Exploratory Drilling for Ground Water in the Mountain Iron-Virginia Area St. Louis County, Minnesota

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1539-A

Prepared in cooperation with the Minnesota Iron Range Resources and Rehabilitation Commission and with the Division of Waters, Minnesota Department of Conservation

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By R. D. COTTER *and* J. E. ROGERS

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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EXPLORATORY DRILLING FOR GROUND WATER IN THE MOUNTAIN IRON-VIRGINIA AREA, ST. LOUIS COUNTY, MINNESOTA

By R. D. Cotter and J. E. Rogers

ABSTRACT

The Mountain Iron-Virginia area is a broad, southwest-trending valley in the central part of the Mesabi Range. The valley, which heads in the Laurentian Divide, and covers about 120 square miles, coincides approximately with a bedrock valley filled with as much as 150 feet of glacial deposits.

A complex sequence of glacioaqueous sediments made up of clay, silt, sand, and gravel was delineated from test holes drilled at 238 sites. These sediments range in thickness from 0 to 125 feet and can be considered a hydrologic unit, bounded below by sandy till or bedrock and above by as much as 60 feet of clayey till. The piezometric surface ranges from 0 to about 70 feet below land surface, thus, the glacioaqueous deposits are not everywhere completely saturated. In places, however, the water is under artesian pressure.

Within the Mountain Iron-Virginia area about 50 square miles are underlain by deposits 20 feet or more in thickness of silt, sand, or gravel that constitute an aquifer that is a large potential source for additional water supplies. Except for iron and manganese, which are present in excessive amounts in some wells, the water meets U.S. Public Health Service standards for municipal supplies. Pumping tests of wells in the permeable sand or gravel deposits at five sites indicate that yields of several hundred gallons per minute and possibly as much as 2,000 gpm (gallons per minute) can be expected.

INTRODUCTION

The ground-water resources of the Mountain Iron-Virginia area are under study in connection with a general investigation of the water resources of the Mesabi Iron Range. This study is being made by the U.S. Geological Survey in cooperation with the Minnesota Iron Range Resources and Rehabilitation Commission. Some of the data for this report were collected in cooperation with the Division of Waters, Minnesota Department of Conservation.

The investigation has been under the direct supervision of Robert Schneider, district geologist for Minnesota.

LOCATION AND DESCRIPTION OF THE AREA

The Mountain Iron-Virginia area is a broad southwestward trending valley that covers approximately 120 square miles in west-central St. Louis County, northeastern Minnesota (fig. 1). The north and northeast limits of the area coincide with the Laurentian Divide, from which waters flow northward to Hudson Bay and southeastward to the Great Lakes (pl. 1). The divide trends east-northeastward about 2 miles north of Mountain Iron and Virginia and then bends sharply to the south, passing southward, 2 miles east of Virginia, to a point about 1 mile northeast of Eveleth, where it again bends sharply and trends east-northeastward. The broad arc thus formed in the vicinity of these three municipalities is the head of a bedrock valley whose

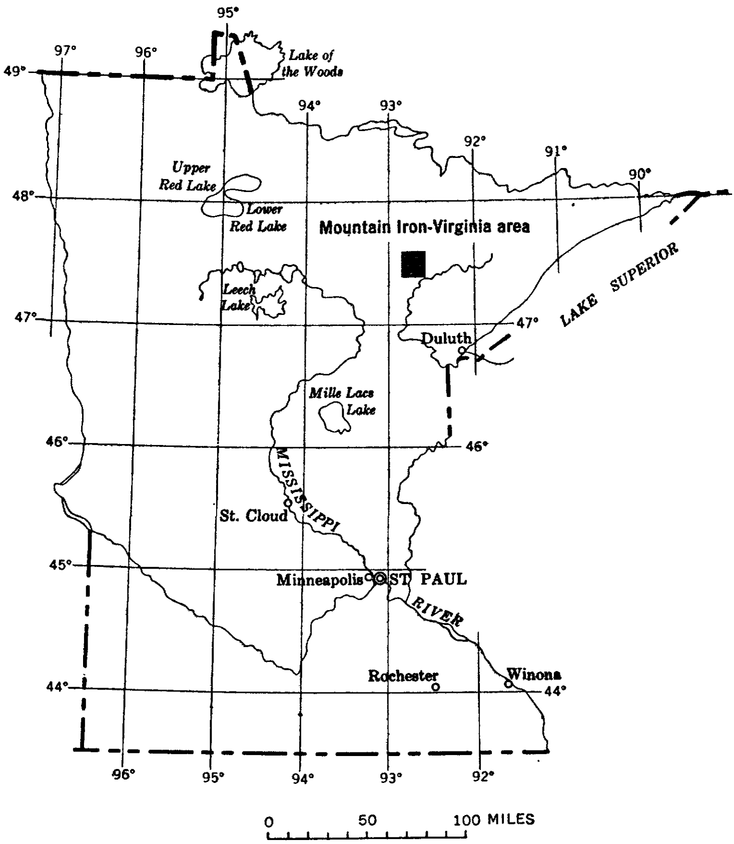

FIGURE 1.—Index map of Minnesota showing location of the Mountain Iron-Virginia area.

axis trends in a southwesterly direction. The topography suggests that the bedrock valley broadens to the southwest.

The northwest boundary of the report area coincides with a spur of glacial deposits that forms a local drainage divide extending southwestward from a point about 3 miles west of Mountain Iron. The southeast boundary of the area is formed by a bedrock knob in Eveleth and a spur of glacial deposits extending southwest of Eveleth. The southern boundary was arbitrarily selected as latitude 47°22′30″ N., which corresponds with the south boundary of the area as shown on plate 1. The area lies within the drainage basin of the St. Louis River, which drains into Lake Superior. Drainage in the area is southward through the East Two and West Two Rivers, and Elbow Creek.

The economy of the Mountain Iron-Virginia area is supported largely by the iron-mining industry. U.S. Highways 53 and 169 and State Route 216 serve the cities of Virginia and Eveleth and the villages of Mountain Iron and Iron Junction.

PURPOSE AND METHOD OF INVESTIGATION

The primary objective of the overall investigation in the Mountain Iron-Virginia area is to appraise the ground-water resources. With the gradual depletion of higher grade iron ores, which require little or no concentration, more low-grade ores, including taconite, are being mined in the Mesabi Range area. A larger labor force is needed to mine and to concentrate these ores, and large quantities of water are needed for washing operations. Thus, the need for additional water supplies is twofold: additional municipal supplies for a larger population, and additional industrial supplies for ore concentration. In addition, an appraisal of the available water resources is important to new industry locating in the area.

In the Mountain Iron-Virginia area a detailed ground-water investigation is being made to locate glacial aquifers, determine their occurrence, and evaluate their yield. It is anticipated that the information obtained will be applicable in locating ground-water supplies elsewhere on the Mesabi Range. The purpose of this report is to present the preliminary results of exploratory drilling that was done to define the subsurface geology and to determine the occurrence of ground water in the glacial deposits.

A study of the available geologic data indicated that the topography of the Mountain Iron-Virginia area resulted from partial filling of a broad, shallow bedrock valley by glacial deposits. During the summers of 1954–56, the Oliver Iron Mining Division of U.S. Steel Corporation permitted geologists of the Geological Survey to observe the drilling of 17 cable-tool test holes and 51 auger holes in the northern part of the area. This drilling indicated that much of the area was underlain by a complex sequence of glacial deposits, including very permeable sands and gravels.

In order to explore the bedrock valley further, a test-drilling program was planned, utilizing a truck-mounted rotary-drilling rig for speed and economy. Test holes, drilled for the Survey, under contract, were spaced at intervals of 0.25 to 1.5 miles along east-west lines nearly normal to the axis of the bedrock valley. Additional test holes were drilled near those test holes that had found relatively thick deposits of sand or gravel in order to estimate the approximate lateral extent of such deposits. During the summers of 1956–58, test holes were drilled at 221 sites, under the supervision of a geologist. Samples were collected at 5-foot intervals in sand or gravel and at 10-foot intervals in other sediments. A written log was made as the hole was drilled, including descriptions of samples, and interpretations of the subsurface geologic conditions based on the action of the drill, drilling-mud loss, and the appearance of the drilling mud. In addition, each hole more than 30 feet deep was logged electrically with single-point-resistance logging equipment, which records the apparent resistivity of the materials in the vicinity of the hole and the spontaneous potential. Electric logs were used for making correlations and for interpreting the physical characteristics of the strata.

TEST-HOLE NUMBERING SYSTEM

The system of numbering test holes and wells is based on the U.S. Bureau of Land Management's system of subdivision of the public lands. The Mountain Iron-Virginia area is in the fourth-principal-meridian and base-line system. The first segment of a well or test-hole number indicates the township north of the base line; the second, the range west of the principal meridian; and the third, the section in which the test hole is situated. The lowercase letters *a*, *b*, *c*, and *d*, following the section number, locate the well within the section. The first letter denotes the 160-acre tract, the second the 40-acre tract, and in the third the 10-acre tract as shown in figure 2. The letters are assigned in a counterclockwise direction, beginning in the northeast quarter. Within one 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Figure 2 illustrates the method of numbering a test hole. Thus, the number 57.18.8ddbl identifies the first well or test hole located in the NW¼SE¼SE¼ sec. 8, T. 57 N., R. 18 W.

SEQUENCE OF STRATA

The sequence of strata in the Mountain Iron-Virginia area is given in table 1, together with the thickness, physical and water-bearing

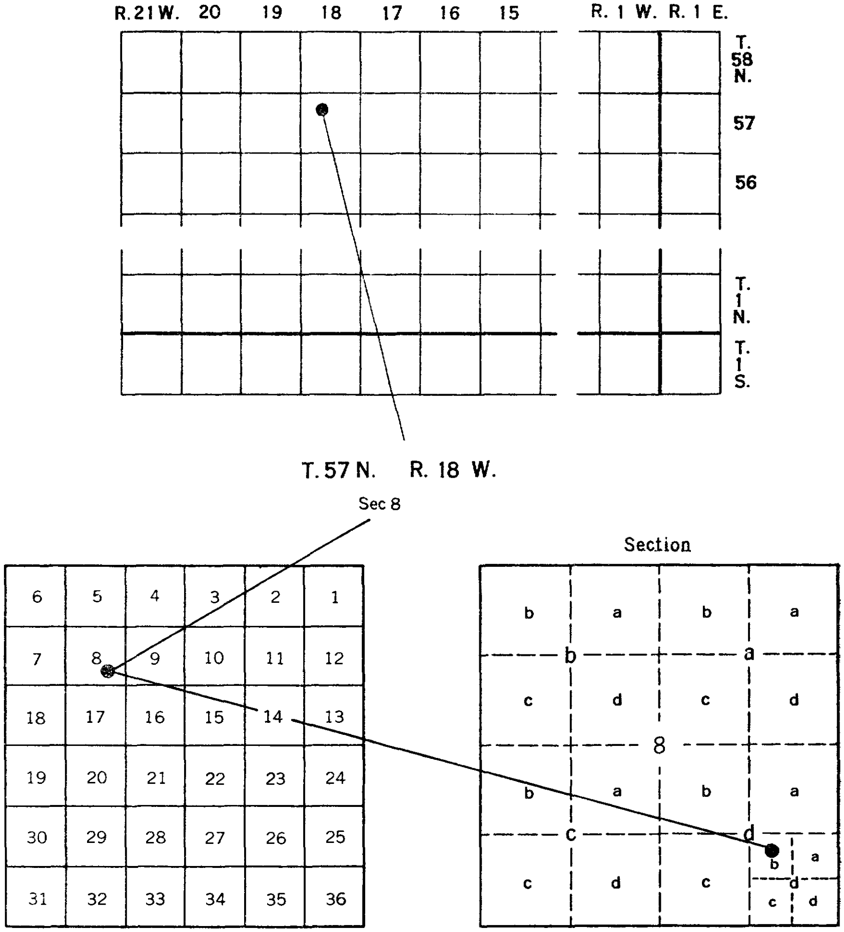

FIGURE 2.—Sketch showing method of numbering test holes and wells.

characteristics, and areal distribution. Because the scope of this report is limited and the area is small, the glacial deposits have not been subdivided on the basis of age or into formational units.

The physical properties of the strata were determined largely from field descriptions of drill cuttings, outcrops, and mine exposures.

The following are definitions of various terms as used in table 1 and elsewhere in this report:

Aquifer: A formation, group of formations, or part of a formation that is water-bearing (Meinzer, 1923, p. 30);

Glacial till: An unsorted sediment, deposited by glacial ice, containing material ranging in size from clay to boulders;

Glacioaqueous deposits: Sediments deposited by glacial melt water, either in streams or lakes;

TABLE 1.—*Physical and water-bearing characteristics of the strata in the Mountain Iron-Virginia area, Minnesota*

Stratum	Approximate range in thickness (feet)	Physical characteristics	Water-bearing characteristics	Areal distribution	Remarks
Swamp deposits	0–20	Peat, dark brown to black; contains varying amounts of silt and sand.	Not known to yield water to wells in the area.	Patchy distribution; confined to low-lying areas.	
Glaciolacustrine deposits	0–30	Sand, tan, orange, and greenish-gray; grain size ranges from very fine to medium; rarely contains coarse to very coarse grains; stratified and moderately to well sorted.	Yields are sufficient for domestic and stock use in a few places, depending on the saturated thickness.	Surficial deposit in the southern quarter of the area; small outliers occur further north.	
	0–20	Clay and silt, buff, gray, and greenish-gray; grades from silty clay to slightly clayey silt; sometimes varved.	Not known to yield water to wells in the area.		
Till	0–20	Till, reddish-brown, clayey, plastic, tough, slightly calcareous. Rock fragments of sand size or larger comprise about 10 percent of material; very fine to very coarse gravel fragments are largely argillite and granite. Calcareous material leached out in upper few feet.	Not known to yield water to wells in the area.	Surficial deposit over entire area except for small "windows" and areas where it is covered by glaciolacustrine or swamp deposits.	
	0–60	Till, reddish-gray to brownish-gray, clayey, plastic, tough. Rock fragments of sand size or larger comprise about 10 percent of material; very fine to very coarse gravel fragments are largely argillite and granite.		Sporadic distribution over entire area. Locally quite thick where it fills low-lying areas.	Appears identical to overlying reddish-brown till except for color. With depth the red color gradually disappears.
	0–40	Till, greenish-gray to bluish-gray, clayey, calcareous; softer and contains more silt than the two overlying till deposits. Rock fragments of sand size or larger comprise about 10 percent of material; very fine to very coarse gravel fragments are largely argillite and granite, with varying amounts of limestone and shale.		Sporadic distribution over entire area. Usually occurs as isolated masses associated with the other clayey tills.	

Glacioaqueous deposits	0–125	Clay, light- to dark-gray. Usually quite silty; occasionally sandy, soft, and plastic. Silt, reddish-brown, brown, light gray, black; occasionally sandy. Sand, tan and gray, very fine to very coarse, moderately sorted, stratified. Gravel, tan and gray, very fine to boulder sizes. Most common size range is from very fine to very coarse. Composed largely of granite, argillite, and metamorphic rock types.	In places yields of about 2,000 gpm are possible from sands and gravels. Most sand yields adequate supplies of water for domestic and stock use. Silt and clay bodies yield water to adjacent sands or gravels by relatively slow movement in response to pumpage from wells.	Occurs in all parts of the area. See plate 1 for extent of areas underlain by 20 feet or more of silt, sand, or gravel.	These deposits are described by lithologic type (clay, silt, sand, and gravel) for convenience. The geologic cross sections (pl. 2) show the general extent and relationship of the deposits.
Till	0–60(?)	Till, buff (weathered) to gray (fresh); composed of pebbles, cobbles, and boulders held together by a sandy, silty matrix. Chief rock types are granite and argillite. May contain bodies of sand and gravel and may be overlain by a boulder layer or a veneer of sand and gravel.	Yields moderate supplies of water to wells completed in the sand and gravel mantle at the top or from bodies of sand and gravel within the till.	Except for the axial portion, underlies most of the bedrock valley.	
Bedrock		Argillite, black to greenish-gray (fresh) to gray (weathered), fine-grained, dense; upper few feet are weathered and fractured.	Many domestic and stock wells are finished in upper few feet of the unit.	Underlies the central and southern part of the area.	Virginia slate (Leith and others, 1935, p. 10).

Glaciolacustrine deposits: Sediments deposited by glacial melt water in lake basins;

Glaciofluvial deposits or *glacial outwash:* Sediments deposited by glacial streams;

Piezometric surface: An imaginary surface that everywhere coincides with the static level of the water in the aquifer (Meinzer, 1923, p. 38).

The broad, shallow bedrock valley extending southwestward from the Laurentian Divide is filled in part with an extensive series of glacioaqueous deposits that are overlain by a thin mantle of swamp and lake deposits and clayey tills. The glacioaqueous sediments rest on a surface of bedrock and sandy till that has been partly scoured by the melt water streams that deposited the sediments. This scouring action produced many channels, which are eroded into or through the sandy till and, in some places, cut rather deeply into bedrock.

The bedrock on the Mesabi Range has been studied extensively because of its economic importance, and Leith and others (1935, p. 10) has described the following sequence of Precambrian rocks: Giants Range granite, Pokegama quartzite, Biwabik iron-formation, and Virginia slate. In this area the Pokegama quartzite extends northward onto the Laurentian Divide, which is composed largely of Giants Range granite. The Biwabik iron-formation overlies the Pokegama quartzite and is overlain by the Virginia slate. The Virginia slate is the bedrock in most of the valley, and for this reason, is the only bedrock unit listed in table 1.

The general relations of the strata are shown in plate 2, by two west-east geologic cross sections, *A–A′* and *C–C′*, and by one southwest-northeast cross section, *B–B′*, which is approximately parallel to the axis of the bedrock valley. These sections were constructed chiefly from U.S. Geological Survey test-hole data, supplemented by a few logs of test-holes of the city of Virginia and the Oliver Iron Mining Division, U.S. Steel Corporation.

The logs of the test holes shown on the sections (pl. 2) are a composite of all the available subsurface and surface geologic data. In places the stratigraphic sequence was interpreted from subsurface geologic and subsurface contour maps. Where drill cuttings did not provide conclusive information, the position of the contact between the glacioaqueous deposits and the underlying sandy till was interpreted on the basis of the action of the drill and the extrapolation from surface or mine exposures, structure-contour maps of the top of the sandy till, cross sections, and drillers' logs. The till units have a rather distinctive color and composition and can be correlated quite easily. However, owing to the complex and variable character of the glacioaqueous sedimentary types, the correlation of individual beds between test holes is more difficult.

One of the more apparent features of the glacioaqueous deposits is the superposition of sand or gravel over silt in much of the area. However, in places the entire section consists largely of silt. Where the silt layers thin or terminate laterally against deposits of sand or gravel, it is possible that the silt had been scoured by outwash streams before the deposition of the coarser sediments. In some localities, the sand and gravel may have been part of the land surface on which the silt was deposited. Despite the fact that extremely abrupt facies changes are common in glacial sediments, it is believed that the general subsurface geologic conditions are adequately represented on the cross sections.

OCCURRENCE AND WATER-BEARING PROPERTIES OF GLACIOAQUEOUS DEPOSITS

The Mountain Iron-Virginia area contains extensive glacioaqueous deposits composed of clay, silt, sand, and gravel that can be considered as a hydrologic unit. They are overlain by a mantle of clayey till and underlain by sandy till and argillite (table 1).

The deposits range in grain size from clay to boulders, and probably occur in every combination of these sizes. They were sorted and deposited by glacial melt water, while the finer, more easily suspended sediments were carried downstream. Near the front of the wasting glacier, the environment of deposition was one of changing stream patterns and streamflow characteristics, of ponding of water by ice or till dams, and of glacial readvances. Consequently, at any given locality the pattern of deposition was changing frequently and the lithology and distribution of the resulting deposits is complex and variable. In places it is difficult to correlate the glacioaqueous strata between test holes and even more difficult to extrapolate them into areas where no holes have been drilled.

Plate 1 shows the extent and distribution of glacioaqueous deposits that are important because of their water-bearing properties. It is evident from the profile of the piezometric surface shown on the geologic cross sections (pl. 2) that the glacioaqueous deposits commonly are only partially saturated. Where the piezometric surface lies within clayey till the ground water is under artesian pressure. Where it is in coarse permeable material, the ground water generally is unconfined. The hachured, dashed lines on plate 1 define areas underlain by 20 feet or more of saturated or partly saturated silt, sand, or gravel. The heavy lines within the hachured boundary enclose areas underlain by 30 feet or more of saturated deposits of permeable sand or gravel, which are most favorable for development of ground-water supplies. In outlining these areas, the areas of fine and very fine sand and clayey or silty sand and gravel were excluded. On the cross sections (pl. 2), correlations of the glacioaqueous deposits are based on gross distinctions between sediment types (clay, silt, sand, and gravel). For this reason, and because the thickness of some deposits have been inferred on the cross sections, the thickness of permeable sand or gravel shown on plate 1 does not always agree with the thickness of sand or gravel on plate 2. The area of glacioaqueous deposits outlined in the southeast corner of plate 1, east of St. Marys Lake, does not lie within the Mountain Iron-Virginia area proper, but it has been included because of its proximity to the area.

Although the areal extent of the relatively thick (more than 30 feet), permeable sections of the outwash deposits may appear to be insignificant in places, they usually are coextensive with thinner outwash deposits of high permeability. Also, they are in contact with bodies of clay, silt, and fine sand which yield appreciable quantities of water to the aquifers when the head is reduced by pumping from wells that tap the more permeable strata. Pumping tests indicate that yields of as much as several hundred gallons per minute can be obtained at the following locations: NE¼SW¼SW¼ sec. 18, T. 58 N., R. 17 W.; SW¼NE¼SW¼ sec. 10, T. 58 N., R. 18 W.; SW¼SW¼SW¼ sec. 12, T. 58 N., R. 18 W.; NE¼NE¼SE¼ sec. 14, T. 58 N., R. 18 W.; SE¼SW¼NW¼ sec. 22, T. 58 N., R. 18 W. A municipal-supply well drilled by the city of Virginia in the SW¼SW¼SW¼ sec. 12, T. 58 N., R. 18 W. was pumped for about 1 hour at 2,000 gpm.

QUALITY OF GROUND WATER

Ground waters from the glacial outwash in the Mountain Iron-Virginia valley are quite similar in chemical composition (table 2). They are not excessively mineralized, compared with glacial drift waters in general, although some constituents are present in excessive amounts, according to the quality standards used.

The principal constituents or properties that may be bothersome are hardness, iron, and manganese. Standards for hardness are arbitrary although, by one definition (Love, 1958, p. 14), water that has less than 60 ppm of hardness can be considered soft; 61 to 120 ppm, moderately hard; and 121 to 200 ppm, hard. Water having a hardness of more than 60 ppm but less than 200 ppm, may require softening for some purposes, and water having a hardness of more than 200 ppm requires softening for most purposes. In domestic use, hard water causes excessive consumption of soap and a resultant sticky curd, as well as formation of a scale on vessels used for boiling water. The range in hardness for the six samples from glacial-

TABLE 2.—*Chemical analyses of ground waters from the Mountain Iron-Virginia area, Minnesota*

[Analyses by Quality of Water Branch, U.S. Geological Survey. Analytical results in parts per million except as indicated]

Well			Sample		Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Manganese (Mn)	Dissolved solids (residue on evaporation at 180° C)	Hardness as $CaCO_3$		Percent sodium	Sodium-adsorption-ratio	Specific conductance (micro-mhos at 25° C)	pH	Remarks
Location	Depth (feet)	Diameter (inches)	Date of collection	Temperature (°F)																Calcium, magnesium	Noncarbonate					
57.18.15daa1	196	6	10-18-57	45	15	0.37	32	9.5	9.7	2.8	167	0	0.3	0.0	0.6	0.8	0.08	0.07	147	119	0	15	0.4	267	7.6	Drilled municipal well of village of Iron Junction. Aquifer, Virginia slate. Owner, D. M. and I. R. RR.
58.17.18bdd3	48	8	9-26-58	43	21	.06	91	40	14	3.8	400	0	87	.4	.2	.2	.06	1.7	452	391	63	7	.3	737	7.2	Drilled test well. Aquifer, glacial outwash.
58.17.18cca3	83	8	10-24-58	43	19	.10	83	38	12	3.5	340	0	103	2.2	.3	.0	.02	.71	431	365	86	7	.3	687	7.4	Do.
58.18.10cac4	66	8	9-11-56	44	15	.05	34	16	7.5	1.8	162	0	24	12	.2	1.2	.05	.00	192	152	19	10	.3	333	7.1	Do.
58.18.12ccc2	97	6	10- 6-54	43	20	.32	64	26	6.8	2.5	283	0	47	2.5	.3	.1	.04	.66	309	266	34	5	----	510	7.5	Do.
58.18.14daa1	82	10	10-12-55	43	24	1.7	64	24	4.9	3.3	294	0	30	1.5	.2	.0	.04	1.6	299	258	17	4	.1	497	7.3	Do.
58.18.22bcd2	58	6	9-22-55	43	26	.27	45	18	6.9	2.4	234	0	5.0	1.0	.2	1.0	.04	.13	222	187	0	7	.2	413	7.6	Do.

outwash aquifers is 152 to 391 ppm. A high content of iron results in "red water" and reddish-brown stains on white enamelware, porcelain fixtures, and fabrics. Excessive manganese in water causes a brown stain similar to those of iron. The recommended limit for the combined total of iron and manganese is 0.3 ppm (U.S. Public Health Service, 1946, p. 13). In the samples tested, values for iron ranged from very low (0.05 ppm) to excessive (1.7 ppm) and manganese ranged from 0 to 1.7 ppm.

The sample of water from the Virginia slate (well 57.18.15daal) was less mineralized than any of the waters from the glacial deposits, although the percent sodium was somewhat higher. Many farm wells in the southern part of the area are finished in the Virginia slate, probably because the water is generally softer than the water in the glacial drift.

CONCLUSIONS

The glacioaqueous deposits in the Mountain Iron-Virginia area constitute an aquifer that is a large potential source for additional water supplies. It ranges in thickness from 0 to 125 feet and is confined in most of the area by clay or clayey till above and by bedrock or sandy till below. Despite its wide range in permeability, it can be considered as a hydrologic unit.

In the coarse outwash deposits, well yields of approximately several hundred gallons per minute can easily be obtained and, with proper construction, screen-size selection, and development, yields on the order of 2,000 gpm are possible. Although large yields cannot be obtained from the fine-grained deposits, these sediments transmit water to the coarse deposits when the head in the latter is reduced by pumping.

It is estimated from plate 1 that about 50 square miles of the Mountain Iron-Virginia area are underlain by 20 feet or more of saturated or only partially saturated silt, sand, or gravel. About 5 square miles are underlain by 30 to 120 feet of saturated, permeable sand or gravel, which constitute the most favorable deposits for ground-water development.

Because of the extreme variability in grain size, sorting, and permeability of the glacioaqueous deposits, large ground-water developments should be preceded by careful test drilling and controlled test pumping. In contemplating the development of relatively shallow outwash deposits, particular attention should be given to the fact that they may be only partially saturated.

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