Ground-Water Exploration and Test Pumping in the Halma-Lake Bronson Area Kittson County, Minnesota

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-BB

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

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By GEORGE R. SCHINER

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GROUND-WATER EXPLORATION AND TEST PUMPING IN THE HALMA-LAKE BRONSON AREA, KITTSON COUNTY, MINNESOTA

GEORGE R. SCHINER

ABSTRACT

The Halma-Lake Bronson area covers about 80 square miles in the northwestern corner of Minnesota. It is a relatively featureless poorly drained glacial drift plain which slopes gently to the west about 10 feet per mile. The plain is interrupted by sand dunes and by beach deposits of Glacial Lake Agassiz. In the northeastern part of the area, the glacial drift rests on Precambrian crystalline basement rock; throughout the rest of the area the drift is underlain by shale, limestone, and sandstone of Ordovician age, and probably by shale and limestone of Cretaceous age.

Information from 75 test holes showed that, except for minor amounts of surficial swamp sediments, eolian sand, and alluvium, the area is underlain by about 320 to 420 feet of glacial drift. The most important aquifers are the relatively coarse-grained glacial outwash deposits that constitute part of the drift. The principal aquifer is a series of outwash deposits, ranging in thickness from 0 to about 280 feet, that fill a north-south trending valley cut in the underlying relatively impermeable drift. The deposits in this buried valley have an average thickness of about 130 feet in an area about 8 miles long and 3 miles wide, and are considered as a hydrologic unit.

The main source of ground-water recharge is precipitation on the part of the area underlain by the principal series of outwash deposits; evapotranspiration accounts for most of the discharge. The sandy texture of the soil and the flat topography are particularly conducive to recharge, and there is extremely little surface runoff. The average depth to the water table is about 8 feet below land surface. Although the regional slope of the water table is probably to the west, locally the gradient is toward Lake Bronson and South Branch Two Rivers.

Pumping tests of the outwash deposits in 2 parts of the buried valley indicate that the average coefficients of transmissibility were about 80,000 gpd per ft and about 50,000 gpd per ft. The field coefficients of permeability were about 800 and 300 gpd per sq ft, respectively.

About 65 billion gallons of ground water is estimated to be in storage in the area underlain by the principal aquifer.

There are no large ground-water developments in the area. The average depth of farm wells and the few municipal wells is about 25 feet.

Chemical analyses of water from the principal aquifer show that the water is primarily of the bicarbonate type. The water is hard, and contains high iron concentrations. Most wells yield water that is softer and less mineralized than ground water from the adjacent area to the west.

Large quantities of water suitable for most industrial purposes are available in the Halma-Lake Bronson area. Yields of 1,000 to 2,000 gpm could probably be obtained from wells located by an adequate program of exploratory drilling and test pumping.

INTRODUCTION

PURPOSE AND SCOPE

The Halma-Lake Bronson area, in northwestern Minnesota, currently has few large supplies of good quality ground water. There is considerable interest in obtaining water supplies adequate to support economic growth of the area.

In July 1953, the U.S. Geological Survey, in cooperation with the Iron Range Resources and Rehabilitation Commission, began an investigation to inventory and evaluate the water resources in parts of Kittson, Marshall, and Roseau Counties. During the investigation, a thick extensive series of water-bearing outwash deposits was discovered in the Halma-Lake Bronson area, Kittson County. This investigation was terminated in 1955.

In July 1957, the U.S. Geological Survey, in cooperation with the Division of Waters, Minnesota Department of Conservation, began a detailed investigation of the Halma-Lake Bronson area to determine the occurrence, availability, and quality of ground water, with special emphasis on the possibilities of developing ground water for industrial purposes.

This report is a summary and interpretation of data obtained from the 1953–55 and 1957–58 studies. It includes also some basic data on surface water.

METHOD OF INVESTIGATION

An inventory of the wells was made, the surficial geology was mapped, and test holes were drilled during 1953–55. Samples of water were collected for chemical analysis from selected wells and two surface-water bodies. The water level in one well has been measured periodically since November 1955 as part of a continuing statewide program of measuring observation wells.

Sample logs were compiled from 80 test holes and wells; 5 of these were drilled by the village of Lake Bronson and 75 by the U.S. Geological Survey. The Survey test holes were drilled under contract; all test holes but one were drilled with a hydraulic rotary-drilling rig. The well drilled in the NE¼NE¼NE¼ sec. 32, T. 161 N., R. 46 W., was drilled partly by the cable-tool method. Electric logs were made for most of the test holes with single point resistance well-logging equipment. The logs of the test holes (table 3) are composites of sample and electric logs.

During the period 1953–55, 43 test holes were drilled in the Halma-Lake Bronson area. In 1957–58, 32 additional test holes were drilled and 2 pumping tests were made.

The work was done under the immediate supervision of Robert Schneider, district geologist for Minnesota.

PREVIOUS REPORTS

Leverett (1932) described the general glacial geology of the region, and Allison (1932) summarized the general geology and made a regional study of ground-water occurrence and quality. However, there are no detailed reports on the geology or ground-water conditions of the area. The only published map of the bedrock formations is a geologic map of Minnesota (Grout and others, 1932).

Descriptions of the genesis of Glacial Lake Agassiz are pertinent to the geology of the area and are included in the following reports: Upham (1895, p. 192–275), Tyrrell (1896, p. 811–815), Johnston (1916, p. 625–638), Leverett (1932, p. 119–141), Flint (1947, p. 264–265), and Nikiforoff (1947, p. 205–239).

ACKNOWLEDGMENTS

The cooperation of well owners, well drillers, civil officials, and private citizens is greatly appreciated.

Special thanks are due Mr. Charles J. McKinley, Superintendent of Lake Bronson State Park, for his cooperation in use of park lands and facilities.

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 first segment of a well or test hole number indicates the township north of a base line; the second, the range west of the nearest 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 test hole within the section. The first letter denotes the 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract, as shown on figure 1. The letters are assigned in a counterclockwise direction, beginning in the northeast quarter. Within one 10-acre tract, consecutively inventoried wells are numbered in order.

The following sketch of a section indicates the method of numbering a test hole (fig. 1). Thus, the number 160.46.8ddbl, identifies the first well located in the NW¼SE¼SE¼ sec. 8, T. 160 N., R. 46 W.

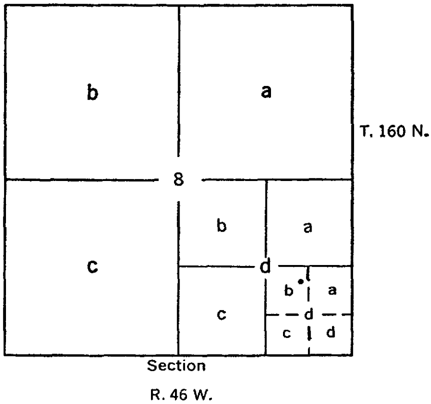

FIGURE 1.—Well-numbering system.

GEOGRAPHY

LOCATION

The Halma-Lake Bronson area is in southeastern Kittson County, about 25 miles south of the Canadian border and about 300 miles northwest of Minneapolis and St. Paul (fig. 2). It is about 16 miles southeast of the village of Hallock, the county seat, and it includes parts of Tps. 159, 160, and 161 N., Rs. 45, 46 and 47 W. The area covers 80 square miles, about 30 of which were studied in detail. The village of Lake Bronson is in the northwest corner, and the village of Halma is near the center of the area; the village of Karlstad is outside the area near the southeast corner.

CULTURE

In 1960 the population of Kittson County was 8,343. The population of Hallock was 1,527, Halma 115, Karlstad 720, and Lake Bronson 421. The Halma-Lake Bronson area is primarily agricultural, but large quantities of sand and gravel are excavated. Recreational facilities are available at Lake Bronson State Park.

The area is served by U.S. Highway 59 and by the Minneapolis, St. Paul, & Sault Ste. Marie Railroad. The Great Northern Railway has a rail line about 15 miles to the west.

CLIMATE

The climate of the Halma-Lake Bronson area is continental. The following data have been taken from records compiled by the U.S. Weather Bureau at Hallock, Minn., the nearest weather station.

The mean annual precipitation for the period 1928–57 is 20.12 inches, the lowest reported in the State. The mean monthly precipitation

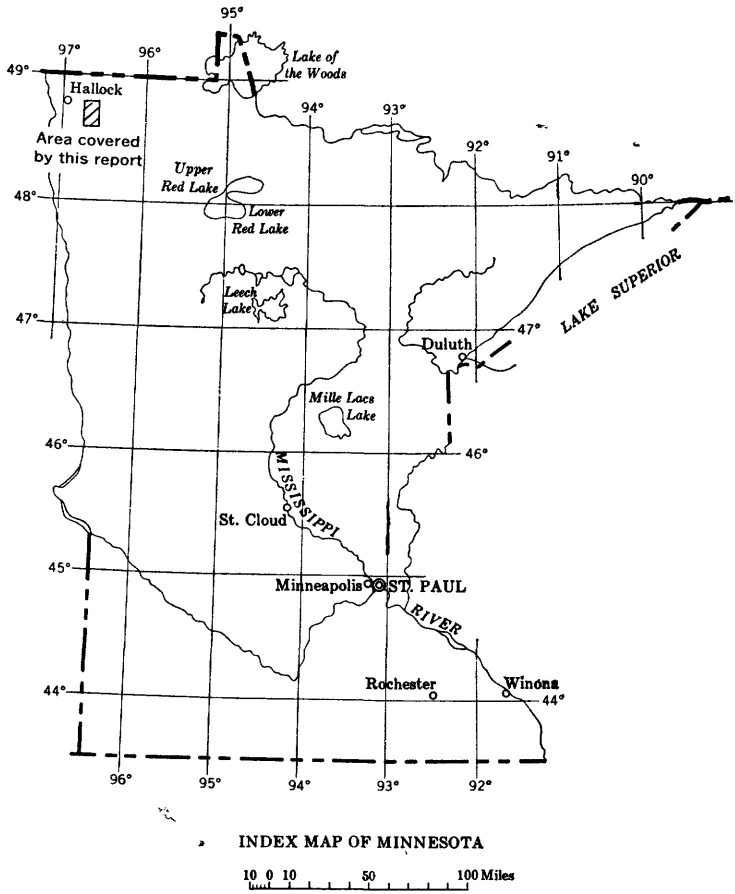

Figure 2.—Index of Minnesota showing the location of the Halma-Lake Bronson area.

ranges from 0.55 inches in December to 3.10 inches in June. About 70 percent of the annual precipitation occurs during the months of April through September. The monthly precipitation from November 1955 to December 1958 is shown graphically on figure 3. Local heavy rain and hail storms occur during the growing season, May to September.

The mean temperature for the winter months of December through February is 6.1°F; that for the summer months of June through August is 66.2°F. Mean monthly temperatures range from a high of 69°F in July to a low of 1.3°F in January. The mean annual temperature is 37.9°F for the period 1928–57. The average number of days without killing frost is about 110.

TOPOGRAPHY AND DRAINAGE

The Halma-Lake Bronson area is in the Western Young Drift section of the Central Lowland physiographic province of Fenneman (1938, p. 559). It is included in the large flat-lying basin of Glacial Lake Agassiz, and slopes gently to the west at about 10 feet per mile, as shown on plate 2. All altitudes used in this report are estimated from the topographic base of plate 2 and are in feet above mean sea level. The lowest altitude, about 950 feet, is in the stream channel directly below the dam in the NW¼NW¼SE¼ sec. 32, T. 161 N., R. 46 W.; the highest altitude, about 1,045 feet, is in the SE¼ sec. 7, T. 159 N., R. 45 W.

The principal relief in the area consists of sand dunes, beach ridges, and a stream valley (pl. 2). Sand dunes about 30 feet high occur in the SE¼ sec. 10, T. 160 N., R. 46 W. Beach ridges about 15 feet high traverse the area in a general north-south direction. They are somewhat higher and better drained than the adjoining lake plain and were used by the early traders as an oxcart route, the "Old Pembina Trail," to the southern part of the State. These features are discussed in detail under "Glacial deposits."

The surface drainage in the Halma-Lake Bronson area is poorly developed. The westward-flowing South Branch Two Rivers, the only major stream in the area, has a narrow and sinuous steep-walled channel and is in a youthful stage of development. Lake Bronson is an artificial lake formed by a dam on the South Branch Two Rivers. The altitude of the lake level is about 975 feet.

Precipitation usually is readily absorbed because the surficial deposits are sandy and the relief is low. After periods of heavy rainfall, low-lying sections of the area generally contain standing water, probably as a result of the rise in the water table.

GEOLOGY

GEOLOGIC HISTORY

The basement rocks of the Halma-Lake Bronson area are among the oldest rocks known in geologic history and are a part of the highly metamorphosed Precambrian rocks of the Canadian Shield of northeastern North America.

Early in the Paleozoic era, the area was covered by a succession of seas whose sediments formed layers of sandstone, limestone, and shale. When the seas were absent from the area, the sediments were exposed to subaerial erosion and continental deposition. A long interval of erosion probably occurred after the disappearance of the Paleozoic seas. If sediments younger than Ordovician age were deposited before the late part of the Mesozoic era, they were removed because no evidence of their presence has been found. Late in the Mesozoic era seas invaded from the west, and beds of shale and some beds of sandstone were laid down. Between the final retreat of the Mesozoic seas and the appearance of the Pleistocene glaciers, the area was subjected to weathering and erosion.

During Pleistocene time continental glaciers advanced and retreated over the area, modifying the topography and depositing glacial drift. The drift was deposited during one or more of the four major glacial stages—the Nebraskan, Kansan, Illinoian, and Wisconsin.

As the last ice sheet retreated northward along the lowlands of the Red River during the Mankato substage of the Wisconsin stage, it dammed a northward sloping basin. The melt water from the waning ice sheet and the runoff in the basin were trapped to form an extensive body of water known as Glacial Lake Agassiz. During the early part of the lake's history, its outlet was southeastward through the Minnesota River Valley to the Mississippi. When the ice sheet retreated into Canada, lower outlets were uncovered to the north. According to Upham (1895, p. 2), at its maximum development, Glacial Lake Agassiz exceeded the combined areas of the present-day Great Lakes. With the northward recession of the ice sheet, the lake level was lowered, and the southern shoreline of the lake moved northward. Shorelines, beaches, and beach ridges were formed at various stages of the lake. After the final withdrawal of the ice sheet from the basin outlet to the north, the present drainage system of the Red River was developed.

Since late Pleistocene time erosion or deposition has slightly modified the terrain.

DESCRIPTION OF GEOLOGIC UNITS

Table 1 shows the geologic units in the approximate sequence in which they occur in the Halma-Lake Bronson area. Brief descriptions of the units and their water-bearing characteristics are also given. Because of the meager data on the bedrock and basement rocks, only general reference has been made to their age; no attempt was made to subdivide the glacial deposits by age.

BASEMENT ROCK

Rocks of Precambrian age form the basement complex in the area. These rocks are overlain in places by undifferentiated Ordovician strata (Grout and others, 1932); elsewhere, they are overlain by Cretaceous strata or by Pleistocene deposits. Two test holes were drilled to the basement rock in the Halma-Lake Bronson area. Test hole 161.46.32aaa1 penetrated 2 feet of gneissoid granite at a depth of 419 feet, about 563 feet above mean sea level. Test hole 161.45.31ddc1

TABLE 1.—*Description and water-bearing characteristics of geologic units in the Halma-Lake Bronson area, Minn.*

Unit			Description	Range of thickness (feet)	Water-bearing characteristics
Alluvium (includes swamp deposits).			Silt, sand, and gravel	(?)	Not known to yield water to wells in the area.
Eolian deposits			Fine sand and silt	0–30±	Generally above water table; serves as infiltration medium for recharge from precipitation; where saturated, may yield sufficient water for domestic and stock use.
Glacial deposits	Lake Agassiz deposits	Beach deposits.	Sand, gravel, cobbles, and boulders.	0–20±	Serves as infiltration medium for recharge from precipitation. Yields may be sufficient for domestic and stock use.
		Lake deposits.	Clay, silt, and sand	0–25±	Yields may be sufficient for domestic and stock use.
	Principal outwash deposits.		Sorted and stratified deposits of clay, silt, sand, gravel, cobbles, and boulders; fills valley in underlying glacial drift unit.	0–280±	Yields of several hundred gallons per minute can be obtained from thick sections of coarse-grained deposits.
	Mankato(?) and undifferentiated older drift deposits.		Largely till; contains small lenses and irregularly shaped bodies of sand and gravel; locally includes lake sediments.	320(?)–420(?)	Generally yields no water to wells; sand, gravel, and silt may yield sufficient water locally for domestic and stock use. Yields saline water to wells about 3 miles west and southwest.
Bedrock (includes Cretaceous and Ordovician rocks).			Limestone, shale, and fine- to coarse-grained sandstone.	0–60±	Unknown in the area. About 12 miles to the northwest, sandstone and limestone yield highly mineralized water under artesian conditions.
Basement rock (Precambrian).			Crystalline rock (gneissic granite). Hard and brittle, except where weathered.	(?)	Unknown; probably cannot yield significant amounts of water.

was drilled 0.5 feet into granite at a depth of 419.5 feet, about 594 feet above mean sea level (pl. 1).

BEDROCK

Pre-Pleistocene sedimentary deposits probably overlie the crystalline basement rock in most of the report area. Test hole 161.46.32aaa1, which is 421 feet deep, penetrated 65 feet of pre-Pleistocene sandstone and shale. The log of this test hole shows 26 feet of fine- to coarse-grained angular sandstone at a depth of 354–380 feet, 35 feet of sandy dolomitic brick-red shale from 380 to 415 feet, and 4 feet of ferruginous quartzose sandstone from 415-419 feet. The age of these strata, although not definitely determined, is shown as undifferentiated Ordovician on the State geologic map (Grout and others, 1932). South of the report area in secs. 24 and 30, T. 159 N., R. 46 W., two test holes penetrated a few feet of shale and limestone which tentatively have been called Cretaceous in age. According to Allison (1932, p. 100), a thin sheet of Cretaceous sediments, consisting largely of soft blue shale and a basal layer of fine white sand, extends across the southwestern part of the county.

The Cretaceous strata are difficult to identify in drillers' logs and in well cuttings because the Cretaceous shale is lithologically similar to glacial clay and clayey till and because the Cretaceous strata are thin.

GLACIAL DEPOSITS

The Halma-Lake Bronson area is underlain by a thick section of glacial deposits, or glacial drift. Glacial drift is a general term for all the material that was deposited by glaciers either directly from the ice of from its melt water. In this area, glacial drift includes Mankato(?) and older drift, a series of outwash deposits, and Glacial Lake Agassiz deposits. On the basis of data from 3 test holes that completely penetrated the drift, these glacial deposits range in thickness from about 320 to 420 feet.

Drift may be subdivided into two general types—till and water-laid glacial deposits. Till consists of a mass of heterogeneous rock fragments ranging in size from clay to large boulders which were deposited by the ice with little or no sorting by water. Water-laid glacial deposits, formed as a result of the combined action of ice and water, may be subdivided into glaciolacustrine and glaciofluvial deposits. Glaciolacustrine sediments are deposited in lakes at or near the margin of the glacier ice and by water flowing directly from the ice into the lakes. The deposits range in grain size from clay to boulders, but the finer materials—clay, silt, and fine sand—are predominant. Glaciofluvial deposits, or outwash, consist of drift that has been sorted and stratified by glacial melt-water streams. Glaciofluvial deposits may include clay, silt, sand, gravel, cobbles, and boulders.

Except for minor amounts of alluvial, eolian, and swamp deposits, the materials immediately underlying the area are glacial deposits formed principally in late Wisconsin time. These, in generally ascending order are (a) Mankato(?) and undifferentiated older drift deposits, (b) outwash deposits, (c) lake deposits, and (d) beach deposits of Glacial Lake Agassiz. The Mankato(?) and undifferentiated older drift deposits were laid during advances of continental glaciers, the outwash deposits during the retreat of the glaciers, and the Lake Agassiz deposits during and after the final retreat of glacial ice from the area.

MANKATO(?) AND UNDIFFERENTIATED OLDER DRIFT DEPOSITS

Underlying the Mankato(?) drift is a series of undifferentiated drift deposits that are probably older than the Mankato(?). The older drift deposits may have been laid down earlier in the Wisconsin or in one of the pre-Wisconsin stages.

Lake sediments occur at depth that are distinct from the near-surface Lake Agassiz deposits and are believed to be part of the series of older drift deposits; however, they appear to be contiguous with the Lake Agassiz deposits in places. In test hole 161.46.32aaa1, glaciolacustrine-type sediments occur from near land surface to a depth of 272 feet. The generally patchy distribution of the older lake deposits and drift indicate that they had been considerably eroded before the Mankato(?) and Lake Agassiz deposits were laid down.

Test holes, such as 160.46.2bab1, 21ccd1, 161.45.31ddc1, and 161.46.32aaa1 (pl. 1), were drilled into older drift that included some thin outwash deposits. Although the distribution of the outwash deposits appears to be random phenomenon, it is possible that some of them may be part of a large outwash body.

PRINCIPAL OUTWASH DEPOSITS

A thick series of water-laid glacial deposits occupies a valley cut into the underlying drift. In the report area these deposits consist largely of outwash deposits. Three cross sections (pl. 1) show the lithology and distribution of the outwash deposits. Widely spaced test holes in other parts of Kittson County and in the northern part of Marshall County indicate that the valley extends in a general north-south direction for at least 33 miles and in places it is as much as 5 miles wide.

Generalized contours drawn on the drift surface underlying the principal outwash deposits (pl. 2) show that the valley is asymmetrical; the east side is steeper than the west. The outwash deposits range in thickness from 0 to 277 feet (test hole 160.46.32adc1). The approximate limits of the area within which the principal outwash deposits are at least 20 feet thick is shown on plate 2. In an area of about 24 square miles, between the two 900-foot contours (pl. 2), the outwash averages about 130 feet in thickness.

The deposits generally range from fine sand to medium gravel, and they include cobble and boulder beds and layers of silt and clay. The coarser outwash extends from the south shore of Lake Bronson to about 2 miles south of the village of Halma, a distance of about 6 miles. North and south of this area and along the flanks of the valley the outwash is fine grained.

Although some correlations can be made within the outwash deposits, the texture of many individual units changes abruptly within short distances and beds cannot be traced for any great distance. The many changes in sorting and stratification of the outwash deposits were probably caused by changes in the velocities of the glacial streams that deposited the outwash material. The depressions in the valley (section *A–A′*, pls. 1, 2) are probably the result of scouring by torrential currents.

The alternation of sandy and clayey deposits in the glaciolacustrine sediments within the principal outwash deposits indicates that the periods of rapid deposition from melt-water streams were interrupted by periods of quiescent deposition in temporary lake basins. Some of these deposits may be correlated long distances, as shown by the clay that occurs at an altitude of about 940 feet in test holes 159.46.5-aaal and 160.46.29daal (section *A–A′*, pl. 1).

The coarse-grained character and the great thickness of much of the water-laid glacial material indicate that it was probably deposited at or near the margin of an ice sheet. Some of the material may have been deposited in Glacial Lake Agassiz, thus being contemporaneous with the surrounding fine-grained lake sediments. Much of the outwash, however, was deposited below a beach ridge on till and was probably laid down before the formation of the lake.

LAKE DEPOSITS

The surficial lake deposits in the area consist primarily of fine to medium sand and lesser amounts of clay and silt. The deposits, which were probably formed during advances and retreats of Glacial Lake Agassiz, border the eastern shore of the lake and are intimately associated with the beach ridges in many places. Although they cover a large area, the deposits are thin in most places; they form a gently undulating plain which has been modified in places by stream and wind action.

BEACH DEPOSITS

A series of north-south trending beach deposits were formed along the shorelines of Glacial Lake Agassiz. The beach deposits form ridges which in most areas do not stand more than 15 feet above the surrounding plain. However, they are conspicuous because of their linear form and steep flanks. The beach deposits consist of well-sorted to moderately well sorted lenticular beds of sand and gravel, some of which are crossbedded at low to high angles. They are composed mostly of sand, but are gravelly and cobbly in places. In most beaches the coarser materials do not exceed 4 inches in diameter. An examination of gravel pits in the beach ridges (pl. 2) indicates that the beach deposits do not extend below the level of the surrounding lake plain.

Two beaches, the McCauleyville and Campbell, traverse the general area. The McCauleyville beach was first described by Upham (1895, p. 427–442), and later by Leverett (1932, p. 139). The beach lies within R. 46 W. at the Marshall-Kittson County line and can be traced northward into Kittson County to the southern part of T. 161 N. Leverett (1932, p. 139) described upper and lower McCauleyville beach lines, stating that the lower McCauleyville beach is a distinct ridge which can be traced along a line from the south border of Kittson County to the South Branch Two Rivers, passing between Lake Bronson and Halma. The upper beach, according to Leverett, is less continuous, but it can be traced to the Minneapolis, St. Paul & Sault Ste. Marie Railroad between Halma and Karlstad.

The lower beach is identified tentatively on plate 2 by the closely spaced contours trending north-south in secs. 8, 17, 20, 29, and 32, T. 159 N., R. 46 W. and secs. 5, 8, and 17, T. 158 N., R. 46 W. In the vicinity of Halma and northward, surficial deposits of sand and gravel form low discontinuous ridges, which are probably an extension of the lower McCauleyville beach. In most places these ridges are contiguous with the underlying series of outwash deposits, and their long axes are in line with the lower McCauleyville beach to the south. The sand and gravel in the lower McCauleyville beach were probably derived from the outwash deposits.

Leverett's upper McCauleyville beach is believed to be the ridge that trends north-south through secs. 14, 23, 26, 35, and 34, T. 159 N., R. 46 W. and secs. 3, 10, and 15, T. 158 N., R. 46 W. The distinct ridge that passes through the village of Karlstad and the one that crosses the railroad tracks about 1 mile southeast of the village have been described as part of the Campbell beach by Leverett (1932, p. 138 and pl. 1).

EOLIAN, ALLUVIAL, AND SWAMP DEPOSITS

The eolian deposits of Pleistocene(?) and Recent age occur locally as dunes or as a thin mantle over the older deposits. Numerous dunes occur in the wooded area east of Lake Bronson in Tps. 160 and 161 N., R. 46 W. A group of sand dunes in sec. 10, T. 160 N., R. 46 W., stands about 30 feet above the surrounding land surface. The stream valleys in the area are underlain by alluvium of Pleistocene(?) and Recent age, consisting predominantly of clay, silt, and fine sand. Swamp deposits of Pleistocene(?) and Recent age occur locally.

GROUND WATER

GENERAL PRINCIPLES OF OCCURRENCE

Ground water as defined by Meinzer (1923, p. 38) is "that part of the subsurface water which is in the zone of saturation." It is the water that supplies springs and is available to wells, and that discharges into lakes and streams to maintain their stages and flows between rains and snowmelt. The zone of saturation includes all rock material whose voids are filled with water at a pressure equal to or greater than atmospheric pressure.

The primary source of all ground water is precipitation in the form of rain or snow. Precipitation is disseminated by runoff into streams or lakes, by evapotranspiration, and by downward percolation into the ground, where it is eventually discharged by way of seeps, springs, wells, or plants.

As water percolates downward to the zone of saturation, a part of it is held by molecular attraction in the interstices through which it passes. This water is said to be in the zone of aeration. The capillary fringe is a belt that overlies the zone of saturation and contains capillary interstices, some or all of which are filled with water that is continuous with the water in the zone of saturation. The water in the capillary fringe is held above the zone of saturation by capillarity acting against gravity. The amount of water in the zone of aeration may be great; it is dependent upon a number of factors, the most important of which are the texture of the material comprising the zone and the thickness of the zone. Water in the zone of aeration is not available to wells, and water requirements of this zone must be satisfied before water can enter the zone of saturation. Much of the water in the zone of aeration may be withdrawn by transpiration of plants and by evaporation from the soil.

The amount of water a rock or soil can retain or transmit is a function of its porosity and permeability. The porosity of a rock or soil is its property of containing interstices; it is expressed quantitatively as the percentage of the total volume of the rock that is not occupied by solid rock material. The capacity of a water-bearing formation to transmit water through its intertices is referred to as permeability. If the interstices of a rock or soil are large and interconnected, as in sorted sand and gravel, water may move through them more or less freely and the material is said to be permeable. Where the interstices are small or poorly connected, as in clay or crystalline rock, water seeps through them slowly and the material is said to be of low permeability. Permeability may be expressed quantitatively as a coefficient which is defined in the section entitled "Pumping Tests."

Geologic formations or parts of formations that have the property to store water and yield it to wells in usable quantity are termed "aquifers." Sorted sand and gravel deposits, such as some glacial outwash, are generally very permeable and are good aquifers. Till and clay are of low permeability and are considered poor aquifers.

The upper surface of the zone of saturation, where not confined by an impermeable bed, is called the water table, and the aquifer is called a water-table aquifer. The shape of the water table generally is a subdued model of the surface topography. Where the water table is at land surface, seeps or springs form, and, depending upon the nature of the terrain, a lake, marsh, or stream may result. A stream or lake whose surface is higher than the regional water table contributes water to the zone of saturation and is referred to as influent. Conversely, when the stream or lake is lower than the regional water table, it receives water from the zone of saturation and is called effluent.

An aquifer is artesian when its water is confined under pressure by relatively impermeable materials. The water level in a well completed in an artesian aquifer will rise above the top of the formation. The water surface in an artesian well is on the piezometric surface, an imaginary surface to which the water from a given aquifer will rise in tightly cased wells. A well tapping an artesian aquifer does not unwater the aquifer unless the water level is drawn down below the bottom of the overlying confining beds. When water is removed from an artesian aquifer, the space which it formerly occupied is compensated for by the expansion of the remaining water and the compression of the aquifer that results from the lowered pressure.

WATER-BEARING CHARACTERISTICS OF GEOLOGIC UNITS

The water-bearing characteristics of the geologic units in the Halma-Lake Bronson area are summarized in table 1.

The presence of the bedrock formations in this area has been established by a few test holes. If these strata contain highly mineralized water under pressure, as they do in other parts of the region, the glacial drift just above the bedrock may also contain some mineralized water. Under these conditions heavy pumping from the principal outwash deposits could induce upward movement of highly mineralized water.

Although large supplies of water are available from the principal outwash deposits, contiguous sediments may add considerably to their potential yield. Pumping of wells in the outwash deposits could induce the movement of appreciable amounts of water from contiguous deposits of silt and fine sand. The water-bearing characteristics of the water-laid glacial deposits are described in detail in the sections that follow.

The lake, eolian, and alluvial deposits serve as an infiltration medium by which recharge from precipitation reaches underlying aquifers. In addition, the saturated permeable parts of these surficial deposits may yield sufficient amounts of water for small domestic and stock supplies.

MOVEMENT, RECHARGE, AND DISCHARGE

Almost all ground water moves from an area of recharge to an area of discharge. The movement is always in the direction of the hydraulic gradient, and, in general, the rate of movement is proportional to the gradient. The rate may range from a fraction of a foot to several hundreds of feet per day; it is affected not only by the gradient, but also by the permeability of the formation and the temperature of the water. Locally, however, the direction of movement probably is controlled by surface features, such as streams, lakes, and swamps. For example, it is probable that the direction of ground-water movement in the immediate vicinity of Lake Bronson and South Branch Two Rivers is toward the lake and river valley.

The amount of precipitation that enters a ground-water reservoir is influenced by a number of factors, including the duration, intensity, and type of precipitation; the density and types of vegetation; the season; the topography; and the porosity and permeability of the soil, subsoil, and underlying rock formations. Although some recharge to the ground-water reservoir in the Halma-Lake Bronson area may occur from lateral ground-water movement into the area, most of it is derived from downward percolation of precipitation. The sandy surficial deposits and the relatively flat topography are particularly conducive to good recharge conditions.

Because the water table is close to the surface in much of the area, most of the natural discharge from the ground-water reservoir occurs through transpiration by plants and by evaporation from water-table ponds, sloughs, gravel pits, and directly from the soil surface. Collectively these processes are known as evapotranspiration. Lake Bronson forms part of the water table and thus contributes to ground-water losses through evaporation from the lake surface and through transpiration by aquatic plants. Ground water is also discharged by seeps and small springs along stream valleys and artificial drains that sustain the flow of streams during periods of no precipitation and by natural ground-water movement out of the area in response to the regional hydraulic gradient.

The average rate of natural discharge in the area over a long period of time is about equal to the average rate of recharge. If heavy pumping of wells is begun, the water table will decline, and natural discharge from the ground-water reservoir by spring flow, seepage, evapotranspiration, and perhaps regional underflow, would be decreased. Initially, the water that is pumped would come mostly from storage. With continued pumping, the water table probably would decline further, and additional amounts of water that would normally be discharged by natural processes may be salvaged. However, if the total pumpage is in excess of the recharge plus the amount of natural discharge that is salvageable, the development will continue to draw from storage and the water table will continue to decline.

At present relatively small amounts of water are discharged from wells in the area. The extent of well development is discussed below under the heading "Present well development."

FLUCTUATIONS OF THE WATER TABLE

Most natural fluctuations of the water table reflect recharge to or discharge from the ground-water reservoir. If discharge from a ground-water reservoir exceeds recharge, the water table will decline; if recharge exceeds discharge, the water table will rise.

To provide a record of natural fluctuations of the water table in the area, one observation well (160.46.5dccl) has been measured periodically since November 1955. This is a dug well, 7.9 feet deep, 36 inches in diameter, and finished in sand and gravel. Although a more comprehensive analysis could be made from a longer record of water levels, some interpretations can be made from the existing measurements.

Figure 3 is a hydrograph of this observation well, which compares water-level fluctuations with precipitation at Hallock, about 15 miles northwest of the well. Recharge is greatest in the sprıng, during the period of snowmelt and spring rains and before evapotranspiration begins to take effect. Water levels usually rise quickly in response to rainfall. The greatest amount of recharge occurred in the spring of 1956 when the water level rose from a low of 4.90 feet below land surface in March to 0.65 foot below land surface in June. During the summer, water levels may rise for short periods of time in response to recharge from rainfall, but normally the trend is downward because the draft by evapotranspiration exceeds recharge. Water levels remained high during the summers of 1956 and 1957, owing to heavy rainfall which exceeded the evapotranspirative draft. In the fall, when evapotranspiration losses are reduced, an amount of precipitation equivalent to that which fell during the summer could result in a greater rise in the water level, provided that water requirements of the zone of aeration have first been satisfied. However, the downward trend common during the summer may continue through the fall if precipitation is deficient, or if an early freeze impedes the infiltration capacity of the soil. During the winter months, water levels usually decline because the frozen ground prevents recharge. The lowest water level recorded was 5.28 feet below land surface in December 1958.

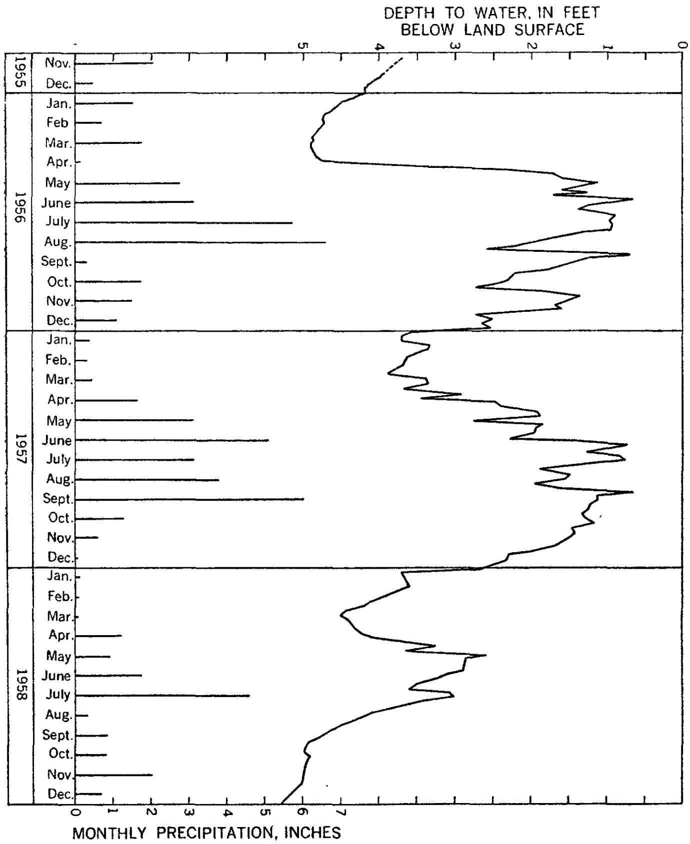

FIGURE 3.—Hydrograph of observation well 160.46.5dccl and graph of monthly precipitation at Hallock, Minn., for the period 1955–58.

The water table during 1958 generally was lower than the levels of the previous 2 years of record, owing to below-average precipitation. In a long period of wet weather the water table may rise to a level where underground storage cannot be increased even by additional heavy precipitation. For example, the peak levels in June 1956 and September 1957 were each 0.65 foot below land surface, which suggests that at these times the reservoir was filled to capacity under the prevailing conditions. During these periods the soil and subsoil were saturated, and there was much standing water in the area.

AQUIFER TESTS

The hydraulic characteristics of an aquifer must be determined to predict the effects of withdrawal of water from it. Two aquifer tests, or controlled pumping tests, were made for this purpose on wells in the outwash deposits. Standard methods of analysis (Wenzel, 1942;

Cooper and Jacob, 1946) were used for determining values of the coefficients of transmissibility (T) and storage (S). The coefficient of transmissibility may be expressed as the number of gallons of water, at the prevailing water temperature, that will pass in 1 day through a vertical strip of the aquifer 1-foot wide extending the saturated height of the aquifer, under a hydraulic gradient of 100 percent. The standard coefficient of permeability used in the hydrologic work of the Geological Survey is defined as the rate of flow of water in gallons per day, through a cross section of 1-square foot, under a hydraulic gradient of 100 percent, at a temperature of 60° F. In the field, usually no correction for temperature is made, and the value determined is called the field coefficient of permeability. The average field coefficient of permeability is equal to the coefficient of transmissibility divided by the saturated thickness of the aquifer. The coefficient of storage of an aquifer is defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

PROCEDURE

In July and August 1958, two pumping tests were made to determine the hydraulic characteristics of the principal outwash deposits. The locations of the wells used in the pumping tests and the distances and directions of the observation wells from the pumped wells are shown on plate 2, inset maps 1 and 2. Screen settings of the pumped wells are shown on the geologic cross sections (pl. 1). In the first test, well 160.46.20aba2 was pumped at an average rate of 458 gpm (gallons per minute) for 6½ hours. The second test was on well 161.46.33dcd3, which was pumped at an average rate of 408 gpm for 24 hours. Hydrographs of the wells used during the tests are shown on figures 4 and 5.

The pumped wells were 8 inches in diameter and were equipped with 20 feet of 8-inch wire-wound screen with 0.035-inch openings. The wells were equipped with turbine pumps, and discharge measurements were made with a circular orifice. To prevent recharge to the aquifer, the discharge water was removed from the test site through irrigation pipe.

The observation wells were completed in the same horizon as the pumped wells and were fitted with recording gages which made continuous records of water-level fluctuations. The observation wells were 6 inches in diameter, and had 3½ feet of 1¼-inch wire-wound screen with 0.015-inch openings.

ANALYSIS

The first test was made about 1 mile northwest of the village of Halma (inset 2, pl. 2). The calculated T (coefficient of transmissibil-

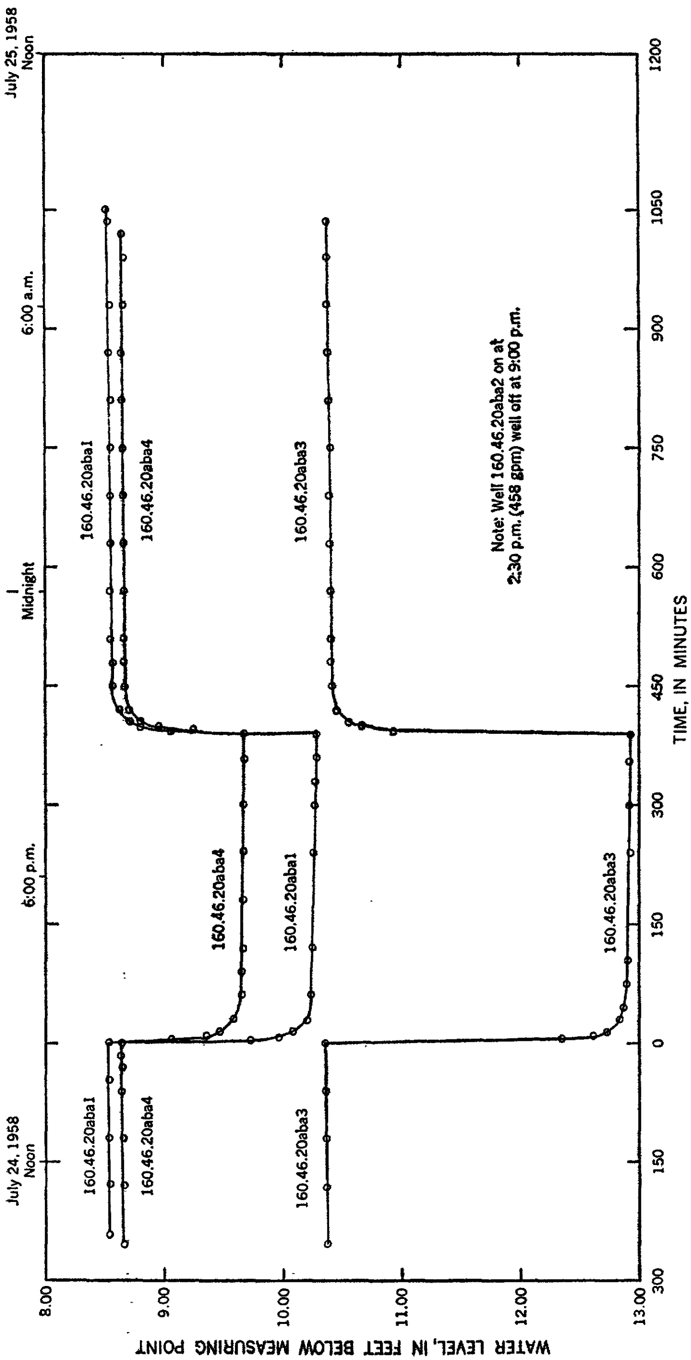

FIGURE 4.—Hydrographs of observation wells during test pumping of well 160.46.20aba2, Halma-Lake Bronson area, Minn. For location of wells, see inset map 2, plate 2.

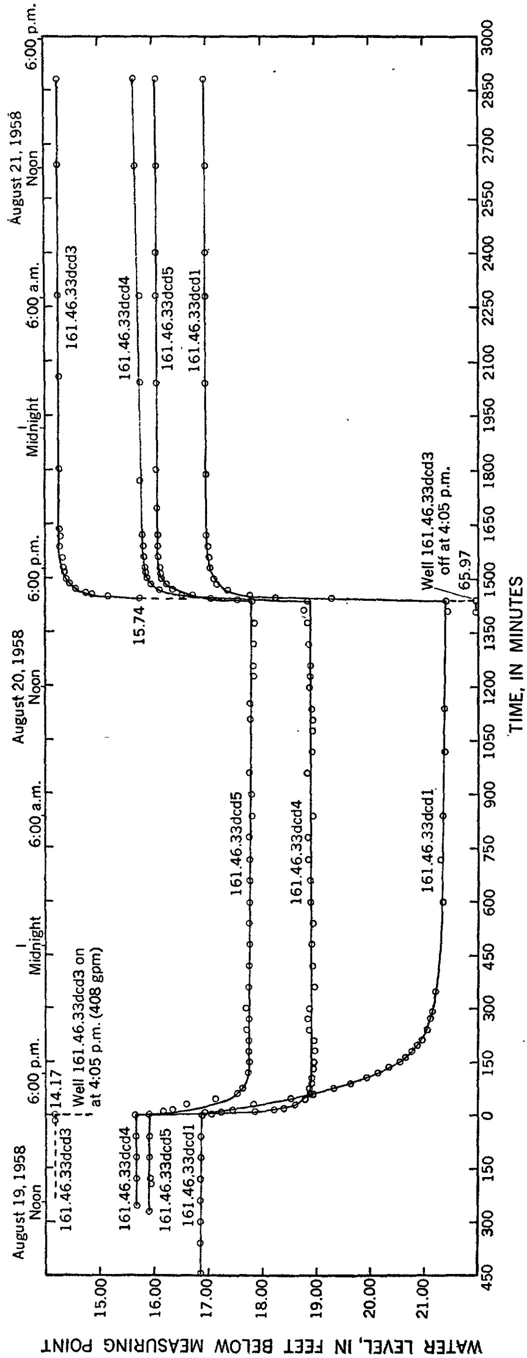

FIGURE 5.—Hydrographs of wells during test pumping of well 161.46.33dcd3, Halma-Lake Bronson area, Minn. For location of wells, see inset map 1, plate 2.

ity) values, obtained from the recovery tests, range from about 70,000 to 90,000 gpd per ft. (gallons per day per foot) and average about 80,000 gpd per ft. The average saturated thickness of the stratum in the area of the test is about 100 feet; therefore, the field coefficient of permeability is about 800 gpd per sq. ft. (gallons per day per square foot).

The second test was made on the south shore of Lake Bronson (inset 1, pl. 2). The calculated values for *T*, based on recovery tests, average about 50,000 gpd per ft. The stratum in the test area is about 140 feet thick; therefore, the field coefficient of permeability is about 300 gpd per sq. ft.

There were marked similarities in the two tests. During the first part of each test, the calculated *S* values definitely are in the range for artesian conditions. This is probably the result of the overlying beds of lower permeability acting as confining strata until the head was lowered sufficiently to induce them to drain and recharge the stratum that was being pumped. The period of pumping was too short to obtain an accurate determination for the values of *S*. The calculations for *S* showed that the coefficients were increasing with time, thus indicating that the overlying materials were still draining. Probably, the values of *S* would ultimately be in the range for water-table conditions, having a value of at least 0.20. Also, during each test, the data indicate that recharge was taking place within 15 minutes after pumping began. Much of the drawdown in well 161.46.33dcd3 was probably caused by low well efficiency; the well was computed to be about 60 percent efficient.

The recharge effect in the first test was probably due largely to induced vertical leakage from the overlying fine sediments, which resulted from lowering the head by pumping (see logs in table 3). However, in view of the extreme variability of the texture of the deposits, it is also possible that part of the recharge resulted from the cone of influence reaching a more permeable section of the aquifer.

One of the objectives of the pumping test on well 161.46.33dcd3 was to determine if it were possible to induce infiltration from Lake Bronson. The recharge effect that was observed during the test could not be ascribed to any one source. It may have been due in part to infiltration of Lake Bronson water, vertical leakage from the overlying finer sediments, or the result of the cone of influence reaching more permeable material. However, considering the great thickness of saturated outwash above the stratum being tested, it is probable that most of the recharge was derived from vertical leakage from overlying strata.

The pumping-test data indicate that there are large variations in the coefficient of transmissibility and permeability between different parts of the principal outwash deposits in the Halma-Lake Bronson area. The tests were made in the more permeable parts of the aquifer, and the deposits, considered as a unit, probably have a smaller coefficient of transmissibility than the values obtained from the pumping tests.

PRESENT WELL DEVELOPMENT

The ground-water development in the Halma-Lake Bronson area consists of two municipal wells and a well at a creamery at Lake Bronson, a well at a creamery at Halma, a municipal well at Karlstad, and numerous farm wells. The location, depth of well, and depth to water of most of the wells that were inventoried in the Halma-Lake Bronson area are shown on plate 2.

The villages in the area are small, and consequently they do not use large quantities of water. The village of Lake Bronson wells, 80 and 96 feet deep, together produced an average of about 30,000 gpd in 1958. It is estimated that in 1954 the village of Karlstad used an average of about 25,000 gpd from a well 150 feet deep. The village of Halma does not have a public water supply, but almost every house in the village has a well. Pumpage data are not available for these wells or for the creamery wells at Halma and Lake Bronson.

Almost every farm in the area has one or more wells which normally provide sufficient water for domestic and stock use. Most of the wells are so constructed that the maximum yield is about 10 gpm, although the yield of some wells is much less.

The wells range in depth from a few feet to a reported maximum depth of 160 feet and average about 25 feet. Water levels range from above land surface to 30 feet below land surface and average about 8 feet below land surface.

Most of the wells are shallow and dug by hand; others are drilled, bored, or driven. The type of well construction is governed largely by the nature of the material penetrated in the well. Where the surficial water-bearing deposits are lake silt and sand, most wells are bored or dug to the underlying "hardpan" (firm till) or to "quicksand" (fine sand) at which depth the well is completed because of the difficulty in digging. Many wells have wood curbs or "jug-shaped" curbs made of glacial boulders, whereas others have curbs made of concrete tile ranging in diameter from 30 to 42 inches. Corrugated steel culvert pipe was used to case numerous dug and bored wells. On the beach ridges some shallow wells are driven using pipe 1¼ inches in diameter, and most of the deeper wells are drilled and cased with 2- to 4-inch diameter steel casing. Some wells are finished with well screens, but most are finished with open-end casing. A problem common to most wells in the area is a tendency for fine sand to fill and plug the casing and seriously reduce the yield and storage capacity of the well.

AVAILABILITY OF WATER FOR FUTURE DEVELOPMENT

The theoretical drawdown resulting from a well yielding about 1 mgd (million gallons per day), about 700 gpm, from an aquifer with *T* values of 80,000 and 50,000 and an *S* of 0.20 is plotted in graphical form on figures 6–9. The data are presented as drawdown versus distance at selected times for as much as 100 days and as drawdown versus time at selected distances as much as 1,000 feet. If the coefficient of storage is less than 0.20, then the drawdown would be more than that shown in figures 6–9. Conversely, a storage coefficient larger than 0.20 would result in less drawdown than that shown. The drawdown in a pumped well or in a well affected by pumping is directly proportional to the rate of discharge of the pumped well. Therefore, the drawdown caused by a well pumping 1,400 gpm would be twice that shown on figures 6–9. The total drawdown at any specified point affected by more than one well is equal to the sum of the drawdowns of the wells affecting that point. For example, if 2 wells each pumping singly, cause a drawdown of 2 and 4 feet, respectively, at a particular point, then the total drawdown at that point when the wells are pumped together is equal to the sum of the drawdowns, or 6 feet.

A large amount of water is stored in the principal outwash deposits. Although the available data are not adequate to make predictions as to the quantity of water that could be withdrawn perennially from the ground-water reservoir, it is useful to make a conservative estimate of the total amount that may be available from storage alone. Assuming that the average coefficient of storage for the principal series of outwash deposits is 0.10 and the average saturated thickness is 130 feet, the amount of water theoretically available by gravity drainage in the 24-square-mile area underlain by the more permeable materials would be about 65 billion gallons. Therefore, for every foot of lowering of the water table in a square mile, about 21 million gallons of water would be available.

The average annual recharge to the principal outwash deposits is not known, but the soil is sandy and it is believed that much of the precipitation becomes recharge. A conservative estimate is that 10 percent of the mean annual precipitation of 20.12 inches is average net recharge. If this is correct, then about 36 million gallons of water would be added to each square mile of the ground water reservoir annually.

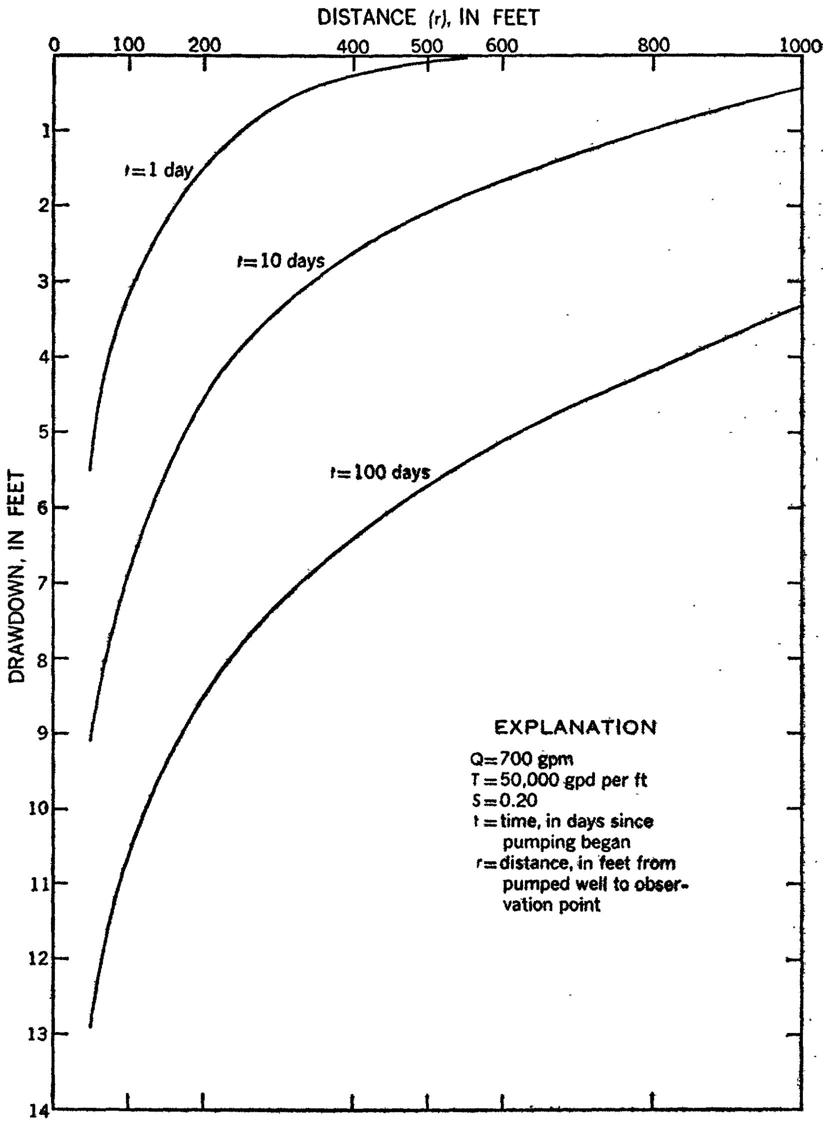

FIGURE 6.—Theoretical relation of drawdown to distance from a pumped well in an aquifer with a transmissibility of 50,000 gpd per ft.

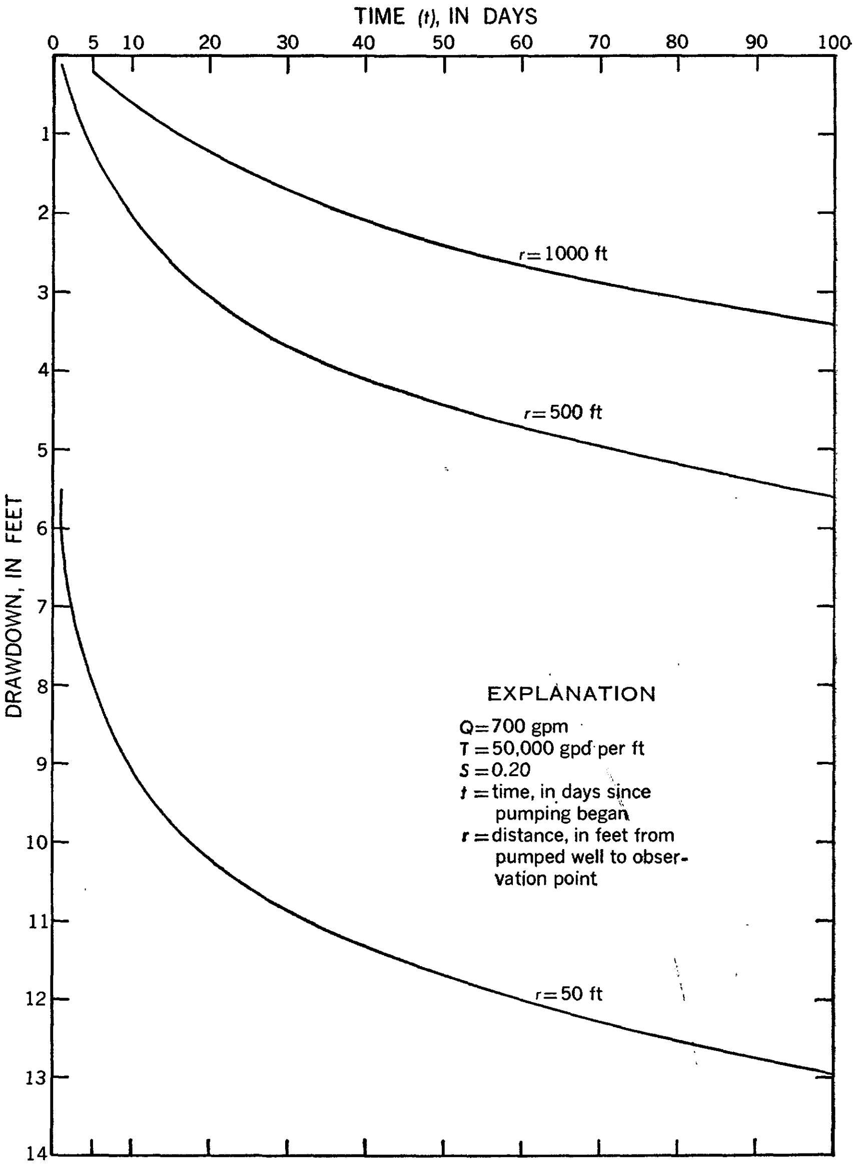

FIGURE 7.—Theoretical relation of drawdown to time since discharge began in an aquifer with a transmissibility of 50,000 gpd per ft.

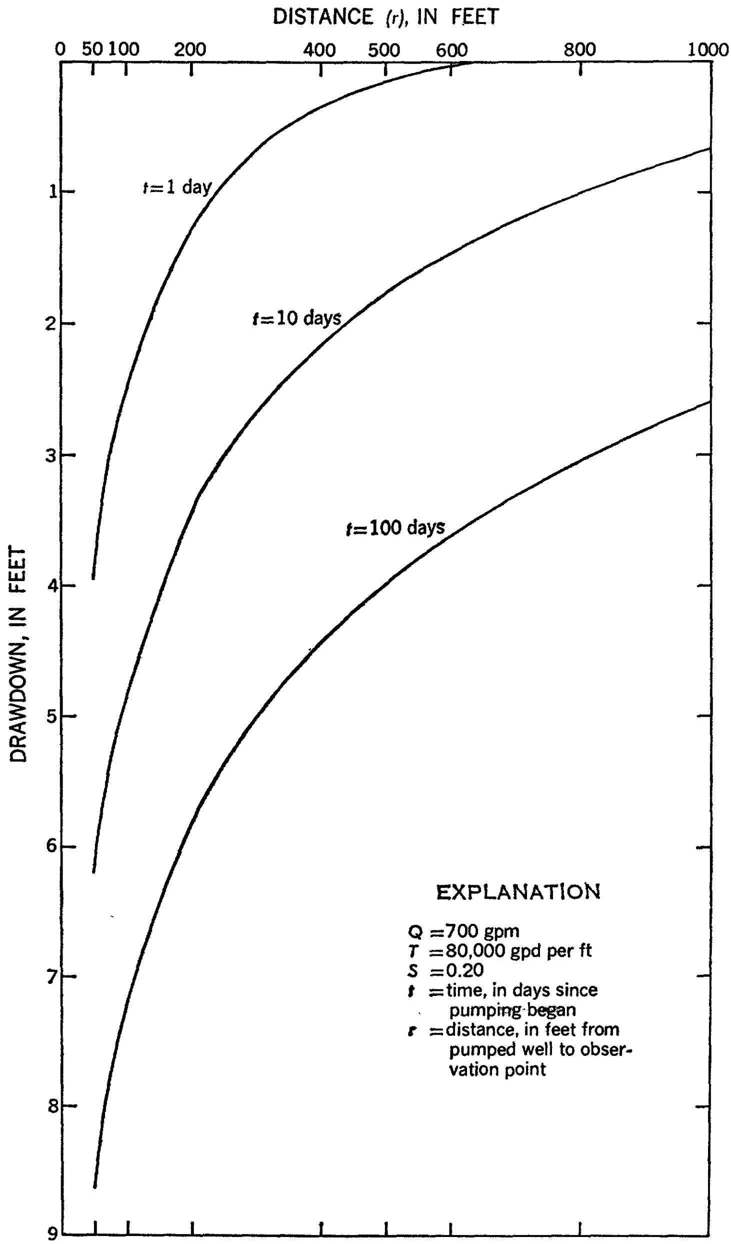

FIGURE 8.—Theoretical relation of drawdown to distance from a pumped well in an aquifer with a transmissibility of 80,000 gpd per ft.

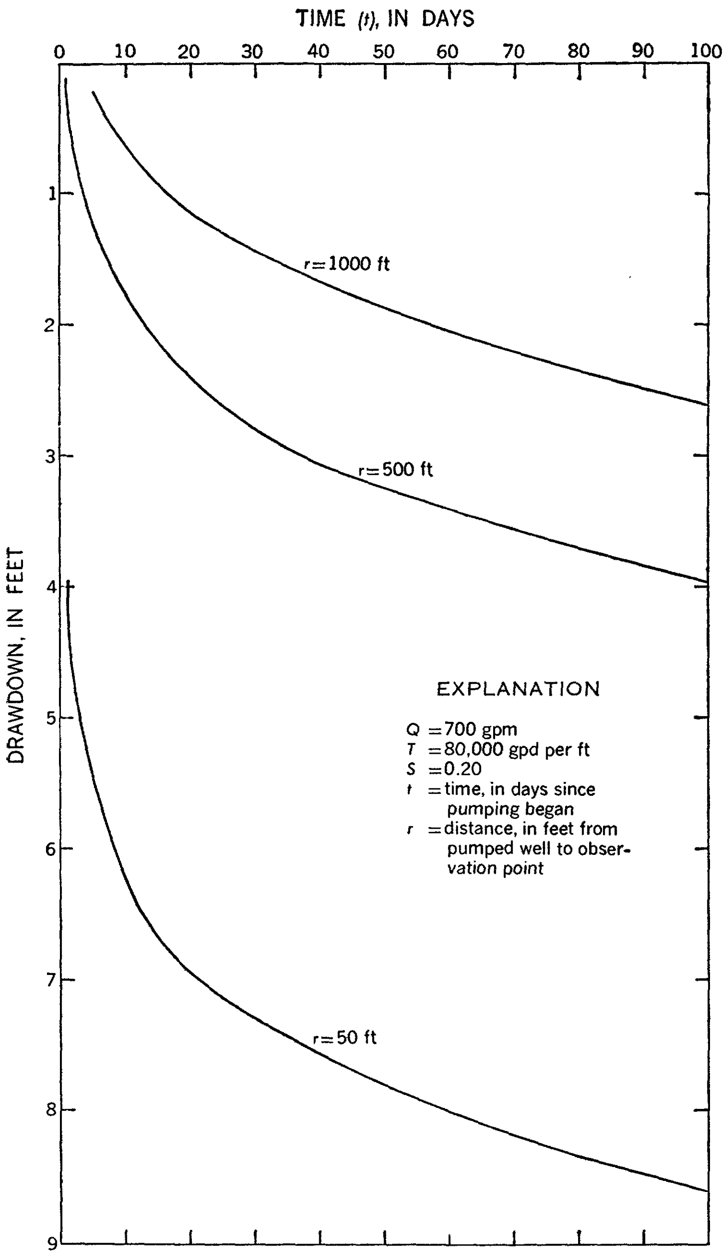

FIGURE 9.—Theoretical relation of drawdown to time since discharge began in an aquifer with a transmissibility of 80,000 gpd per ft.

Considering the relative ease with which the temporary test wells were developed for the pumping tests, it is likely that properly constructed permanent supply wells would have considerably higher yields. Furthermore, pumping from large-capacity wells close to the south shore of Lake Bronson would probably induce infiltration of lake water into the ground-water reservoir, thereby supplementing the normal recharge from precipitation. It is estimated that a well 100 feet from Lake Bronson, pumping from an aquifer having a transmissibility of 50,000 gpd per ft. and a storage coefficient of 0.20, would take about 85 percent of its water from the lake after 1 day of pumping; after 40 days of pumping the well would be taking more than 95 percent of its water from the lake.

Pumpage of ground water in the area would probably reduce losses resulting from rejected recharge and evapotranspiration, and the cone of influence formed would salvage water normally leaving the area under the natural gradient by imposing a gradient towards the development. In these respects the recharge would then be increased.

SURFACE WATER

The westward flowing South Branch Two Rivers is the only major stream in the area. A recording stream gaging station (South Branch Two Rivers at Lake Bronson) in the SW¼SW¼SW¼ sec. 30, T. 161 N., R. 46 W. has been in continuous operation since 1953 (pl. 2). The drainage area covered by the station is 444 square miles. For the 8 years of record, 1941–43, 1945–47 and 1953–57, the discharge ranged from no flow to a maximum of 2,650 cfs (cubic feet per second) and averaged 111 cfs (Wells, 1959, p. 92). No flow was reported at times during the late summers of 1937 and 1941.

The low streamflow has been regulated since 1937 by Lake Bronson. If the streamflow were not regulated, there would probably be periods of little or no flow during 2 or 3 months of the winter. This indicates that under natural conditions effluent seepage at this time would be slight. In most years from 95 to 100 percent of the yearly runoff occurs in the period of April to September. Maximum flow usually occurs during the spring when snowmelt and rain combine to produce high discharges. Because the stream gradient is low, velocities are slow, peak flows cover a relatively long period of time, and the durations of the high-water periods are prolonged. The prolonged peak flows and high-water periods are probably due to a combination of bank storage, temporary surface storage, channel storage, and ground-water discharge.

Lake Bronson was formed by a dam completed in 1937 to provide recreational facilities and a water supply for Hallock and the village of Lake Bronson, although only Hallock is now utilizing this source.

The following data on Lake Bronson were obtained from S. A. Frellsen (written communication, Minnesota Department of Conservation, 1952). The usable storage capacity of Lake Bronson is 3,700 acre-feet, of which about 1,700 (554 million gallons) should be available for municipal water supplies. Evaporation from free-water surfaces in this area is about 25 inches per year. During most of the years of record there was sufficient water to fill the reservoir and maintain it at the maximum storage level until September 1 or later.

QUALITY OF WATER

Chemical analyses of 12 samples of ground water and 4 samples of surface water are listed in table 2. The ground-water samples were collected from 9 wells ranging in depth from 7.2 to 136 feet.

The chemical constituents of ground water are often an indication of the chemical characteristics of the strata through which it has moved. As water percolates through the soil and rocks, various chemical and physical reactions take place. The quality of natural waters is influenced by many factors, the most important of which are the composition and thickness of the strata through which the water passes and the length of time the water is in contact with the strata. Other factors, such as the amount of plant and animal life and the temperature of the region, also affect the quality of natural waters. In general, water from deep wells and wells in discharge areas is likely to be more highly mineralized than water from shallow wells in recharge areas.

The chemical analyses show that the quality of the ground water in the area is generally similar regardless of depth. It is primarily of the bicarbonate type. This type is typical of glacial drift which has a high percentage of limestone and dolomite particles. The iron content of the ground water is high, ranging from 0.20 to 8.1 ppm (parts per million) and averaging 3.4 ppm. With some exceptions, the amount of iron seems to increase with the depth of the well—0.53 ppm in well 160.46.5cba2, 7.2 feet deep; 3.4 ppm in well 161.46.30cdc1, 96 feet deep; and 5.3 ppm in well 161.46.33dcd3, 136 feet deep. The U.S. Public Health Service (Hopkins and Gullans, 1960, p. 1161–1168) recommends a limit of 0.3 ppm iron. Ground water in the area is hard (208 to 415 ppm, averaging 315 ppm), but because it is a recharge area it is generally slightly softer and lower in dissolved-solids content than ground water from adjacent areas. The dissolved-solids content ranges from 245 to 576 ppm and averages 330 ppm; a limit of 500 ppm is recommended by the Public Health Service. The higher-than-average dissolved-solids content of the water from wells 161.46.30ccd1 and cdc1 probably indicates that the drift in that part of the report area has a low permeability. Highly mineralized water occurs in the bedrock formations and in the glacial drift in adjacent areas, but there is no indication that such water occurs in the Halma-Lake Bronson area.

Water samples were taken periodically during the two pumping tests for chemical analyses to detect possible changes in the quality of the water (the first and last samples taken are listed in table 2; wells 160.46.20aba2 and 161.46.33dcd3). There were no significant chemical changes in either test.

Surface water in the area is of the calcium bicarbonate type; it also contains significant amounts of sulfate. The chemical limits of the water, however, are within the quality standards recommended by the Public Health Service, except for excessive color. The extent to which water is colored by material in solution is based on a comparison of a column of the water sample with a column of equal height of an arbitrary standard whose color is rated at 500. The standard used is a platinum-cobalt scale in which color in water is expressed in terms of units between 0 and 500 or more; the recommended limit is 15. Some samples of surface water from the Halma-Lake Bronson area have color rated as high as 50.

SUMMARY

The Halma-Lake Bronson area is underlain by about 320 to 420 feet of glacial drift, except for thin surficial swamp deposits, dune sand, and alluvium. The glacial drift overlies either Precambrian crystalline rocks or sedimentary formations of Paleozoic or Mesozoic age.

The most important and extensive water-bearing strata are included in the water-laid glacial deposits and are referred to collectively as the principal outwash deposits in the area. These outwash deposits are considered as a single aquifer because they appear to be connected hydrologically. The aquifer occupies a valley in the underlying drift which is composed largely of till of low permeability. The outwash deposits are exposed at the surface in some areas and are hydraulically connected with overlying surficial dune sand or beach deposits in other areas. The coarsest and most permeable part of the aquifer averages about 130 feet in thickness and underlies an area of about 24 square miles.

Precipitation is the main source of recharge in the area, and evapotranspiration accounts for most of the natural discharge. The total amount of water discharged from wells in the area is very small.

Large well yields of 1,000 to 2,000 gpm probably can be obtained from the outwash deposits. However, because of the complex and

TABLE 2.—*Chemical analyses of water in the Halma-Lake Bronson area, Kittson County, Minn.*

[Analytical results, in parts per million except as indicated]

Location No.	Depth of well (feet)	Date of collection	Temperature (°F)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)
160.46.5cba2	7.2	6-28-55		12	0.53	66	28	14	2.2	325	0	30
20aba2	107	7-24-58	45.5	25	4.5	80	32	7.0	2.2	405	0	4.3
Do	107	do	45.5	25	4.4	80	31	6.9	2.4	403	0	3.3
160.46.20dcc1	15.9	6-28-55		14	.20	68	23	5.8	7.4	288	0	16
21ccb1	21	5-13-54	46	7.3	1.5	59	15	2.0	.7	220	0	24
21ddd1	21.4	6-28-55	49	13	.20	70	28	20	6.4	332	0	28
28abd1	11.5	do	52	11	2.8	84	32	18	3.0	399	0	22
South Branch Two Rivers:												
161.46.30ccc		4-8-54 to 4-11-54		12	.03	71	31	7.1		285	0	76
Do		9-6-54 to 9-30-54		12	.02	72	33	6.9		305	0	74
161.46.30ccd1	70	6-22-55		39	6.8	78	54	52	5.1	662	0	3.0
30cdc1	96	5-7-54	44	38	3.4	73	42	31	5.0	534	0	1.0
Do	96	6-22-55		38	8.1	78	50	42	4.7	609	0	1.8
Lake Bronson:												
161.46.32d		9-16-53	63	6.2	[1]0			10		231		85
33dca		8-19-58	70	13	.20	67	33	6.1	2.9	280	0	79
161.46.33dcd3	136	do	44.6	22	5.3	73	25	5.4	2.3	356	0	3.8
Do	136	8-20-58	44.6	22	3.1	70	27	5.4	1.9	352	0	2.5

Location No.	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids		Hardness as $CaCO_3$		Specific conductance (micromhos at 25° C)	pH	Remarks
					Calc.	Residue on evaporation at 180° C	Calcium magnesium	noncarbonate			
160.46.5cba2	7.0	0.1	2.1	0.07	322	342	281	14	568	7.5	
20aba2	2.0	.1	.1	.05		349	330	0	610	7.1	3:00 p.m.; color, 1.
Do	.5	.1	.1	.03		346	328	0	607	7.1	8:00 p.m.; color, 1.
160.46.20dcc1	5.5	.1	23	.04	305	329	265	29	535	7.6	
21ccb1	3.5	.1	12	.01		245	208	28	403	7.7	
21ddd1	14	.1	17	.12	361	400	288	16	620	7.5	
28abd1	19	.2	.3	.05	389	406	341	14	686	7.5	
South Branch Two Rivers:											
161.46.30ccc	2.0	.2	3.4	.08		369	303	69	568	7.5	Color, 17.
Do	.5	.6	1.1	.09		384	315	65	589	7.7	Color, 50.
161.46.30ccd1	11	.4	.3	.27	576	576	415	0	990	7.3	Total Mn, 0.11; color, 21.
30cdc1	2.0	.3	.2	.18		457	354	0	786	7.3	Total Mn, 0.10; turbidity, 20; color, 20.
Do	7.5	.3	.2	.23	531	524	400	0	906	7.4	Color, 14.
Lake Bronson:											
161.46.32d	.5	.4	4.7				261	72	504	7.3	
33dca	.1	.4	.5	.07		393	304	74	555	7.9	
161.46.33dcd3	.1	.1	.3	.09		302	286	0	528	7.3	4:30 p.m.
Do	.1	.1	.1	.03		298	284	0	527	7.3	3:30 p.m.

[1] In solution at time of analysis.

variable geologic and hydrologic characteristics of the outwash deposits, additional test drilling and pumping would be necessary prerequisite to any large-scale ground-water development. Without recharge it is estimated that about 21 million gallons of water per square mile would theoretically be available from storage for each foot of lowering of the water table. A large ground-water development would not only reduce natural discharge losses and increase the percent of precipitation that became recharge, but would also intercept water that would have left the area by lateral subsurface movement.

Both surface and ground water are high in calcium and magnesium content, which are the chief contributing factors to hardness in water. The ground water contains less calcium and magnesium than from adjacent areas to the west. Neither the surface or ground waters contain excessive quantities of dissolved solids. The ground water has a high iron content, and the surface water is excessively colored.

WELL LOGS

Table 3 contains 16 logs selected from 80 logs of wells and test holes drilled in the Halma-Lake Bronson area. Well cuttings from the 75 test holes of the U.S. Geological Survey were collected and described by Survey geologists. The locations of the 5 test holes and wells of the village of Lake Bronson and the 75 test holes and wells of the Survey are shown on plate 2. Logs of all these test holes and wells in the Halma-Lake Bronson area are on file in the offices of the U.S. Geological Survey, Branch of Ground Water, District Office, St. Paul, Minn.

TABLE 3.—*Selected logs of test holes and wells in the Halma-Lake Bronson area*

159.46.6bbb1

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Soil, silty, sandy	1	1
Silt, clayey, buff; fine clayey buff sand; contains some gravel	4	5
Till, very silty and sandy, yellowish-brown; contains some gravel	2	7
Till, very silty and sandy, gray; contains some gravel	8	15
Till, very sandy, gray, compact; contains some silt and gravel	15	30

160.46.6cbd1

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Soil, silty, sandy, black	1.5	1.5
Sand, fine to very coarse; contains very fine to fine gravel	3.5	5
Clay, very silty, sandy, gravelly, brown	3	8
Clay, very silty, sandy, gravelly, gray	13	21
Clay, silty, sandy, gray	13	34
Sand, fine; some very fine, medium, coarse, and very coarse	11	45
Clay, silty, sandy, gravelly, gray	13	58
Clay, partly silty, dark-gray; contains some sand	24	82
Sand, fine to medium	10	92
Clay, very sandy, gray; contains some silt	7	99
Clay, very silty, dark-gray	21	120
Silt, clayey, dark-gray	4	122
Till, very silty, gray; contains some sand and gravel	14	136

TABLE 3.—*Selected logs of test holes and wells in the Halma-Lake Bronson area*—Con.

160.46.16aaa1

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Soil, silty, sandy, brownish-black	1.5	1.5
Sand, fine, medium, coarse, and very coarse; contains very fine to fine gravel	3.5	5
Sand, medium to very coarse; very fine to fine gravel; contains yellow clay, silt, and carbonaceous material	10	15
Sand, medium; some fine and coarse	13	28
Clay, partly silty and sandy, gray	22	50
Till, silty, sandy, gray	10	60

160.46.9cdd1

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Soil, silty, sandy, brownish-black	1	1
Sand, fine	2	3
Boulder	1	4
Clay, very sandy and gravelly, buff	6	10
Sand, very fine, fine, and medium; contains very fine to fine gravel	39	49
Clay, silty, dark-gray	2	51
Sand, very fine, fine, medium, and coarse; contains very fine to fine gravel	32	83
Clay, silty, gray	3	86
Gravel, very fine to fine; contains medium sand	5	91
Clay, gray	2	93
Sand, medium to very coarse; contains very fine to medium gravel	30	123
Sand, medium, some fine, coarse, and very coarse; contains very fine to fine gravel	36	159
Clay, gray; contains layers of sand and gravel	4	163
Gravel, very fine to fine; contains medium sand	8	171
Gravel, very fine to fine; contains thin layers of gray clay	4	175
Gravel, very fine to fine	31	206
Gravel, very fine to fine; contains boulders	22	228

160.46.20aba1

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Soil, silty, sandy, black	1.5	1.5
Cobbles	.5	2
Sand, fine, buff	1	3
Sand, fine to medium, gray	11	14
Sand, very fine to very coarse; very fine to medium gravel	19	33
Sand, fine to medium, gray	30	63
Sand, medium, to coarse gravel	10	73
Sand, very coarse, to fine gravel	29	102
Gravel, coarse, to fine sand	14	116
Clay, silty, gray	6	122

TABLE 3.—*Selected logs of test holes and wells in the Halma-Lake Bronson area*—Con.

160.46.20aba2

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Soil, silty, sandy, black	1.5	1.5
Cobbles	.5	2
Sand, medium; some very fine, fine, and coarse	31	33
Sand, medium; some fine, coarse, and very coarse	30	63
Sand, medium, coarse, and very coarse; contains very fine to fine gravel	51	114
Clay, silty, sandy, gray	6	120

160.46.20aba3

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Soil, silty, sandy, black	1.5	1.5
Sand, fine; cobbles; boulders	.5	2
Sand, fine, to coarse gravel; contains cobbles	23	25
Clay, gray	1	26
Sand, fine, to coarse gravel	36	62
Clay, gray	.5	62.5
Sand, fine, to coarse gravel	7.5	70
Gravel, medium, to fine sand	42	112
Clay, dark-gray; contains silt and fine sand	8	120

160.46.20aba4

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Soil, silty, sandy, black	1	1
Sand, fine, to medium gravel	41	42
Clay, gray	1	43
Gravel, medium, to fine sand	33	76
Clay, gray	1	77
Sand, fine, to medium gravel	33	110
Clay, silty, sandy, gray	5	115

160.46.20aba3

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Soil, silty, sandy, black	1.5	1.5
Sand, fine; cobbles; boulders	.5	2
Sand, fine, to coarse gravel; contains cobbles	23	25
Clay, gray	1	26
Sand, fine, to coarse gravel	36	62
Clay, gray	1	26
Sand, fine, to coarse gravel	36	62
Clay, gray	.5	62.5
Sand, fine, to coarse gravel	7.5	70
Gravel, medium, to fine sand	42	112
Clay, dark-gray; contains silt and fine sand	8	120

TABLE 3.—*Selected logs of test holes and wells in the Halma-Lake Bronson area*—Con.

160.46.25bbc1

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Soil, sandy, dark-brown	1	1
Sand, very fine, fine, and very coarse, tan; contains very fine to fine gravel	3.5	4.5
Till, silty, sandy, gravelly, tan	7.5	12
Till, silty, sandy, gray	18	30
Till, silty, sandy, brownish-gray	22	52
Clay, silty, blackish-brown	6	58
Till, silty, sandy, light-brown	2.5	60.5
Clay, sandy, light- to dark-green; becomes gravelly with depth	16.5	77
Till, silty, sandy, light-brown	43	120
Till, clayey, silty, sandy, brown	10	130
Gravel, very fine to fine; contains very coarse sand	13	143
Till, clayey, silty, sandy, brown	7	150
Till, clayey, silty, sandy, dark-brown	30	180
Sand, very coarse to coarse; contains very fine to fine gravel and layers of clay	21	201
Sand, very coarse to coarse; very fine to fine gravel; contains	21	222
layers of clay	44	266
Clay, sandy, dark-grayish-brown		
Till, clayey, silty, sandy, dark-brown	49	315
Till, clayey, silty, sandy, light-brown	7	322
Shale, soft, dark-brownish-gray, calcareous	1	323
Limestone, brownish-white, hard	1	324

160.47.24dcd1

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Soil, silty, sandy, black	1	1
Silt, clayey; contains sand and gravel	4	5
Sand, very fine, fine, medium, and coarse; contains silt	12	17
Sand, very fine; some fine and very coarse; contains silt	21	38
Sand, very fine, fine, and medium, clayey, silty; clayey silt	25	63
Sand, medium; some very fine, fine, and coarse, clayey, silty; clayey silt	50	113
Clay, silty, bluish-gray; contains a thin layer of sand and gravel at bottom	7	120
Till, clayey, silty, sandy, gravelly, gray, compact	8	128

161.46.30cdc

[Village of Lake Bronson well]

Material	Thickness (feet)	Depth (feet)
Soil, black	1	1
Sand, fine, clayey, yellow	2	3
Clay, dark-gray	7	10
Boulder	1	11
Sand; gravel	6	17
Clay, sandy, blue	6	23
Sand; coarse gravel	14	37
Sand, silty, blue-gray	3	40
Clay, sandy, blue-gray	22	62
Clay, blue	10	72
Sand, fine	23	95
Peat	1	96

TABLE 3.—*Selected logs of test holes and wells in the Halma-Lake Bronson area*—Con.

161.46.33dcd1

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Sand, fine; silt; upper part stained by humus	3.5	3.5
Cobbles	.5	4
Sand, very fine to very coarse; very fine to coarse gravel	12	16
Sand, very fine to very coarse; very fine to coarse gravel; contains cobbles and boulders	17	33
Sand, very fine to very coarse; very fine to coarse gravel; contains thin layers of gray clay	30	63
Sand, fine to very coarse; contains very fine to fine gravel	10	73
Sand, very fine to very coarse; very fine to coarse gravel	20	93
Sand, medium to very coarse; some gravel	47	140
Clay, very sandy	2	142
Sand, very fine to very coarse; very fine to coarse gravel	14	156
Silt, clayey, gray	1	157

161.46.33dcd2

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Sand, fine; silt; upper part stained by humus	2.5	2.5
Cobbles	.5	3
Sand, coarse; some medium and very coarse; contains very fine to fine gravel	60	63
Sand, fine, medium, and coarse; contains very fine to fine gravel	52	115
Sand, medium; some very fine, fine, and coarse; contains very fine to fine gravel	25	140
Clay, sandy	1	141
Gravel, very fine to fine; contains very coarse sand	16	157
Till, clayey, silty, sandy, gray; contains layers of sand and gravel	25	182

161.46.33dcd3

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Sand, fine; silt; upper part stained by humus	2.5	2.5
Cobbles	.5	3
Sand, fine to very coarse; contains very fine to coarse gravel	20	23
Cobbles; boulders	3	26
Sand, fine to very coarse; contains very fine to fine gravel	38	64
Sand, fine to coarse; some gravel	48	112
Sand, fine to coarse; contains very fine to fine gravel	28	140
Gravel, coarse; cobbles; boulders	5	145
Gravel, very fine to coarse	11	156
Sand; gravel; clay; interbedded	11	167

TABLE 3.—*Selected logs of test holes and wells in the Halma-Lake Bronson area*—Con.

161.46.33dcd4

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Sand, fine; silt; upper part stained by humus	2.5	2.5
Cobbles	.5	3
Sand, fine to coarse; contains very fine to medium gravel	37	40
Sand, fine to very coarse; contains thin layers of gravel	19	59
Sand, fine to very coarse; contains very fine to medium gravel	4	63
Sand, fine to very coarse; contains thin layers of gravel	50	113
Sand, fine to medium	27	140
Clay, sandy, gray	.5	140.5
Sand, fine to very coarse; contains very fine to medium gravel	11.5	152

161.46.33dcd5

[USGS test hole]

Material	Thickness (feet)	Depth (feet)
Sand, fine; silt; upper part stained by humus	2.5	2.5
Cobbles	.5	3
Sand, fine to very coarse; contains very fine to medium gravel	34	37
Silt, gray; grades to gray clay	8	45
Sand, fine to coarse; contains very fine to medium gravel	91	136
Clay, gray	2	138
Sand; gravel; cobbles; boulders	7	145

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