Area 3 is underlain by ice-contact sediments ranging in grain size from clay to gravel. It is the southwest extension of Gilbert, area 1 and McKinley, area 1 that flank the southeast side of the "Virginia Horn." Two geologic sections (pl. 1) show the variability of the stratified drift. Test hole 57.17.20aab1 penetrated 26 feet of sand and gravel and 49 feet of silt and clay above the gray bouldery till. Three test holes in secs. 8 and 17 penetrated from 9 to 37 feet of sand and gravel below the reddish-brown clayey till, and test hole 57.17.21 cdd1, in the southeast extension of area 3, penetrated 106 feet of well-sorted sand and gravel.

The land surface in much of area 3 is above the level of the adjacent lakes, and water levels in wells within the area are close to lake levels. The upper part of the stratified drift is commonly unsaturated, and the thickest saturated sections are adjacent to Ely and St. Marys Lakes. The lake levels of Mud, Horseshoe, Long, and Pleasant Lakes range from 19 to 36 feet above the level of St. Marys and Ely Lakes, and the saturated thickness of adjacent drift is proportionally less.

Area 3 has very good potential for the development of large ground-water supplies. It is underlain by thick sections of saturated sand

and gravel. Recharge available to the drift underlying area 3 exceeds the amount available to its northeast extension. Recharge results from infiltration of precipitation within area 3 and from lateral ground-water movement from the north.

Except for the areas previously described, the remainder of the Eveleth map area (pl. 1) has a low potential for ground-water development. The ridge extending southwest from Eveleth is composed of gray bouldery till overlain by reddish-brown-clayey till and very little, if any, intermediate stratified drift. Test drilling elsewhere within the map area penetrated mainly till, silt, and clay (pl. 1).

GILBERT

Population: 2,591

The city of Gilbert is on the southeast flank of the flexure in the Giants Range called the "Virginia Horn." Although the northward flowing Pike River crosses the northwest corner of the Gilbert map area (pl. 1) most of the area drains to the southeast into the Embarrass River and thence into the St. Louis River.

Except for the northwestern part, the area is underlain by the Virginia Argillite. In the northwest are the other two members of the Animikie Group—the Biwabik Iron-Formation and the Pokegama Quartzite—and the basement complex of the Knife Lake Group, Ely Greenstone, and Giants Range Granite. The glacial-drift cover thickens southeast of the north limit of the iron-formation and is nearly 300 feet thick south of Silver Lake. (See geologic section A–A', pl. 1.)

The city of Gilbert obtains its water supply from Ely Lake.

PRESENT WATER SUPPLY

Source of information: J. J. Kraker, water superintendent; city records.
Ownership of water supply: Municipal.
Number of customers: 858 (1960).
Average consumption: 200,000 gpd (estimated, 1960).
Storage: Clear well, 100,000 gal; elevated steel tank, 100,000 gal.
Treatment: Prechlorination, coagulation with alum; sedimentation; filtration; postchlorination.
Source of supply: Ely Lake.
Pumping station, at north end of Ely Lake (58.17.35cbc), equipped with two 60 hp pumps having capacities of 350 gpm each; one an auxiliary unit. A 10-inch intake pipe extends 607 feet into the lake.

Quality of water.—Water from Ely Lake has a low dissolved-solids content and is moderately hard. (See table 4.) Except for iron and manganese, the chemical constituents probably do not exceed the recommended maximum for drinking water most of the time. The saturation index of −1.1 calculated for September 26, 1957, indicates that the water is somewhat corrosive. The treatment process reduces the color and turbidity and partially reduces the iron content of the water.

TABLE 4.—*Chemical analyses, in parts per million, of water in the Gilbert vicinity*

[Analyses of finished water by the Minnesota Dept. of Health; all others by the U.S. Geol. Survey]

Water source	Present water supply			Potential water supply	
	Surface water			Surface water	
	Finished		Ely Lake [1] 58.17.35 cbc	Embarrass River near McKinley (Station 180)	
				Average	Maximum
Silica (SiO_2)			4.7	9.9	14
Iron (Fe)	0.06	[2] 0.44	.26	.40	.88
Manganese (Mn)	0		.00	.0	.0
Calcium (Ca)			19	15	22
Magnesium (Mg)			6.5	4.8	6.0
Sodium (Na)			4.0	2.7	3.9
Potassium (K)			1.7	1.0	1.6
Bicarbonate (HCO_3)			84	55	80
Sulfate (SO_4)	8.8		8.8	14	21
Chloride (Cl)	6.5		2.8	.6	2.2
Fluoride (F)	0		.1	.2	.3
Nitrate (NO_3)			.8	1.2	2.3
Boron (B)			.02	.07	.20
Dissolved solids			97	103	128
Hardness as $CaCO_3$	90		74	56	82
Noncarbonate hardness as $CaCO_3$			5	11	16
Alkalinity as $CaCO_3$	80		69	45	66
Percent sodium				9	11
Specific conductance (micromhos at 25°C)			164	120	180
pH	7.5		7.1	7.1	7.5
Color (units)			6	80	150
Turbidity as SiO_2			3		
Date of collection	Oct. 9, 1951	July 23, 1955	Sept. 26, 1957	1955-60	

[1] Location of well.
[2] Concentration of iron in raw water was 1.3 ppm.

POTENTIAL WATER SUPPLY

PRESENT SURFACE-WATER SOURCE

The towns of Gilbert and Sparta obtain their water supply from Ely Lake. The combined capacity is 700 gpm of which 350 gpm is an auxiliary supply. No data are available regarding the maximum which might be pumped.

OTHER WATER SOURCES

SURFACE WATER

The Ely Lake supply could be augmented by pumping from the Embarrass River about 3½ miles southeast. The lift is less than 40 feet. (See pl. 1.)

FLOW DATA

EMBARRASS RIVER NEAR MCKINLEY

Location.—Lat 47°27′10″, long 92°23′00″, in NW¼ sec. 4, T. 57 N., R. 16 W., on left bank 40 feet upstream from highway bridge, 0.9 mile downstream from outlet of Esquagama Lake, 4.5 miles southeast of McKinley.

Drainage area.—171 square miles.

Records available.—October 1953–September 1960.

Average discharge.—7 years, 109 cfs.

Extremes: 1953–60.—Maximum discharge, 1,690 cfs (cubic feet per second), April 20, 1954 (gage height, 11.72 ft); minimum, 11 cfs, September 7, 1955; minimum gage height, 2.66 feet, June 26, 1959; minimum daily discharge, 12 cfs, September 6, 7, 1955.

Flood frequency.—10-year flood, 1,570 cfs; 20-year flood, 1,910 cfs; 30-year flood, 2,260 cfs.

Low-flow frequency.—Annual 7-day minimum discharges: 2-year, 20 cfs; 10-year, 15 cfs; 20-year, 12 cfs.

Quality of water.—The chemical quality of the water available from the Embarrass River in the vicinity of Gilbert is indicated by data in table 4. The water has a low dissolved-solids content and is soft most of the time and only moderately hard other times. It is, however, highly colored and has much iron.

GROUND WATER

The Biwabik Iron-Formation lies in a northeastward trending belt, and its northwest edge abuts the city of Gilbert. As is evidenced by the many open-pit mines, a considerable part of the iron-formation has been altered to ore in the area. No data are available on wells in the iron-formation near Gilbert, but the Biwabik is a potential source of ground water. Large quantities of water can be obtained only from oxidized and leached, or highly-fractured parts of the formation. Wells completed adjacent to active open-pit mines, where the water level is artificially depressed by mine drainage and where the saturated thickness is less, have a smaller potential yield.

Recharge to the iron-formation from precipitation is limited by the nearness of the Laurentian Drainage Divide. The principal recharge to the formation is through lakes and abandoned mines, and by infiltration through the overlying glacial drift. Additional recharge takes place from lateral ground-water movement from the northeast through the overlying permeable glacial drift.

Two ice-contact areas shown on the map on plate 1 have been outlined as potential sources of ground water from glacial drift. Buried ice-contact sediments deposited along the front of the Giants Range are outlined as area 1. The southwest lineation is emphasized by the trend of Deep and Ely Lakes and by the eskers in sec. 19, T. 58 N., R. 16 W., and sec. 24, T. 58 N., R. 17 W. Prominent southeast linear features include Leaf and Lost Lakes and their swampy extensions and the eskers in sec. 25 and 36. The deposits of sand and gravel associated with these linear deposits are shown on the west end of geologic sections *A–A′* and *B–B′*, plate 1. Test hole 57.17.3dcc2 south of Ely Lake penetrated 88 feet of sand and gravel overlying gray bouldery till. A city test well, 58.17.35dbb3, between Deep Lake and Ely Lake was completed in the stratified drift within area 1. It was reportedly pumped at 600 gpm for 10 days and showed a specific capacity of about 10 gpm per foot of drawdown. The pumping level in this test was only a few feet above bedrock and was undoubtedly sustained by recharge from Deep Lake.

Regional ground-water movement is to the southeast although local movement is toward lakes within area 1. The recharge area for area 1 is bounded on the north and west by the Laurentian Divide, and is about 12 square miles.

Area 1 contains thick sections of very permeable sand and gravel, which are capable of sustaining large-capacity wells. The long-term yield of area 1 is limited by the small area of recharge and dewatering of open-pit mines.

The chain of lakes and their associated sand and gravel deposits described under Biwabik, area 3, extend into the Gilbert map area (pl. 1). This ice-contact topography, which is underlain by coarse-grained water-laid sediments, is outlined as area 2. It contains deposits of sand and gravel which underlie surface or near-surface reddish-brown clayey till (section *B–B′*, pl. 1).

Regional ground-water movement is to the south toward the St. Louis River, but local movement is into lakes and streams. Area 2 has a much larger recharge area than the areas adjacent to the Giants Range. The water levels in area 2 are generally within 20 feet of the land surface (pl. 1).

South and east of area 2 the land surface is relatively flat and the clayey till is more deeply buried. The stratified drift under the till is finer textured and (or) thinner and probably will not yield large quantities of water to wells. An exception to this is along a second chain of lakes that trend northeastward and that are just southeast of the Gilbert map area. Along this trend the reddish-brown clayey till is shallow and is underlain by permeable sand and gravel. The sand and gravel section shown in the easternmost test hole on geologic section *A–A′* thickens to 64 feet in test hole 57.16.2cdc1, 0.3 mile east of the map area shown on plate 1. Other test holes indicate that this stratified drift is a channel fill underlying the chain of lakes.

Both area 2 and its counterpart to the southeast are good potential sources of water. Wells near one of these lakes could induce recharge from the lake.

Quality of Water.—The average analyses in Cotter and others (1965a, table 6) indicate the probable quality of water from potential ground-water supplies where the influence of lake seepage is small or absent. Where the influence of lake seepage is significant, the water would probably be better than the average analyses because the water from the lakes has less dissolved solids, silica, iron, manganese, and hardness. It is unlikely that water from either the Biwabik or the glacial drift would be as good as the water of the present supply.

McKINLEY AND BIWABIK

The village of McKinley and the city of Biwabik lie on the south flank of the Giants Range (pl. 1). Except for the northwest corner, the area drains south into the St. Louis River. The northward-flowing Pike River drains the area north of the Laurentian Divide.

The Giants Range is made up of Ely Greenstone, Knife Lake Group, and Giants Range Granite. The southward-dipping Animikie Group laps onto the Giants Range Granite. The glacial drift is thin or absent on the Giants Range and thickens to the southeast. It is 70 feet thick at the McKinley well, 150 feet thick at the Biwabik wells, and 198 feet thick at test hole 58.16.13ada1. The two municipalities overlie the Biwabik Iron-Formation and obtain their water supply from this unit.

McKINLEY

Population: 408

PRESENT WATER SUPPLY

Source of information: Jake Butala, water supervisor.
Ownership of water supply: Municipal.
Number of customers: 112 (1960).
Average consumption: 18,000 gpd (estimated, 1955).
Storage: Elevated steel tank, 75,000 gal.
Treatment: None.
Source of supply: One well.

Well location 58.16.8ddd1. Nine-tenths of a mile northeast of McKinley on State Highway 135; drilled in 1921; 6 inches in diameter; 270 feet deep. It is screened and has a 150 gpm airlift pump. Water obtained from Biwabik Iron-Formation below 179 feet.

Quality of Water.—The water meets the drinking-water standards for all chemical constituents (table 5). It has a low dissolved-solids content, is moderately hard, and is siliceous. The saturation index of −0.9 calculated for 80°F indicates that the water has a tendency to be corrosive; however, at higher temperatures the tendency probably disappears.

TABLE 5.—*Chemical analyses, in parts per million, of water in the McKinley vicinity*

[Analyses by the U.S. Geol. Survey]

Water source	Present water supply	Potential water supply	
	Ground water	Surface water	
	Biwabik Iron-Formation [2] 58.16.8ddd1	Pike River near Embarrass [1] (Station 1285)	
		Average	Maximum
Silica (SiO_2)	21	9.0	13
Iron (Fe)	.10	1.0	1.5
Manganese (Mn)	.00	.0	.0
Calcium (Ca)	18	7.3	9.4
Magnesium (Mg)	6.6	2.7	3.5
Sodium (Na)	4.1	1.8	2.0
Potassium (K)	.9	.5	.9
Bicarbonate (HCO_3)	94	22	26
Sulfate (SO_4)	7.5	14	20
Chloride (Cl)	.0	.4	.8
Fluoride (F)	.0	.2	.4
Nitrate (NO_3)	.2	1.3	2.3
Boron (B)	.01	.07	.08
Dissolved solids	104	98	128
Hardness as $CaCO_3$	72	29	38
Noncarbonate hardness as $CaCO_3$	0	11	18
Alkalinity as $CaCO_3$	77	18	21
Percent sodium	------	12	15
Specific conductance (micromhos at 25°C)	162	62.4	80.7
pH	7.3	6.4	6.6
Color (units)	3	200	280
Turbidity as SiO_2	2	------	------
Temperature (°F)	44	------	------
Date of collection	Sept. 21, 1956	1955–60	

[1] Sampling site is 7 miles north of the area shown on pl. 1.
[2] Location of well.

POTENTIAL WATER SUPPLY

PRESENT GROUND-WATER SOURCE

The village well penetrates permeable zones of the upper slaty and upper cherty members of the Biwabik Iron-Formation. This permeability may be due to either leaching or fracturing of the iron-formation

The well is pumped at less than 100 gpm and is adequate for present needs. A mine-dewatering well in the ore body in the Corsica mine, sec. 18, T. 58 N., R. 16 W., was formerly pumped continuously at 860 gpm and the specific capacity was about 20 gpm per foot of drawdown.

Recharge to the Biwabik Iron-Formation is confined to its outlined extent (pl. 1) and its recharge area is bounded on the north by the Laurentian Divide and on the south by the contact of the Biwabik and the Virginia. The village well receives recharge from the entire width of the recharge area. Additional ground water from this formation could probably be best developed in an altered zone in the vicinity of an abandoned mine. The water level in an abandoned mine will assume the level of the regional water table and the open pit will serve as a storage basin from which recharge can be induced.

Quality of Water.—Water for potential supplies from the upper members of the Biwabik would probably be similar in quality to the present supply. Water from the lower members of the Biwabik would probably contain more dissolved solids, iron, and manganese, and be harder than the present supply and would be similar to the average quality of water from the Biwabik (Cotter and others, 1965a, table 6).

OTHER WATER SOURCES

GROUND WATER

Two areas have been outlined as potential sites for the development of ground water from the glacial drift (pl. 1). Area 1 is the northeast end of a linear body of ice-contact sand and gravel (Gilbert, area 1). No test drilling has been done within area 1, but an examination of the Corsica mine at the north end of the area shows that the glacial drift is about 50 feet thick and contains little permeable sand and gravel. Much of area 1 is occupied by open-pit mines. The main potential of area 1 is in its southwestward extension into Gilbert, area 1 and Eveleth, area 3, where it contains thick sections of permeable sand and gravel.

The valley of the Pike River is outlined as area 2. Its potential as a source of ground water is indicated by the topography. The flat valley floor suggests the presence of underlying water-laid sediments, and the irregular and locally pitted configuration of the flanking hills indicates ice-contact deposition. Water-bearing sand and gravel probably occur in area 2, but the deposits have not been drilled, and test drilling would be necessary to locate thick and permeable saturated sections.

Area 2 receives recharge from a large catchment basin bounded by the Laurentian Divide. Surface- and ground-water movement is from 3 miles southwest and 1½ miles west of the McKinley-Biwabik map (pl. 1). The water table is probably very near the surface, which results in nearly complete saturation of the underlying sediments.

The belt of eastward-trending swamps in the south-central part of the area shown on plate 1 may be underlain by outwash deposited by glacial melt water that passed through the notch in the Giants Range northeast of Embarrass Lake. If test drilling shows the deposits are permeable and thick, large supplies might be obtained in this area.

The deposits associated with Embarrass and Cedar Island Lakes are described in Biwabik, area 3.

SURFACE WATER

A surface water supply could be obtained for McKinley from the Pike River, which is slightly more than a mile to the northwest. The lift from the river would be from altitude 1,480 to 1,550 and then back to about 1,500 feet.

Three miles east of McKinley is the Embarrass River, from which a moderate supply could be obtained.

FLOW DATA

PIKE RIVER NEAR EMBARRASS, MINN.

Location.—Lat 47°39′36″, long 92°18′54″, in NE¼NW¼ sec. 25, T. 60 N., R. 16 W., on left bank 75 feet below bridge on County Road 373, 5.4 miles west of Embarrass, and 8.5 miles downstream from Sandy River.

Drainage area.—115 square miles.

Records available.—October 1953–September 1960.

Average discharge.—7 years, 78.2 cfs.

Extremes: 1953–60.—Maximum discharge, 1,750 cfs, April 17, 1954 (gage height, 10.28 ft); minimum daily, 3.2 cfs, February 24–26, 1955; minimum gage height, 3.19 feet September 3, 4, 1954, August 3, 1956.

The flood in May 1950 reached a stage of approximately 11.3 feet. This information obtained from local residents (discharge 2,400 cfs).

Flood frequency.—10-year flood, 1,930 cfs; 20-year flood, 1,990 cfs; 30-year flood, 2,350 cfs.

Low-flow frequency.—Annual 7-day minimum discharges: 2 years, 5.6 cfs; 10 years, 2.9 cfs.

See Gilbert for Embarrass River near McKinley.

Quality of water.—The chemical quality of the water from the Pike River in the vicinity of McKinley is best indicated by data for Pike River near Embarrass (table 5). The water has a low dissolved-solids content, is free of manganese, and is soft, but it is very highly colored and has a high iron content.

BIWABIK

Population: 1,836

PRESENT WATER SUPPLY

Source of information: Warrent Guimont, former city clerk: Vern Manley, water and light clerk; city records.

Ownership of water supply: Municipal.

Number of customers: Approximately 650 (1960).

Average consumption: 250,000 gpd (estimated, 1960).

Storage: Elevated steel tank, 125,000 gal.

Treatment: Polyphosphate stabilization of iron and manganese.

Source of supply: Two wells, 15 feet apart.

Well location: 58.16.11.bac1. One block north of D. M. & I. R. Railway depot on Sixth Avenue South; drilled in 1953; 8 inches in diameter; 262 feet deep. Cased to 148 feet; is not screened; has a 225 gpm turbine pump. Water is obtained from the Biwabik Iron-Formation between 187 and 262 feet. It has been pumped at 225 gpm for 8 hours. The static water level is 60 feet below land surface.

Well location: 58.16.11bac2. One block north of D. M. & I. R. Railway depot on Sixth Avenue South; drilled in 1954; 16 inches in diameter; 278 feet deep. Cased to 170 feet; is not screened; has a 400 gpm turbine pump. Water obtained from Biwabik Iron-Formation between 191 and 278 feet. When pumped at 400 gpm for 24 hours, water level lowered 100 feet below static water level of 60 feet.

Quality of water.—Water from the Biwabik supply has a moderate dissolved-solids content, is very hard, moderately siliceous, and contains much iron and manganese (table 6). The quality of water from the two wells is probably identical because the wells are about 15 feet apart and are drilled to about the same depth. Because treatment consists only of stabilization of iron and manganese, the analysis also represents the quality of the finished water.

POTENTIAL WATER SUPPLY

PRESENT GROUND-WATER SOURCE

The two city wells, 58.16.11bac1 and 2, are completed in fractured taconite in the upper cherty and upper slaty members of the Biwabik Iron-Formation. The wells are pumped on alternate days, one well serving as a standby in case of mechanical failure of the other. The specific capacity of 58.16.11bac2 was 4 gpm per foot of drawdown after after 24 hours of pumping at 400 gpm.

The Biwabik Iron-Formation is recharged by precipitation falling on the area between its southern limit and the Laurentian Divide (pl. 1). Part of this precipitation that enters the ground enters the iron-formation by vertical infiltration through the overlying glacial drift. Wells in the Biwabik adjacent to Embarrass Lake could induce recharge from the lake. The rate at which recharge could be induced would be controlled by the permeability of the drift between the lake

TABLE 6.—*Chemical anlayses, in parts per million, of water in the Biwabik vicinity*

[Analyses by U.S. Geol. Survey]

Water source	Present water supply	Potential water supply	
	Ground water	Surface water	
	Biwabik Iron-Formation [1] [3] 58.16.11bac 1 and 2	Embarrass River at Embarrass [2] (Station 170)	
		Average	Maximum
Silica (SiO_2)	18	10	21
Iron (Fe)	.13	.45	2.8
Manganese (Mn)	.59	.0	.0
Calcium (Ca)	59	7.9	19
Magnesium (Mg)	28	2.4	6.5
Sodium (Na)	11	1.7	3.6
Potassium (K)	1.7	.8	1.4
Bicarbonate (HCO_3)	292	26	89
Sulfate (SO_4)	30	9.4	15
Chloride (Cl)	6.5	.2	.7
Fluoride (F)	.2	.2	.6
Nitrate (NO_3)	.2	2.0	4.1
Boron (B)	.09	.08	.14
Dissolved solids	292	92	147
Hardness as $CaCO_3$	264	30	74
Noncarbonate hardness as $CaCO_3$	25	8	15
Alkalinity as $CaCO_3$	239	21	73
Percent sodium	------	11	16
Specific conductance (micromhos at 25° C)	514	61	152
pH	7.4	6.9	7.5
Color (units)	0	153	400
Turbidity as SiO_2	.7		
Temperature (°F)	43		
Date of collection	Sept. 25, 1957	1955–57	

[1] Composite sample from both wells.
[2] Sampling site is 8 miles northeast of the area shown on pl. 1.
[3] Location of well.

bottom and the surface of the iron-formation. The yield of the wells would also be dependent on the degree of fracturing and consequent permeability of the iron-formation in the area of recharge.

Leached or fractured parts of the Biwabik Iron-Formation are a good potential source of ground water in the vicinity of Biwabik.

OTHER WATER SOURCES

GROUND WATER

Area 3 is underlain by a complex sequence of stratified drift. Glacial drainage from the north, through the Embarrass channel, deposited this drift. The Embarrass channel, half a mile northeast of the

McKinley-Biwabik map (pl. 1), was cut through the Giants Range by glacial and preglacial drainage. Surface and near-surface sand and gravel form the ice-contact topography of area 3 (pl. 1). The north half of the west boundary of area 3 is formed by shallow bedrock and by a southwestward-trending spur of gray bouldery till represented by a small ridge in secs. 1, 2, and 11. The glacial strata penetrated by city well 58.16.11bac1 consisted of 15 feet of reddish-brown clayey till, 35 feet of sandy clay, and 97 feet of gray bouldery till above the bedrock. The south half of the west boundary is approximate because of the lack of subsurface data in the adjacent swamp.

Plate 1 shows the general sequence of deposits and the range in grain size of the stratified drift within area 3. Logs of other test holes in the area show the variability in the texture and thickness of the stratified drift. Test hole 58.16.11adc1 penetrated 11 feet of reddish-brown till and 121 feet of sand and gravel above bedrock. The city formerly obtained its water supply from a dug and driven well, 58.16.1ccd1, on the west edge of Embarrass Lake. It was finished in gravel at a depth of 78–89 feet.

Ground water and surface water from the Embarrass River basin north of the Giants Range enters area 3 through the Embarrass channel. The southwestern part of the area receives some recharge from precipitation falling south of the Giants Range. Regional ground-water movement is to the south, but locally is toward the lakes.

Large quantities of ground water are available from coarse sand and gravel within area 3. Because the texture and thickness of the stratified drift are extremely variable, test drilling is necessary to locate thick and permeable sections. A well adjacent to a lake within the area could induce recharge from the lake.

Quality of water.—The best estimate of the quality of water for potential supplies from the glacial drift is indicated by the average analysis of water from drift in Cotter and others (1965a, table 6). Water that might be induced into aquifers from the Embarrass River would improve the quality of ground water (tables 4 and 6). The large amount of organic matter, indicated by the color of the river water, could cause a bad taste where natural filtration was slight.

SURFACE WATER

Biwabik lies between the Pike River draining north and the Embarrass River draining south (pl. 1). The boundary of the city extends to within less than a mile of the Pike River and includes part of Embarrass Lake through which the Embarrass River flows. To obtain a supply of water from the Pike River would require a lift of about 60 feet over the divide. On the east, the supply could be obtained from

Embarrass Lake at less cost because the distance to the supply is shorter, although the lift is about the same.

Flow data.—See Gilbert for data on Embarrass River near McKinley. See McKinley for data on Pike River near Embarrass.

Quality of water.—Water from both the Pike and the Embarrass Rivers generally has a low dissolved-solids content and is soft (tables 4–6). Hardness of water from the Embarrass River at Embarrass exceeds 60 ppm only about 15 percent of the time and then only by a few parts per million. The manganese content of water from each of the streams is low, but the iron content is high and the water is colored.

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WATER RESOURCES IN THE VICINITY OF MUNICIPALITIES ON THE EAST-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 east-central Mesabi Iron Range. Both ground water and surface water offer good potential supplies. For the ground-water supplies, the most productive aquifers are the Biwabik Iron Formation and the stratified glacial drift. Surface-water supplies are variable. Streams in the western part of the report area are too small to yield supplies of importance, but lakes are a good potential supply. Eveleth and Gilbert are the only towns presently utilizing this source. In the eastern part of the area of this report, the Pike and Embarrass Rivers offer good potential supplies. Flow records from two gaging stations are presented as are data from many wells and test holes.

Surface water generally has a high concentration of iron and is colored. Most ground water has a high concentration of iron and manganese and is hard. Analyses of water from many sources are presented.

INTRODUCTION

This report describes existing and potential water supplies on the east-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 are 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.

Surface-water supplies in the east-central Mesabi Iron Range are variable. In the western part, drainage areas are too small to yield supplies of any importance. The city of Eveleth obtains water from St. Marys Lake and has good potential supplies from other lakes. Gilbert, the only other town in the area of this report using a surface-water supply, obtains water from Ely Lake. Lakes afford potential supplies to other towns in the region. Near the eastern edge of the area of this report, the Pike and Embarrass Rivers offer a good potential supply. Flow records of two stations in the area are presented.

The quality of ground water 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 6 and 7 in Cotter and others (1965a) 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 57.18.8ddb1 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.

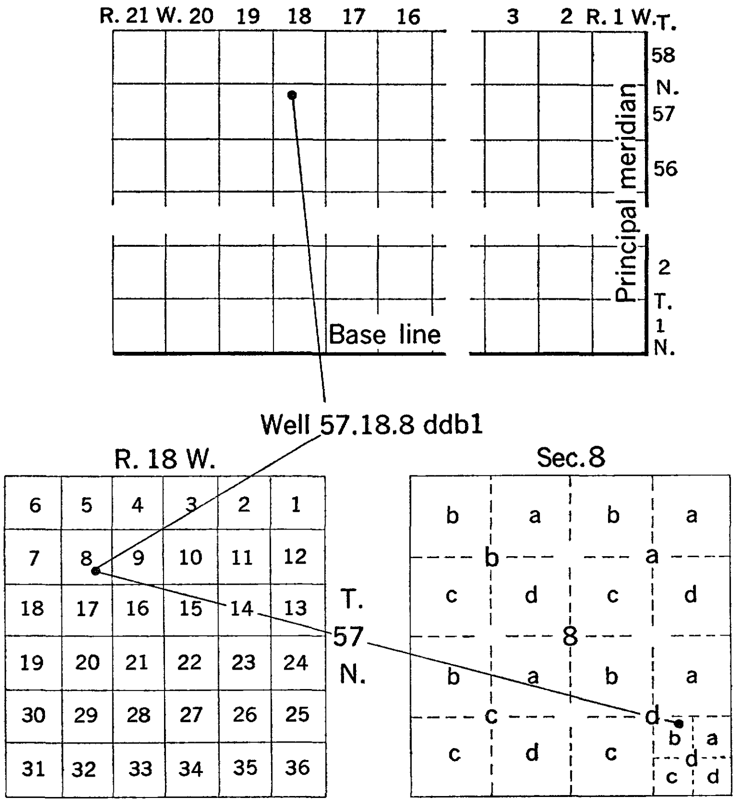

FIGURE 1.—Sketch showing method of numbering test holes and wells

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.

VIRGINIA

Population: 14,034

Virginia is the second largest city on the Mesabi Range. It lies inside the north bend of the "Virginia Horn" about 2 miles west and south of the Laurentian Divide. Drainage is to the north and southwest, away from the divide. The southwestward-flowing drainage reaches the St. Louis River by way of East Two and West Two Rivers.

Near Virginia the Giants Range is composed of Ely Greenstone and the Knife Lake Group, which are intruded by Giants Range Granite (pl. 1). Flanking these rocks on the south and on the west are the Pokegama Quartzite and Biwabik Iron-Formation. In the southwestern part of the area, the bedrock is Virginia Argillite.

The city obtains its water supply from the Biwabik Iron-Formation and the glacial drift.

PRESENT WATER SUPPLY

Source of information: Ed Kozan, assistant superintendent, water and light commission; Forty-sixth annual report of the Water and Light Commission, 1960.

Ownership of water supply: Municipal (pumpage is controlled to some extent by Pacific Isle Mining Co. for the purpose of facilitating mining operations).

Number of customers: 4,217 (1959–60). Also supplies Parkville and West Virginia.

Average consumption: 1,238,000 gpd (gallons per day) (1960).

Storage: Concrete reservoir, 1 million gal.; elevated steel tank, 1 million gal.

Treatment: Coagulation with sodium aluminate, lime and bentonite; chlorination; sedimentation; polyphosphate stabilization; rapid sand filtration.

Source of supply: Missabe Mountain mine and two wells. Most of city's water obtained from Missabe Mountain open-pit mine, not presently active; a small lake has formed in bottom of pit. Pumping station (58.17.8aca) at top of a 12- by 14-foot shaft, 157 feet deep; 2 horizontal shafts at 142 feet extend laterally into lake bottom. Shaft contains 3 turbine pumps, having capacities of 1,000, 2,000, and 2,000 gpm (gallons per minute). The 2,000 gpm units are auxiliary pumps. Water obtained principally from Biwabik Iron-Formation.

Well location 58.17.8cbb1. At Sixth Avenue West and First Street South. This is an auxiliary drilled well; 14 inches in diameter; 450 feet deep. Not screened; has a 500 gpm turbine pump. Water obtained from Biwabik Iron-Formation between 118 and 450 feet; static water level 75 feet below land surface.

Well location 58.18.12ccc3. At McInnis Road and Virginia Road, 0.5 mile west of West Virginia. This is an auxiliary well drilled in 1958; 16 inches in diameter; 94 feet deep. Finished between 69 and 94 feet with 16-inch stainless steel screen; has a turbine pump. Water obtained from glacial sand and gravel. When pumped at 1,400 gpm for 3 days, water level lowered 30 feet below static level of 21 feet.

Quality of water.—The raw water has a moderate dissolved-solids content and is very hard. (Table 1.) The water from the Missabe Mountain open-pit mine is moderately siliceous but is better in quality than that from auxiliary well 58.17.8cbb1 because it contains less iron and manganese. Exposure of the water to air in the open pit probably causes precipitation of much of the iron and manganese. The water quality from auxiliary well 58.18.12ccc3 is represented by the analysis for 12ccc2. It has a high concentration of iron and manganese but not as high as water from 58.17.8cbb1. The finished water meets cur-

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

[Analyses for 58.18.23cbb6 by Oliver Mining Div., U.S. Steel Corp.; all others by the U.S. Geol. Survey]

	Present water supply				Potential water supply								
	Ground water				Ground water						Surface water		
Water source	Biwabik Iron-Formation		Glacial drift		Glacial drift						Manganika Lake outlet		Mashkenode Lake outlet
Location	58.17.8 aca	----------	58.17.8 aca	58.17.8 cbb1	58.17.18 bdd3	58.17.18 cca3	58.18.12 ccc2	58.18.14 daa1	58.18.14 dca1	58.18.23 cbb6			
Silica (SiO_2)	14	14	16	4.1	21	19	20	24	22	----------	12	9.9	4.4
Iron (Fe)	.08	.04	.07	4.9	.06	.10	.32	1.7	2.1	0.8	.05	.01	.14
Manganese (Mn)	.00	.00	.05	1.8	1.7	.71	.66	1.6	2.7	1.2	1.2	.06	.60
Calcium (Ca)	47	30	52	76	91	83	64	64	100	----------	59	49	31
Magnesium (Mg)	19	.1	21	36	40	38	26	24	33	----------	32	21	9.6
Sodium (Na)	7.9	20	9.0	12	14	12	6.8	4.9	5.1	----------	22	25	7.3
Potassium (K)	1.4	1.3	2.6	3.9	3.8	3.5	2.5	3.3	3.0	----------	4.8	4.5	2.9
Bicarbonate (HCO_3)	203	0[1]	225	332	400	340	283	294	385	----------	190	200	120
Sulfate (SO_4)	35	35	44	88	87	103	47	30	73	----------	112	52	29
Chloride (Cl)	10	12	8.0	4.8	.4	2.2	2.5	1.5	3.1	----------	33	31	4.7
Fluoride (F)	.1	.1	.1	.2	.2	.3	.3	.2	.2	----------	.3	.0	.2
Nitrate (NO_3)	3.4	2.2	.5	.0	.2	.0	.1	.0	.1	----------	11	3.1	2.3
Boron (B)	----------	----------	.03	.04	.06	.02	.04	.04	.02	----------	.08	.11	.04
Dissolved solids	248	148	264	396	452	431	309	299	434	----------	428	311	159
Hardness as $CaCO_3$	197	75	217	339	391	365	266	258	384	197	278	210	117
Noncarbonate hardness as $CaCO_3$	31	41	32	67	63	86	34	17	68	----------	122	46	19
Alkalinity as $CaCO_3$	166	34	185	272	328	279	232	241	316	197	156	164	98
Specific conductance (micromhos at 25°C)	400	272	443	648	737	687	510	497	693	----------	625	511	262
pH	7.6	10.6	7.8	7.6	7.2	7.4	7.5	7.3	7.5	7.0	7.3	7.6	7.2
Color (units)	2	1	3	4	----------	----------	----------	4	----------	----------	10	13	13
Turbidity as SiO_2	5	5	3	.3	----------	----------	----------	----------	----------	----------	----------	----------	----------
Temperature (°F.)	----------	43	55	44	43	43	43	43	42	----------	----------	----------	----------
Date of collection	May 3, 1951		Sept. 26, 1957	Dec. 13, 1960	Sept. 26, 1958	Oct. 24, 1958	Oct. 6, 1954	Oct. 12, 1955	Sept. 1, 1959	Nov. 16, 1960	April 17, 1958	Sept. 27, 1962	April 17, 1958

[1] Hydroxide (OH), 10 ppm; carbonate (CO_3), 20 ppm.

rent drinking-water standards (U.S. Public Health Service, 1962). It has a low dissolved-solids content, is moderately hard, and has little iron or manganese.

POTENTIAL WATER SUPPLY

PRESENT SOURCE

The Virginia water supply from the Missabe Mountain mine is a combination of ground water and surface water. Although some surface water runoff enters the manmade lake, most of the water pumped is from ground water discharged from the lower cherty member of the Biwabik Iron-Formation. Two mine shafts "feeding" the pumps increase the area of exposure to the aquifer tremendously and allow rapid inflow of ground water. Because the pumping is from an open body of water and the level of this water surface is affected by adjacent mine pumpage, drawdown data are meaningless.

Locally, ground-water movement is toward the open pits where the water level is depressed by mine drainage. When drainage of adjacent sections of the pit are discontinued, recharge to the lake in the Missabe Mountain mine should be ample to supply the city.

Auxiliary city well 58.17.8cbb1 penetrates the Virginia Argillite and is finished in the upper slaty and upper cherty members of the iron-formation, which are fractured taconite at this location. This well has been pumped at a rate of 450 gpm, but a higher rate reportedly caused excessive drawdown. The static water level in an observation well about 500 feet southwest of this well is about 45 feet below the land surface. The water level in this well is lowered when city well 58.17.8cbb1 is pumped, but it shows no response to periods of heavy rainfall. The low permeability of the overlying glacial drift and Virginia Argillite near the observation well prevents infiltration to the aquifer.

Recharge to the iron-formation in the vicinity of Virginia is greater than in other areas bounded by the Laurentian Divide because of the funneling effect produced by the arcuate shape of the "Virginia Horn."

Auxiliary well 58.18.12ccc3 is finished in a thick section of permeable sand and gravel (pl. 1). It is within area 1, one of two numbered areas known to contain permeable stratified drift aquifers.

Area 1 delineates ice-contact sediments overlain by reddish-brown clayey till. The texture and thickness of the water-laid sediments are variable, but some of the material is very permeable as indicated by the specific capacities of wells 3–7. (See table 2.)

TABLE 2.—*Specific capacities of test wells in the Virginia vicinity*

Well	Location	Pumping rate (gpm)	Period of pumping (hours)	Specific capacity (gpm per foot of drawdown)
1	58.17.18bdd3	260	24	137
2	18cca3	455	24	38
3	58.18.12ccc2	142	24	51
4	12ccc3	1,400	72	47
5	14daa1	325	½	168
6	14dca1	192	24	34
7	23cbb6 [1]	210	24	40?

[1] This site is 100 ft west of the area shown on pl. 1 along *B–B′*.

The most permeable deposits are alined in a southwest trend along the trace of geologic section *B–B′* (pl. 1) from 23cbb6 to 12ccc2 and 3. Testing indicates that wells along this trend can supply a large volume of ground water. The character of the deposits in the southeast part of Area 1 is inferred from topography, and the location of this boundary is approximate.

Recharge to the stratified drift in Area 1 is derived from precipitation falling south of the Laurentian Divide within the Virginia map area (pl. 1). Ground-water movement is to the south through Area 1 and some recharge can undoubtedly be induced from the lakes and streams. The principal deterrent to recharge of the stratified drift by infiltration is the overlying reddish-brown clayey till. Observation wells 58.18.12ccc1 and 13aba1 are finished in sand and gravel beneath 10–30 feet of surficial clayey till. However, the till pinches out less than half a mile north of well 58.18.12ccc1. Both observation wells show a rapid rise in water level following periods of heavy rainfall. It is not known whether these rises in water level represent recharge to the aquifer or loading of the surface.

Area 1 has a very good potential for the development of groundwater from glacial drift.

OTHER WATER SOURCES

GROUND WATER

Area 2 outlines outwash deposits in a buried channel which has no surficial expression. The outwash aquifer in Area 2 underlies a thick section of reddish-brown clayey till (section *A–A′*, pl. 1). (See Cotter and Rogers, 1961, pl. 2 for a more detailed section.) Table 2 (wells 1 and 2) lists the test pumping of outwash in Area 2.

The test pumping of 58.17.18bdd3 was from a thin permeable section of outwash. The test indicated that water was drawn from a small part of the aquifer that was receiving little or no recharge during the period of pumping. The outwash penetrated in well 58.17.18cca3 was thicker and a pumping test showed a greater volume of water in storage. However, recharge to Area 2 from the north and west is limited by the nearness of the Laurentian Divide, the open-pit mines, and the city of Virginia. Within the city much of the potential recharge from precipitation is diverted through storm sewers. A permanent well at 58.17.18bdd3 probably would soon deplete the aquifer. The pumping rate of a well-field development at 58.17.18caa3 would have to be controlled to avoid dewatering the aquifer.

The southern extent of this channel deposit has not been determined, but it may extend into the area of ice-contact deposits outlined under Iron Junction in area 1 (Cotter and others, 1965b). The northern part of the area is in a bedrock low (Oakes, 1964, map 2), which appears to extend north into the vicinity of Virginia Lake.

Quality of water.—The quality of the potential supply of water from the glacial drift is indicated by analyses in table 1. Water for potential supplies from the Biwabik and the drift is not likely to be as good as the water from the open pit now in use because of higher dissolved solids, hardness, iron, and manganese.

SURFACE WATER

Virginia and Silver Lakes lie within the city limits of Virginia. A tributary of East Two River flows through these lakes. Because it heads at the nearby Laurentian Divide, the stream is small. No flow records on this creek are available, but it is doubtful if the flow would be great enough to sustain the lake levels if water were withdrawn for use by the city. The East Two River drainage and Mashkenode and Manganika Lakes southwest of Virginia form small potential supplies.

Quality of water.—According to the two analyses of lake outflow given in table 1, water from Manganika Lake is poorer in quality than water from the present supply; it has a much higher dissolved-solids content and is much harder. At times, the manganese content of the water is also very high. Discharge from the Virginia sewage-disposal plant into Manganika Lake alters the chemical and bacterial quality of the water. Comparison of the two analyses indicates significant fluctuations in sulfate, nitrate, and fluoride content of the water.

Water from Mashkenode Lake, less than a mile west of Manganika Lake, seems from the one analysis available to be of much better quality than water from Manganika Lake but not as good as the present supply.

EVELETH

Population: 5,721

The city of Eveleth is on the south flank of a large flexure in the Giants Range known as the "Virginia Horn." Drainage in this area is away from the Laurentian Divide, to the south into the St. Louis River.

As shown on plate 1, the Biwabik Iron-Formation and the Pokegama Quartzite parallel the Laurentian Divide, which follows the curvature of the "Horn." The Virginia Argillite underlies the area to the south and west. The Giants Range is composed of Ely Greenstone and the Knife Lake Group and has a thin mantle of glacial drift. South and west of the Giants Range within the Eveleth map area (pl. 1), the glacial drift has an average thickness of about 100 feet. Eveleth's water supply is obtained from St. Marys Lake.

PRESENT WATER SUPPLY

Source of information: J. V. Anderson, public utilities superintendent; city records.

Ownership of water supply: Municipal.

Number of customers: Approximately 1,750 (1960). Also supplies village of Leonidas.

Average consumption: 700,000 gpd (estimated, 1960).

Storage: Clear well, 100,000 gal.; elevated steel tank, 310,000 gal.

Treatment: Prechlorination; coagulation with alum; sedimentation; rapid sand filtration; postchlorination.

Source of supply: St. Marys Lake. Pumping station at north end of St. Marys Lake (57.17.9cac) equipped with three pumps having capacities of 1,150 gpm each. Two of these are auxiliary units. A 16-inch intake pipe extends 100 feet into the lake and the point intake is 20 feet below lake level.

Quality of water.—Water from St. Marys Lake has a low dissolved-solids content but is moderately hard (table 3). The chemical constituents except for iron and manganese meet the drinking-water standards. The saturation index of about −1.4 determined for September 26, 1957, indicates that the water has a tendency to be corrosive. The municipal treatment reduces the color and turbidity; the chemical composition of the finished water is probably similar to that of the raw water.

POTENTIAL WATER SUPPLY

PRESENT SURFACE-WATER SOURCE

The city of Eveleth obtains its water from St. Marys Lake. The pumping capacity is 3,450 gpm of which 2,300 gpm are auxiliary units. With no apparent inlet or outlet, St. Marys Lake is evidently dependent on ground water to maintain its supply. No data is available regarding the maximum pumpage that might be developed.

TABLE 3.—*Chemical analyses, in parts per million, of the public water supply at Eveleth*

[Analyses of finished water by the Minnesota Dept. of Health; analyses of 57.17.9 cac by U.S. Geol. Survey]

Water source	Finished	St. Marys Lake [1] 57.17.9 cac
Silica (SiO_2)		0.9
Iron (Fe)	0.26	.17
Manganese (Mn)	.09	.06
Calcium (Ca)		16
Magnesium (Mg)		6.6
Sodium (Na)		3.3
Potassium (K)		1.9
Bicarbonate (HCO_3)		71
Sulfate (SO_4)	10	13
Chloride (Cl)		3.2
Fluoride (F)	.14	.1
Nitrate (NO_3)		.7
Boron (B)		.01
Dissolved solids		93
Hardness as $CaCO_3$	79	67
Noncarbonate hardness as $CaCO_3$		9
Alkalinity as $CaCO_3$	65	58
Specific conductance (micromhos at 25°C)		150
pH	7.7	6.9
Color (units)		7
Turbidity as SiO_2		1
Date of collection	Dec. 8, 1949	Sept. 26, 1957

[1] Location of well.

OTHER WATER SOURCES

SURFACE WATER

Northwest of Eveleth lies Manganika Lake (pl. 1), which is near the headwaters of East Two River. Adjacent to St. Marys Lake are Ely and Horseshoe Lakes, and to the south are Long and Pleasant Lakes. These lakes have potential supplies as great as St. Marys Lake.

Quality of water.—The water from Manganika Lake is discussed on page E8 and in table 1. An analysis of the water from Ely Lake is given in table 4. No chemical quality data are available for Long, Horseshoe, and Pleasant Lakes.

GROUND WATER

The rich ore from the mines in this area indicates the extensive leaching and oxidation which has taken place in the Biwabik Iron-Formation near Eveleth. Bodies of permeable low grade ore probably occur adjacent to mined-out areas. However, these mines are high on the flank of the Giants Range, and recharge to wells near the mines would be extremely limited. The inactive pits in the area are either dry or contain little water, indicating that the glacial drift and at least 100 feet of the Biwabik is unsaturated.

Test holes west and south of the Giants Range penetrated permeable sand and gravel deposits in the Eveleth map area (pl. 1). (See also Cotter and Rogers, 1961, pls. 1 and 2.) On the basis of test drilling and a study of the topography, three areas have been outlined that are favorable for the development of ground water from glacial drift.

Although its limits are poorly controlled, area 1 is probably an extension of the bedrock channel in Virginia, area 2. Reported logs of test holes 58.18.25acb1 and 25abb1, 0.2 mile north of the Eveleth map area, show 41 feet of sand and 88 feet of sand and gravel, respectively. Test hole 58.18.25cab1 penetrated outwash consisting of 88 feet of silt underlain by 5 feet of sand and gravel. The depth at which bedrock was found in these three holes (106–157 ft) was 15–55 feet below the altitude at which it was found in 58.18.26add1, and this indicates a bedrock low in area 1.

The recharge area is bounded on the east by the Laurentian Drainage Divide, and ground-water movement down gradient from the north would be the principal source of recharge to a well in area 1.

Area 2 is a small part of the ice-contact area that is described under Iron Junction, area 2 (Cotter and others, 1965b). Test hole 57.18.25 bbc2 penetrated sand and gravel from 26 feet to the bottom of the hole at 66 feet (pl. 1). Both areas 1 and 2 have better potential for ground-water development in their extensions described under Iron Junction and Virginia than they do within the Eveleth map area.

Area 3 is underlain by ice-contact sediments ranging in grain size from clay to gravel. It is the southwest extension of Gilbert, area 1 and McKinley, area 1 that flank the southeast side of the "Virginia Horn." Two geologic sections (pl. 1) show the variability of the stratified drift. Test hole 57.17.20aab1 penetrated 26 feet of sand and gravel and 49 feet of silt and clay above the gray bouldery till. Three test holes in secs. 8 and 17 penetrated from 9 to 37 feet of sand and gravel below the reddish-brown clayey till, and test hole 57.17.21 cdd1, in the southeast extension of area 3, penetrated 106 feet of well-sorted sand and gravel.

The land surface in much of area 3 is above the level of the adjacent lakes, and water levels in wells within the area are close to lake levels. The upper part of the stratified drift is commonly unsaturated, and the thickest saturated sections are adjacent to Ely and St. Marys Lakes. The lake levels of Mud, Horseshoe, Long, and Pleasant Lakes range from 19 to 36 feet above the level of St. Marys and Ely Lakes, and the saturated thickness of adjacent drift is proportionally less.

Area 3 has very good potential for the development of large ground-water supplies. It is underlain by thick sections of saturated sand

and gravel. Recharge available to the drift underlying area 3 exceeds the amount available to its northeast extension. Recharge results from infiltration of precipitation within area 3 and from lateral ground-water movement from the north.

Except for the areas previously described, the remainder of the Eveleth map area (pl. 1) has a low potential for ground-water development. The ridge extending southwest from Eveleth is composed of gray bouldery till overlain by reddish-brown-clayey till and very little, if any, intermediate stratified drift. Test drilling elsewhere within the map area penetrated mainly till, silt, and clay (pl. 1).

GILBERT

Population: 2,591

The city of Gilbert is on the southeast flank of the flexure in the Giants Range called the "Virginia Horn." Although the northward flowing Pike River crosses the northwest corner of the Gilbert map area (pl. 1) most of the area drains to the southeast into the Embarrass River and thence into the St. Louis River.

Except for the northwestern part, the area is underlain by the Virginia Argillite. In the northwest are the other two members of the Animikie Group—the Biwabik Iron-Formation and the Pokegama Quartzite—and the basement complex of the Knife Lake Group, Ely Greenstone, and Giants Range Granite. The glacial-drift cover thickens southeast of the north limit of the iron-formation and is nearly 300 feet thick south of Silver Lake. (See geologic section *A–A′*, pl. 1.)

The city of Gilbert obtains its water supply from Ely Lake.

PRESENT WATER SUPPLY

Source of information: J. J. Kraker, water superintendent; city records.
Ownership of water supply: Municipal.
Number of customers: 858 (1960).
Average consumption: 200,000 gpd (estimated, 1960).
Storage: Clear well, 100,000 gal; elevated steel tank, 100,000 gal.
Treatment: Prechlorination, coagulation with alum; sedimentation; filtration; postchlorination.
Source of supply: Ely Lake.
Pumping station, at north end of Ely Lake (58.17.35cbc), equipped with two 60 hp pumps having capacities of 350 gpm each; one an auxiliary unit. A 10-inch intake pipe extends 607 feet into the lake.

Quality of water.—Water from Ely Lake has a low dissolved-solids content and is moderately hard. (See table 4.) Except for iron and manganese, the chemical constituents probably do not exceed the recommended maximum for drinking water most of the time. The saturation index of −1.1 calculated for September 26, 1957, indicates that the water is somewhat corrosive. The treatment process reduces the color and turbidity and partially reduces the iron content of the water.

TABLE 4.—*Chemical analyses, in parts per million, of water in the Gilbert vicinity*

[Analyses of finished water by the Minnesota Dept. of Health; all others by the U.S. Geol. Survey]

Water source	Present water supply			Potential water supply	
	Surface water			Surface water	
	Finished		Ely Lake [1]58.17.35 cbc	Embarrass River near McKinley (Station 180)	
				Average	Maximum
Silica (SiO_2)			4.7	9.9	14
Iron (Fe)	0.06	[2] 0.44	.26	.40	.88
Manganese (Mn)	0		.00	.0	.0
Calcium (Ca)			19	15	22
Magnesium (Mg)			6.5	4.8	6.0
Sodium (Na)			4.0	2.7	3.9
Potassium (K)			1.7	1.0	1.6
Bicarbonate (HCO_3)			84	55	80
Sulfate (SO_4)	8.8		8.8	14	21
Chloride (Cl)	6.5		2.8	.6	2.2
Fluoride (F)	0		.1	.2	.3
Nitrate (NO_3)			.8	1.2	2.3
Boron (B)			.02	.07	.20
Dissolved solids			97	103	128
Hardness as $CaCO_3$	90		74	56	82
Noncarbonate hardness as $CaCO_3$			5	11	16
Alkalinity as $CaCO_3$	80		69	45	66
Percent sodium				9	11
Specific conductance (micromhos at 25°C)			164	120	180
pH	7.5		7.1	7.1	7.5
Color (units)			6	80	150
Turbidity as SiO_2			3		
Date of collection	Oct. 9, 1951	July 23, 1955	Sept. 26, 1957	1955–60	

[1] Location of well.
[2] Concentration of iron in raw water was 1.3 ppm.

POTENTIAL WATER SUPPLY

PRESENT SURFACE-WATER SOURCE

The towns of Gilbert and Sparta obtain their water supply from Ely Lake. The combined capacity is 700 gpm of which 350 gpm is an auxiliary supply. No data are available regarding the maximum which might be pumped.

OTHER WATER SOURCES

SURFACE WATER

The Ely Lake supply could be augmented by pumping from the Embarrass River about 3½ miles southeast. The lift is less than 40 feet. (See pl. 1.)

FLOW DATA

EMBARRASS RIVER NEAR MCKINLEY

Location.—Lat 47°27′10″, long 92°23′00″, in NW¼ sec. 4, T. 57 N., R. 16 W., on left bank 40 feet upstream from highway bridge, 0.9 mile downstream from outlet of Esquagama Lake, 4.5 miles southeast of McKinley.

Drainage area.—171 square miles.

Records available.—October 1953–September 1960.

Average discharge.—7 years, 109 cfs.

Extremes: 1953–60.—Maximum discharge, 1,690 cfs (cubic feet per second), April 20, 1954 (gage height, 11.72 ft); minimum, 11 cfs, September 7, 1955; minimum gage height, 2.66 feet, June 26, 1959; minimum daily discharge, 12 cfs, September 6, 7, 1955.

Flood frequency.—10-year flood, 1,570 cfs; 20-year flood, 1,910 cfs; 30-year flood, 2,260 cfs.

Low-flow frequency.—Annual 7-day minimum discharges: 2-year, 20 cfs; 10-year, 15 cfs; 20-year, 12 cfs.

Quality of water.—The chemical quality of the water available from the Embarrass River in the vicinity of Gilbert is indicated by data in table 4. The water has a low dissolved-solids content and is soft most of the time and only moderately hard other times. It is, however, highly colored and has much iron.

GROUND WATER

The Biwabik Iron-Formation lies in a northeastward trending belt, and its northwest edge abuts the city of Gilbert. As is evidenced by the many open-pit mines, a considerable part of the iron-formation has been altered to ore in the area. No data are available on wells in the iron-formation near Gilbert, but the Biwabik is a potential source of ground water. Large quantities of water can be obtained only from oxidized and leached, or highly-fractured parts of the formation. Wells completed adjacent to active open-pit mines, where the water level is artificially depressed by mine drainage and where the saturated thickness is less, have a smaller potential yield.

Recharge to the iron-formation from precipitation is limited by the nearness of the Laurentian Drainage Divide. The principal recharge to the formation is through lakes and abandoned mines, and by infiltration through the overlying glacial drift. Additional recharge takes place from lateral ground-water movement from the northeast through the overlying permeable glacial drift.

Two ice-contact areas shown on the map on plate 1 have been outlined as potential sources of ground water from glacial drift. Buried ice-contact sediments deposited along the front of the Giants Range are outlined as area 1. The southwest lineation is emphasized by the trend of Deep and Ely Lakes and by the eskers in sec. 19, T. 58 N., R. 16 W., and sec. 24, T. 58 N., R. 17 W. Prominent southeast linear features include Leaf and Lost Lakes and their swampy extensions and the eskers in sec. 25 and 36. The deposits of sand and gravel associated with these linear deposits are shown on the west end of geologic sections *A–A′* and *B–B′*, plate 1. Test hole 57.17.3dcc2 south of Ely Lake penetrated 88 feet of sand and gravel overlying gray bouldery till. A city test well, 58.17.35dbb3, between Deep Lake and Ely Lake was completed in the stratified drift within area 1. It was reportedly pumped at 600 gpm for 10 days and showed a specific capacity of about 10 gpm per foot of drawdown. The pumping level in this test was only a few feet above bedrock and was undoubtedly sustained by recharge from Deep Lake.

Regional ground-water movement is to the southeast although local movement is toward lakes within area 1. The recharge area for area 1 is bounded on the north and west by the Laurentian Divide, and is about 12 square miles.

Area 1 contains thick sections of very permeable sand and gravel, which are capable of sustaining large-capacity wells. The long-term yield of area 1 is limited by the small area of recharge and dewatering of open-pit mines.

The chain of lakes and their associated sand and gravel deposits described under Biwabik, area 3, extend into the Gilbert map area (pl. 1). This ice-contact topography, which is underlain by coarse-grained water-laid sediments, is outlined as area 2. It contains deposits of sand and gravel which underlie surface or near-surface reddish-brown clayey till (section *B–B′*, pl. 1).

Regional ground-water movement is to the south toward the St. Louis River, but local movement is into lakes and streams. Area 2 has a much larger recharge area than the areas adjacent to the Giants Range. The water levels in area 2 are generally within 20 feet of the land surface (pl. 1).

South and east of area 2 the land surface is relatively flat and the clayey till is more deeply buried. The stratified drift under the till is finer textured and (or) thinner and probably will not yield large quantities of water to wells. An exception to this is along a second chain of lakes that trend northeastward and that are just southeast of the Gilbert map area. Along this trend the reddish-brown clayey till is shallow and is underlain by permeable sand and gravel. The sand and gravel section shown in the easternmost test hole on geologic section *A–A′* thickens to 64 feet in test hole 57.16.2cdc1, 0.3 mile east of the map area shown on plate 1. Other test holes indicate that this stratified drift is a channel fill underlying the chain of lakes.

Both area 2 and its counterpart to the southeast are good potential sources of water. Wells near one of these lakes could induce recharge from the lake.

Quality of Water.—The average analyses in Cotter and others (1965a, table 6) indicate the probable quality of water from potential ground-water supplies where the influence of lake seepage is small or absent. Where the influence of lake seepage is significant, the water would probably be better than the average analyses because the water from the lakes has less dissolved solids, silica, iron, manganese, and hardness. It is unlikely that water from either the Biwabik or the glacial drift would be as good as the water of the present supply.

McKINLEY AND BIWABIK

The village of McKinley and the city of Biwabik lie on the south flank of the Giants Range (pl. 1). Except for the northwest corner, the area drains south into the St. Louis River. The northward-flowing Pike River drains the area north of the Laurentian Divide.

The Giants Range is made up of Ely Greenstone, Knife Lake Group, and Giants Range Granite. The southward-dipping Animikie Group laps onto the Giants Range Granite. The glacial drift is thin or absent on the Giants Range and thickens to the southeast. It is 70 feet thick at the McKinley well, 150 feet thick at the Biwabik wells, and 198 feet thick at test hole 58.16.13ada1. The two municipalities overlie the Biwabik Iron-Formation and obtain their water supply from this unit.

McKINLEY

Population: 408

PRESENT WATER SUPPLY

Source of information: Jake Butala, water supervisor.
Ownership of water supply: Municipal.
Number of customers: 112 (1960).
Average consumption: 18,000 gpd (estimated, 1955).
Storage: Elevated steel tank, 75,000 gal.
Treatment: None.
Source of supply: One well.

Well location 58.16.8ddd1. Nine-tenths of a mile northeast of McKinley on State Highway 135; drilled in 1921; 6 inches in diameter; 270 feet deep. It is screened and has a 150 gpm airlift pump. Water obtained from Biwabik Iron-Formation below 179 feet.

Quality of Water.—The water meets the drinking-water standards for all chemical constituents (table 5). It has a low dissolved-solids content, is moderately hard, and is siliceous. The saturation index of −0.9 calculated for 80°F indicates that the water has a tendency to be corrosive; however, at higher temperatures the tendency probably disappears.

TABLE 5.—*Chemical analyses, in parts per million, of water in the McKinley vicinity*

[Analyses by the U.S. Geol. Survey]

Water source	Present water supply	Potential water supply	
	Ground water	Surface water	
	Biwabik Iron-Formation [2] 58.16.8ddd1	Pike River near Embarrass [1] (Station 1285)	
		Average	Maximum
Silica (SiO_2)	21	9.0	13
Iron (Fe)	.10	1.0	1.5
Manganese (Mn)	.00	.0	.0
Calcium (Ca)	18	7.3	9.4
Magnesium (Mg)	6.6	2.7	3.5
Sodium (Na)	4.1	1.8	2.0
Potassium (K)	.9	.5	.9
Bicarbonate (HCO_3)	94	22	26
Sulfate (SO_4)	7.5	14	20
Chloride (Cl)	.0	.4	.8
Fluoride (F)	.0	.2	.4
Nitrate (NO_3)	.2	1.3	2.3
Boron (B)	.01	.07	.08
Dissolved solids	104	98	128
Hardness as $CaCO_3$	72	29	38
Noncarbonate hardness as $CaCO_3$	0	11	18
Alkalinity as $CaCO_3$	77	18	21
Percent sodium	------	12	15
Specific conductance (micromhos at 25°C)	162	62.4	80.7
pH	7.3	6.4	6.6
Color (units)	3	200	280
Turbidity as SiO_2	2	------	------
Temperature (°F)	44	------	------
Date of collection	Sept. 21, 1956	1955–60	

[1] Sampling site is 7 miles north of the area shown on pl. 1.
[2] Location of well.

POTENTIAL WATER SUPPLY

PRESENT GROUND-WATER SOURCE

The village well penetrates permeable zones of the upper slaty and upper cherty members of the Biwabik Iron-Formation. This permeability may be due to either leaching or fracturing of the iron-formation

The well is pumped at less than 100 gpm and is adequate for present needs. A mine-dewatering well in the ore body in the Corsica mine, sec. 18, T. 58 N., R. 16 W., was formerly pumped continuously at 860 gpm and the specific capacity was about 20 gpm per foot of drawdown.

Recharge to the Biwabik Iron-Formation is confined to its outlined extent (pl. 1) and its recharge area is bounded on the north by the Laurentian Divide and on the south by the contact of the Biwabik and the Virginia. The village well receives recharge from the entire width of the recharge area. Additional ground water from this formation could probably be best developed in an altered zone in the vicinity of an abandoned mine. The water level in an abandoned mine will assume the level of the regional water table and the open pit will serve as a storage basin from which recharge can be induced.

Quality of Water.—Water for potential supplies from the upper members of the Biwabik would probably be similar in quality to the present supply. Water from the lower members of the Biwabik would probably contain more dissolved solids, iron, and manganese, and be harder than the present supply and would be similar to the average quality of water from the Biwabik (Cotter and others, 1965a, table 6).

OTHER WATER SOURCES

GROUND WATER

Two areas have been outlined as potential sites for the development of ground water from the glacial drift (pl. 1). Area 1 is the northeast end of a linear body of ice-contact sand and gravel (Gilbert, area 1). No test drilling has been done within area 1, but an examination of the Corsica mine at the north end of the area shows that the glacial drift is about 50 feet thick and contains little permeable sand and gravel. Much of area 1 is occupied by open-pit mines. The main potential of area 1 is in its southwestward extension into Gilbert, area 1 and Eveleth, area 3, where it contains thick sections of permeable sand and gravel.

The valley of the Pike River is outlined as area 2. Its potential as a source of ground water is indicated by the topography. The flat valley floor suggests the presence of underlying water-laid sediments, and the irregular and locally pitted configuration of the flanking hills indicates ice-contact deposition. Water-bearing sand and gravel probably occur in area 2, but the deposits have not been drilled, and test drilling would be necessary to locate thick and permeable saturated sections.

Area 2 receives recharge from a large catchment basin bounded by the Laurentian Divide. Surface- and ground-water movement is from 3 miles southwest and 1½ miles west of the McKinley-Biwabik map (pl. 1). The water table is probably very near the surface, which results in nearly complete saturation of the underlying sediments.

The belt of eastward-trending swamps in the south-central part of the area shown on plate 1 may be underlain by outwash deposited by glacial melt water that passed through the notch in the Giants Range northeast of Embarrass Lake. If test drilling shows the deposits are permeable and thick, large supplies might be obtained in this area.

The deposits associated with Embarrass and Cedar Island Lakes are described in Biwabik, area 3.

SURFACE WATER

A surface water supply could be obtained for McKinley from the Pike River, which is slightly more than a mile to the northwest. The lift from the river would be from altitude 1,480 to 1,550 and then back to about 1,500 feet.

Three miles east of McKinley is the Embarrass River, from which a moderate supply could be obtained.

FLOW DATA

PIKE RIVER NEAR EMBARRASS, MINN.

Location.—Lat 47°39′36″, long 92°18′54″, in NE¼NW¼ sec. 25, T. 60 N., R. 16 W., on left bank 75 feet below bridge on County Road 373, 5.4 miles west of Embarrass, and 8.5 miles downstream from Sandy River.

Drainage area.—115 square miles.

Records available.—October 1953–September 1960.

Average discharge.—7 years, 78.2 cfs.

Extremes: 1953–60.—Maximum discharge, 1,750 cfs, April 17, 1954 (gage height, 10.28 ft); minimum daily, 3.2 cfs, February 24–26, 1955; minimum gage height, 3.19 feet September 3, 4, 1954, August 3, 1956.

The flood in May 1950 reached a stage of approximately 11.3 feet. This information obtained from local residents (discharge 2,400 cfs).

Flood frequency.—10-year flood, 1,930 cfs; 20-year flood, 1,990 cfs; 30-year flood, 2,350 cfs.

Low-flow frequency.—Annual 7-day minimum discharges: 2 years, 5.6 cfs; 10 years, 2.9 cfs.

See Gilbert for Embarrass River near McKinley.

Quality of water.—The chemical quality of the water from the Pike River in the vicinity of McKinley is best indicated by data for Pike River near Embarrass (table 5). The water has a low dissolved-solids content, is free of manganese, and is soft, but it is very highly colored and has a high iron content.

BIWABIK

Population: 1,836

PRESENT WATER SUPPLY

Source of information: Warrent Guimont, former city clerk: Vern Manley, water and light clerk; city records.
Ownership of water supply: Municipal.
Number of customers: Approximately 650 (1960).
Average consumption: 250,000 gpd (estimated, 1960).
Storage: Elevated steel tank, 125,000 gal.
Treatment: Polyphosphate stabilization of iron and manganese.
Source of supply: Two wells, 15 feet apart.

Well location: 58.16.11.bac1. One block north of D. M. & I. R. Railway depot on Sixth Avenue South; drilled in 1953; 8 inches in diameter; 262 feet deep. Cased to 148 feet; is not screened; has a 225 gpm turbine pump. Water is obtained from the Biwabik Iron-Formation between 187 and 262 feet. It has been pumped at 225 gpm for 8 hours. The static water level is 60 feet below land surface.

Well location: 58.16.11bac2. One block north of D. M. & I. R. Railway depot on Sixth Avenue South; drilled in 1954; 16 inches in diameter; 278 feet deep. Cased to 170 feet; is not screened; has a 400 gpm turbine pump. Water obtained from Biwabik Iron-Formation between 191 and 278 feet. When pumped at 400 gpm for 24 hours, water level lowered 100 feet below static water level of 60 feet.

Quality of water.—Water from the Biwabik supply has a moderate dissolved-solids content, is very hard, moderately siliceous, and contains much iron and manganese (table 6). The quality of water from the two wells is probably identical because the wells are about 15 feet apart and are drilled to about the same depth. Because treatment consists only of stabilization of iron and manganese, the analysis also represents the quality of the finished water.

POTENTIAL WATER SUPPLY

PRESENT GROUND-WATER SOURCE

The two city wells, 58.16.11bac1 and 2, are completed in fractured taconite in the upper cherty and upper slaty members of the Biwabik Iron-Formation. The wells are pumped on alternate days, one well serving as a standby in case of mechanical failure of the other. The specific capacity of 58.16.11bac2 was 4 gpm per foot of drawdown after after 24 hours of pumping at 400 gpm.

The Biwabik Iron-Formation is recharged by precipitation falling on the area between its southern limit and the Laurentian Divide (pl. 1). Part of this precipitation that enters the ground enters the iron-formation by vertical infiltration through the overlying glacial drift. Wells in the Biwabik adjacent to Embarrass Lake could induce recharge from the lake. The rate at which recharge could be induced would be controlled by the permeability of the drift between the lake

TABLE 6.—*Chemical anlayses, in parts per million, of water in the Biwabik vicinity*

[Analyses by U.S. Geol. Survey]

Water source	Present water supply	Potential water supply	
	Ground water	Surface water	
	Biwabik Iron-Formation [1] [3] 58.16.11bac 1 and 2	Embarrass River at Embarrass [2] (Station 170)	
		Average	Maximum
Silica (SiO_2)	18	10	21
Iron (Fe)	.13	.45	2.8
Manganese (Mn)	.59	.0	.0
Calcium (Ca)	59	7.9	19
Magnesium (Mg)	28	2.4	6.5
Sodium (Na)	11	1.7	3.6
Potassium (K)	1.7	.8	1.4
Bicarbonate (HCO_3)	292	26	89
Sulfate (SO_4)	30	9.4	15
Chloride (Cl)	6.5	.2	.7
Fluoride (F)	.2	.2	.6
Nitrate (NO_3)	.2	2.0	4.1
Boron (B)	.09	.08	.14
Dissolved solids	292	92	147
Hardness as $CaCO_3$	264	30	74
Noncarbonate hardness as $CaCO_3$	25	8	15
Alkalinity as $CaCO_3$	239	21	73
Percent sodium	------------	11	16
Specific conductance (micromhos at 25° C)	514	61	152
pH	7.4	6.9	7.5
Color (units)	0	153	400
Turbidity as SiO_2	.7		
Temperature (°F)	43		
Date of collection	Sept. 25, 1957	1955–57	

[1] Composite sample from both wells.
[2] Sampling site is 8 miles northeast of the area shown on pl. 1.
[3] Location of well.

bottom and the surface of the iron-formation. The yield of the wells would also be dependent on the degree of fracturing and consequent permeability of the iron-formation in the area of recharge.

Leached or fractured parts of the Biwabik Iron-Formation are a good potential source of ground water in the vicinity of Biwabik.

OTHER WATER SOURCES

GROUND WATER

Area 3 is underlain by a complex sequence of stratified drift. Glacial drainage from the north, through the Embarrass channel, deposited this drift. The Embarrass channel, half a mile northeast of the

McKinley-Biwabik map (pl. 1), was cut through the Giants Range by glacial and preglacial drainage. Surface and near-surface sand and gravel form the ice-contact topography of area 3 (pl. 1). The north half of the west boundary of area 3 is formed by shallow bedrock and by a southwestward-trending spur of gray bouldery till represented by a small ridge in secs. 1, 2, and 11. The glacial strata penetrated by city well 58.16.11bac1 consisted of 15 feet of reddish-brown clayey till, 35 feet of sandy clay, and 97 feet of gray bouldery till above the bedrock. The south half of the west boundary is approximate because of the lack of subsurface data in the adjacent swamp.

Plate 1 shows the general sequence of deposits and the range in grain size of the stratified drift within area 3. Logs of other test holes in the area show the variability in the texture and thickness of the stratified drift. Test hole 58.16.11adc1 penetrated 11 feet of reddish-brown till and 121 feet of sand and gravel above bedrock. The city formerly obtained its water supply from a dug and driven well, 58.16.1ccd1, on the west edge of Embarrass Lake. It was finished in gravel at a depth of 78–89 feet.

Ground water and surface water from the Embarrass River basin north of the Giants Range enters area 3 through the Embarrass channel. The southwestern part of the area receives some recharge from precipitation falling south of the Giants Range. Regional ground-water movement is to the south, but locally is toward the lakes.

Large quantities of ground water are available from coarse sand and gravel within area 3. Because the texture and thickness of the stratified drift are extremely variable, test drilling is necessary to locate thick and permeable sections. A well adjacent to a lake within the area could induce recharge from the lake.

Quality of water.—The best estimate of the quality of water for potential supplies from the glacial drift is indicated by the average analysis of water from drift in Cotter and others (1965a, table 6). Water that might be induced into aquifers from the Embarrass River would improve the quality of ground water (tables 4 and 6). The large amount of organic matter, indicated by the color of the river water, could cause a bad taste where natural filtration was slight.

SURFACE WATER

Biwabik lies between the Pike River draining north and the Embarrass River draining south (pl. 1). The boundary of the city extends to within less than a mile of the Pike River and includes part of Embarrass Lake through which the Embarrass River flows. To obtain a supply of water from the Pike River would require a lift of about 60 feet over the divide. On the east, the supply could be obtained from

Embarrass Lake at less cost because the distance to the supply is shorter, although the lift is about the same.

Flow data.—See Gilbert for data on Embarrass River near McKinley. See McKinley for data on Pike River near Embarrass.

Quality of water.—Water from both the Pike and the Embarrass Rivers generally has a low dissolved-solids content and is soft (tables 4–6). Hardness of water from the Embarrass River at Embarrass exceeds 60 ppm only about 15 percent of the time and then only by a few parts per million. The manganese content of water from each of the streams is low, but the iron content is high and the water is colored.

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