Geology and Ground-Water Conditions in the Southern Part of the Camp Ripley Military Reservation Morrison County, Minnesota

By J. R. JONES, P. D. AKIN, *and* ROBERT SCHNEIDER

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GEOLOGY AND GROUND-WATER CONDITIONS IN THE SOUTHERN PART OF THE CAMP RIPLEY MILITARY RESERVATION, MORRISON COUNTY, MINNESOTA

By J. R. JONES, P. D. AKIN, and ROBERT SCHNEIDER

ABSTRACT

The southern part of the Camp Ripley Military Reservation, in central Minnesota, includes an area of about 20 square miles. This investigation was conducted to assist the U.S. National Guard Bureau in locating adequate water supplies for expansion and standby needs.

Bedrock in the area consists of Precambrian phyllite which is equivalent to the Virginia slate. The area is covered largely by Pleistocene deposits in the form of moraines, ice-contact features, outwash plains, and the valley train of the Mississippi River. Almost all the surface deposits consist of outwash-plain and valley-train sediments that are generally permeable. Test drilling and an electrical-resistivity survey indicate that the post area, in the southeast part of the reservation, is underlain by about 50 to 115 feet of glacial drift. The west side of the post area is underlain by a bedrock valley filled in part by permeable glaciofluvial deposits in which there is a narrow, highly permeable channel deposit of sand and gravel. Aquifers of this type are probably the most important source of ground water in the area, although substantial quantities of water also may be obtained from other types of glacial aquifers. Properly constructed and developed wells tapping the channel deposits should yield 2,000 to 3,000 gallons per minute, or more.

Recharge to the aquifers in the reservation is derived from the downward percolation of local precipitation. Most recharge occurs during the spring breakup when accumulated winter snows melt and during the warmer months when the heaviest rains occur.

Sufficient water is stored in sands and gravels in the area to support substantial water-supply developments for several years, even without normal recharge.

The water is harder than is desirable for domestic uses, and it is relatively highly colored, probably owing to the presence of iron. Otherwise, the water is satisfactory for most domestic purposes as it contains only about 250 parts per million of dissolved solids.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

This investigation was undertaken at the request of the U.S. National Guard Bureau for the purpose of determining the general geology and the occurrence of ground water in the southern part of the Camp Ripley Military Reservation. Need for the investigation arose from anticipation of an increase in the camp's water requirements due to an enlargement of the training program. Adequate standby wells will be necessary in case of failure of present facilities or other emergencies. The investigation was requested after considerable test drilling, done under contract for the U.S. National Guard Bureau, failed to locate suitable sites for additional wells.

A brief reconnaissance of the geology and ground-water conditions in the reservation area was made in the spring of 1948 by P. E. Dennis, district geologist, North Dakota, and recommendations for further detailed work were made at that time. Late in the summer of 1948, a series of 41 electrical-resistivity probes was made and, in the spring of 1949, 16 test holes were drilled. The resistivity probes and test drilling were done in a relatively small area near the post buildings. A reconnaissance geologic map was made and water levels and records were obtained from existing wells in the area. Three aquifer tests were made to determine the hydraulic characteristics of the water-bearing formations.

Periodic water-level measurements were made during 1951–59 as part of the statewide ground-water investigation by the U.S. Geological Survey in cooperation with the Division of Waters, Minnesota Department of Conservation.

LOCATION AND GENERAL FEATURES OF THE AREA

The Camp Ripley Military Reservation is in Morrison County, central Minnesota, about 100 miles northwest of Minneapolis and St. Paul (fig. 1). The southern part of the reservation, with which this report is concerned, has an area of about 20 square miles. The Mississippi River forms the eastern boundary of the reservation and a flat alluvial plain associated with the river occupies much of its eastern part. Glacial deposits cover the rest of the area. The reservation is wooded, covered mostly by second-growth deciduous trees and shrubs, except where cleared for now-abandoned farms and in the areas occupied by the post buildings, airfield, and practice ranges.

The annual precipitation averaged a little less than 25 inches for the period 1921–50, and the temperature averaged about 42° F. Extreme temperatures ranged from about −46° to 106° F.

Little Falls, with a population of 7,551 in 1960, is 7 miles south of

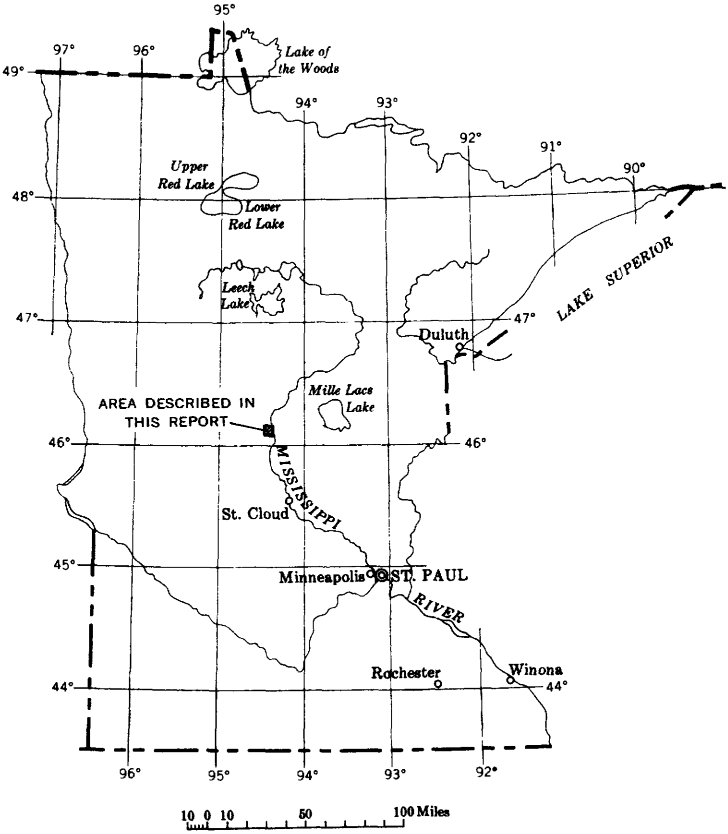

FIGURE 1.—Map of Minnesota showing location of report area.

the reservation. Randall, with a population of 516, is 8 miles west, and the village of Fort Ripley is just northeast of the reservation. Transportation facilities include a spur line of the Northern Pacific Railway, U.S. Highway 371 and Minnesota Highway 115, and a military airfield.

PREVIOUS INVESTIGATIONS

The general geology of a more extensive area which included the reservation was investigated by Winchell (1878) and Upham (1888). Allison (1932, p. 128–135) described the general ground-water conditions of Morrison County. The regional Pleistocene geology was summarized by Leverett (1932, p. 40–44) and Cooper (1935). P. E. Dennis, district geologist for North Dakota, made a preliminary reconnaissance of the Camp Ripley area in 1948. In 1954, A. F. Schneider (1961) completed mapping the Pleistocene geology in parts of western Morrison and eastern Todd Counties for a doctoral dissertation. The area mapped by Schneider lies between the Mississippi River and long 94°45′ W. and between lat 46°00′ N. and lat 46°15′ N.

PERSONNEL AND ACKNOWLEDGMENTS

This investigation was conducted under the direct supervision of P. E. Dennis, district geologist, North Dakota, who was succeded by P. D. Akin, district engineer. Field direction of the investigation was assigned to J. R. Jones, geologist. H. C. Spicer, geophysicist, and G. J. Edwards, of the U.S. Geological Survey, conducted the electrical-resistivity survey. Robert Schneider, district geologist for Minnesota, completed the report by revising an earlier draft of the manuscript and by including additional data and interpretations.

Col. R. A. Rossberg, Property and Disbursing Officer; Capt. T. W. Emerson, construction quartermaster; and members of his section greatly facilitated the investigation by extending many courtesies and services. H. R. Cook, post engineer, determined altitudes and made rectangular surveys of the test holes. Lt. F. A. Nelson, USN, supplied a microbarograph for the period of one of the aquifer tests.

WELL-NUMBERING SYSTEM

Wells and test holes in Minnesota are numbered by the U.S. Geological Survey in accordance with the Bureau of Land Management's system of subdivision of the public lands. Because this land-coordinate system is not used on maps of the reservation, the land coordinates were superimposed on plate 2. The area is in the fifth principal meridian and base line system.

The first segment of a well 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 well is situated. The lowercase letters, a, b, c, and d, following the section number, locate the well within the section (fig. 2); the first letter denotes the 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. The letters are assigned in a counter clockwise direction, beginning in the northeast quarter. If the location is known within a 10-acre tract, three lowercase letters are shown in the well number. Generally, when more than one well is situated in the smallest significant tract, consecutive numbers beginning with 1 are added as suffixes. The diagram of the section in figure 2 shows the method of numbering a well. Thus, the number 130.29.8ddbl identifies the first well recorded in the NW¼SE¼SE¼ sec. 8, T. 130 N., R. 29 W.

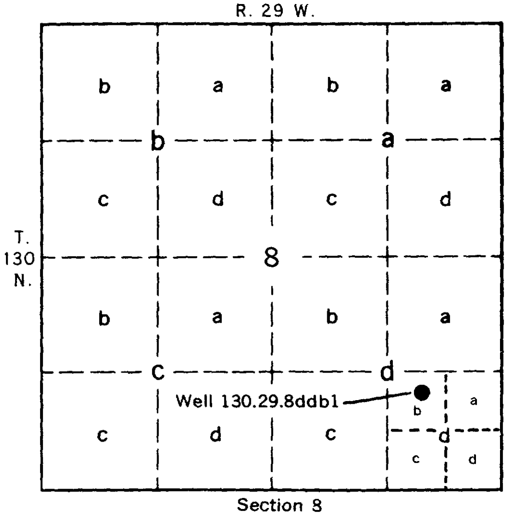

FIGURE 2.—Diagram of a section showing method of numbering wells.

GEOLOGY

HISTORICAL SUMMARY

Precambrian time was an era of marine deposition in the Camp Ripley area. The resulting sedimentary rocks were metamorphosed, possibly at the time of the Killarney revolution which occurred at the close of the Precambrian. Paleozoic sediments may have been deposited over the area but if they were, erosion has removed them. It is probable that sediments of Cretaceous age were deposited in the area, as marine Cretaceous deposits have been found elsewhere in Morrison County (Upham, 1888, p. 601–603). The fact that no Cretaceous rocks have been found on the post leads to the assumption that they were largely or wholly removed by erosion. There is no evidence of other pre-Pleistocene deposits in the region.

Glacial ice covered the area several times during the Pleistocene epoch. Although only middle(?) and late Wisconsin drift has been mapped in or near Camp Ripley, there is sufficient evidence of the deposition of Nebraskan, Kansan, Illinoian, and early Wisconsin drift elsewhere in Minnesota (Leverett, 1932, p. 14–35) to justify the assumption that glaciers advanced over the area during each of those stages.

Most of the Recent deposits consist of organic material accumulated in swamps and some deposits laid down by slope wash and wind. In Recent time the dominant geologic processes have been stream erosion, largely by the Mississippi River, and erosion by slope wash and wind.

690-462—63——2

GLACIAL DEPOSITS

TERMINOLOGY AND GENERAL CHARACTERISTICS

The general term "glacial drift" includes all deposits predominantly of glacial or glaciofluvial origin. Glacial deposits may be divided into two major categories: those that were deposited by melting ice with little or no action of running water, and those that were sorted and stratified by melt water. Glaciofluvial is an adjective applied to the deposits or processes related to water flowing from melting glacial ice. Material deposited in place when the matrix of ice that held it melted is distinctive because of an almost complete lack of sorting. This material, heterogeneous as to size of fragment and rock type, is called till.

Glacial deposition produces a large variety of landforms which may be classified in three major categories: moraines, ice-contact features, and proglacial features. Deposits of the three types commonly grade into each other.

A moraine is composed of earth and rock debris that has been carried and finally deposited by a glacier to form a ridgelike accumulation along the margin of glacial ice. Normally, it formed as a result of direct deposition by ice, deformation by ice thrust, or both. Usually, most of the material composing moraines is till.

Ice-contact features are composed of stratified drift which, characteristically, contains material with an extreme range of grain size—from clay-size particles to boulders. Other characteristics are: abrupt changes in grain size, intimate association with till, and deformed bedding. Several types of ice-contact features have been differentiated on the basis of topographic form and genesis. Kames are steep-sided hills, frequently of conical shape, that are composed of material deposited by streams that flowed from or over the edge of a glacier. They were built like steep alluvial fans along an ice front. Some kames probably were formed in moulins—openings in the surface of a glacier into which streams plunged. Crevasse fillings are, as the name implies, sediments deposited in crevasses or large fissures in the ice. Eskers are long narrow ridges, commonly sinuous, and composed largely of stratified materials. In general they appear to have originated in tunnels at the base of the ice where streams dropped their debris in confined channels. In some places the streams may have flowed in crevasses. Kettles are depressions in glacial drift caused by collapse of material that laterally surrounded or buried blocks of ice which persisted after the retreat of the ice border. Other irregularities in the drift surface may have resulted from differential deposition by a glacier.

Proglacial features include outwash plains and valley trains. Outwash plains were built up beyond the margins of a glacier from glacially derived material. Outwash deposits, like normal stream deposits, show crossbedding and sharp variation in grain size. They formed as a fan or group of coalescent fans from points of exit from the ice of one or more proglacial streams. A valley train is a long, narrow body of outwash confined between the walls of a valley.

DEPOSITS IN THE CAMP RIPLEY AREA

Most of the Camp Ripley Military Reservation is underlain by materials of the St. Croix morainic system and associated ice-contact and outwash deposits, all of Wisconsin age. The St. Croix moraine was named by Berkey (1897, p. 360) for the area of its conspicuous development in western Wisconsin. According to Leverett (1932, p. 8), it was deposited in middle Wisconsin time at the margin of a lobe of ice that spread out from or passed over the District of Patricia in Ontario, Canada, north of the Great Lakes. However, according to Wright (1955, p. 407–408) and Schneider (1956, p. 33), Leverett's Patrician drift can be subdivided into at least two distinct types, one having been deposited by a Cary advance of the Superior lobe which originated in the Lake Superior basin, the other deposited by the Rainy lobe which entered Minnesota from the northeast and moved toward central Minnesota beside the Superior lobe.

The distribution of the principal surficial glacial deposits in the report area is shown on plate 1 and the subsurface deposits in the post area are shown in the sections in figure 3.

Two areas of end-moraine deposits extend approximately east-west nearly across the reservation. They are distinguishable from the surrounding areas by their higher altitudes and more rugged topography.

The northern end moraine is higher than the southern one, but its slopes, except for those facing south, are more gentle. The highest part of the northern area is more than 100 feet above the neighboring area of outwash and its average altitude is about 50 feet above the outwash. There are few depressions on the surface of the northern moraine, although in the northwesternmost part of the report area (NW¼NW¼NW¼ sec. 14, T. 131 N., R. 30 W.) there is a steep-walled kettle that is more than 30 feet deep.

The drift deposited by the ice lobe that formed the St. Croix moraine contains an unusually small amount of clay (Cooper, 1935, p. 8). The only deposit observed in the reservation area that contains an appreciable amount of clay is a red-brown till exposed in a road cut in the SE¼SE¼SE¼ sec. 11, T. 131 N., R. 30 W. Much of the till and other drift deposits composing the northern body of end moraine within the reservation are largely sand and gravel. In some of the exposures these materials are stratified, in others stratification is not evident. At least some of the material composing the morainal mass was deposited as outwash, rather than merely being dumped as the ice melted.

The southern end moraine is characterized by many knolls and depressions. The moraine generally is 20 to 40 feet higher than the adjacent outwash, but in some places it is as much as 90 feet above the surrounding area. Many of the knolls are kames, as indicated by their shapes and, where exposed, their materials. This moraine might be referred to as a kame moraine because of the many kames occurring here. Depressions in the moraine are of two types. Many are true kettles, but others, particularly in the eastern part of the moraine, are the result of differential deposition rather than the melting of buried ice masses; that is, the hollows are areas where the drift is relatively thin.

The materials composing the southern end moraine are sand and gravel at all places observed. In many places the sediments are stratified, elsewhere stratification is not evident.

The distribution of outwash adjacent to the southern moraine indicates that the bulk of the glacier that deposited the moraine lay to the north and east of the ice margin along which the drift was laid down.

Outwash covers a large part of the reservation. Kettles and partly buried kames lend some relief to the generally flat topography of the outwash.

In the southwest part of the reservation there is an outwash plain more than a square mile in area. Because so much of the surface of this outwash lies between 1,230 and 1,250 feet above sea level, it is referred to in this report as the 1,240-foot outwash plain. Schneider (1961, p. 84–85) referred to it as the Camp Ripley terrace. The surface of the plain slopes evenly to the south with a gradient of about 20 feet per mile. The evenness of its surface is interrupted only by a few shallow kettles. The plain was formed when the margin of the glacier lay at about the position of the ridge parallel to the east side of Ferrell Lake (E½ sec. 35, T. 131 N., R. 30 W.). The outwash plain was bordered on the east and north by a group of ice blocks, the burial and subsequent melting of which formed the hollows now occupied by the large swamps in parts of secs. 1 and 2, T. 130 N., R. 30 W., the basin of Ferrell Lake (sec. 35, T. 131 N., R. 30 W.), and the kettles at the north end of Ferrell Lake.

The area of outwash directly north of the 1,240-foot outwash plain is much more rugged, although it is probably contemporaneous in origin with the 1,240-foot plain and genetically a part of it. Several partly buried kames project above the general surface of the area. Kettles are so numerous as to suggest that a large part of the area was occupied by stagnant ice at the time the outwash was deposited. Although most of them are not apparent on the topographic map (pl. 1), there are several ridges in the SE¼ sec. 26 and the NE¼ sec. 35, T. 131 N., R. 30 W., which were deposited as crevasse fillings between blocks of ice. The fact that the altitude of the northern area of outwash generally is less than the 1,240-foot altitude of the southern outwash plain is due to deposition of the northern outwash on or around ice. The ice may have been partly buried or, if completely buried, the outwash cover was so thin that when the ice melted the previously continuous surface collapsed.

The largest area of outwash in the reservation lies east of the 1,240-foot outwash plain and south of the southern end moraine. It is bounded on the east by an alluvial plain composed, in part, of the Mississippi valley train. In general, the surface of the outwash is gently rolling. There are several kettles in the northeast part of the outwash area. Partly buried kames project above the general level of the outwash; an example of these is the group of kames in the W½ sec. 31, T. 131 N., R. 29 W., and the isolated kame in the NW¼ sec. 6, T. 130 N., R. 29 W. The outwash probably was deposited by melt water from the ice that formed the contiguous moraine to the north.

A small area of outwash, mostly in the S½ sec. 25 and the N½ sec. 36, T. 131 N., R. 30 W., is practically surrounded by deposits of the southern end moraine. A steep scarp that faces the valley of the Mississippi bounds the plain on the northeast, and the moraine confines it on all other sides. This outwash area is flat except for two projecting kames—a large one near the center of the area and a small one in the west part. Kettles are present only along the northwest border of the area.

Another area of outwash lies between the two end moraines. The topography of this area is less regular than that of the areas of outwash previously described. Numerous kames stand more than 40 feet above the intervening flats. The distribution of the flat areas and kames strongly suggests that the flat areas were formerly occupied by ice blocks. Most of the flats are swampy and underlain by sand. The largest dry flat areas are in the vicinity of the junction of Cunningham and Cody Roads (SE cor. sec. 23, T. 131 N., R. 30 W.) and along the scarp bordering the valley of the Mississippi River.

The valley train of the Mississippi River is a body of outwash derived from sources more distant than those heretofore described. At the time of formation of the valley train, the overloaded river constantly shifted by a cut-and-fill process. The valley train occupies a definite trench cut by the river through the glacial drift, parts of which are of the St. Croix morainic system. At one stage, an inner valley was cut into the valley train and formed a low terrace along the

Mississippi River. The terrace is rarely more than 200 yards wide and is usually only a few yards in width or absent entirely.

It was not possible to differentiate the alluvium bordering the Mississippi River from the valley-train deposits.

A prominent esker in the east-central part of the reservation, close to the Mississippi River, extends about 1,500 yards in a southeasterly direction from the NE¼NE¼NE¼ sec. 31, T. 131 N., R. 29 W. The narrow, steep-sided, winding ridge in places is more than 40 feet above the adjacent land. The top of the ridge is level in places, and uneven elsewhere. A smooth plain of sand and gravel slopes gently away from the south end of the esker. This sand plain terminates abruptly at the edge of the valley train and is a delta or an alluvial fan which was deposited where the stream that formed the esker emerged from the confining walls of glacial ice. The upstream or north end of the esker merges imperceptibly with the southern end moraine. The materials composing the esker are largely stratified gravel and sand, however an appreciable part of these deposits consists of cobbles and boulders. The esker deposits have been used as a source of road metal.

According to the test-hole and electrical-resistivity data, available only for the post area (fig. 3, pl. 2), the glacial drift ranges in thickness from about 50 to 115 feet. Except for till penetrated by a few holes at depth, the subsurface glacial deposits are almost entirely of glaciofluvial origin. (See tables 1 and 2 for records and logs of test holes.)

The till is light gray to grayish tan, sandy and clayey, and it contains silt, pebbles, cobbles, and boulders. The gray color contrasts sharply with the reddish brown of the drift observed in other places on the reservation and elsewhere in the St. Croix morainic system in Morrison County. Glaciofluvial deposits were penetrated below the till only in test hole 130.29.17abc1, in which there is 8 feet of very coarse, silty sand between the till and the bedrock.

Where the till is present, its upper surface varies in altitude from 1,077 to about 1,100 feet above sea level. However, in test holes 130.29.17abb1 and 130.29.17abb4 bedrock is at altitudes of 1,064 and 1,053 feet respectively, and no till was penetrated. It is possible that at the sites of these test holes some of the sand immediately above the bedrock is related to, and contemporaneous with, the till. On the other hand, the sand may be a channel filling deposited by the glacial Mississippi River.

Although no direct evidence of its age was found, it is believed that the gray till penetrated by the test holes was deposited before the reddish-brown till and other reddish-brown drift elsewhere in the area. The gray color suggests that the source lay to the west and

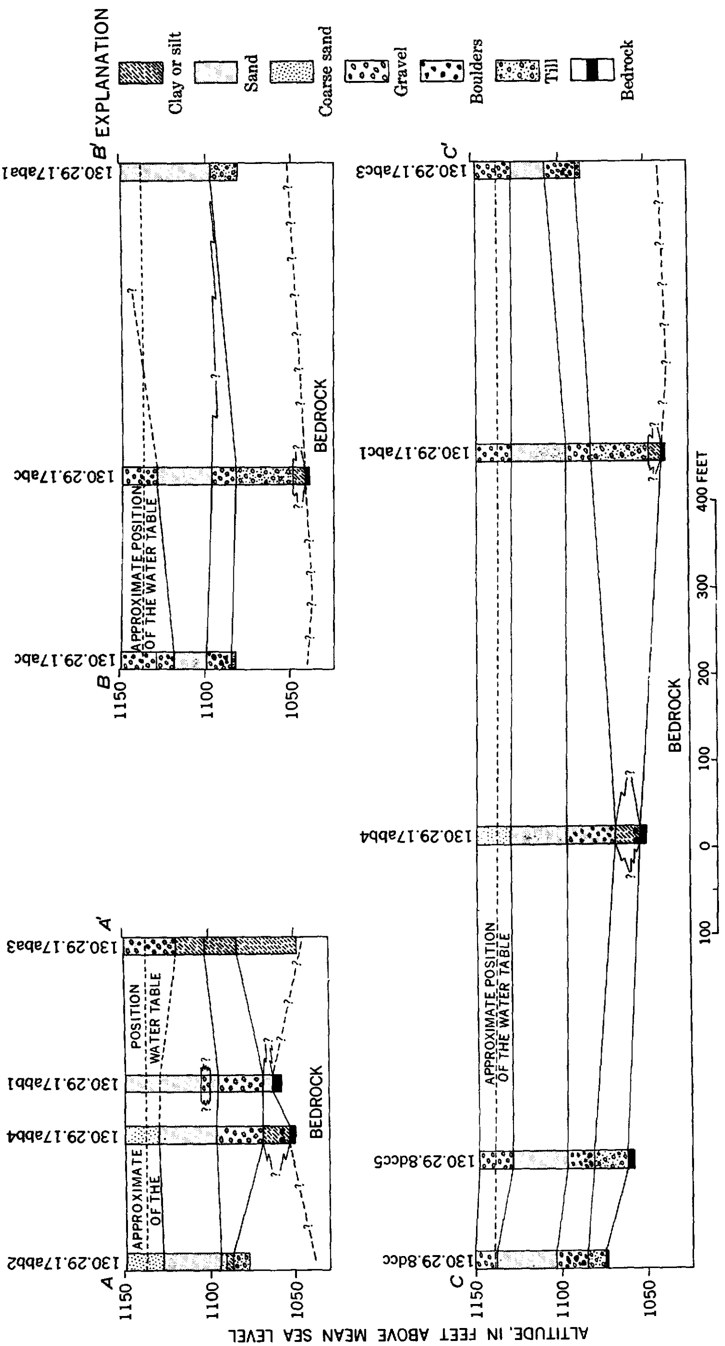

FIGURE 3.—Geologic sections of parts of the Camp Ripley post area.

north because the bedrock formations in northwestern Minnesota and southern Manitoba include much limestone. According to Wright (1956, p. 6–19), during the Cary substage of the Wisconsin, the Wadena lobe which moved south-southeast across central Minnesota, was contemporaneous with the Superior and Rainy lobes and, in its eastern part (vicinity of Morrison County), was generally buried by Cary ice lobes that originated from the east and northeast. The result is the occurrence of Wadena gray drift beneath reddish-brown drifts; also, the interbedding of gray and reddish-brown drifts in the area of overlap.

Thus it is possible that the till that was penetrated in the test holes is of Cary age, although it may have been deposited earlier in the Pleistocene.

BEDROCK

Ten of the test holes that were drilled reached bedrock and, in all except one hole, the cuttings were dark grayish-green chloritic phyllite. In test hole 130.29.17aaa5 the rock was dark grayish-green chloritic schist.

The bedrock is part of the group of rocks that Grout and others (1932) mapped as the Virginia slate or its equivalent and is of Precambrian age.

Prior to test drilling, an electrical-resistivity survey was made in the area in order to ascertain whether any significant bedrock channels could be defined by this method and whether the presence of highly permeable water-bearing materials could be detected. The locations of the electrical-resistivity probes are shown on plate 2.

The position of bedrock was interpreted from the resistivity data by H. C. Spicer of the U.S. Geological Survey. Generalized contours were drawn on the bedrock surface (pl. 2), using the electrical-resistivity probes and test holes for control points. The most significant feature interpreted is a valley that trends north-northwest across the west side of the post area. The lowest known altitude of the valley bottom is 1,034 feet—115 feet below the land surface. Although the extent of the valley is unknown, it appears to be at least about 3,000 feet wide and 9,000 feet long in this area. There appears to be another valley between two 1,060-foot contours under the east side of the post.

OCCURRENCE OF GROUND WATER

PRINCIPLES

The Camp Ripley Military Reservation is in the Superior Drift-Crystalline ground-water province as delineated by Meinzer (1923, pl. 31). In the reservation area, as almost everywhere in the province, water is obtained generally from glacial drift rather than bedrock.

Precipitation is the source of almost all ground water. Water may directly enter the ground as rainfall or melting snow, or it may percolate to the ground-water body from streams, lakes, or ponds.

Almost all ground water is in the process of movement from a place of intake or recharge to a place of disposal or discharge. The rate of movement varies considerably, but velocities of a few tens to a few hundreds of feet a year are probably most common under natural conditions.

Discharge of ground water may occur by direct evaporation from the soil surface or indirectly from lakes and ponds, by transpiration of plants in areas where the ground-water level is at or near the surface, and by seepage to streams. Under certain conditions, water may discharge from one ground-water reservoir to another by slow percolation through the separating materials.

Any rock formation or stratum that will yield water to wells in sufficient quantity to be of importance as a source of supply is called an aquifer (Meinzer, 1923, p. 52). The water moving in an aquifer from recharge areas to discharge areas may be thought of as being in "transient storage" in the ground. The amount of water that can be stored in an aquifer is dependent upon the volume and porosity of the aquifer.

The capacity of a rock, geologic formation, or stratum to yield water to wells by gravity drainage may be much less than would be indicated by its porosity because part or all of the water may be held in the pore spaces by molecular attraction between the water and the rock material. If the pore spaces are large, as in coarse gravel, much of the water stored in the pore spaces may be removed by gravity drainage. If the individual particles composing the rock are small, as in clay, the porosity of the rock may be considerable but almost none of the stored water can be removed by gravity drainage. The volume of water, expressed as a percentage, that will drain by gravity from a unit volume of the saturated rock material is called its specific yield.

If the water in an aquifer is not confined by impermeable strata above, the water is said to occur under water-table conditions. In this case, water may be obtained from storage in the aquifer by lowering the water level, as in the vicinity of a well being pumped, thus initiating gravity drainage. Ground water in the area of this report is considered to be mainly under water-table conditions.

If water is confined in an aquifer by an overlying impermeable stratum and hydrostatic pressure causes the water in a tightly cased well to rise above the top of the aquifer, the water is said to occur under artesian conditions. In this case, if ideal conditions prevail, water is yielded as the water level in the well is lowered, but the

690-462—63——3

aquifer remains saturated. Water is yielded because of its own expansion and the compression of the aquifer due to lowered hydrostatic pressure, rather than by gravity drainage. The water-yielding capacity is called the coefficient of storage and is generally much smaller than the specific yield of the same material when drained by gravity. The coefficient of storage is defined as the volume of water that will be released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

If the pore spaces are large and interconnected, as they commonly are in sand and gravel, the water is transmitted more or less freely, and the rock is said to be permeable. On the other hand, if the pore spaces are very small or not connected, as in clay, the water is transmitted slowly, and the rock is said to be impermeable or to have a low permeability.

The permeability of a rock may be expressed quantitatively by the coefficient of permeability, defined in laboratory use as the number of gallons of water that will pass in 1 day through a cross section of the aquifer of 1 square foot under a hydraulic gradient of 100 percent at a temperature of 60°F. It also may be defined in field use as the number of gallons of water that will pass in 1 day through a strip of the aquifer 1 foot high and 1 mile wide under a hydraulic gradient of 1 foot per mile at the prevailing field temperature.

The coefficient of transmissibility is convenient to use in groundwater studies because it indicates characteristics of large segments of the aquifer. It is the average permeability of the aquifer multiplied by the saturated thickness.

As ground water moves through the earth, it dissolves a part of the more soluble mineral constituents of the rock particles. The amount of mineral matter dissolved is determined by the kind and amount of soluble minerals present and the length of time the water is in contact with them. In general, water that has been underground longest and has traveled the greatest distance will be most highly mineralized.

An aquifer's capacity for furnishing a water supply for any given purpose will depend upon the permeability of the materials composing the aquifer and upon its volume or capacity to store water. In addition, there must be adequate recharge to the aquifer if the water-supply development is to last indefinitely, for it is apparent that even a small draft will eventually deplete the water in storage unless there is adequate recharge.

AQUIFERS IN THE CAMP RIPLEY MILITARY RESERVATION AND HISTORY OF WATER-SUPPLY DEVELOPMENT

Almost all the materials exposed at the surface in the area of the investigation are sufficiently permeable to constitute aquifers. With the possible exception of the northern end moraine, which includes some clayey till, and of a few layers of silt in some of the outwash, the surface materials will everywhere yield sufficient water to wells for domestic and larger supplies. Some parts of this more or less widespread aquifer will yield water more freely than others.

The metamorphic bedrock that lies under the reservation has a low permeability. The gray till that was found close to or immediately over the bedrock also transmits water slowly. For practical purposes, all the glacial deposits above the bedrock or the gray till may be regarded as one water-table aquifer.

The area in which wells have been developed for camp use and in which the test drilling and electrical-resistivity survey were done is in the post area in the southeast part of the reservation, where the surface deposits consist of alluvium and sediments of the Mississippi River valley train (fig. 3 and pl. 2).

The history of the development of ground-water supplies at the camp is somewhat unique in that considerable difficulty has been experienced in developing suitable wells under what appear to be quite favorable ground-water conditions. Three 12-inch wells, 130.29.17aaa1, 130.29.17aaa2, and 130.29.17aaa3, were drilled in 1931 to depths of 100, 100, and 166 feet, respectively. (See table 1.) These wells were drilled a considerable distance into the bedrock, probably in order to provide necessary submergence for the operation of airlift pumps. The wells originally pumped about 200 gpm (gallons per minute) each. Well 130.29.17aaa3 apparently became clogged by fine sand and was abandoned. Wells 130.29.17aaa1 and 17aaa2 are used as a camp supply during the winter and when field training is not in progress. These wells have a combined yield of about 250 gpm.

In 1933, well 130.29.17aaa4 was drilled. This well was 165 feet deep and was pumped by airlift at a rate of about 240 gpm. By 1942, when the well was cleaned out, iron incrustation and clogging by sand had greatly reduced its capacity. It is reported that 14 cubic yards of sand were bailed from the well and the well was then acid treated and surged. The original yield of 240 gpm was again attained and a turbine pump was installed. Shortly thereafter, the well became clogged with sand and the yield continually declined until it was reduced to about 70 gpm and use of the well was discontinued.

In 1939, well 130.29.17abb1 was drilled. Unlike the previously drilled wells, this one was gravel packed using an outside casing 24 inches in diameter and a 16-inch inner casing. The well was equipped with a turbine pump and is reported to have yielded 1,320 gpm during a test. It furnishes about 850 gpm to the camp water system.

In 1939, an attempt was made to locate a site favorable for the construction of another well that would yield as much water as well 130.29.17abb1. Five test holes were drilled in different directions from the well and at distances of 200 feet and less. According to the driller's report, no suitable materials for developing a large-capacity well were found in these test holes.

Since the present investigation was begun, two wells have been completed in the area on the west side of the post. Well 130.29.17abd4 was drilled in 1949. It is 63 feet deep and yielded more than 1,000 gpm during a 3-day test with a reported drawdown of 7 feet. Well 130.29.8dcc4 was drilled in 1950; it is 69 feet deep and yielded more than 1,100 gpm during a short pumping test. The water level at observation well 130.29.8dcc, about 200 feet away, lowered about 0.1 foot during this test.

The reason for the clogging of wells 130.29.17aaa3 and 17aaa4 by sand is not known. Probably good production could have been obtained in this area by gravel packing of wells or by the use of well screens with smaller openings. As will be shown later in the section "Aquifer Tests," the coefficient of transmissibility in this area is sufficiently high to support wells with considerably greater yields than were obtained from any of these wells.

The wells on the west side of the post penetrate a relatively narrow body of very coarse permeable sediments in the drift filling a glacial, or preglacial, bedrock valley. On the geologic sections (fig. 3) it is part of the unit of coarse outwash (sand and gravel; some boulders) the top of which occurs at an altitude of around 1,100 ft. Its possible extent and alinement may be inferred from the configuration of the bedrock valley shown on plate 2.

Aquifers similar to that mentioned above may be present elsewhere in the area. However, there appear to be no surface indications of the presence of these deposits; consequently, they must be located by test drilling. Electrical-resistivity surveys possibly can be used to locate other bedrock valleys but test drilling would then have to be done to determine whether they are associated with permeable aquifers.

AQUIFER TESTS

Three aquifer tests were made in the Camp Ripley Military Reservation, in order to obtain data for the computation of the coefficients of transmissibility and storage, or specific yield, of the aquifers and to ascertain whether any lateral boundaries adjacent to the aquifers could be identified from the results of the tests. The data obtained from the tests were analyzed for the coefficients of transmissibility and storage and for the presence of boundaries using various methods (Theis, 1935; Wenzel, 1942; Cooper and Jacob, 1946; Jacob, 1947; Ferris, 1948). However, the conditions under which the tests were made were far from ideal, and the data obtained are subject to numerous interpretations. Therefore, the results as described below represent principally the writers' opinion in regard to what appear to be reasonable conclusions.

The first of these tests was conducted during the first reconnaissance of the area in the spring of 1948. On April 27, 1948, wells 130.29.17aaa1 and 17aaa2 were pumped continuously for a period of about 5 hours and water-level measurements were made in well 130.29.17aaa4 during the pumping period. Pumping was stopped and water-level measurements were continued in well 130.29.17aaa4 for the next 21 hours.

Discharge measurements could not be made at the two pumping wells; however, it was assumed that the combined rate of discharge from the two wells was 250 gpm with each well pumping at half that rate. The coefficient of transmissibility, estimated from the data obtained, was about 200,000 gpd per ft (gallons per day per foot) and the estimated coefficient of storage was about 0.008. It would appear from this low value for the storage coefficient that the aquifer contains water under artesian pressure. However, this apparently anomalous condition is believed to result from the fact that the aquifer is overlain by sediments of lower permeability which, for the relatively short period of the test, acted as a confining layer.

Also, on April 27, 1948, well 130.29.17abb1, approximately 2,000 feet west of well 130. 29.17aaa4, was pumped for about 21 hours. No observation wells were available in which to take water-level measurements, but measurements were made in the pumping well during the pumping period and for about 16 hours after pumping stopped. No discharge measurements were obtained, but it was estimated that the well was pumped at a rate of about 900 gpm. From the data obtained, the coefficient of transmissibility was estimated to be about 500,000 gpd per ft.

On March 30, 1949, another aquifer test was made by pumping well 130.29.17abb1 and measuring the water level in the pumped well and in observation wells 130.29.8dcc, 17aaa5, and 17abc1. Well 130.29.17abb1 was pumped continuously for about 53 hours, after two brief pumping trials during which there was mechanical trouble. Water-level measurements were obtained at all the observation wells for a considerable length of time after pumping stopped. Water-level and pumping data obtained during the test are shown graphically on plate 3. It is apparent that interference from pumping was measured only in observation well 130.29.17abc1, about 440 feet south of the pumped well, and in observation well 130.29.8dcc, about 520 feet to the northwest. Several factors made it difficult to analyze and interpret the data in a straightforward manner. Among the most important of these were: (a) the observation wells may have been partly plugged, and, consequently, the reaction to the effect of pumping may have been incomplete, and (b) the coefficient of storage appeared to vary. The data show the effects of hydraulic boundaries outward from the pumped well, along which the coefficient of transmissibility changes from a high value to one that is considerably lower. The boundaries are believed to indicate lateral changes in the lithology of the aquifer, from coarse highly permeable outwash to finer grained material of low permeability.

It was estimated that the coefficient of transmissibility in the immediate vicinity of well 130.29.17abb1 may be as high as 800,000 gpd per ft. The coefficient of storage was estimated to be about 0.06. At the end of the pumping period the magnitude and rate of drawdown at observation wells 130.29.17abc1 and 8dcc were about equivalent to that caused by a well pumping from an aquifer of large areal extent, having a coefficient of transmissibility of about 270,000 gpd per ft and a coefficient of storage of about 0.06.

The results of the aquifer tests appear to be of little value except as rough guides for planning additional ground-water developments. It may be concluded that the coefficient of transmissibility of the glacial materials in the vicinity of wells 130.29.8dcc, 17abb1, and 17abc1 is quite high, perhaps on the order of 200,000 gpd per ft. It is believed, however, that the estimated values for the coefficient of storage mentioned above are too low, especially as applicable to long-term pumping. It is believed that a coefficient of storage of about 0.20 would more nearly represent the long-term yield of the materials.

Figure 4 is a plot showing the drawdowns to be expected from pumping 1 million gpd from a well in an areally extensive artesian aquifer having a coefficent of transmissibility (T) of 200,000 gpd per ft and a coefficient of storage (S) of 0.20. The plot may be used as a rough guide for determining the spacing of any new wells that are drilled in the camp area. The effect of pumping a well at a different rate can easily be determined because the drawdowns are directly proportional to the pumping rate. In order to compute the drawdown to be anticipated at any place due to pumping two or more wells, the drawdowns to be expected due to pumping the wells individually are simply added.

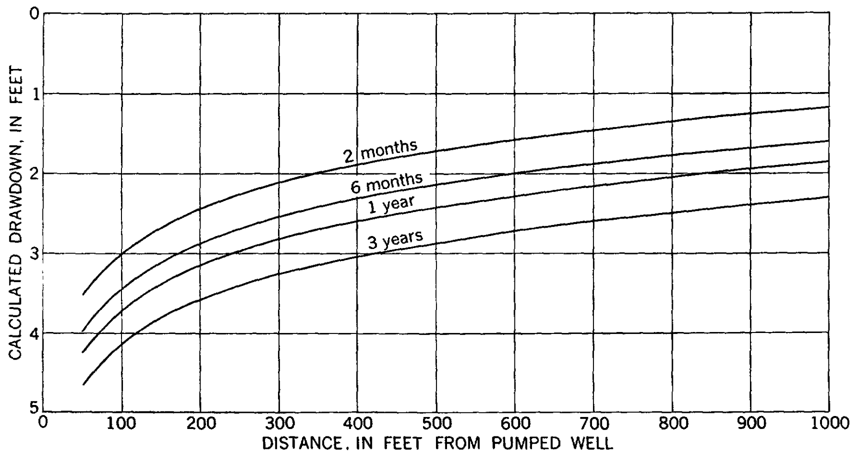

FIGURE 4.—Theoretical drawdown in an aquifer of infinite areal extent due to pumping a well at a rate of 1 million gallons per day.

The high value for the coefficient of transmissibility that was estimated for the immediate vicinity of well 130.29.17abb1 (800,000 gpd per ft) corroborates the interpretation of subsurface hydrologic conditions that had been made on the basis of test drilling and an appraisal of well-performance data. (See section entitled, "Aquifers in the Camp Ripley Military Reservation and History of Water-supply Development.") The relatively narrow body of highly permeable material probably fills a channel in other glaciofluvial deposits of considerably lower permeability, and the coefficient of transmissibility of the aquifer as a whole, including the alluvial and glaciofluvial deposits that are hydraulically interconnected, is also high.

RECHARGE, STORAGE, AND MOVEMENT OF THE GROUND WATER

The aquifers in the Camp Ripley Military Reservation are recharged by downward percolation of local precipitation. With the possible exception of the northern end moraine, which may include some fine-textured materials, the surface deposits are permeable and permit ready percolation of water from the surface to the water table. In general, most of the recharge occurs during the spring breakup when the accumulated winter snows melt, and as a result of heavy rains during the warmer months. Little recharge occurs during the winter when practically all the precipitation occurs as snow which remains on the ground or is lost by sublimation and evaporation. During the warmer months, some recharge may be derived from light rains but most of this precipitation probably is used to satisfy the soil-moisture deficiency, is evaporated, or is transpired by plants before it can reach the water table.

Figure 5 shows a hydrograph for well 130.29.8dcc for the period

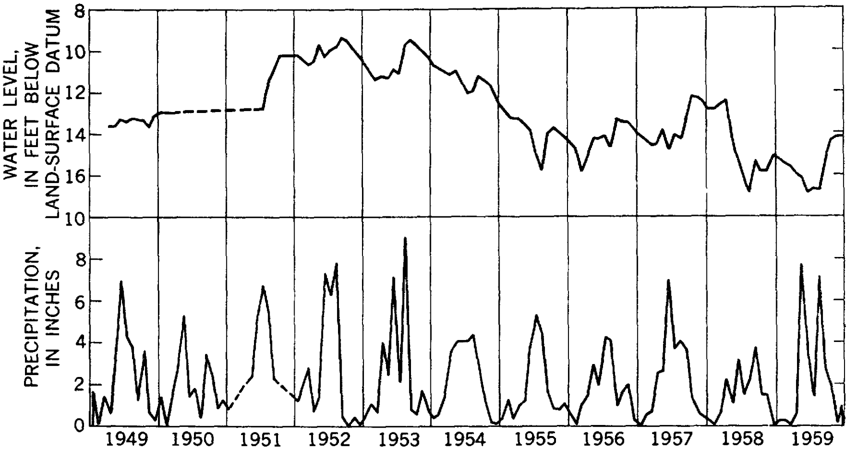

FIGURE 5.—Hydrograph of monthly low water levels in well 130.29.8dcc and graph of precipitation at Little Falls, Minn. Records from U.S. Weather Bureau stations at Little Falls and Little Falls Water Works.

1949–59 together with precipitation data for the U.S. Weather Bureau station at Little Falls. During several months in 1949–51, when the records for this station were missing, data from the Weather Bureau station at the Little Falls Water Works were substituted.

During the period 1921–50, the average annual precipitation at the Little Falls station was 24.82 inches and was distributed throughout the year as follows:

Month	*Average precipitation, inches*	*Month*	*Average precipitation, inches*
January	0.82	July	3.52
February	.90	August	3.31
March	1.08	September	2.62
April	1.97	October	1.74
May	2.92	November	1.34
June	3.90	December	.70

In general, significant rises of the water level can be correlated with precipitation during the wet months and with the spring breakup. It can be demonstrated that when the water level is high, even large amounts of precipitation have little effect in raising the water level, whereas during a dry period when the water level is lower, a significant portion of the annual precipitation may reach the water table. During 1953, a year following one in which the water level had been high, the annual precipitation was about 6 inches more than the average, yet there was no net change in the water level. However, in both 1957 and 1959, when the annual precipitation was only about 2.7 inches more than the average, there were net yearly rises of the water level of about 1.3 feet and 1.0 foot, respectively. It would appear that in 1953, when the average depth to water was around 10 or 11 feet, the average rate of natural discharge from the aquifer was about equal to the rate of recharge. In other words, when the water table is near this level the aquifer may be considered to be filled to its full storage capacity and potential recharge from rainfall is lost to surface runoff. When the average depth to water was around 14 or 15 feet, as in 1957 and 1959, it was possible for significant quantities of recharge to go into storage.

Using a coefficient of storage of 0.20 (see p. 18), it is estimated that in 1957 and 1959 more than 10 percent of the annual precipitation reached the water table. In view of the possibility that 10 percent may be somewhat higher than the average on a long-term basis, it was assumed that only about 7 or 8 percent of the average annual precipitation effectively recharged the ground-water reservoir. This would amount to about 2 inches or 35 million gallons per square mile per year. To support indefinitely a pumping development of 1,000,000 gpd, it would require the diversion of the natural recharge that occurs over about 10 square miles or within a radius of less than 2 miles from the center of pumping.

The amount of water in storage in the sands and gravels in the reservation area is quite substantial and would support a considerable development through dry seasons or drought years when little or no recharge would occur. Assuming a specific yield of 0.20, about 40 million gallons would be available by gravity drainage from each foot of thickness of saturated aquifer having an area of 1 square mile.

If the average yearly recharge over each square mile were 35 million gallons, a withdrawal rate of 1 million gpd for 1 year would result in a water-level decline of about 8 feet over a 1-square-mile area.

Movement of ground water is south and east across the reservation area. The water table varies in altitude from almost 1,330 feet above sea level in the northwest part of the area to about 1,120 feet in the extreme southeast corner. Although the general slope of the water table is not unusually steep, it reaches a maximum of about 250 feet per mile in one area of outwash near the scarp bordering the valley train. The slope of the water table from the northern area of end moraine to the adjacent outwash area is about 200 feet per mile. The relative steepness of the water table near these two places suggests that the permeability of the materials under these areas is lower than that of the materials under most of the reservation.

In the valley train where the post supply wells are located and where most of the test drilling was done, the water table slopes at a rate of about 13 to 15 feet per mile toward the southeast.

Discharge of the ground water occurs largely by underflow to the Mississippi River; by transpiration, principally in the forested areas; and by evaporation from the lake and swamp areas.

QUALITY OF THE GROUND WATER

The following analysis of water from well 130.29.17abb1 was obtained from the camp records and is dated April 1, 1943. It is not known what organization made the analysis.

	Parts per million
Iron (Fe)	1.8
Manganese (Mn)	.0
Calcium (Ca)	56
Magnesium (Mg)	12
Carbonate (CO_3)	.0
Bicarbonate (HCO_3)	238
Sulfate (SO_4)	29
Dissolved solids	246
Hardness as $CaCO_3$:	
Total	189
Noncarbonate	0
Color	40
Carbon dioxide (CO_2)	13

This water is harder than is desirable for domestic uses and it contains an excessive amount of iron. The indicated color is higher than is desirable. The water is otherwise satisfactory for most domestic purposes as it contains only 246 parts per million dissolved solids. It can be softened satisfactorily and the objectionable iron can be removed. The high color may be due to the presence of iron and, if so, it could be removed by treatment.

CONCLUSIONS

The Precambrian metamorphic bedrock in the Camp Ripley area is covered by glacial drift and alluvium. The glacial deposits include end moraines, ice-contact deposits, outwash, and the valley train of the Mississippi River. Most of the surface deposits in the area consist of outwash-plain and valley-train deposits that are generally permeable. The surface of the post area in the southeast part of the reservation consists of alluvium and valley-train deposits and it is underlain by about 50 to 115 feet of drift and alluvium. In the west side of the post area there is a north-northwest-trending bedrock valley the lowest known point of which is about 115 feet below the land surface. The glacial drift in the valley includes permeable glaciofluvial sand and gravel. Filling a narrow channel in the glaciofluvial deposits is a highly permeable body of sand and gravel. It is possible that a similar bedrock valley underlies the east side of the post area.

Properly constructed and developed wells completed in these channel deposits should yield on the order of 2,000 to 3,000 gpm or more. Because the deposits include considerable fine sand, it will be necessary to either gravel pack the wells or to use much care in selecting sizes of screen openings.

Additional large quantities of water probably could be obtained from other permeable channel deposits in the reservation area. If a large increase in water use is contemplated, it would be justifiable to conduct test drilling and geophysical exploration programs to locate other aquifers of this type.

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TABLE 1.—*Records of wells and test holes, Camp Ripley Military Reservation, Minn.*

[Type of well: Unless otherwise indicated, the wells were drilled. Owner: Unless otherwise indicated, the owner is the Minnesota Departmen tof Milita ryAffairs. Depth to water: Unless otherwise indicated, water levels have been measured. Use of water: D, domestic; O, observation; P, public supply; T, test hole; U, unused]

Well or test hole	Driller	Depth of well (feet)	Diameter of well (inches)	Date completed	Depth to water (feet below land surface)	Date of measurement or date reported	Use of water	Altitude of land surface (feet above mean sea level)	Remarks
130.29.									
5cac		33	1¼		15.6	4-27-48	U		Driven well; aquifer, sand.
8bbb		12	1¼		11.0	4-27-48	D		
8bbd1	Western Drilling Co	47	5	March 1949			T		Log in table 2.
8bbd2	do	65	5	do	17	3-17-49	T		Log in table 2.
8dcc	do	77½	5	do			T, O	1,149	Completed as 2-inch observation well; 58½ feet deep. Log in table 2. For water-level data see sections on "Aquifer tests" and "Recharge, storage, and movement of ground water."
8dcc1	do	94	5	do	18.2	3-21-49	T	1,154	Log in table 2.
8dcc2	McCarthy Well Co	15		April 1949			T	1,154	Drilled with reverse rotary rig. Drilling stopped because of boulders. Log in table 2.
8dcc3	Keys Well Drilling Co	111	6	May 1949			T	1,154	Log in table 2.
8dcc4	McCarthy Well Co	69	16	Nov. 1950	17.2	12- 1-50	P	1,154	Log in table 2. Screen, 26′-8″, Everdur bronze. Well yielded more than 1,100 gpm during short test with reported drawdown of 27½ feet.
8dcc5	Western Drilling Co	90	5	March 1949	8	3-22-49	T	1,149	Log in table 2.
9ccd1	do	52	5	do	18	3-10-49	T	1,150	Log in table 2.
9cdc1	do	70	5	do	11	3- 6-49	T	1,148	Log in table 2.
9cdc2	do	52	5	do	22	3-12-49	T	1,147	Log in table 2.
16bcb1		50	2		21.4	4-27-48	D		Owner, William Melberg.
16bcb2		23	1¼		20.1	4-27-48	U		Owner, William Melberg.
17aaa1	McCarthy Well Co	100±	12	1930	19.2	3-30-49	P		Pumped together with well 130.29.17aaa2 by air lift. Combined pumping rate approximately 250 gpm.
17aaa2	do	100±	12	1930	22.5	3-30-49	P		See remarks under well 130.29.17aaa1.
17aaa3	do	166	12	1931			U		Original yield about 200 gpm. Yield declined because well pumped sand.
17aaa4	do	165		1933	18.0	4-27-48	U	1,150	Original yield 240 gpm with air lift pump; drawdown 11 ft. Yield declined because of iron incrustation on screen and inflow of sand.
17aaa5	Western Drilling Co	59	5	March 1949	16.8	4-20-49	T, O	1,149	Log in table 2. Completed as 2-inch observation well; 39 feet deep. For water-level data see section on "Aquifer tests."
17aba1	McCarthy Well Co	68					T		Well is 180 feet south and 180 feet east of well 130.29.17abb1. Log in table 2.
17aba2	do	60					T		Well is about 180 feet northeast of well 130.29.17abb1. Log in table 2.

17aba3	do	100					T		Well is about 160 feet east of well 130.29.17abb1. Log in table 2.
17abb1	do	90	16	1939			P		Screen length, 35 feet. Gravel packed. Log in table 2. Chemical analysis in section on "Quality of the ground water."
17abb2	do	72					T		Well is about 200 feet west of well 130.29.17abb1. Log in table 2.
17abb3	do	89					T		Well is about 135 feet north of well 130.29.17abb1. Log in table 2.
17abb4	Western Drilling Co	99½	5	March 1949			T	1,149	Log in table 2.
17abb5	do	113	5	do	11	3-20-49	T	1,148	Log in table 2.
17abb6	do	80	5	do	13.3	3-24-49	T	1,149	Log in table 2.
17abc1	do	108½	5	do			T, O	1,148	Completed as 1¼-inch observation well; 57 feet deep. Log in table 2. For water-level data see section on "Aquifer tests."
17abc2	do	66	5	do			T	1,149	Log in table 2.
17abc3	do	60	5	do			T	1,148	Log in table 2.
17abd1	do	71	5	do			T	1,147	Log in table 2.
17abd2	McCarthy Well Co	45		April 1949	20		T	1,147	Drilled with reverse rotary rig. Drilling stopped because of boulders. Log in table 2. Reported depth to water.
17abd3	Keys Well Drilling Co	116	6	May 1949			T	1,147	Log in table 2.
17abd4	do	63	16	1949			P	1,147	See logs of wells 130.29.17abd1 and 130.29.17abd3 in table 2. Well yielded more than 1,000 gpm during 3-day test with drawdown of 7 ft.

TABLE 2.—*Logs of wells and test holes, Camp Ripley Military Reservation, Minn.*

[Logs of U.S. Geological Survey test holes are a composite of the driller's log and a study of the samples. Altitudes, where given, are the position of the land surface in feet above mean sea level]

Material	Thickness (feet)	Depth (feet)
130.29.8bbd1 [U.S. Geol. Survey test hole]		
Sand, fine, brown, with pebbles	5	5
Sand, medium to very coarse, tan; and medium gravel	15	20
Sand, fine to medium, light-tan; and some pebbles	22	42
Boulders	2	44
Chloritic phyllite, dark grayish-green	3	47
130.29.8bbd2 [U.S. Geol. Survey test hole]		
Sand, fine to medium, brown; and some pebbles	5	5
Sand, very coarse, light-brown; and fine gravel	10	15
Sand, coarse to very coarse, light-brown; with some pebbles	5	20
Sand, fine to medium, tan; and fine gravel	5	25
Sand, fine, tan; and some coarse sand	31	56
Clay, sandy, light-gray	6	62
Chloritic phyllite, dark grayish-green	3	65
130.29.8dcc [U.S. Geol. Survey test hole. Alt 1,149 ft]		
Sand, very coarse, brown; and coarse gravel	5	5
Sand, silty, very coarse, brown; and medium gravel	8	13
Sand, medium, light-tan	35	48
Gravel, fine; some cobbles and boulders; and coarse to very coarse, light-tan sand	18	66
Clay, sandy, gray; with some cobbles and boulders	11	77
Chloritic phyllite, dark grayish-green	½	77½
130.29.8dcc1 [U.S. Geol. Survey test hole. Alt 1,154 ft]		
Sand, fine to very coarse, light-tan; and pebbles	5	5
Sand, medium, light-brown; and fine gravel	25	30
Sand, medium, light-tan	12	42
Gravel, coarse	3	45
Sand, fine to very coarse, light-tan; and fine to coarse gravel	6	51
Gravel, coarse; cobbles; and boulders	8	59
Gravel, with sand, coarse; and cobbles	9	68
Sand, medium, light-tan; some pebbles	9	77
Clay, sandy, dirty gray; some cobbles and boulders	17	94
130.29.8dcc2 [Driller's log. Alt 1,154 ft]		
Sand, fine	5	5
Sand, coarse; and gravel	5	10
Boulders	5	15

TABLE 2.—*Logs of wells and test holes, Camp Ripley Military Reservation, Minn.*—Continued

Material	Thickness (feet)	Depth (feet)
130.29.8dcc3		
[Driller's log. Alt 1,154 ft]		
Sand, red, fine	20	20
Sand and gravel, red	10	30
Sand, red, fine	10	40
Sand and gravel, red	4	44
Sand and gravel, gray	16	60
Sand, gray	11	71
Conglomerate (sand, gravel, clay)	38	109
Granite	2	111
130.29.8dcc4		
[Driller's log. Alt 1,154 ft]		
Sand, fine	10	10
Gravel	15	25
Sand	15	40
Sand, coarse; gravel; and stones	10	50
Gravel, coarse; and rocks	10	60
Sand, medium; gravel; and rocks	9	69
Clay	11	80
130.29.8dcc5		
[U.S. Geol. Survey test hole. Alt 1,149 ft]		
Sand, coarse to very coarse, brown; and fine to medium gravel	10	10
Gravel, coarse; and coarse to very coarse light-brown sand	10	20
Sand, medium to very coarse, light-brown	10	30
Sand, medium, light-tan	22	52
Gravel, fine to coarse	8	60
Sand, fine to very coarse, gray and tan; and gravel	5	65
Boulders	2	67
Clay, silty, dirty gray, with small quantities of sand and gravel	19	86
Chloritic phyllite, dark grayish-green	4	90
130.29.9ccd1		
[U.S. Geol. Survey test hole. Alt 1,150 ft]		
Sand, loamy, dark-brown	3	3
Sand, silty, fine to coarse, brown	7	10
Sand, medium to very coarse, brown	5	15
Sand, very coarse, brown; fine gravel; and cobbles	10	25
Sand, fine to coarse, brown; and fine gravel	5	30
Sand, fine to medium, light-brown; and a few thin layers of silt and gravel	16	46
Boulders; silty, very coarse, brownish-gray sand	4	50
Clay or till	2	52

TABLE 2.—*Logs of wells and test holes, Camp Ripley Military Reservation, Minn.*—Continued

Material	Thickness (feet)	Depth (feet)
130.29.9cdc1		
[U.S. Geol. Survey test hole. Alt 1,148 ft]		
Sand, loamy, brown	3	3
Gravel, coarse to very coarse; and dark-brown sand	2	5
Sand, coarse to very coarse, dark-brown	5	10
Sand, medium to coarse, brown	5	15
Sand, medium, brown	15	30
Sand, medium, brown, with thin layer of clay	5	35
Sand, medium, brown, with cobbles and boulders	10	45
Sand, silty, medium, dark-brown; and boulders	3	48
Chloritic phyllite, dark grayish-green	22	70
130.29.9cdc2		
[U.S. Geol. Survey test hole. Alt 1,147 ft]		
Sand, medium, brown; and pebbles	5	5
Sand, medium to coarse, brown; and gravel	5	10
Sand, medium to coarse, brown; and fine gravel	10	20
Sand, medium, light-tan	25	45
Boulder	1½	46½
Chloritic phyllite, dark grayish-green	5½	52
130.29.17aaa5		
U.S. Geol. Survey test hole. Alt 1,149 ft]		
Sand, brown; and gravel	6	6
Sand, fine to very coarse, light-brown	15	21
Sand, medium, light-tan	20	41
Sand, very coarse, some fine, light-tan; some fine gravel	12	53
Chloritic schist, dark grayish-green	6	59
130.29.17aba1		
[Driller's log]		
Sand, fine	9	9
Quicksand	21	30
Sand, fine	17	47
Sand, medium-fine	5	52
Hardpan	16	68
130.29.17aba2		
[Driller's log]		
Sand and gravel	30	30
Sand, fine, dirty	17	47
Sand and gravel, dirty	13	60

TABLE 2.—*Logs of wells and test holes, Camp Ripley Military Reservation, Minn.*—Continued

Material	Thickness (feet)	Depth (feet)
130.29.17aba3 [Driller's log]		
Sand and gravel	30	30
Sand, fine, dirty	17	47
Sand and gravel, muddy	18	65
Mud	35	100
130.29.17abb1 [Driller's log]		
Sand	10	10
Sand, very fine	20	30
Sand, fine	14	44
Sand, coarse; and some gravel	5	49
Sand, fine	5	54
Sand, coarse; and ¼-inch-diameter gravel (water)	14	68
Sand, fine; and gravel (water)	12	80
Sand, fine	5	85
Rock	5	90
130.29.17abb2 [Driller's log]		
Sand, coarse	22	22
Sand, medium-fine	8	30
Sand, fine	25	55
Sand, coarse	3	58
Sand, coarse, muddy	4	62
Hardpan and fine gravel	10	72
130.29.17abb3 [Driller's log]		
Sand and gravel	23	23
Sand, fine; and gravel	12	35
Sand, medium; some gravel	16	51
Sand, gray, muddy	4	55
Sand, gray; and gravel	2	57
Sand, coarse, dirty; and gravel	3	60
Sand, muddy	5	65
Sand, black, muddy	2	67
Sand, muddy; and gravel	8	75
Hardpan	14	89

TABLE 2.—*Logs of wells and test holes, Camp Ripley Military Reservation, Minn.*—Continued

Material	Thickness (feet)	Depth (feet)
130.29.17abb4		
[U.S. Geol. Survey test hole. Alt. 1,149 ft]		
Sand, medium, brown	5	5
Sand, coarse to very coarse, light-tan; and layers of gravel	15	20
Sand, medium, light-tan	20	40
Sand, medium to coarse, light-tan	8	48
Gravel	½	48½
Sand, medium to coarse, light-tan	1½	50
Sand, medium to very coarse, tan and gray; and thin layers of gravel	3	53
Gravel, coarse and loose; some sand	18½	71½
Gravel, with cobbles and boulders	9	80½
Sand, fine to medium, tan and gray; some fine gravel	5	85½
Sand, fine to medium, grayish-tan; and layers of brown silt	6	91½
Sand, fine to medium, grayish-tan, with brown silt; and boulders	4½	96
Chloritic phyllite, dark grayish-green	3½	99½
130.29.17abb5		
[U.S. Geol. Survey test hole. Alt 1,148 ft]		
Sand, very coarse, light-brown	5	5
Gravel, fine to coarse; and predominantly very coarse, light-brown sand	15	20
Sand, medium, light-brown; and thin layers of coarse sand	33	53
Gravel; cobbles; and coarse sand	11	64
Clay, sandy, gray; some pebbles, cobbles, and boulders	44½	108½
Chloritic phyllite, dard grayish-green	4½	113
130.29.17abb6		
[U.S. Geol. Survey test hole. Alt 1,149 ft]		
Sand, medium, brown; and small amount of gravel	10	10
Sand, medium to very coarse, light-brown; and some gravel	10	20
Sand, medium, light-tan	35	55
Gravel, coarse	3	58
Sand, coarse to very coarse	4	62
Clay, sandy, gray; with gravel and cobbles	18	80

TABLE 2.—*Logs of wells and test holes, Camp Ripley Military Reservation, Minn.*—Continued

Material	Thickness (feet)	Depth (feet)
130.29.17abc1		
[U.S. Geol. Survey test hole. Alt 1,148 ft]		
Gravel, fine to medium; coarse to very coarse, light-brown sand	10	10
Sand, coarse to very coarse, light-brown; with fine to medium gravel	10	20
Sand, fine to medium, light-tan	31½	51½
Gravel; cobbles; and coarse to very coarse, gray sand	3½	55
Gravel, coarse; and some very coarse, gray sand	5	60
Gravel, medium; very coarse, gray sand; and some boulders	6	66
Clay, sandy, gray; with silt and gravel	34	100
Sand, silty, very coarse, tannish-gray	8	108
Chloritic phyllite, dark grayish-green	½	108½
130.29.17abc2		
[U.S. Geol. Survey test hole. Alt 1,149 ft]		
Sand, very coarse, light-brown	5	5
Sand, very coarse, grayish-brown; and gravel	10	15
Gravel, coarse	2	17
Sand, very coarse, grayish-brown	3	20
Gravel, fine to coarse; and very coarse, grayish-brown sand	10	30
Sand, medium, light-tan	19½	49½
Gravel, coarse; very coarse sand; and boulders	14½	64
Clay, sandy, light-gray; and pebbles	2	66
130.29.17abc3		
[U.S. Geol. Survey test hole. Alt 1,148 ft]		
Sand, medium to very coarse, brown; includes some gravel	15	15
Gravel, fine to medium; and fine to very coarse, gray and tan sand	5	20
Sand, medium, light-tan	20	40
Gravel and cobbles; with thin layers of coarse to very coarse, gray sand	5	45
Gravel; cobbles; boulders; and very coarse, gray sand	12½	57½
Clay, sandy, gray	2½	60

TABLE 2.—*Logs of wells and test holes, Camp Ripley Military Reservation, Minn.*—Continued

Material	Thickness (feet)	Depth (feet)
130.29.17abd1		
[U.S. Geol. Survey test hole. Alt 1,147 ft]		
Sand, medium, brown; and pebbles	5	5
Sand, very coarse, light-brown; and fine gravel	5	10
Sand, very coarse. light-brown; and fine to medium gravel	10	20
Sand, very coarse, light-brown; and coarse gravel	10	30
Sand, fine to very coarse, light-tan	10	40
Gravel, coarse; and very coarse, brown sand; cobbles and boulders	10	50
Gravel, medium; very coarse sand; cobbles and boulders	10	60
Sand, very coarse, brown	5	65
Sand, fine to medium, brown	4	60
Boulder, chloritic phyllite, dark grayish-green	2	71
130.29.17abd2		
[Driller's log. Alt 1,147 ft]		
Gravel, coarse; and large boulders	15	15
Gravel, coarse; with cobbles	5	20
Sand, fine; and medium-coarse gravel; 6-inch layer of white clay	5	25
Sand, very fine; some stones	5	30
Gravel, coarse; and sand	7	37
Sand, medium-coarse	3	40
Boulders; coarse gravel; and sand	5	45
130.29.17abd3		
[Driller's log. Alt 1,147 ft]		
Loam, black	1½	1½
Sand	13½	15
Sand and gravel	5	20
Sand, fine	20	40
Gravel	14	54
Gravel and coarse sand	14	68
Conglomerate (sand, gravel, and clay)	30	98
Sand	10	108
Sand (slightly consolidated)	4	112
Sand	2	114
Black slate and granite	2	116