UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GEOLOGY AND GROUND-WATER RESOURCES OF PARTS OF CASS AND CLAY COUNTIES NORTH DAKOTA AND MINNESOTA

By

P. E. Dennis, P. D. Akin,
and G. F. Worts, Jr.

North Dakota Ground-Water Studies No. 10
Minnesota Ground-Water Studies No. 1

Prepared in cooperation with the Cities of
Fargo and Moorhead, the Counties of Cass and
Clay, and the States of North Dakota and
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GEOLOGY AND GROUND-WATER RESOURCES OF PARTS OF CASS COUNTY, NORTH DAKOTA, AND CLAY COUNTY, MINNESOTA

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ABSTRACT

The investigation covered by this report extended over an area of 360 square miles lying within the valley of the Red River of the North and including the municipalities of Dilworth and Moorhead, Clay County, Minnesota; and Fargo, Southwest Fargo, West Fargo, Mapleton, and Casselton, Cass County, North Dakota. It was begun at the request of, and with financial cooperation from, the Cities of Fargo and Moorhead, the Counties of Cass and Clay, and the States of North Dakota and Minnesota.

Study of the geology of the area is greatly hampered by the almost complete absence of outcrops of rocks other than the deposits of Lake Agassiz, which blanket the entire area. Extensive test drilling by the Geological Survey and the Cities of Fargo and Moorhead has produced new evidence regarding the extent of the underlying rock units, which necessititates some revision of earlier interpretations. The rock units encountered in the test wells in and near the area described, in descending order are as follows: (1) Deposits of Lake Agassiz, which have been divided into two units---silt and clay; (2) till and associated glaciofluvial deposits; (3) older lake clay and drift deposits; (4) the Dakota sandstone; and (5) "granite" (gneisses and other crystalline rocks), the basement rocks beneath the area.

The silt unit of the Lake Agassiz deposits is the surface rock throughout the area and rests disconformably upon the clay unit of the Lake Agassiz deposits. It is composed primarily of silt, buff to yellow to gray in color, but locally contains sand or clay. In thickness it ranges from 15 to 25 feet, and it is present beneath the entire surface of the area except where cut through by the major streams. It contains water at shallow depths which is under water-table conditions. Only locally can water of adequate quality and quantity be obtained from wells in this material.

The clay unit of the Lake Agassiz deposits is predominantly a dark-gray to blue-gray clay of lacustrine origin. It lies beneath the silt unit and rests unconformably upon the till and associated glaciofluvial deposits. It ranges in thickness from 15 feet near Casselton to 85 feet near Fargo. It does not yield water to wells.

Throughout the area the till and associated glaciofluvial deposits occur beneath the clay unit of the Lake Agassiz deposits, and, where drilled, range in thickness from 70 feet to 250 feet. They rest unconformably upon the "granite" from the Red River west to the Sheyenne River. East of the Red River and west of the Sheyenne they rest unconformably upon older lake clay and drift.

The strictly unsorted portion of the till is essentially non-water-bearing, but the glacifluvial deposits contained in it yield small to copious amounts of water. All the municipal and industrial ground-water supplies in the area, with the possible exception of the city supply at Casselton, have been developed in these deposits.

The general extent and thickness of six principal aquifers of glaciofluvial origin have been incompletely determined. For convenience they are called the Dilworth, East Moorhead, West Moorhead, Fargo, West Fargo, and Maple Ridge aquifers, respectively.

The older lake clay and drift deposits have not been identified as such in previous investigations. Their presence has been established principally in the area west of the Sheyenne River, where they were penetrated by 10 test holes and ranged up to 250 feet in thickness. They yield little or no water to wells.

The Dakota sandstone was not encountered by any of the test holes drilled within the area, but in one test hole drilled a few miles west of the area a sandstone believed to be a remnant of the Dakota was encountered just above the granite. It is quite possible that outliers of the formation may be found in other parts of the valley. Where present the Dakota sandstone yields moderate quantities of rather highly mineralized water.

Gneisses and other crystalline rocks, generally referred to as "granite," compose the basement rocks of the area and extend downward for an unknown depth. In the old Moorhead well, 1,536 feet of "granite" was penetrated without passing completely through it. The upper 100 feet or more of the "granite" is greatly weathered. For all practical purposes, the "granite" is non-water-bearing.

Within the area several low ridges break the monotony of the flat surface. The most prominent of these is the ridge near Mapleton, running roughly parallel to and west of the Maple River and referred to in this report as the Maple Ridge. It is a curving linear feature standing from 5 to 20 feet above the plain and having a length of about 14 miles within the area. Two other ridges of lesser extent and prominence occur, at the western edge of Fargo and near the eastern limits of West Fargo. They are designated here, respectively, the Fargo Ridge and the West Fargo Ridge.

Test drilling indicates that there is a relation between these ridges and the occurrence of ground water in shallow deposits.

The origin of the ridges is problematical. The most probable explanation of the ridges appears to be that they are the result of differential compaction of the underlying and adjacent deposits. Also, it has been suggested that the ridges may be end moraines or at least of morainic origin but this mode of origin appears to be improbable.

The first ground-water developments in the area were wells for supplying domestic and stock water for farms and individual needs in small communities. The search for ground-water supplies for municipal and industrial uses began in 1872, when the City of Fargo drilled a test well in Island Park. Since that time many test holes and a number of wells have been drilled with varying degrees of success. Since the turn of the century municipal ground-water supplies have been developed by Moorhead, Dilworth, Southwest Fargo, Casselton, and Fargo; industrial supplies have been developed by the Fairmont Creamery Co., Moorhead Laundry, Great Lakes Pipeline Co., the Union Stockyards Co., and the Northern Pacific Railroad. Except for the municipal supply at Casselton, these supplies have all been developed from the principal glaciofluvial aquifers associated with the till.

It is estimated that since 1905 about 8.3 billion gallons of water has been pumped from the East and West Moorhead aquifers, about 1.7 billion gallons from the West Fargo aquifer, and about 140 million gallons from the Fargo aquifer. About 13 billion gallons has been pumped from all wells in the area since 1905 for all purposes. In 1947, the total pumpage in the area was of the order of 880 million gallons, or an average of about 2½ million gallons a day for the year.

Of this total, 570 million gallons, 142 million gallons, and 223 million gallons were pumped from the Moorhead, Fargo, and West Fargo aquifers, respectively, for municipal and industrial purposes.

Since the beginning of the development of municipal and industrial supplies withdrawals have been made in ever-increasing yearly amounts. At the current rate it would require only about 15 years to pump an amount of water equivalent to that used during the past 42 years. There is reason to believe that the demands for ground water in the area generally will continue to increase as the population grows and industrial activities expand.

From early records it appears quite probable that at one time flowing wells could be obtained at almost any place in the area. Pumping of farm and domestic wells had lowered the artesian head considerably by 1885, so that many of the wells did not flow although the water levels were, for the most part, at or very near the land surface. The records also indicate that there was no great lowering of water levels in the area during the period 1885-1910, when ground-water developments still consisted chiefly of widely spaced wells yielding small supplies for domestic and farm purposes.

The development and use of ground water for municipal and industrial purposes has been accompanied by a lowering of water levels and artesian pressures over the entire area and in adjacent areas. As would be expected, the greatest amount of lowering has occurred in the areas of greatest use. From Moorhead to Dilworth water levels are now 100 to 195 feet below land surface. In the vicinity of the Fargo City well they are about 40 feet below land surface and near West Fargo more than 57 feet below land surface. Water-level measurements in 1940 and 1941 indicate an area of about 80 square miles surrounding these points of large ground-water development in which the water level is over 30 feet below land surface and an area of about 140 square miles in which the water level is more than 20 feet below land surface.

The results of the test drilling indicate that the highly permeable glaciofluvial aquifers in which the larger ground-water developments have been made may be quite limited areally and may be more or less separated from one another by much less permeable material. On the other hand, there is considerable hydrologic evidence to indicate interconnection between the aquifers in such a manner that pumping from one development will influence the water levels at the other developments; and, therefore, that one development may receive and utilize water derived from the same sources that supply water for the other developments. For this and other reasons, it is believed that practically all the lowering of the water levels in the area since 1910 has been caused by removal of water from ground-water storage through pumping of the municipal and industrial wells in the area.

Results of pumping tests indicate that the coefficient of transmissibility of the more permeable sections of the Fargo and West Fargo aquifers is of the order of 70,000 gpd/ft. In a regional sense, however, the coefficient of transmissibility of the till and associated glaciofluvial deposits, considered as a unit, is probably of the order of 1,000 gpd/ft. The coefficient of storage of the till and associated glaciofluvial deposits is on the order of 0.0005 so long as the water is confined by the clay units of the Lake Agassiz deposits and therefore under artesian conditions. Once the water levels are drawn below these clays, water will be derived from drainage of the glaciofluvial deposits and the coefficient of storage locally may be as high as 0.25. Regionally, however, the coefficient of storage of the till and associated glaciofluvial materials under water-table conditions would be considerably less and is estimated to be on the order of 0.07.

There appear to have been only two possible sources of recharge to the aquifers in the till and associated glaciofluvial deposits prior to the construction of wells in the area: (1) water derived from precipitation on the upland areas along both the east and west margins of the valley; and (2) water from the Dakota sandstone which could move laterally and upward into the till along the western part of the valley. The water from these sources moved laterally through the till toward the central part of the valley. Natural discharge occurred by upward percolation of water through the clay unit of the Lake Agassiz deposits and into the overlying silt of the Lake Agassiz deposits probably over the greater part of the valley. Considerable natural discharge must have occurred also by upward percolation into the shallow-lying gravel aquifer east of Dilworth, which was deposited in a channel cut entirely through the lake deposits and rests directly upon the till.

Accompanying the development and use of ground water, water levels declined in the valley area. Hydraulic gradients from the areas of recharge toward the valley were increased, and as a consequence the amount of water reaching the valley areas from the original sources of recharge was increased. In the areas where the artesian head of the aquifers in the till was drawn below the shallow water level in the silt unit of the Lake Agassiz deposits natural discharge through upward percolation stopped, the water being diverted to the wells.

As the water levels were lowered further, opportunity developed for downward percolation of water from the silt into the aquifers in the till, reversing the original arrangement of recharge and discharge between these two units, and an excellent opportunity was afforded for recharge from such sources as the shallow gravel aquifer east of Dilworth.

It is estimated that recharge to the principal glaciofluvial aquifers at the present time is on the order of 1 million gallons a day. This is only 40 percent of the 2½ million gallons a day now being withdrawn through wells, indicating that about 1½ million gallons a day is being removed from underground storage through lowering of the water levels. However, recharge rates will be increased as the water levels are further lowered, so that ultimately the total recharge to the area may be considerably greater than it is at the present time. Further lowering of water levels to increase the rate of recharge can be accomplished only by spreading new developments over a wider area and by decreasing pumping rates in those locations where pumping water levels are already about as low as can be attained.

It is estimated that about 900 billion gallons of water is contained in storage in the till and associated glaciofluvial deposits in the 360-square-mile area covered by this report, and only a fraction of the water could be recovered economically. The maximum production of the water from storage could be accomplished only by means of a large number of wells spread over the entire area, in which case many of the wells would have yields of only a few gallons a minute. Nevertheless, it should be possible to recover a large amount of the stored water, though only a small part of the total through wells having sufficient yields for irrigation, municipal, and industrial purposes. Such wells could be developed only in the more permeable aquifers, and it would be necessary to adjust pumping rates and limit the number of wells that could be constructed in any locality so as to prevent short-term local overdevelopment.

The West Fargo and Maple Ridge aquifers will permit the largest amount of additional ground-water development without excessive lowering of water levels.

INTRODUCTION

LOCATION AND GENERAL FEATURES OF THE AREA

This report covers an area of 360 square miles within the valley of the Red River of the North, at altitudes ranging from 860 to 980 feet. It extends from the village of Dilworth in Clay County, Minnesota, westward beyond the city of Casselton in Cass County, North Dakota, an over-all distance of 30 miles. The area is 12 miles wide from north to south and includes the principal cities of Fargo, North Dakota, and Moorhead, Minnesota, which are on opposite banks of the Red River. Fargo, which is the largest city in North Dakota, has a population estimated in 1947 to be 38,000. Moorhead, Minnesota, has a population estimated in 1947 to be 13,000. These two cities form an industrial and agricultural hub in a famous agricultural area. They are the site of several large creameries, a beet-sugar factory, stockyards, several farm implement houses, and other business establishments.

The course of the Red River, which forms the boundary between North Dakota and Minnesota, is so sinuous that parts of Minnesota lie west of adjacent parts of North Dakota. Drainage tributary to the Red River is furnished by the Sheyenne and Maple Rivers from the west,

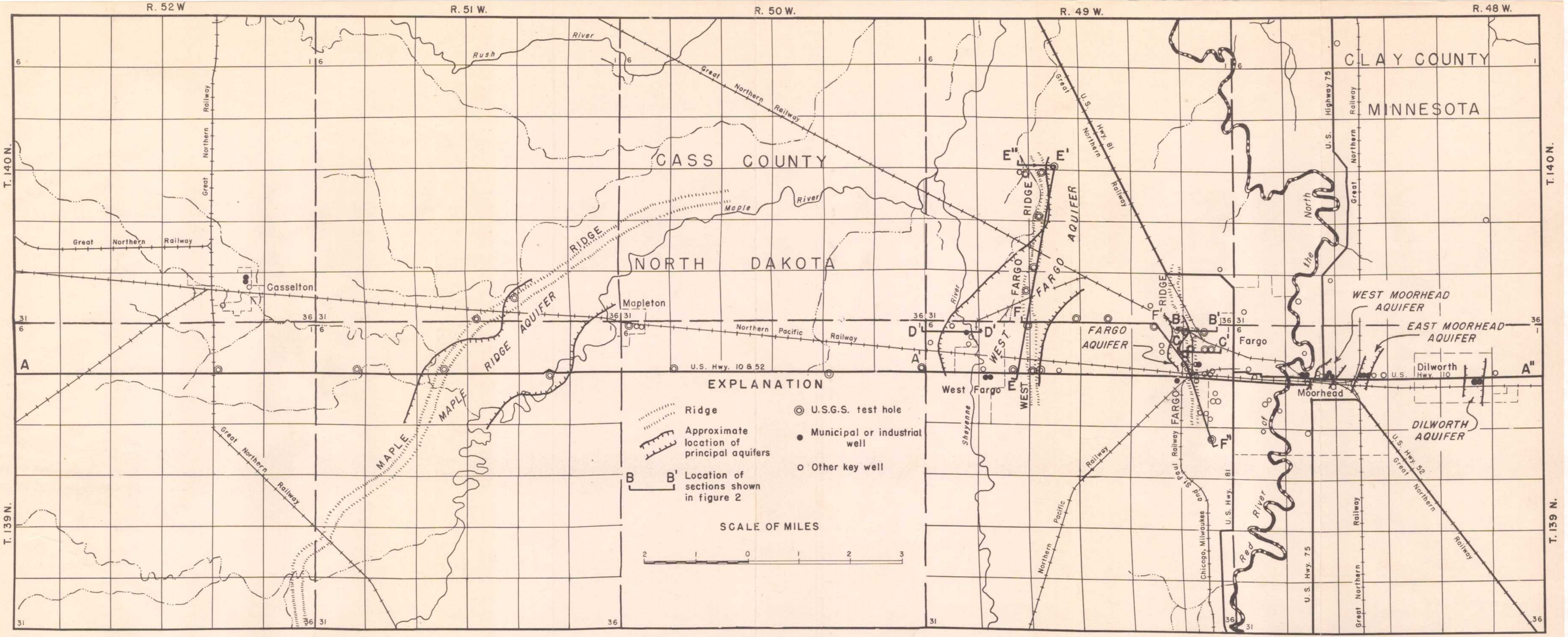

FIGURE 1. MAP OF CASS AND CLAY COUNTIES AREA SHOWING PHYSIOGRAPHIC FEATURES, LOCATION OF PRINCIPAL AQUIFERS, AND LOCATION OF CROSS SECTIONS, TEST HOLES, AND KEY WELLS.

and by the Buffalo River from the east. The Maple joins the Sheyenne within the area, but both the Sheyenne and Buffalo join the Red River north of the area. These three streams are perennial except during infrequent periods of drought, and afford a source of water supply for both municipal and industrial use — the principal withdrawal in the area being from the Red River for the city of Fargo. Spring floods, which are the result of melting snow and ice, and summer rainstorms often cause inundation of lands and dwellings along all three rivers.

Topographically the area is a flat, nearly featureless plain into which the northward-flowing rivers have entrenched their meandering courses to depths of 15 to 30 feet. The plain has a northward slope of only about 1½ feet per mile. The Red River lies along the axis of the valley, and the gentle slopes toward the river range from about 2 feet per mile near the river to about 4 feet per mile near Casselton. This relatively flat plain is not the product of river erosion, but of lake deposition. The present surface was the bed of glacial Lake Agassiz,[1] which extended over the entire Red River Valley in late Pleistocene time. Judging from the elevation of old shore lines, the lake at its maximum extent covered the present site of Fargo by more than 200 feet of glacial melt water. After the lake had withdrawn from the valley, the drainage pattern on the lake bed was essentially the same as that of today. Presumably, the river is continuing to entrench itself into the lake deposits underlying the plain.

Within the area several low ridges break the monotony of the flat surface. The most prominent of these is the ridge near Mapleton, running roughly parallel to and west of the Maple River and referred

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[1] Upham, Warren, The glacial Lake Agassiz: U. S. Geol. Survey Mon. 25, 1896.

to in this report as the Maple Ridge. It is a curving linear feature standing from 5 to 20 feet above the plain and having a length of about 14 miles within the area. Two other ridges of lesser extent and prominence occur, at the western edge of Fargo and near the eastern limits of West Fargo. They are designated here, respectively, the Fargo Ridge and West Fargo Ridge. Test drilling indicates that there is a relation between these ridges and the occurrence of ground water in shallow deposits.

The area is served by three major railroads and four arterial highways. The railroads are the Great Northern, Northern Pacific, and Chicago, Milwaukee, and St. Paul; and the principal highways are U. S. Highways 10, 52, 75, and 81. In addition, air travel is furnished by Northwest Airlines to Hector Airport, Fargo.

The climate of the region is characterized by cold winters with temperatures commonly 20 to 30 degrees below zero, and relatively hot summers with temperatures up to 100 degrees. The mean annual temperature is 39.9 degrees. Precipitation averages about 22 inches a year, of which about 65 percent occurs from May to September. This rainfall, in conjunction with the exceptionally fertile soil of the Red River Valley, supports the agriculture of the area. The products include grain, potatoes, sugar beets, dairy products, and beef cattle.

PURPOSE AND SCOPE OF THE INVESTIGATION

This investigation is the second of several comprehensive investigations of the geology and ground-water resources of parts of Cass County, North Dakota, and Clay County, Minnesota, that are designed ultimately to cover all of both counties. The present investigation was begun at the request of, and with financial cooperation from, the Cities of Fargo and Moorhead, the Counties of Cass and Clay, and the States of North Dakota and Minnesota. The formal cooperative agreement was made between the U. S. Geological Survey and the North Dakota State Water Conservation Commission and the Minnesota State Department of Conservation. The need for the investigations has arisen out of the increased demands upon ground water for industrial, municipal, and other uses throughout these and other counties within the two States.

Because the demands upon ground water are greatest in and near the larger cities, the first investigation was confined largely to the Fargo area. The present study is founded upon and amplifies the first and has been extended to cover an area of 360 square miles including the following cities and towns: Fargo, West Fargo, Southwest Fargo, Mapleton, Casselton, Moorhead, and Dilworth.

This report presents the findings of the investigation, and sets forth data regarding the geology, the location and size of aquifers (water-yielding deposits), and the results of test drilling. In addition, it presents data regarding the development and use of ground water and information pertaining to many wells in the area. It includes interpretative data regarding water-level fluctuations and their relation to ground-water storage and interconnection of aquifers, the effect of pumping on storage of water in other aquifers, and the quality and quantity of available ground water.

The investigation, which was started July 1, 1945, under the direction of O. E. Meinzer, former geologist in charge of the Ground Water Division, was completed under the direction of his successor,

A. N. Sayre. The work was carried on under the supervision of P. E. Dennis, district geologist, and the field work was begun by A. M. Morgan, who resigned in 1947. The work was completed in 1948 by the authors.

PREVIOUS INVESTIGATIONS

In 1940 and 1941 the U. S. Geological Survey, in cooperation with the North Dakota Geological Survey and the City of Fargo, made an intensive investigation of the ground-water conditions in and around Fargo. The results of the investigation have been released.[2] Subjects covered by the report include the occurrence of ground water in the glacial drift, source and movement of ground water, fluctuations of water levels, quality of water, and general geology of the area. Previous investigations have been outlined in the report as follows:[3] "The Quaternary geology of the Red River Valley was first described in detail by Upham[4] who also made a study of the ground-water conditions of the valley and adjacent areas, discussing the strata from which the water is obtained and outlining recharge areas for the different aquifers. He gives several analyses of water from the different sources and concludes that water from wells in the Cretaceous strata and from wells in the older drift, which contains materials derived from the underlying Cretaceous formations, is unsuitable for irrigation purposes because of its highly alkaline and saline quality.

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[2] Byers, A. C., Wenzel, L. K., Laird, W. M., and Dennis, P. E., Ground water in the Fargo-Moorhead Area, North Dakota and Minnesota: U. S. Geol. Survey mimeographed report, Sept. 1946.

[3] Byers, A. C., et al., op. cit., pp. 6-7.

[4] Upham, Warren, The glacial Lake Agassiz: U. S. Geol. Survey Mon. 25, 1896.

He also notes that shallow wells in the alluvial and lacustrine materials give alkaline water. He reports that at the time of his investigation several flowing wells existed in Fargo and Moorhead, and that those which did not flow, but in which the water rose nearly to the land surface, maintained their level under pumping.

"The first investigation of the general geology of the Fargo-Moorhead area was made by Hall and Willard.[5] They studied the water resources in considerable detail, cataloging the wells of the region and tabulating and analyzing the available logs. The area in which flowing wells could be obtained in the Cretaceous strata at depths of 300 to 600 feet was mapped, and several smaller basins in which there were small flowing wells in the Quaternary materials were outlined. At the time of the investigation the supply of ground water seemed nearly inexhaustible.

"More recently Leverett[6] restudied the Quaternary geology of the region, amending and extending the work of Upham in detail. He made, however, no investigation of the ground-water resources of the area. Simpson's report[7] includes a brief discussion of the geology and ground-water conditions in Cass County and Fargo, and Allison's report[8] includes information on geology and ground-water resources in Clay County, Minnesota.

"In 1939 Voedisch[9] assembled and summarized the ground-water data available for the Fargo area. Well records were brought up to

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[5] Hall, C. M., and Willard, D. E., U. S. Geol. Survey Geol. Atlas, Casselton-Fargo folio (no. 117), 1905.

[6] Leverett, Frank, Quaternary geolgy of Minnesota and parts of adjacent States: U. S. Geol. Survey Prof. Paper 161, pp. 119-141, 1932.

[7] Simpson, H. E., Geology and ground-water resources of North Dakota: U. S. Geol. Survey Water-Supply Paper 598, pp. 97-108, 1929.

[8] Allison, I. S., The geology and water resources of northwestern Minnesota: Minnesota Geol. Survey Bull. 22, 1932.

[9] Voedisch, F. W., Geology and ground-water resources of the Fargo area. Unpublished report in the files of the City Engineer's Office, Fargo, N. D.

date and logs were given in both graphic and tabular forms. The pumping tests made on the exploratory wells drilled by Fargo in 1935 were described and the detailed data were given."

In 1947, two mimeographed releases[10] presented the results of an investigation of a large shallow-lying gravel aquifer 2½ miles east of Dilworth, Minnesota. Its extent, probable yield, and transmissibility were largely determined; and further study of its northern extent is now contemplated.

ACKNOWLEDGMENTS

The authors wish to acknowledge the splendid cooperation extended by J. E. Young, Moorhead city water and light superintendent, W. P. Tarbell, Fargo city engineer, Fred Hagen, Fargo city commissioner of water, J. H. Deems, Moorhead city commissioner of water, Ray Olson, Union Stockyards Co., Homer Ludwig, Fargo Chamber of Commerce, A. P. Diercks, Moorhead Chamber of Commerce, C. J. Ferch, owner of Southwest Fargo waterworks, M. B. Collins, Casselton city water commissioner, W. F. Wahowske, superintendent of the Casselton city water plant, A. N. Chrisses, Dilworth Village Water Commissioner, W. B. Rae, superintendent of the Dilworth water plant and other officials. All kindly furnished data regarding wells, pumpage, water levels, and other related factual information about the area.

Carl Larson, Julius Fugere, the McCarthy Well Company, and other drillers gave freely of their time and information concerning well

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[10] Dennis, P. E., and Morgan, A. M., Water supply of a gravel aquifer east of Moorhead, Clay County, Minnesota: U. S. Geol. Survey mimeographed release, May 1947.
Dennis, P. E., and Akin, P. D., Gravel aquifer map issued. U. S. Geol. Survey mimeographed release, July 29, 1947.

logs and drilling operations. Residents of the area cooperated fully by furnishing information about their wells and allowing test holes to be drilled on their property.

GEOLOGY AND OCCURRENCE OF GROUND WATER

GENERAL FEATURES

The regional geology of the Red River Valley has been described in previous reports which have treated the geology of this area in various degrees of detail. (See references, pp.13-14.) These works have been consulted freely in the preparation of this report. The study of the geology is greatly hampered by the almost complete absence of outcrops of rocks other than the deposits of glacial Lake Agassiz, which blanket the entire area. Thus, the knowledge of the rocks underlying these deposits was obtained solely from information obtained from wells and test holes.

Extensive test drilling in this area by the Geological Survey and the Cities of Fargo and Moorhead has produced new evidence regarding the extent of the rock units underlying this portion of the Red River Valley. This necessitates some revision of earlier interpretations, which were based on less precise data. The test drilling has made possible more detailed conclusions regarding the extent, thickness, and irregularities of the underlying rock units and the contained water bodies. From these data the rock units and associated water bodies, where present, have been identified. In descending order they are as follows: (1) Deposits of Lake Agassiz, which have been divided into two units — the silt unit, which contains a shallow water body, and the clay unit; (2) Till and associated glaciofluvial deposits (the latter, where present, form the principal aquifers of varying extent beneath the area, and all large-capacity wells derive their supply from them); (3) older lake clay and drift deposits; (4) the Dakota (?) sandstone, which in the western part of the area yields some water of rather poor quality; and (5) "granite" (gneisses and crystalline rocks, the basement rocks beneath the area). These units are discussed separately in the pages that follow.

ROCK UNITS AND THEIR WATER-BEARING PROPERTIES

Lake Agassiz Deposits
(Late Pleistocene)

General

The modern Red River Valley has a gentle northward slope and it is generally believed that the preglacial Red River Valley also sloped northward. As a consequence of this northward slope of the land surface, glacial meltwater was ponded in front of the ice at times when the ice front was in the northern part of the valley and blocked the natural drainage outlets. During the last glaciation the northward retreat of the front of the Dakota ice lobe permitted the formation of a lake which at its maximum extent exceeded the combined areas of the present great lakes.[11] This lake was named Lake Agassiz by Upham.[12] Tyrrell and Johnston have presented evidence indicating that there were at least two periods when the basin was occupied by a lake, separated by a period when the basin was partially or wholly

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[11] Flint, R. F., Glacial geology and the Pleistocene epoch, p. 264, New York, John Wiley & Sons, 1947.

[12] Upham, Warren, op. cit., p. 5.

drained.[13] The two units described in the present report as the clay and silt units of the Lake Agassiz deposits may correspond with the laminated stony clays and the deposits of Lake Agassiz, respectively, as described by Johnston.[14]

Within the area covered by this report the Lake Agassiz deposits range in thickness from 40 feet in the western part of the area to 110 feet near Fargo. Their lithologic character was determined chiefly from the samples obtained from the 31 test holes drilled by the Geological Survey.

Silt unit

The silt unit of the Lake Agassiz deposits is the surface rock throughout the area and rests disconformably upon the clay unit of the Lake Agassiz deposits. As the name implies, it is composed primarily of silt, buff to yellow to gray in color, but locally it contains sand or clay. In a few places the entire unit is composed of clay. The yellow to buff color of the deposits is believed to be the product of weathering wherein the iron compounds in the deposit have been oxidized. Rarely, the deposits are light gray to gray in color. In general, the unit is coarser-grained near the base than near the surface. It ranges in thickness from 15 to 25 feet, and is present beneath the entire surface of the area except where cut through by the major rivers (fig. 2).

The silt unit is believed to be a lacustrine deposit laid down under shallow-water conditions in a transgressing lake. The fairly

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[13] Tyrell, J. B., The genesis of Lake Agassiz: Jour. Geology, vol. 4, pp. 811-815, 1896.
Johnston, W. A., The genesis of Lake Agassiz: Jour. Geology, vol. 24, pp. 625-638, 1916.

[14] Op. cit., pp. 630-631.

uniform lithology of the upper beds, their flat surface expression, and their uniformly laminated bedding all tend to substantiate this hypothesis. The silt may correspond to the material which Upham described as flood-plain deposits of the Red River and its tributaries, and which he believed to be commonly greater in thickness and extent than the underlying lake silt.[15]

Locally, and in many places associated with the low ridges, are deposits of sand and gravel, underlying or associated with the silt unit, and occurring down to depths of 60 feet below the land surface. These coarse deposits, and the common presence elsewhere of a thin sandy bed at the base of the silt, suggest a transgressing lake and the possibility of fluvial deposition following deposition of the clay unit and preceding the deposition of the silt unit. Such a hypothesis requires the assumption that there was at least one withdrawal and readvance of the ice sheet in the region of the lake's northern outlet, causing it to drain and refill. As yet very little is known about the probable extent of the drainage system that may have developed during this "interlake" period. Because these coarse deposits are of limited extent and because their origin is not definitely known, they are included in the silt unit.

A shallow ground water body is contained in the silt unit of the Lake Agassiz deposits. Its base rests upon the clay unit, which separates it from the principal aquifers in the till and associated glaciofluvial deposits, and its upper surface lies from 10 to 18 feet below the land surface. In extent it covers the entire area except where cut through by the major streams. However, in some areas the deposits are

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[15] Op. cit., p. 202.

too fine-grained to yield appreciable quantities of water to wells. The water body occurs under watertable conditions and is commonly not more than 15 feet thick, but beneath the ridges and other localities where it extends downward into coarser materials it may be in excess of 50 feet. Recharge to this body takes place by infiltration of rain and melting snow and by seepage from the imperfectly developed drainage courses which cross the divides between the main streams.

A large number of wells have been dug or bored to the shallow water body, but generally small yields and poor quality of the water in much of the area has resulted in the abandonment of most of the wells. Some domestic and stock wells, especially at farms located along the ridges, obtain an adequate supply of potable water from this source. No municipalities or industries utilize the shallow water. Consequently, except for the problem of drainage from the soils where the water table is too high, the shallow water body is of little economic importance.

Clay unit

The clay unit of the Lake Agassiz deposits is predominantly a dark-gray to blue-gray clay of lacustrine origin. Occasional ice-rafted boulders, cobbles, pebbles, and sand are encountered in the clay. It lies beneath the silt unit of the Lake Agassiz deposits and rests unconformably upon the till and associated glaciofluvial deposits. In thickness it ranges from 15 feet near Casselton to 85 feet near Fargo. It is thinnest near the margins of the old lake bed and thickest near the center. The time necessary for the accumulation of this deposit must have been considerable, and indicates that this stage of glacial Lake Agassiz must have persisted for many years. Furthermore, the relatively fine-grained character of the deposit indicates that the materials were carried in suspension by the lake waters for relatively long distances before being deposited, and that deposition took place in relatively deep lake waters.

The clay unit does not yield water to wells. Such water as it contains between the microscopic particles cannot be withdrawn by such mechanical means as pumping. It forms an extensive blanket resting upon and confining the water in the till and glaciofluvial deposits. That the "watertightness" of the clay unit was early recognized by well drillers is attested to by an excerpt from the report by Hall:[15] "From whatever horizon the water is derived the same general conditions prevail----a compact and impermeable layer or bed of clay overlies the water-bearing stratum, and no sign of water appears until the bottom of the clay is reached. The water rushes up the tube (well) often with considerable force....." The confining effects of the clay still produce artesian conditions in the underlying glaciofluvial deposits, although the head has been reduced and the wells no longer flow.

Till and associated glaciofluvial deposits
(Pleistocene)

The till and associated glaciofluvial deposits have been termed by Simpson[16] the till and associated sand and gravel. However, it seems more desirable to use the term glaciofluvial for the "associated sand and gravel" of Simpson in order to denote the mode of origin and to explain the presence of fine-grained materials in the deposits. The age of the till and associated glaciofluvial deposits is Pleistocene, and

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[15] Hall, C. M., and Willard, D. E., op. cit., p. 4.
[16] Simpson, H. E., op. cit., p. 28.

perhaps a part or all of them are products of the last glaciation of the region. Leverett[17] states that the most recent glacial materials are the product of the Keewatin ice sheet, of late Wisconsin age, which moved southward from the northern limits of the Province of Manitoba up the Red River Valley and adjacent areas into South Dakota and Iowa.

The till and associated glaciofluvial deposits occur beneath the clay unit of the Lake Agassiz deposits throughout the Red River Valley. Beyond the upper shore lines of the lake, and hence beyond the limits of the area treated in this report, the till and associated glaciofluvial deposits constitute the surface rock. Where exposed at the surface these deposits form a rough, hilly topography, but beneath the clay unit their upper surface is apparently very smooth (fig. 2). Within the area the minimum thickness encountered in drilling was 70 feet at well 140-49-34cdd;[18] the maximum was 250 feet at well 139-49-3ccc. However, between these extremes they commonly range in thickness from 100 to 150 feet. The deposits rest unconformably upon the "granite" from the Red River west to the Sheyenne River. East and west of this area they rest unconformably upon the older lake clay and drift deposits. It is not known whether the till and associated glaciofluvial deposits were formed during a single advance and retreat of the ice or even during a single glacial stage, hence, in the absence of evidence to the contrary, they are treated here as a single rock unit.

The manner in which the till and the associated glaciofluvial deposits were laid down synchronously may be deduced from their location in a broad valley which sloped northward in the direction from which the ice advanced. Under such conditions it appears likely that a lake

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[17] Leverett, Frank, op. cit., p. 8.

[18] For a description of the well-numbering system used in this report see page 108 .

of greater or lesser extent would form in front of the advancing ice as soon as the natural drainage outlets to the north were blocked. As the ice front pushed its way up the valley the melting frontal ice must have dropped its sediment into the lake waters; and similarly, as the ice disappeared from the valley, the material carried by it must have accumulated in the lake waters. Much of the debris carried in the ice would then be deposited as unsorted material or till in the lake waters at the ice margin. Such clayey till deposited under water would have a smaller angle of repose than similar material deposited upon land. Wave and current action in the lake waters along the ice margin would also tend to distribute and smooth out the deposits, thereby accounting for their relatively flat upper surface.

It is believed that the glaciofluvial deposits were laid down largely during periods of ice retreat. Runoff probably occurred from some distance back of the edge of the ice sheet, and within the melting ice sheet itself, and emerged from crevasses along the south face of the sheet, both above and below the surface of the lake. These glacial streams would deposit well-sorted and coarse materials near the ice front and carry the finer material southward into the lake to be deposited later as lake clay. As the ice front advanced or melted back the fluvial deposits would continue to be laid down by the streams issuing from the ice sheet, and a trail of coarse material would be left behind for varying distances, depending upon the length and persistence of the glacial streams. Other glaciofluvial deposits would likely be formed by the sorting action of the waves and currents in the lake, especially where its waters were shallow.

Glaciofluvial deposits formed under the conditions postulated above would vary considerably in extent, thickness, and degree of sorting and would be interbedded with till and lake clay, every gradation occurring between strictly unsorted till and well-sorted sand and gravel. This is true of the deposits under consideration. In some instances the glaciofluvial deposits extend vertically nearly the full thickness of the unit as, for example, beneath the vicinity of West Fargo (fig. 2). On the other hand, and for the most part, they occur as elongate lenses of varying size and extent encased in the till. Their lateral margins are extremely irregular, and marginal thinning usually occurs by the disappearance of the lower portions of the deposits. In general, as the deposits become thinner along their margins, the amount of clay and silt contained in them increases.

A study of test-hole samples indicates that the till comprises about 73 percent of the formation and the glaciofluvial deposits about 27 percent. The till is composed of boulders, cobbles, pebbles, and sand intermixed heterogeneously in a matrix of hard gray clay. The larger particles consist principally of shale, with lesser quantities of limestone and crystalline rocks. The shale was derived from the bedrock, locally or from adjacent areas but most of the crystalline rocks and all the limestone were transported many miles by the ice from regions in Canada. In drilling, the till is recognized by a marked change in the lithology of the samples and by an abrupt increase in the difficulty of drilling.

The till yields little or no water to wells and the more clayey portions of it are essentially non-water-bearing. However, as the percentage of partly sorted materials contained within it increases, the water-transmitting ability also increases. Thus, there is probably no extensive section of the till which will not transmit some water.

On the other hand, the glaciofluvial deposits contained within the till are composed predominantly of gravel and sand intermixed with varying amounts of silt and clay. The composition of the coarse constituents is essentially the same as those in the till, with the important exception that the percentage of shale pebbles is much smaller in the better-sorted deposits. Wells tapping these deposits obtain small to copious amounts of water, depending upon the degree of assortment and thickness of the materials penetrated.

The extent of the aquifers within the till and their degree of interconnection within the area have been clarified somewhat by test drilling (p. 32) and by a study of water-level fluctuations (pp. 60-81). Because of the complex mode of their deposition, and because of their marginal irregularities, many more test holes would have to be drilled in order to outline completely any given aquifer. The fact that these aquifers occur at various horizons throughout the till makes their correlation from well to well extremely difficult. Simpson[19] states that these gravelly and sandy deposits are found at the base of the till. This condition may exist in most of the areas he canvassed, but it is not true in the area covered by this report. Hall[20] is more correct in making the general statement that water in tubular (drilled) wells is derived from gravel and sand strata in the till. He does not limit these strata to any specific horizon, which is in agreement with the findings of this investigation.

From the data obtained by drilling, the general extent and thickness

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[19] Simpson, H. E., op. cit., p. 99.
[20] Hall, C. M., and Willard, D. E., op. cit., p. 5.

of six principal aquifers have been incompletely determined, as shown in figure 1 and the cross sections in figure 2. These aquifers underlie parts of Dilworth, Moorhead, Fargo, West Fargo, and the area between Mapleton and Casselton. The individual aquifers range in thickness from less than 1 foot to maximums of 112 feet in the east Moorhead aquifer, 35 feet in the Fargo aquifer, 135 feet in the West Fargo aquifer, and 180 feet in the Maple Ridge aquifer. The most productive parts of these aquifers are at least 25 feet thick.

The glaciofluvial deposits are without question the best water-yielding deposits in the area. The gravel and sand portions yield water most readily, and lesser amounts are obtained from sandy and clayey portions. All industrial and municipal supply wells tap these deposits, and obtain yields up to 1,100 gallons a minute.

Older lake clay and drift deposits
(Pleistocene)

The older lake clay and drift deposits have not been identified as such in previous investigations. It appears that both Simpson[21] and Hall,[22] on the basis of the scanty information then available, identified the deposits that underlie the till and glaciofluvial deposits as rocks of Cretaceous age. However, a careful study of test-hole samples reveals that these rocks consist of till, occasional thin glaciofluvial beds, and probably old lake clay. Of these the till is the most easily identified, but the coarse pebbles of limestone and crystalline rocks embedded in a matrix of hard blue-gray to gray clay. The beds of till are generally thin and are intercalated with thicker

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[21] Simpson, H. E., op. cit., fig. 4 (after Upham).
[22] Hall, C. M., and Willard, D. E., op. cit., p. 2 and fig. 1.

beds of lake clay. Within the area these deposits rest unconformably upon the granite except in the extreme western part where they may rest upon rocks of Cretaceous age.

From the present distribution of the older lake clay and drift (section A-A'-A") it appears that they had been considerably eroded, and in some parts of the area were completely removed before the till and associated glaciofluvial deposits were laid down. Some beds of the lake clay are black in color and relatively soft and plastic; other beds are gray in color, relatively hard, and more or less fissile. From these and other characteristics of the deposits they are believed to be the product of an older or more likely of several older glacial stages. It is presumed that their accumulation took place in much the same manner as that of the younger drift that overlies them and that the Red River Valley was the site of at least one and perhaps several lakes older than Lake Agassiz. Leverett[23] has indicated that an ice sheet of the Kansan glacial stage passed over much of North Dakota and Minnesota, but no evidence was obtained during the present study to indicate whether a part or all of the older lake clay and drift may be a product of that glacial stage.

The presence of the older lake clay and drift deposits has been established principally in the area west of the Sheyenne River, where they were penetrated by 10 test holes. Between the Sheyenne and Red Rivers the surface of the "granite" rises, and these deposits are not present. East of the Red River, in the vicinity of Moorhead, logs of a few wells indicate that the older lake clay and drift may be present in a depression in the "granite". However, no samples from test holes

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[23] Leverett, Frank, op. cit., pp. 20-22.

or wells are available from this part of the area to establish definitely its presence there.

The top of the older lake clay and drift deposits lies between 150 and 200 feet below the surface in the western part of the area and is believed to be about 250 feet below the surface near Moorhead. In thickness it ranges from a feather edge to about 250 feet in the western part of the area, and it may have a maximum thickness in the eastern part of about 120 feet. In general these deposits contain considerably less coarse material and drill more easily than the overlying till.

In the absence of drill cores, the distinction between the older lake clay and drift deposits and the younger till and associated glaciofluvial deposits is sometimes difficult to make. They are both calcareous and consist of essentially similar materials in varying proportions. The principal distinguishing characteristics follow: Very few beds of clay occur in the younger till, and these are generally thin, whereas the older drift consists largely of clay. A thin black carbonaceous bed is commonly found at or near the top of the older lake clay and drift, and similar beds may occur within the deposits. Some of this carbonaceous material resembles peat and may represent interglacial swamp deposits. The older lake clay is commonly somewhat variable in color, especially near its base, where it may be brown, black, or white. Upon the basis of these distinctions the contact was traced from well to well (fig. 2).

The older lake clay and drift deposits yield little or no water to wells. In the test holes very few lenses of sand were encountered in the unit and these were thin. In the extreme western part of the area the deposits may rest upon the Dakota sandstone and may receive water from that formation. Flowing wells from the more permeable parts of the older lake clay and drift may result from the head imparted from the Dakota sandstone. It is not known whether the flowing wells at Casselton obtain their water in this manner or whether they obtain it directly from the Dakota sandstone.

Dakota sandstone[24]
(Cretaceous)

As a water-yielding rock, the Dakota sandstone of Cretaceous age,[25] is well known for its wide areal distribution and original high head throughout North and South Dakota. However, both productivity and head have fallen off sharply since the first wells were drilled,[26] and because of its greater depth and the high mineralization of its water the Dakota sandstone is now secondary to the drift in its importance as a water-bearing formation in most parts of North Dakota.

There have been several interpretations as to the extent of the Dakota sandstone beneath the area. Hall[27] believed that the Cretaceous rocks extend across the entire width of the Red River Valley, although the eastern limit of the Cretaceous artesian basin as shown on one of his maps[28] is located about 2 or 3 miles east of Casselton. Clays described by the driller as "light green," "decided green," "white and chalky," and "putty-like" at depths of 208 to 250 feet, and at 370 feet in the Moorhead well (139-48-8baa) were assigned by Hall to the rocks

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[24] The term Dakota sandstone as used in this report includes the Lakota sandstone of Lower Cretaceous age if that formation is present in this area.

[25] Wilmarth, M. Grace, Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, pt. 1, p. 566, 1938.

[26] Wenzel, L. K., and Sand, H. H., Water supply of the Dakota sandstone in the Ellendale-Jamestown area, N. Dak.: U. S. Geol. Survey Water Supply Paper 889-A, pp. 31-48, 1942.

[27] Hall, C. M., and Willard, D. E., op. cit., p. 2 and fig. 1.

[28] Op. cit., fig. 2.

of Cretaceous age. Allison[29] concluded that the clays are decomposed granite, and samples obtained from test holes drilled during the present investigation substantiate that conclusion. From information obtained in the line of test holes drilled along U. S. Highway 10 it seems certain that the Dakota sandstone does not extend eastward very far beyond the western edge of the area covered by the present investigation. As indicated by Allison,[30] it is quite possible that outliers of the Dakota sandstone and other Cretaceous formations may be found in other parts of the valley, although none were encountered in the test holes or were recognized in the logs of other wells.

The Dakota sandstone rests unconformably upon the "granite" and has a westward dip of about 10 feet per mile.[31] In the western part of the area it yields rather limited quantities of highly mineralized water which is used on a number of farms and by the City of Casselton.

"Granite"
(Pre-Cambrian)

Gneisses and other crystalline rocks generally referred to as "granite" form the basement rocks beneath the area and extend downward to unknown depth. In the old Moorhead well (139-48-8baa) 1,536 feet of "granite" was penetrated without passing through it. It is by far the oldest rock in the area, being assigned by Winchell and others[32] to the pre-Cambrian. It underlies the area everywhere and rises from a depth of about 500 feet below the land surface at the west edge of the area to about 200 feet at West Fargo, then declines to a depth of about 340 feet and rises again to about 150 feet below the land surface at

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[29] Allison, I. S., op. cit., footnote on p. 61.

[30] Op. cit., p. 60.

[31] Ballard, Norval, Regional geology of Dakota basin: Am. Assoc. Petroleum Geologist Bull., vol. 26, p. 1568, 1922.

[32] Winchell, N. H., Upham, Warren, Todd, A. E., Grant, U. S., and others, Final report of the Minnesota Geological and Natural History Survey, 1888.

Fargo. East of the Red River another depression in the "granite" carries it to about 250 feet below the surface.

The upper part of the "granite" consists of clay and quartz grains thought to be the products of decomposition during long periods of weathering. Allison[33] describes the decompositional clays as follows: "On top they are red or yellow, but through most of their upper and central portions they are nearly white. Their lower portions grade downward into tougher, incompletely weathered material that is green or gray, and finally into fresh, hard crystalline rock". In the test holes drilled during the present investigation the color of the decompositional clay was generally white or greenish gray, suggesting that a part of the decomposition products may have been removed by erosion prior to the deposition of the drift.

Both the decomposed and the unaltered "granite" yield no appreciable quantities of water, and for all practical purposes they are considered to be non-water-bearing. However, Hall[34] states that, according to a resident of Moorhead who kept a record of the drilling of the old Moorhead well, water was encountered in the "granite" at depths of 800, 950, 1,200, and 1,700 feet. Presumably these water-producing horizons, if they actually exist, consist of fractures in the "granite", and their yield would be small. Obviously, if their yield had been appreciable, the city would have developed the well for municipal use. Thus, in searching for water, it is believed that once the decomposed "granite" has been entered a further search for water at greater depth is fruitless.

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[33] Op. cit., p. 5.
[34] Hall, C. M., and Willard, D. E., op. cit., fig. 6.

TEST DRILLING

Scope and purpose

At the outset of the investigation it was evident that the available logs of wells were inadequate to fulfill the scope and requirements of the investigation. Therefore, in 1946 the North Dakota State well-drilling rig was used to drill 10 testholes along U. S. Highway 10 from Fargo to a point beyond Casselton. In 1947, 21 additional holes were drilled in the vicinity of the more promising aquifers previously encountered. The locations of these holes, except No. 10 which was west of the area, are shown on figure 1. Each of 31 test holes penetrated the full thickness of the glacial drift and entered the decomposed "granite". The depth of these holes, which depended on the distance down to the "granite," ranged from 154 to 608 feet.

The purpose of the test drilling was to ascertain insofar as possible the geologic and hydrologic conditions beneath the area, and specifically to determine: (1) the rock units present, their extent, characteristics, and water-bearing properties; (2) the thickness, character, and extent of the glaciofluvial deposits, which are the principal productive aquifers in the area; and (3) the degree of interconnection among these aquifers. Of these three objectives, the test drilling accomplished most successfully the first, and the results have been covered in the preceding section. The second and third objectives were largely accomplished in areas where concentrated drilling was undertaken; but the 31 holes drilled could not possibly outline the full extent and degree of interconnection of aquifers in the 360 square miles covered by this report. Nevertheless, from these test holes and from other logs, many valuable data were obtained and tentative conclusions have been drawn therefrom.

Results of test drilling

Identification of rock units

The identification of the rock units is of prime importance in the study of the geology and ground-water resources of any area. This end is usually accomplished by a study of existing well logs and of rocks that crop out in the area under consideration. Such a study leads to conclusions as to what rock units are present, their extent, and whether or not they will yield water to wells. In the absence of outcrops and of detailed logs, test drilling is used to supplement the existing subsurface data.

During the course of the test drilling, samples were collected at 5-foot intervals and at every recognizable change in formation. To insure samples from each interval which were unmixed with cuttings from other parts of the hole, the mud was circulated in the hole for a period of time after the drilling of each 5-foot section. This circulation was continued until the hole was free of drill cuttings, after which another 5-foot section was drilled and a sample was taken. The periods of circulation without drilling were commonly much longer than the drilling periods. Records were also kept of the time necessary to drill unit distances, relative ease or difficulty, of drilling, the amount of bentonite added to the drilling fluid, and the amount of drilling fluid lost into each permeable formation. In addition, a driller's log was kept for each well. The cuttings subsequently were studied and analyzed, and detailed logs are given on pages 133-177 . These logs show stratigraphic correlations, or depths at which the various rock units were encountered. Using these correltations as guides, similar but tentative correlations are made for all other available logs of wells in the area, with varying degrees of certainty which was highest where test holes were closely spaced and lowest where tests were widely spaced or absent.

In order to show the subsurface conditions, the logs are presented graphically in cross sections on figure 2.[35] The lines along which the sections are drawn are indicated on figure 1. Obviously, the disposition of the various rock units between wells is largely conjectural, particularly the lenticular glaciofluvial deposits. However, the cross sections indicate correctly the rock units present at each test hole,. their thickness at that point, and their general extent and relation to one another.

Extent of the principal aquifers

The principal aquifers are the larger bodies of glaciofluvial deposits. Virtually all industrial and municipal users of ground water in the area derive their supply from this source. In all, six aquifers have been differentiated, and for convenience of discussion they will be referred to in order from east to west as follows: (1) the Dilworth; (2) the east Moorhead, (3) the west Moorhead, (4) the Fargo, (5) the West Fargo; and (6) the Maple ridge aquifers, respectively. For the most part the position of the east and west margins of these aquifers are known only across the central part of the area, where the data are best. The northern and southern limits are not known, but it is presumed that the aquifers are considerably elongated in those directions, and some of them possibly may be tributary to one another within the area or beyond. The areal extent of the thicker and more permeable parts of each aquifer is shown on figure 1. In the cross sections (fig. 2), the relation between the aquifers and the till is shown diagrammatically,

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[35] See page 108 for explanation of well numbering system.

and their continuation as shown between wells a considerable distance apart may be open to question.

One of the objectives of the test drilling was to determine the degree of interconnection between the Fargo and the West Fargo aquifers, which are several miles apart. Cross section A'-A" and F-F'-F" show that the two aquifers approach each other fairly closely. Along U. S. Highway 10 they approach each other at the same level or horizon; whereas farther north they approach each other at different horizons. In areas not drilled they may actually be joined. The two short sections, C-C' and D-D', show the eastern limit of the Fargo aquifer in the northwest part of Fargo.

The degree of interconnection between the two aquifers underlying Moorhead is not known from geologic data. One well drilled between the two aquifers reportedly penetrated the Lake Agassiz deposits and the underlying till without encountering any water-bearing material. Cross section A'-A" shows that the two aquifers approach each other closely and at the same horizon but through extremely thin beds which may not actually connect. It is possible that they may be connected some distance to the north or south of this section. That there must be some connection is indicated by the low water level, about 80 feet below the surface, encountered in the east Moorhead aquifer when the first municipal well was drilled there, whereas early water levels in the same area were only a few feet below the surface. The low level was presumably the result of nearly 20 years of pumping from the West Moorhead aquifer.

The degree of interconnection between the West Moorhead aquifer and the Fargo aquifer appears to be rather poor. Cross section A'-A" shows that the Fargo aquifer thins rapidly towards the east and is offset upward in the section, whereas the West Moorhead aquifer thins westward at a somewhat lower horizon. However, hydrologic data indicate that some interconnection exists, possibly south of the area for which test hole and well data are available.

Thus, the four most highly developed aquifers, the two beneath Moorhead and one each beneath Fargo and West Fargo, all seem to have various degrees of interconnections. It is not known whether they are in turn connected with the other two aquifers, near Mapleton and beneath Dilworth, but interconnection is not precluded by the available data.

Relation of ridges to underlying deposits

The origin of the three linear ridges mentioned on pages 10-11 is problematical. Hall[36/] noted the persistence of the Maple Ridge and states that its origin is obscure, that it probably is not related to the beach ridges, and that it may be related in some way to deposition from the Maple River. Leverett[37/] shows the feature as a "sandy ridge" on a map, but makes no mention of it in his report. The West Fargo Ridge and the Fargo Ridge appear not to have been described elsewhere. All three are shown on figure 1.

The test drilling in 1946 on and adjacent to these ridges suggested that they might indicate the presence of lenses of glaciofluvial deposits in the till, for test holes 139-49-4ccc and 139-51-4cdd, drilled respectively on the West Fargo and Maple Ridges, showed considerable thicknesses of glaciofluvial deposits. Similarly, test holes drilled by the City of Fargo on the Fargo Ridge encountered glaciofluvial

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[36/] Hall, C. M., and Willard, D. E., op. cit., pp. 2-3.
[37/] Leverett, Frank, op. cit., fig. 19.

deposits. However, the question arose as to why, if the ridges were indicators of deep aquifers, there are no ridges above the aquifers at Moorhead and Dilworth.

The test drilling in 1947 north along the West Fargo Ridge showed conclusively that, in its northern extent, the ridge does not overlie the West Fargo aquifer. Also, test holes drilled on the Maple Ridge near Mapleton showed that the ridge does not everywhere overlie the deep aquifer in that area. However, one common characteristic was observed in all the test holes drilled on the ridges. Beneath the usual 15 to 25 feet of the surficial silt unit of the Lake Agassiz deposits, sand and gravel up to 25 feet thick was always encountered. It is not known whether these coarse materials represent near-shore deposits formed in an encroaching lake, in whose deeper waters the silt was subsequently deposited, or if they may be fluvial deposits formed during the interlake period. The fact that the sand and gravel usually extends downward into the underlying clay unit of the Lake Agassiz deposits would be more easily explained on the basis of a fluvial origin. In either case, the ridges appear to be in some way related to these deposits, and to have no direct relation to the deeper glaicofluvial deposits.

Differential compaction of the underlying and adjacent deposits may account for the formation of the ridges. Thus, if after the deposition of the silt unit of the Lake Agassiz deposits the surface of the plain was essentially featureless, the silt and underlying clay units of the Lake Agassiz deposits subsequently may have compacted or settled downward about 5 to 20 feet more than the coarse materials underlying the ridges. In other words, the silt and clay may have been considerably compacted, whereas there may have been little or no compaction of the coarser materials underlying the ridges. For example, the Fargo Ridge along cross section A'-A" has a relief of about 6 feet, and approximately 35 feet of the clay unit of the Lake Agassiz deposits lies beneath the coarse sediments. Under the surrounding plain the lake clay is about 70 feet thick. It follows that for every foot of compaction of the 35 feet of clay beneath the ridge there must have been compaction of 2 feet in the adjacent area, where the clay is twice as thick. In order to attain the present 6-foot differential, an over-all compaction in the full thickness of the clay amounting to 12 feet would have been necessary. Twenhofel[38] states that compaction of clays due to explusion of water and consequent closer spacing of particles commonly exceeds 40 to 50 percent of the volume. Thus, a compaction of only about 15 percent in this case appears to be quite reasonable.

The possibility that the ridges may be moraines or of morainic origin has been suggested. However, the general absence of ground-moraine deposits above the clay unit of the Lake Agassiz deposits, as well as the nature of the material comprising the ridges, appears to exclude the possibility that the ridges are morainic. The absence of ground-moraine deposits between the silt and clay unit also appear to exclude a glaciofluvial origin for the coarse material beneath the ridges. That the ridges may be a reflection of moraines in the till and associated glaciofluvial deposits underlying the lake deposits appears to be obviated by the absence of any unusual ridge or uneveness in the upper surface of this unit as determined from the logs of the test holes. However, the suggestion that the ridges may be moraines or of morainic origin should not be overlooked during future investigation in the area.

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[38] Twenhofel, W. H., Treatise on sedimentation, 2d ed., Williams and Wilkins Co., Baltimore, Maryland, pp. 744-745, 1932.

HYDROLOGY

GENERAL DISCUSSION OF THE PROBLEM

An "aquifer" is any rock formation that will yield water in sufficient quantity to be of importance as a source of supply.[39] In the area covered by this report, there are three distinct geologic horizons where aquifers are encountered. Small ground-water supplies are obtained from shallow aquifers in the silt unit of the Lake Agassiz deposits including sand and gravel deposits at the base of the silt. The most important aquifers occur in the underlying glaciofluvial deposits of sand and gravel. In the westernmost part of the area some wells probably obtain water from the Dakota sandstone.

Some of the more important aquifers in the glaciofluvial deposits have been developed for municipal and industrial supplies and have yielded considerable quantities of water. The largest ground-water developments in the area have been made by the City of Moorhead and the Fairmont Creamery Co. in Moorhead, by the City of Fargo in the western part of Fargo, and by the Union Stockyard Co. near West Fargo. Smaller developments for municipal and industrial supplies have been made by Dilworth, Southwest Fargo, the Great Lakes Pipe Line Co., and the Moorhead Laundry. Results of test drilling indicate that the highly permeable glaciofluvial deposits in which these developments were made may be quite limited areally and may be more or less separated from one another. On the other hand, there is considerable hydrologic evidence to indicate interconnection among the aquifers in such a manner that pumping from one development will influence the water levels at the other developments; and therefore that one development may

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[39] Meinzer, O. E., The occurrence of ground water in the United States: U. S. Geol. Survey Water-Supply Paper 489, p. 52, 1923.

receive and utilize water derived from the same sources which supply water for the other developments.

The quantitative determination of the safe perennial yield of an aquifer, or of its probable useful life for a yield greater than the safe perennial yield, requires a determination of the amount and nature of the recharge to the aquifer, the amount and nature of the discharge from the aquifer---by both natural and artifical processes, the amount of water contained in the aquifer by virtue of its storage capacity, and the relative ease with which water may move within the aquifer.

Direct measurement of natural recharge and natural discharge is often impractical if not impossible to obtain, and quite often the relative importance of the various processes by which natural recharge and natural discharge may occur is not apparent. These quantities, therefore, must often be estimated or inferred insofar as is practical from data on water levels, pumpage from wells, hydraulic gradients within the aquifer, and the coefficients of transmissibility and storage of the aquifers. These factors generally can be obtained by direct measurement, except for the coefficients of transmissibility and storage, which generally are obtained through mathematical analysis of data from pumping tests. The coefficient of transmissibility is a measure of the relative ease with which water can be transmitted within the aquifer, and the coefficient of storage is a measure of the amount of water contained in the aquifer which will be yielded to wells as the water level is lowered. These coefficients are defined technically in a later section.

In the following sections data on pumpage and water levels are presented, and interpretations and applications of the data are given toward the solution of problems concerning the safe yield and proper development of the aquifers. Many of the calculations regarding recharge and storage are based upon insufficient data and are not rigorous mathematical estimates. It is believed, however, that the results are of the correct order of magnitude and that they are more likely to be conservative than excessive.

DEVELOPMENT AND PRODUCTION OF GROUND WATER

General

The search for ground-water supplies for municipal and industrial use in the area began in 1872 when the City of Fargo drilled a test well in Island Park. Since that time many test holes and a number of wells have been drilled by different agencies with varying degrees of success. Municipal ground-water supplies have been developed by Moorhead, Dilworth, Southwest Fargo, Casselton, and by Fargo; industrial supplies have been developed by the Fairmont Creamery Co., Moorhead Laundry, Great Lakes Pipe Line Co., the Union Stockyard Co., and the Northern Pacific Railroad. Of these, the Northern Pacific Railroad and the Great Lakes Pipe Line Co. developed supplies since 1946, and no pumpage data are yet available. The City of Fargo developed only one well, and it is used during the summer months to supplement the principal supply, which is diverted from the Red River.

In the following sections, information on the development and pumpage of ground-water by each agency is given and, finally, an estimate of total pumpage by all consumers is made. Since the early 1900's the use of ground water has steadily increased and has led to local over-development of some of the existing supplies. In 1947 the total draft in the area was about 880 million gallons, or a daily average of almost

2½ million gallons.

Municipal supplies

City of Moorhead

It is reported by Mr. R. G. Price[40] that from about 1878 to 1910 the city supply was furnished solely from the Red River by a large steam-driven centrifugal pump which was owned and operated by a flour mill. Distribution was accomplished through a limited system of mains and was augmented by tank wagons in outlying parts of town. The annual report of the Moorhead City Water and Light Department for 1908,[41] one of the earliest available, states as follows: "Source of supply, gravity flow from the Red River of the North, through 360 feet of 14-inch pipe, having a drop of 4 feet to a well in the bottom of main pump pit 26 feet deep."

In 1888, the City began a search for an adequate supply of ground water by drilling a well (139-48-8baa) 1,901 feet deep near the corner of 7th Street and Center Avenue.[42] However, the yield was insufficient for a municipal supply and the well was abandoned. A few years later a grain elevator company drilled a successful supply well near 1st Avenue North and 12th Street, and for some time thereafter local residents hauled water from this source. On the strength of this well the City, in 1906, drilled a test hole at the present so-called 12th Street well field and encountered the west Moorhead aquifer. In 1910 a 10-inch supply weill (139-48-5dddl) was drilled at this site and put into

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[40] Former City Clerk and present City advisor of the City of Moorhead, oral communication, Dec. 1947.

[41] Water and Light Dept., City of Moorhead, Minn., Bookkeeper and Collectors Annual Report, 1 sheet, Dec. 31, 1908.

[42] Hall, C. M., and Willard, D. E., op. cit., p. 5.

service. It is city well 1, and only recently was its use discontinued. Two more 10-inch wells were drilled in 1913 and 1916, respectively.[43]

In 1912 a 6-inch well (139-48-7daa) was drilled at the city power plant near the river in an attempt to obtain water for the boilers and condensers. However, as the log indicates (p. 140), only 4 feet of water-bearing material was encountered and the yield was inadequate.

The 1921 and 1922 annual city reports[44] apparently indicate that the second and third 10-inch wells failed, because in each of these years a new 12-inch well was drilled. These are present city wells 2 and 3, and are 219 and 223 feet deep, respectively (wells 139-48-5ddd2 and 3). According to the annual reports the yield of the three wells was sufficiently large so that they were operated on the average only about 8 hours a day. However, because of declining water levels and consequent declining yields from the wells, the City began a search for additional ground-water supplies about 1924. Test holes were drilled near the northern, eastern and southern city limits in an attempt to intercept the same aquifer or to discover new ones, but were largely unsuccessful.

Finally, in 1927 a test hole was drilled about a mile east of the 12th Street field, and located the 22d Street well field in the east Moorhead aquifer. A 20-inch supply well (city well 4, 139-48-4dcc1) was drilled to a depth of 242 feet on the site of the test hole and had an original capacity of about 720,000 gpd. Several years later the City drilled another large-diameter well (139-48-4dcc4) 150 feet east of this well, but it encountered no water-bearing material and was abandoned.

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[43] Water and Light Dept., City of Moorhead, Minn., Bookkeeper and Collectors Annual Report, 1913 and 1916.

[44] Water and Light Dept., City of Moorhead, Minn., Bookkeeper and Collectors Annual Report, 1921 and 1922.

Again the City resorted to test drilling, and in 1930 was successful in locating additional test wells in the aquifer tapped by well 4. In the same year a 20-inch supply well was drilled 78 feet west of well 4 to a depth of 265 feet; and in 1932 another 20-inch supply well was drilled to a depth of 281 feet about 200 feet southwest of well 4. These are, respectively, city wells 5 and 6 (139-48-4dcc2 and 3); each originally had a capacity somewhat in excess of 1,000,000 gpd.

In succeeding years the demand for water increased progressively, whereas the water levels declined and the yield of the wells decreased. For example, by 1947 the average demand was about 1.2 million gallons a day. The depth to water was about 190 feet in the 12th Street field and about 185 feet in the 22d Street field. The pumping water level in city well 1 was at or very near the bottom, and its use was discontinued. The yield of well 4 had decreased so much that it, too, was left idle. During the summer of 1947 it was necessary to ration water throughout the city. Thus, the city again had need for additional ground-water supplies. In 1946 the Geological Survey investigated the geology and ground-water resources of an area east of Dilworth. In connection with this study test holes were drilled and a gravel aquifer about 5½ miles east of Moorhead was mapped.[45] Pumping tests were then made on two test wells drilled by the City. On the basis of the information thus obtained, the City has drilled three supply wells in the aquifer, and plans to pipe the water into town.

Records of yearly water consumption by the City of Moorhead have been maintained since 1903, and are shown below. River water was used in conjunction with well water from 1910 to 1918, but only in cases of

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[45] Dennis, P. E., and Morgan, A. M., op. cit., pp. 1-3.
Dennis, P. E., and Akin, P. D., op. cit., pp. 1-2 and fig. 1.

emergency from 1916 to 1918. In 1918 the use of river water was discontinued in favor of well water, which required less treatment.

Yearly pumpage by the City of Moorhead, 1903-47 46/
(Except as indicated, water supplied from wells)

Year	Pumpage (gallons)	Year	Pumpage (gallons)	Year	Pumpage (gallons)
1903	a96,777,000	1918	c68,326,780	1933	171,853,000
1904	a90,166,000	1919	87,148,420	1934	169,047,000
1905	a73,005,000	1920	91,806,355	1935	162,389,000
1906	ab100,000,000	1921	110,480,270	1936	212,820,000
1907	a124,000,000	1922	106,792,116	1937	204,425,000
1908	a112,453,700	1923	94,488,991	1938	214,994,000
1909	a122,454,000	1924	100,895,470	1939	249,897,000
1910	c160,809,700	1925	108,030,161	1940	257,112,000
1911	c139,066,000	1926	112,234,524	1941	271,846,000
1912	c151,329,600	1927	117,259,000	1942	284,582,575
1913	c156,002,300	1928	123,356,020	1943	296,679,450
1914	cd94,547,150	1929	130,634,000	1944	285,749,745
1915	c81,307,350	1930	143,853,000	1945	336,169,326
1916	c79,282,250	1931	144,875,000	1946	e450,000,000
1917	c73,604,937	1932	177,898,000	1947	e470,000,000

45 YEARS' TOTAL	7,500,000,000
Total pumpage from wells, 1910-47	f 6,000,000,000

a. From Red River.
b. Interpolated.
c. River and well water used together.
d. Decrease in pumpage due to power plant taking water from river; city supply from wells during this period.
e. Estimated.
f. In part estimated.

There was an over-all increase in yearly pumpage throughout the period of record except for the drop in 1914, when the power plant discontinued the use of city water. The pumpage from wells, which may have been about 20 million gallons in 1910, has increased nearly 25-fold. The total pumpage for the period 1910-47 by the City of Moorhead is estimated to have been about 6 billion gallons, or enough water to

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46/ Data obtained from the City Water and Light Dept. reports, 1903-28, and 1944-45; for 1929-43 from figures compiled by A. M. Morgan.

cover an area of 1 square mile to a depth of nearly 29 feet.

The daily pumpage has always had a wide seasonal fluctuation. In recent years the daily pumpage in winter has been less than 1 million gallons, whereas the daily pumpage in summer has been as high as 3 million gallons, which necessitates the continuous operation of the city wells at full capacity.

City of Fargo

The City of Fargo derives its water supply almost entirely from the Red River, but uses ground water from one well to meet peak summer demands. It is probable that Fargo would have developed a ground-water supply in preference to its surface-water supply if adequate ground water had been available, inasmuch as development and operation costs would have been less. The history of the water-supply problems has been presented by Byers and Wenzel,[47] and pertinent sections of their report are quoted as follows:

> "In the earliest days of Fargo the settlers obtained water chiefly from shallow wells dug in the lake silt. As the population increased a more satisfactory supply was needed and deeper wells were drilled.**** The Lee Roberts well, near the corner of Eighth Avenue South and Seventeenth St., was 475 feet deep. The water flowed from the drilled part of the well into an underground reservoir from which it was pumped to an elevated tank. A well, probably also owned and operated by Lee Roberts and known as the Old City Well (139-49-12cac), was drilled about 1,000 feet west and 300 feet north. This well was 216 feet deep and obtained its water from sand and gravel from 147 feet to the bottom of the hole. The Carl Miller well (139-49-12acb), on Third Avenue South near Sixteenth Street, found water in a sand at about 200 feet. A fourth well in this general area was the Oder well, at 203 Sixteenth Street South, 175 feet deep. These wells have long since been abandoned.****
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> "Water from the wells was hauled through the City in tank wagons and was sold from door to door for drinking. Every home had eave troughs, water barrels, cisterns, or a shallow well to supply water for other domestic purposes.
>
> "***About 1890 a pumping station and a system to distribution mains were installed for fire protection, sprinkling, and sanitary uses. The water was taken directly from the Red River, and as it was not treated

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[47] Byers, A. C., et al., op. cit., pp. 2-5.

in any way it contained large amounts of fine silt. This necessitated frequent cleaning and flushing of the distribution mains.***

"By 1910 the city's population had risen to 14,331, and the increased requirements led to the construction in 1912 of a rapid-sand filtration plant on the bank of the river*****. This plant******was operated by steam and used the lime-soda method of water softening. A dam was constructed across the river above all sewer outlets to provide a reservoir.

"The flow of the Red River past Fargo, because of increasing use upstream and because of deficient precipitation over the drainage basin, has deminished in recent years, and at times there has been no flow past Fargo. One such period lasted for 179 days. In such circumstances the city has been forced to ration severely the use of water in order to exist on the supply stored in the reservoir.

"The quality of the water is not always satisfactory and, in spite of all treatment, the color, odor, and taste sometimes become objectionable, particularly during periods when there is no flow in the river. This fact and the increasing demand in the face of a diminishing supply have led the city to consider the possibility of using ground water as a supplementary source. In 1935 nine test holes were drilled, of which four were dry, three encountered only fine sand, and two penetrated permeable sand and gravel. A 16-inch gravel-packed well (139-49-1cbd2) was developed at the best site as determined from the test holes. This well is operated part-time in the summer during times of peak water consumption, but its capacity is insufficient to offer any satisfactory long-period alleviation of Fargo's water problems."

Since 1935 no additional wells have been drilled. The city used about 1.2 billion gallons of water in 1946, or an average of about 3.3 million gallons per day. In order to meet the average daily city demand from wells alone, a well field would have had to produce an average of about 2,300 gallons per minute continuously, and the summer demand would have been much greater. No such ground-water supply appears to be available in the immediate vicinity of Fargo. Consequently, the City is now participating in the Bald Hill reservoir project on the Sheyenne River, in order to stabilize the flow in the Red River during drought periods and to assure an adequate supply.

The pumpage from well 139-49-1cbd2 since its completion in 1938 is given below. Years for which no pumpage is given were usually wet years in which runoff in the Red River was adequate and the well was not operated.

Yearly pumpage of ground water by the City of Fargo, 1938-47 [48]

Year	Pumpage (gallons)	Year	Pumpage (gallons)	Year	Pumpage (gallons)
		1940	13,934,000	1944	0
		1941	51,783,000	1945	0
1938	23,544,000	1942	8,842,000	1946	9,284,000
1939	18,166,000	1943	2,078,000	1947	13,852,000
	Total				141,483,000

The maximum pumpage of nearly 52 million gallons took place in 1941, but it was only a very small percentage of the total consumed. Because the City uses river water for the most part, variations in ground-water use do not indicate the usual increased demand which accompanies the growth of a community; rather, the variations indicate the additional amount of water needed to meet the peak summer demands. For the 10-year period 1938-47, the total ground-water use of slightly more than 140 million gallons is less than one-third the amount used by Moorhead in a year.

City of Southwest Fargo

The city of Southwest Fargo, which is 4 miles west of Fargo and on the south side of U. S. Highway 10, is largely supplied with well water by a private company operated by Mr. C. J. Ferch. In 1937 two wells were drilled, and by 1938 a distribution system was installed which served 74 establishments. By 1948 the service had been extended to include 111 establishments. The wells derive water from the West Fargo aquifer, which is tapped also by the Union Stockyard Co. wells to the north.

Estimates of yearly pumpage from the water-company wells have been made indirectly, there being no master meters on the well-discharge pipes. A comparison of KWH records with incomplete consumer meter records

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[48] Data obtained from W. P. Tarbell, Fargo City Engineer.

indicates that 1 KWH is consumed in pumping about 650 gallons of water. Monthly records of KWH are available for the period 1942-47, and estimates have been made for those years, based on the above electrial-energy factor. For years prior to 1942, the yearly estimates are based on the number of establishments using water as compared to the average consumption by each consumer as determined for the years 1942-47. Estimates for these earlier years are based on a constant demand per customer —— a procedure which in all probability is not very accurate.

Estimated yearly pumpage, in millions of gallons, for Southwest Fargo, 1937-47

Year	Pumpage	Year	Pumpage	Year	Pumpage
1937	0.5	1941	1.4	1945	1.6
1938	1.1	1942	1.5	1946	2.1
1939	1.2	1943	1.2	1947	2.6
1940	1.3	1944	1.2		
	Total				15.7

In general, there has been an over-all increase in pumpage from 1937 through 1947, in which year the pumpage was at a maximum of 2.6 million gallons. Not shown by the table is the fact that summer pumpage is considerably greater than winter pumpage. Months of largest consumption are usually July and August, and months of least pumpage are usually February and March. In 1947 the lowest monthly consumption was about 143,000 gallons, in March, and the highest was about 350,000 gallons, in August.

City of Casselton

The City of Casselton, which in 1947 had an estimated population of 1,500, obtains its supply directly or indirectly from the Dakota sandstone. It is reported by Mr. W. F. Wahowske[49] that the municipal water system and one well were placed in operation in 1923. This well flowed when first drilled, but with use the head dropped until by 1936 the level was 32 feet below the land surface and by 1948 it was 92 feet. The well field is on the east side of the city, and pressure is furnished by a tall cylindrical water tower.

In 1936 a second well was drilled about 100 feet southwest of the first, and it is still in use. Soon after the second well was placed in service the first well failed, and was recently capped. In August 1947 a third well was drilled about 150 feet west of the second well in order to assure a supply in case of well failure or other emergency. All three wells reportedly tap the Dakota sandstone and are about 317 feet deep.

Pumpage data for the city wells are scant. In March 1947 a fire destroyed the pump house in which were kept nearly all the records of the wells. However, the most recent meter-record book was not in the pump house at the time, and pumpage records for the period 1943-47 are available. According to the records the pumpage was as follows, in millions of gallons: 1943 - 7.3; 1944 - 7.2; 1945 - 7.3; 1946 - 8.6; and 1947 - 6.5. The total for the 5-year period was about 37 million gallons. The decrease in pumpage in 1947 was due principally to pump failure and to broken water mains. However, the per-capita consumption appears to be quite low even during years of normal use, being only about 14 gpd per person as computed from the above figures.

According to the water superintendent the average winter demand is about 45,000 gpd, and the average summer demand is about 60,000 gpd.

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[49] Water superintendent, oral communication, Feb. 1948.

These data are based on readings from master meters on the wells for which no records are maintained. According to these figures the per-capita use ranges from 30 to 40 gpd, which is more nearly in line with usual consumption rates. This rate of use would indicate a yearly pumpage of about 19 million gallons, which is nearly 3 times the amount computed from the consumer meter books.

Village of Dilworth

The village of Dilworth is at the east-central edge of the area. In 1947 the estimated population was 1,200. Mr. W. B. Rae[50] kindly furnished historical and pumpage data for the community. In 1907 a 10-inch well was drilled to a depth of 154 feet, and tapped glaciofluvial deposits in the till. Residents either hauled water from the well or were served from it by tank wagons until 1926. In that year the water tower and a system of mains were installed and are still in use. In 1931 a second well, also 10-inches in diameter, was drilled 19 feet south of the first and to the same depth. These two wells are near the northeast corner of the water tower and are housed in a building which also serves as a firehouse. When the first well was drilled in 1907 the water level was about 6 feet below the land surface; it is now about 120 feet.

Pumpage data are available for years since 1926 in the form of individual quarterly meter readings. In 1946, the latest year for which complete data are available, the pumpage, according to the meter readings, was 8.1 million gallons. The per-capita consumption as indicated by the meter readings was only 18gpd. As at Casselton, this figure seems unduly low.

The water-plant superintendent reports that the total daily pumpage ranges from 30,000 gallons during the winter to over 40,000 gallons

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[50] Water-plant superintendent, oral communication, Feb. 1948.

during the summer. These data are estimated and based on the known yields of the pumps, which are about 50 gpm for well 1 and about 100 gpm for well 2, and the average hours of operation each day. Unfortunately, there are no master meters on the pump discharge lines. From these estimates of total daily pumpage, the average daily per-capita consumption is computed to be about 30 gpd, which is more nearly the normal consumption in communities the size of Dilworth. This rate would give a yearly pumpage of about 13 million gallons, or about 1½ times the amount computed from the meter-book records. Thus, it would appear that the estimates of pumpage made by the water-plant superintendents of both Casselton and Dilworth are more nearly of the correct order of magnitude than the totals derived from the consumer meter records.

Industrial supplies

Fairmont Creamery Company

The Fairmont Creamery Co. has its largest plant in Moorhead at the corner of 1st Avenue North and 8th Street North. Mr. J. H. Deems[51] of this company kindly furnished the data regarding the wells which, until recent years, largely supplied their needs. The plant location was contingent upon the development of an adequate water supply from wells and when, in August 1923, the first well (139-48-5cdd1) produced a little more than 200 gpm, construction of the plant went forward, and in the spring of 1924 it was in operation.

As the creamery expanded more water was needed. In 1928 well 2 (139-48-5cdd2) was drilled and had a yield of about 200 gpm. Together, wells 1 and 2 supplied the needs of the plant through 1931.

In 1932 and 1933 the company had seven test holes drilled in an

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[51] Plant superintendent, oral communication, Dec. 1947.

attempt to locate an additional supply, but none appeared to indicate sufficient water-bearing material even though they all were drilled within 200 feet of wells 1 and 2. Nevertheless, in the absence of another source of ground water, the company proceeded to have a supply well drilled on the site of the most favorable test hole. This became well 3 (139-48-5cdd3), which had a yield of about 200 gpm when completed.

During the war years more water was needed than the wells alone could furnish, and city water has been used in appreciable quantity to supplement the supply from wells since 1942. As the yields of the wells continue to decrease, it is reasonable to assume that the creamery will rely more and more heavily on the municipal supply.

Estimates of pumpage for the period 1924-47 are based on the reported yields of the wells and hours of operation. For the period 1924-41, it is estimated that the yearly pumpage averaged about 85 million gallons. During the period of high production, 1942-47, the yearly pumpage increased to about 100 million gallons. Thus, for the entire period of operation it is estimated that the Fairmont Creamery Co. wells have pumped a total of about 2 billion gallons.

Moorhead Laundry

The Moorhead Laundry started using ground water when it was established about 1906, and was dependent solely on this source of supply until recent years. The laundry is near the corner of 5th Street North and the Great Northern Railroad, and has two supply wells. The data regarding the wells and pumpage were obtained from Mr. Tritchler, former owner and present manager.

In about 1906, a 3-inch well was drilled to a depth of 153 feet, and the laundry building was then constructed over the well. The second well, which is about 50 feet east of the building, was drilled afterwards. It is 4 inches in diameter and about 150 feet deep. The wells originally supplied the needs of the laundry but, because of decreased yields accompanied by lowering water levels, they have been pumped only on Monday and Tuesday of each week since 1943. During the remaining days city water is used.

Estimates of yearly pumpage by the Moorhead Laundry for the period 1906-47, based on the reported daily pumpage, are as follows: for the years 1906-37, from somewhat less than 3 million gallons a year in 1906 to nearly 4 million gallons in 1937; for the years 1938-42, from somewhat less than 4 million gallons a year to slightly more than 4 million gallons a year in 1942; and for the years 1942-47, during which time the pumps were operated only on Mondays and Tuesdays, about 2 million gallons a year. Total pumpage for the 42-year period was roughly 125 million gallons.

Union Stockyards Company

The Union Stockyards are near the community of West Fargo, and water for stock and other purposes is supplied from wells. According to Mr. Roy Olson,[52] the company drilled several wells in 1935 and the present water system was installed and placed in operation in 1936. In all, three wells were drilled (139-49-6ab2, 6ac, and 6ad). Of these wells 6ab2 is used principally, well 6ac is a standby, and well 6ad has no pump. All of the wells were drilled to depths of 230 to 240 feet and tapped the West Fargo aquifer. In 1945 the company drilled two test holes (139-49-6baa and 6bcc) near the north and western edges of the

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[52] Manager, oral communication, Jan. 1948.

property, respectively, to determine the extent of the West Fargo aquifer and the adequacy of the supply for additional development. Both test holes showed considerable thicknesses of glaciofluvial deposits, but as yet no additional supply wells have been drilled in the area.

Estimates of yearly pumpage for the Union Stockyards Co. well have been made for the period 1936-47 and are based on the number of gallons of water pumped per KWH of electricity consumed. An efficiency test run on the pumping plant indicated that 1 KWH would deliver about 1,400 gallons of water. From records of electricity consumed in pumping, the yearly estimates of pumpage were derived and are shown in the following table:

Estimated yearly pumpage, in millions of gallons, for the Union Stockyards Co., 1936-47.

Year	Pumpage	Year	Pumpage	Year	Pumpage
1936	26.0	1940	97.1	1944	188.2
1937	44.5	1941	115.8	1945	248.8
1938	62.9	1942	161.6	1946	227.4
1939	90.0	1943	193.6	1947	220.3
Total					1,676.2

The yearly pumpage increased steadily from 1936 through 1945, when it reached a maximum of nearly 250 million gallons. Since 1945 the pumpage has decreased somewhat. Variations in yearly pumpage are due principally to variations in the number of cattle in transient storage at the stockyards, which in turn determines the amount of water needed. Monthly records show that pumpage is greatest in the autumn and early winter, as it is in these months that most cattle are brought to market.

Domestic and stock supplies

Wells supplying domestic and stock water for farms and individual needs in small communities were, of course, the first ground-water developments in the area. Most of the communities in the area have largely replaced the need for individual wells by constructing water-supply systems or community wells. Water for domestic and stock use on the farms, however, is still obtained from individual wells.

Individually, the farm wells produce only an insignificant amount of ground water, but in the aggregate the production from these wells is significant. In the early days of the development of the Red River Valley, when flowing wells could be obtained generally, many of the wells were allowed to flow continuously and much water was wasted. However, in most of the area covered by this report flowing wells no longer can be obtained and waste from this cause is negligible. On the other hand, the number of farm wells has increased considerably, so that the production of water from the farm wells in the area as a whole probably has not changed greatly.

It is estimated from the latest Highway Planning Survey maps that there are about 600 occupied farm units in the area. If it is assumed that each unit will use on the average about 200 gallons of water a day for all purposes, the total daily production from all farm wells in the area would be 120,000 gallons. This production would amount to roughly 44 million gallons a year and would total nearly 2 billion gallons over the 42-year period 1906-47, inclusive, or approximately one-fifth as high as the estimated numicipal and industrial ground-water production from the area during the same period.

Most of the water for farm purposes is derived from aquifers in the glaciofluvial deposits. Some water is obtained from shallow aquifers in the silt unit of the Lake Agassiz deposits and, in the extreme western part of the area, some supplies may come directly or indirectly from the Dakota sandstone.

Estimates of total production

During the past 35 years large demands for ground water for municipal and industrial purposes have been made upon the aquifers underlying Moorhead, Fargo, and West Fargo. Inasmuch as pumpage estimates for the municipal and industrial developments in these aquifers are fairly good and complete, yearly estimates and accumulated yearly totals for this pumpage are given below for reference and for use in following sections. Production from the Lee Roberts and Old Fargo City wells has been neglected in compiling these estimates, inasmuch as the wells have not been used for many years and no pumpage data for them are available. The water hauled from these wells was reportedly used only for drinking purposes and the total production probably was not large.

Estimated total yearly and accumulated pumpage in millions of gallons for municipal and industrial use, from Moorhead, Fargo, and West Fargo aquifers, 1906-47.

Year	Moorhead 1/		Fargo 2/		West Fargo 3/		Total	
	Yearly	Accumulated	Yearly	Accumulated	Yearly	Accumulated	Yearly	Accumulated
1906	3	3					3	3
1907	3	6					3	6
1908	3	9					3	9
1909	3	12					3	12
1910	23	35					23	35
1911	28	63					28	63
1912	28	91					28	91
1913	33	124					33	124
1914	43	167					43	167
1915	63	230					63	230
1916	82	312					82	312
1917	78	390					78	390
1918	71	461					71	461
1919	90	551					90	551
1920	95	646					95	646
1921	114	760					114	760
1922	110	870					110	870
1923	98	968					98	968
1924	154	1,122					154	1,122
1925	196	1,318					196	1,318
1926	200	1,518					200	1,518
1927	205	1,723					205	1,723
1928	211	1,934					211	1,934
1929	219	2,153					219	2,153
1930	232	2,385					232	2,385
1931	233	2,618					233	2,618
1932	266	2,884					266	2,884
1933	260	3,144					260	3,144
1934	257	3,401					257	3,401
1935	250	3,651					250	3,651
1936	301	3,952			26	26	327	3,978
1937	292	4,244			46	72	338	4,316
1938	304	4,548	24	24	64	136	392	4,708
1939	339	4,887	18	42	91	227	448	5,156
1940	346	5,233	14	56	98	325	458	5,614
1941	361	5,594	52	108	117	442	530	6,144
1942	389	5,983	9	117	163	605	561	6,705
1943	399	6,382	2	119	195	800	596	7,301
1944	388	6,770	0	119	189	989	577	7,878
1945	438	7,208	0	119	250	1,239	688	8,566
1946	550	7,758	9	128	230	1,469	789	9,355
1947	570	8,328	14	142	223	1,692	807	10,162
Total	8,328		142		1,692		10,162	

1/ Includes pumpage by City of Moorhead, Fairmont Creamery Co., and Moorhead Laundry.

2/ Pumpage by City of Fargo.

3/ Includes pumpage by City of Southwest Fargo and Union Stockyards Co.

More than 10 billion gallons of water has been pumped from the glaciofluvial deposits underlying Moorhead, Fargo, and West Fargo for municipal and industrial purposes alone since 1905. About 82 percent of the total has been produced from the aquifers underlying Moorhead and about 17 percent has been produced from the West Fargo aquifer. Only a little over 1 percent of the total has been taken from the Fargo aquifer.

A rough estimate of the pumpage by the village of Dilworth since 1910 can be obtained by using the growth in population in conjunction with the estimated daily per-capita consumption of 30 gpd. The population according to the U. S. Census Bureau was 882 in 1920, 983 in 1930, and 1,068 in 1940. For 1910 and 1947 it is estimated to have been 700 and 1,200, respectively. From these data the total pumpage by Dilworth during the period 1907-47 would be roughly 400 million gallons. On a similar basis, pumpage by Casselton probably has amounted to somewhat more than 300 million gallons during the period 1923-47.

The rural domestic and stock use during the period 1906-47 has been estimated at about 2 billion gallons. Thus, for the entire area the total estimated ground-water pumpage for the period 1906-47 is the sum of the estimated municipal, industrial, and rural pumpage and amounts to roughly 13 billion gallons. Aside from a small amount of water produced from the Dakota sandstone in the extreme western part of the area and an insignificant amount produced from the silt of the Lake Agassiz deposits, this water has been produced from the glaciofluvial deposits, principally in the Moorhead and West Fargo areas.

Since the development of municipal and industrial supplies, ground-water withdrawals have been made in ever-increasing yearly amounts, and in 1947 the total pumpage was of the order of 880 million gallons, or an average of nearly $2\frac{1}{2}$ million gallons a day.

At the current rate of withdrawal, it would require only about 15 years to pump the amount of water that has been used during the past 42 years. There is reason to believe that the yearly demands on ground water in the area generally will continue to increase as the population grows and industrial activities expand. For example, the Great Lakes Pipe Line Co. began withdrawals from a new well in 1947, and the Northern Pacific Railroad recently completed a well near the western city limits of Fargo which will be placed in operation sometime in 1948. On the other hand, the City of Moorhead is developing a new ground-water supply in a shallow gravel aquifer located east of the area covered by this report, and Fargo is participating in the Bald Hill reservoir project to assure an adequate surface-water supply. This will probably cause a reduction in the rate of ground-water production for municipal purposes from the Fargo-Moorhead area, but new industrial developments probably will be made at favorable locations and thus will offset the reduction in municipal production from this area.

WATER-LEVEL CHANGES AND FLUCTUATIONS

General

Water-level changes in an aquifer are the results of (1) changes in the natural forces acting upon the aquifer and its contained water, and (2) changes in the amount of water stored in the aquifer.

Examples of variable forces which cause water-level fluctuations in wells in this area are barometric pressure, water loads in the Red River, train loads, and water loads from precipitation. Water-level fluctuations resulting from these forces do not indicate changes in the amount of water in storage in the aquifer; rather, they indicate pressure changes due to variable external loading.

Changes in storage in the aquifer result from variations in the rate of recharge to the aquifer or from changes in the rate of discharge from the aquifer by either natural or artificial means. Drawdowns in the aquifer caused by pumping wells indicate changes in the amount of water contained in the aquifer in the areas where the drawdowns occur. Because certain water-level changes indicate changes in the amount of water in storage, water-level fluctuations over a number of seasons may indicate whether the aquifer is overdeveloped or underdeveloped, as the case may be. Finally, indications as to the amount of recharge reaching the aquifer and the source of the recharge may be obtained by a study of the water-level fluctuations in conjunction with data on pumpage, precipitation, stream flow, and other pertinent factors.

Water-level changes and fluctuations in aquifers in this area are described in the following sections and discussions are given of their probable causes and relation to the hydrologic problems. Because considerable data are available for the Moorhead, Fargo, and West Fargo aquifers in the glaciofluvial deposits, they are discussed in detail. Data for wells tapping aquifers in the glaciofluvial deposits at some distance from the areas of heavy pumping and for wells tapping the shallow water body in the silt unit of the Lake Agassiz deposits are less complete and are treated briefly.

Water-level changes in the principal aquifers

Figure 3 shows graphically the following data for the years 1940-46, inclusive: (1) The daily precipitation at the Hector airport at Fargo; (2) the stage of the Red River of the North at Fargo; (3) the estimated pumpage from the Moorhead City wells; (4) pumpage from the Fargo municipal well; (5) hydrographs of wells 139-48-6ccd, 7acb, 18aba, and 139-49-1ccd2 in Fargo; and (6) the hydrograph of well 139-49-6ad at the Union Stockyards near West Fargo.

The daily precipitation at the Fargo airport was obtained from records of the U. S. Weather Bureau. The stage of the Red River is plotted from daily gage height readings furnished by the Surface Water Branch of the U. S. Geological Survey. Daily pumpage from the Moorhead City wells was obtained from meter readings for part of the period and by estimating the daily pumpage from records of pumping time for the period when meter readings were not available. Records of daily production from the Fargo municipal well were obtained from the Fargo Waterworks Department. The water levels plotted are lowest daily levels obtained from water-stage recorder charts and published in U. S. Geological Survey Water-Supply Papers 908, 938, 946, 988, and 1,108 for the years 1940-44, inclusive. Records for 1945 and 1946 have not yet been published. Detailed water-level records are also available for wells 139-49-1cbd1 and 1cbd2 in Fargo but are not presented in this report.

Daily water-level fluctuations in the observation wells are caused by barometric-pressure changes, passing trains, changes in water loads in the Red River, compression of the earth materials from water loading in the area during periods of heavy rainfall, and by pumping and possibly by recharge to the aquifers. Only the pumping effects and possible recharge effects are significant with respect to changes in ground-water storage in the area. The fluctuations not related to changes in storage are discussed briefly below so that they may be discounted in the later discussion of the more significant changes.

Fluctuations not related to changes in storage

Water levels in all of the observation wells respond to changes in barometric pressure, except possibly in well 139-48-6cdd where such fluctuations are very small or absent. On the small scale of figure 3, the barometric fluctations appear as small daily variations, as only, the lowest daily water levels are shown.

The water level in well 139-49-1ccd2 reacts sharply to the passing of trains along the Northern Pacific railroad immediately south of the well. These fluctuations have been removed from the hydrograph to avoid confusion. The effect is local and observation wells located some distance from the railroads do not show similar fluctuations.

The water levels in wells 139-48-7acb and 18aba are affected by compression of the till and glaciofluvial deposits due to the additional weight of waters in the Red River channel when the river is in flood stage. These effects are of considerable magnitude and are readily correlated with the stage of the river (fig. 3). The most notable fluctuations occurred in the springs of 1943 and 1945. Similar effects of lesser degree are readily discernible throughout the entire period of record. Fluctuations of this type have not been observed in the other observation wells, which are farther from the river.

Occasional distinct rises in water level occur as a result of heavy or sustained rains in the area. The most notable example of a rise of this type occurred as a result of the heavy rainfall of August 8, 1943, when about 4.7 inches of rain fell in the Fargo area in one afternoon. The water levels in wells 139-48-6ccd, 6cdd, 7acb, 18aba, and 139-49-1ccd2 rose sharply 0.20 to 0.40 foot at the various wells, and this rise was sustained for a period of several weeks. The possibility that this rise resulted from recharge to the aquifer is discounted by the immediate rise of water-levels following the rain and by the absence of a period of continually rising levels subsequent to the rain. From a geologic standpoint, too, it appears unlikely that recharge could be so readily transmitted to the aquifer as a result of rainfall in the immediate vicinity of Fargo, inasmuch as the aquifer is overlain by approximately 80 feet of comparatively impermeable lake clay.

There is no possibility that the rises in wells 139-48-6ccd, 6cdd, and 139-49-1ccd2 were caused by compression of the aquifer due to a rising stage of the Red River, because there was only a comparatively small rise in the stage of the river as a result of the rain and the wells are too far from the river to show appreciable fluctuations with changes in river stage. On the other hand, a part of the rises at wells 139-48-7acb and 18aba can be attributed to the rise in the river stage.

The most plausible explanation of the rise appears to be that it was due to compression of the aquifer and adjacent materials from the weight of the rain water itself. The depth of rain water was insignificant as compared to the changes in stage of the river during major floods, but its weight would be distributed over a large area, whereas the weight of the flood waters is concentrated in a relatively narrow channel. Also, there appears to have been only a small amount of surface runoff from the rain, because the stage of the river increased only a comparatively small amount. A considerable part of the water that fell collected in shallow depressions or was absorbed by the soil of the area. Much of the water doubtless percolated downward to the shallow water table in the silts of the Lake Agassiz deposits where it largely escaped removal through evaporation and transpiration and remained for a long period following the rain. This would account for the long period that the rise in the water levels was sustained.

Another example of fluctuations of this type occurred as a result of rains during the last part of April 1942. Other examples probably are present but are not evident because they are masked by fluctuations due to other causes.

Water levels prior to municipal and industrial development of ground water

From the early records of wells given by Upham[53] and by Hall and Willard,[54] it appears quite probable that at one time flowing wells could be obtained at almost any point in the area. Development of farm and domestic wells probably had lowered the artesian head considerably by 1885, when Upham visited the area, so that many wells did not flow at that time, though the water levels were, for the most part, at or very near the land surface. He lists several flowing wells in Moorhead and several wells in Fargo in which the water level was 8 to 10 feet below land surface. In 1900, when Hall visited the area, flowing wells could be obtained generally near Casselton and in small areas south of Harwood, North Dakota, and Kragnes, Minnesota. Water levels ranging down to 14 feet below land surface in Moorhead and from near land surface to 1¼ feet below land surface in Fargo were reported. Near West Fargo, water levels were reported as about 6 feet below land surface. East of the area, flowing wells were common in a large region east of the South Branch of the Buffalo River.

It is reported that when the first Moorhead supply well was drilled in 1910, the static water level was approximately 6 feet below land surface. Similarly, the water level in the first Dilworth well, which was drilled in 1907, also is reported to have been about 6 feet below land surface. These figures, together with the data reported by Upham and by Hall and

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[53] Upham, Warren, op. cit., pp. 555 and 567.
[54] Hall, C. M., and Willard, D. E., op. cit., pp. 4-7.

Willard, indicate that there had been no great lowering of the water levels in the area during the period 1885-1910. During this interval ground-water developments consisted chiefly of widely spaced wells yielding small supplies for domestic and farm purposes. No developments for muncipal or industrial purposes had as yet been made, aside, possibly, from the Lee Roberts or Old Fargo City wells.

The supply well at the Union Stockyards was drilled in 1935 and was put into use in 1936. The water level at the time of construction is not known. As reported by Hall and Willard,[55] however, the water level in the area was about 6 feet below land surface in 1900. It is probable that the water level in the area was lower than this by 1936, owing to withdrawals from the old Armour and Company well, which supplied a part of the water to West Fargo and the packing plant in early years. It is also probable that some lowering had occurred as a result of large withdrawals from the Moorhead area. When the State-wide program of water-level measurements was begun in 1937, well 139-49-6ad, which is approximately 700 feet east of the supply well, was selected as an observation well and a water-level recorder was subsequently installed on the well. When first measured in December 1937, the water level in this well was 25.62 feet below land surface.

Water-level changes accompanying development of municipal and industrial supplies

General

The development of ground water for municipal and industrial purposes has been accompanied by a lowering of water levels and artesian pressures over the entire area covered by this report and in adjacent areas. As would be expected, the greatest amount of lowering has occurred in the areas

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[55] Op. cit., p. 7.

of heaviest development. Considerable water-level data are available to show the manner in which the lowering has occurred in the Moorhead, Fargo, and West Fargo areas and these are presented in the following sections. In 1940 and 1941, Byers and Wenzel canvassed wells in the eastern half of the area and measured water levels in many of them. Water levels in wells in the western half of the area were obtained during the present investigation in 1946.

The water-level data are not sufficiently complete during any one brief period to allow construction of accurate water level maps, but they do indicate in general the amount of lowering that has occurred in the area. In a considerable area in and between Moorhead and Dilworth, the water levels are now from 100 to 195 feet below the land surface. In 1947, the water levels in the vicinity of the Fargo City well were more than 40 feet below land surface during the highest stage of the year, and at the Union Stockyards Co. well, near West Fargo, the 1947 high water level was more than 57 feet below land surface. Water-level measurements in 1940 and 1941 indicate an area of about 80 square miles surrounding these points of large ground-water use in which the water level is more than 30 feet below land surface and an area of about 140 square miles in which the water level is more than 20 feet below land surface. Water-level measurements in 1946 in the western part of the area near Casselton indicate that present water levels are generally below land surface and that flowing wells can no longer be obtained generally in this area. To the east of the area of this report, wells have ceased to flow in a strip from 2 to 5 miles wide which supported flowing wells in Hall's time.

It has been stated that there was no great lowering of water levels in the area during the 25-year prior to 1910, when the first major ground-water development was undertaken in Moorhead. It has been indicated also that the production from stock and domestic wells probably has not increased significantly since the early days. Therefore, it is probable that practically all the lowering of the water levels in the area since about 1910 has been caused by removal of water from ground-water storage through pumping of the municipal and industrial wells in the area.

Moorhead area

Reported water levels at the Moorhead well fields for the period 1910-47 are given in the following tables. These water levels were obtained from the report by Byers and Wenzel[56] and from the Moorhead City Water and Light Dept. The methods used in measuring these water levels are not known, and in most cases the exact date of measurements or the particular well measured are not known.

Reported water levels at Moorhead 12th Street well field
(Feet below land surface)

	1910	6	Apr. 30	1940	170	July 31	1941	187	Oct. 31	1942	180
	1913	40	May 31	"	172	Aug. 31	"	186	Nov. 30	"	181
	1915	42	June 31	"	172	Sept. 30	"	181	Dec. 31	"	179
	1916	50-51	July 31	"	172	Oct. 31	"	181	Jan. 31	1943	189
	1917-18	44	Aug. 31	"	181	Nov. 30	"	179	Feb. 28	"	189
	1919	60	Sept. 30	"	181	Dec. 31	"	179	Mar. 31	"	188
	1920	85	Oct. 31	"	163	Jan. 31	1942	180	Apr. 30	"	176
	1921	60	Nov. 30	"	180	Feb. 28	"	179	May 31	"	178
	1923	83	Dec. 31	"	180	Mar. 31	"	179	June 30	"	178
	1924	110	Jan. 31	1941	180	Apr. 30	"	179	July 31	"	178
	1930	110-120	Feb. 28	"	180	May 31	"	179	Aug. 31	"	178
Jan. 1	1940	172	Mar. 31	"	180	June 30	"	179	Sept. 30	"	178
Jan. 31	"	172	Apr. 30	"	180	July 31	"	180	Oct. 31	"	178
Feb. 29	"	170	May 31	"	179	Aug. 31	"	180	Jan. 31	1944	178
Mar. 31	"	169	June 30	"	181	Sept. 30	"	181	Dec. 31	1947	195

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[56] Byers, A. C., and others, op. cit., pp. 14-15.

Reported water levels at Moorhead 22nd Street well field
(Feet below land surface)

	1927	80	Dec. 31	1940	151	Nov. 30	1941	140	Feb. 28	1943	134
	1930	102	Jan. 31	1941	152	Dec. 31	"	140	Mar. 31	"	134
	1932	115	Feb. 28	"	156	Jan. 31	1942	140	Apr. 30	"	134
Jan. 1	1940	150	Mar. 31	"	139	Feb. 28	"	142	May 31	"	134
Jan. 31	"	155	Apr. 10	"	138	Mar. 31	"	142	June 30	"	134
Feb. 28	"	148	Apr. 15	"	136	Apr. 30	"	144	July 31	"	140
Mar. 31	"	148	Apr. 20	"	135	May 31	"	144	Aug. 31	"	134
Apr. 30	"	148	Apr. 30	"	139	June 30	"	150	Sept. 30	"	134
May 31	"	148	May 1	"	135	July 31	"	152	Oct. 31	"	134
June 30	"	153	May 31	"	135	Aug. 31	"	152	Nov. 30	"	134
July 31	"	155	June 30	"	135	Sept. 30	"	154	Dec. 31	"	134
Aug. 31	"	153	July 31	"	136	Oct. 31	"	134	Jan. 31	1944	134
Sept. 30	"	153	Aug. 31	"	138	Nov. 30	"	134	Feb. 29	"	134
Oct. 31	"	153	Sept. 30	"	138	Dec. 31	"	134	Dec. 31	1946	181
Nov. 30	"	154	Oct. 31	"	140	Jan. 31	1943	134	Dec.	1947	184

Fairmont Creamery Co. wells.--- When the first of the Fairmont Creamery Co. wells was drilled in 1923, the water level is reported to have been about 80 feet below the land surface. A second well was drilled by the company in 1928, and the original water level in this well is reported to have been about 120 feet. A third well was drilled in 1933, and the water level was 155 feet below land surface. In 1947 the "static" water levels in these wells were reported as 194 feet at well 1 and 196 feet at wells 2 and 3. These and other water-level measurements which were made occasionally in the wells are summarized below:

Reported water levels in Fairmont Creamery wells, Moorhead, Minnesota
(Feet below land surface)

Year	Well 1	Well 2	Well 3
1923	80		
1928	120	120	
1933			155
1934	159		
1935	162		
1936	171		
1937		161	
1945	187		
1947	194	196	196

The three Fairmont Creamery Co. wells are situated within one city block in Moorhead and are within 100 to 150 feet of each other, and the water level in any one well is probably approximately representative of those in the others.

Moorhead Laundry wells.— It is believed that the water levels in the Moorhead Laundry wells were close to the land surface in 1906, but by 1930 they were about 100 feet below land surface. As the water levels declined, the pump cylinders had to be lowered periodically until by 1943 they were placed within 2 feet of the bottom of the wells. In recent years the water levels have been about 145 feet below land surface and the pumps have been breaking suction.

Interconnection of aquifers.— Direct evidence of a hydrologi interconnection of the aquifers in the Moorhead area is to be found in the fact that water levels were lowered at the sites of the newer developments before those developments occurred. Thus the water level in the west Moorhead aquifer was about 6 feet below land surface in 1910, when the first city supply well was drilled; and in 1923, when the first Fairmont Creamery Co. well was drilled in the same aquifer, the nonpumping water level was about 80 feet below land surface. Similarly, when the first well was completed in the east Moorhead aquifer in 1927, the nonpumping water level there was about 80 feet below land surface. The low water levels in the Fairmont Creamery Co. wells and in the east Moorhead aquifer can be explained only as a result of ground-water withdrawal in the area. Inasmuch as the only large ground-water developments in the area prior to the development of the Fairmont Creamery Co. wells was the city wells in the west Moorhead aquifer, it is evident that the low water level in the creamery well field before pumping began was due to removal of water from storage by the pumping of the city wells. Likewise, the original low water levels in the east Moorhead aquifer before pumping began was due to withdrawals from the west Moorhead aquifer by the City and Fairmont Creamery Co. wells.

Relation between ground-water production and lowering of water levels.-- Figure 4 is a plot of the reported water levels in the Moorhead City wells, the Fairmont Creamery Co. wells, and the Moorhead Laundry wells against the estimated accumulated ground-water production from these wells during the period from 1910 to 1947. The significance of this graph results from the fact that there has never been a material decrease in production since pumping began. With a constant rate of production, or with production rates increasing only a small amount from one year to another, the lowering of water levels should become about proportional to the ground-water production if the water were being taken from storage in a small area receiving no water laterally from across its boundaries and no direct recharge of significance. This relationship would, of course, be affected by decreasing the pumping rate at any particular well field, and at the same time increasing the production at another location. However, in recent years, except during 1944, production has increased at both of the city well fields and at the Fairmont Creamery Co. field. The present rate of lowering of the water levels amounts to about 5 or 6 feet for every billion gallons of water produced, but the graph indicates that a true proportional relationship between the lowering of the water levels and the ground-water production has not been reached. This indicates that pumping effects have not yet become stabilized over the entire area from which the ground water is derived; and it suggests either that there is a relatively large area over which water is derived from storage, or

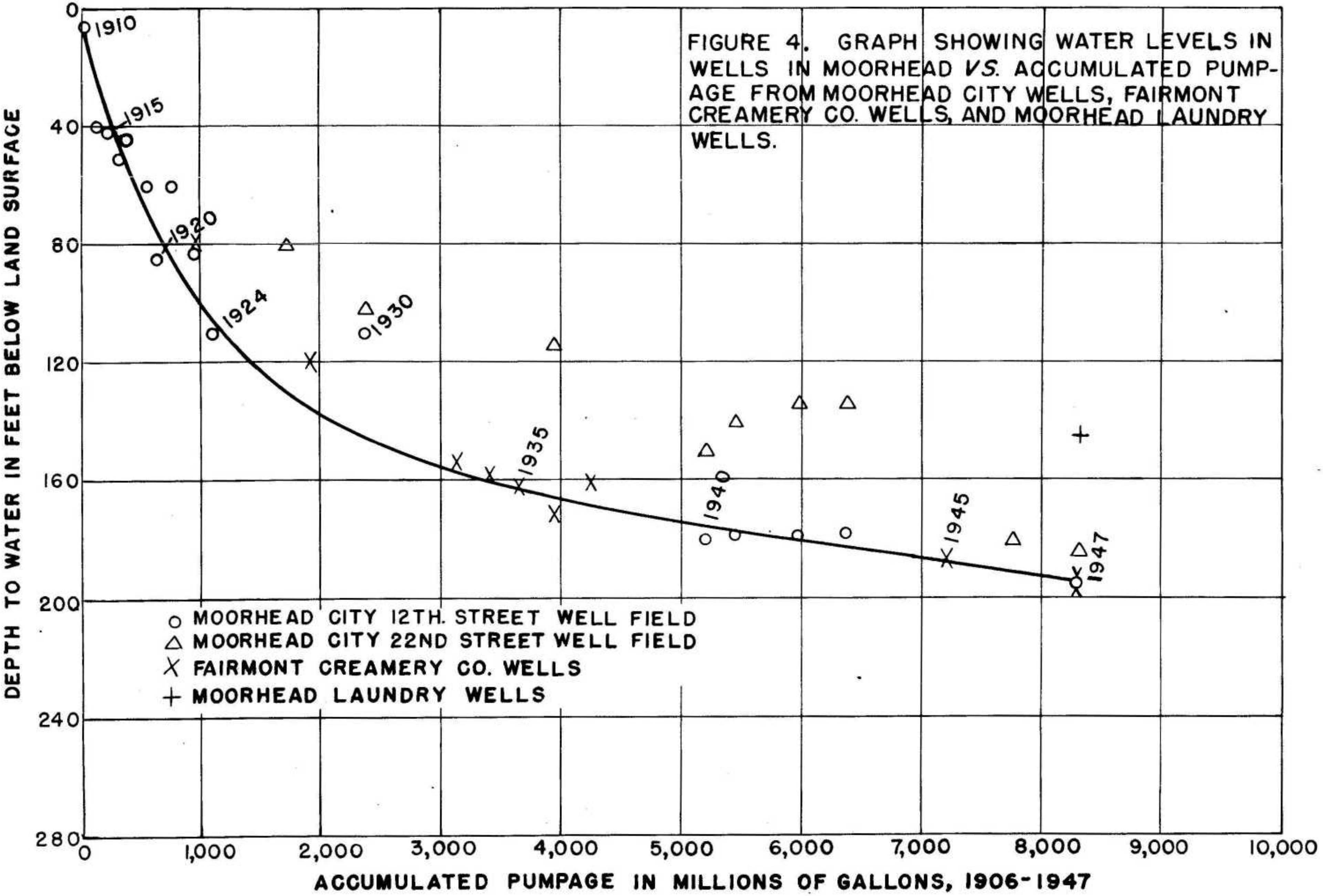


FIGURE 4. GRAPH SHOWING WATER LEVELS IN WELLS IN MOORHEAD *VS.* ACCUMULATED PUMPAGE FROM MOORHEAD CITY WELLS, FAIRMONT CREAMERY CO. WELLS, AND MOORHEAD LAUNDRY WELLS.

that increasing amounts of recharge may be reaching the area as the water levels are lowered.

Fargo area

In 1937 the U. S. Geological Survey, in cooperation with the North Dakota Geological Survey, began a State-wide program of water-level measurements in wells. As a part of this program water-level observations were begun in four wells in the Fargo area (139-48-18aba, 139-49-1cbd1, 1cbd2, and 1ccd2). In 1940 a number of other wells in the area were added to the program in connection with the investigation of the ground-water resources of the Fargo area. Five of the wells (139-48-6ccd, 6cdd, 7acb, 18aba, and 139-49-1ccd2) were equipped with water-level recorders in 1940 and about 8 years of nearly continuous record are available for these wells. Water levels were measured in other wells in the area at approximately weekly intervals during the latter part of 1940, during 1941, and in January 1942. Well 139-49-1cbd2 is the Fargo city supply well. It was drilled in 1936 but was not pumped until 1938, except for a test period of about a week in December 1937.

Comparative water levels in the above wells for 1937, 1941, and 1946 are tabulated below:

Water levels in observation wells in Fargo
(Feet below land surface)

Observation well	Date of measurement	Depth to water	Water-level elevation (feet above sea level)
139-48-6ccd	May 31, 1941	28.72	877.41
	May 31. 1946	31.35	874.78
139-48-6cdd	May 31, 1941	29.13	875.94
	May 31, 1946	31.55	873.52
139-48-7acb	May 31, 1941	37.32	864.04
	May 31, 1946	40.33	861.03
139-48-18aba	Dec. 23, 1937	29.66	875.29
	May 31, 1941	32.52	872.34
	May 31, 1946	34.13	870.74
139-49-1cbd1	Dec. 18, 1937	21.31	
139-49-1cbd2	Oct. 2, 1937	21.00	
139-49-1ccd2	Dec. 18, 1937	23.66	881.83
	May 31, 1941	31.06	874.43
	May 31, 1946	39.82	865.67

The 1937 measurements indicate the depth to water in the aquifer beneath Fargo before the city supply well was pumped to any considerable extent. Assuming that the water levels in the area of these wells were about the same as in Moorhead in 1910 when the first Moorhead city supply well was drilled-- that is, about 6 feet below land surface, it is indicated that there had been a lowering of water levels of the order of 16 to 23 feet in the Fargo area between 1910 and 1937 and before any major pumping from the Fargo city well had occurred. From the water-level elevation, it is seen that the water level at well 139-48-18aba was approximately 6 feet lower than that at well 139-49-1ccd2 in December 1937, indicating a hydraulic gradient to the east or southeast. From December 1937 to May 1941 the water level lowered 7.40 feet at well 1ccd2 but only 2.46 feet at well 18aba; pumping from the nearby

Fargo city well accounted for the greater lowering at 1ccd2. The difference in water-level elevation between these two wells was considerably less in May 1941 than in December 1937, though the level was still 2.09 feet lower at well 18aba. However, by 1946 the water-level elevation was lower in 1ccd2 than in 18aba, reversing the hydraulic gradient between these two wells.

Interconnection between Fargo and Moorhead aquifers.-- The comparative elevations of the water levels in the observation wells in Fargo in 1937, before pumping of any magnitude had occurred from either the Fargo or the West Fargo aquifer, is good evidence of hydrologic interconnection between the Moorhead and Fargo aquifers. The water levels at the observation wells in Fargo apparently had declined 16 to 23 feet in the area during the period 1910-37. Inasmuch as the Moorhead developments were the only ones of magnitude in the area during this period, at least the major part of the lowering is ascribed to a decrease in storage in the aquifer in the Fargo area caused by pumping from the Moorhead aquifers. The existence of a hydraulic gradient from well 139-49-1ccd2 to wells 139-48-18aba and 139-48-7acb and thence to the Moorhead well fields, as evidenced by both the 1937 and 1941 water levels, is further proof of the interconnection between these aquifers.

By 1941 the effects of pumping the Fargo and Union Stockyards wells decreased the gradient between wells 139-49-1ccd2 and 139-48-18aba, and by May 1946 a reversal of the hydraulic gradient between the two wells had developed. The water level at well 139-48-7acb, however, was still lower than at any of the other observation wells in Fargo, indicating that the hydraulic gradient toward the Moorhead well fields still existed in this area.

Relation between water-level fluctuations and recharge.--- The relatively small seasonal drawdown and yearly lowering of water levels in the observation wells during 1942, 1943, and 1944 suggests the possibility of significant seasonal recharge during these years. The annual precipitation at Fargo was considerably above average in 1944 but was about average in 1942 and 1943. On the other hand, the pumpage from the Fargo city well was considerably less during 1942 and 1943 than in the preceeding 4 years, and there was no pumpage from this well during 1944. The seasonal increase in pumpage from the Moorhead City wells during the summers of 1942 and 1943 was somewhat less than in previous years, although the total pumpage during both years was greater than for prior years. In 1944 the total pumpage from the Moorhead wells was less than in 1943, and the seasonal pumpage variation was considerably less. It is probable, therefore, that the seasonal water-level fluctuations do not represent significant amounts of recharge as suggested above, but rather represent water-level adjustments in the aquifer due to variations in pumping during these years.

Relation between ground-water production and lowering of water levels.--- The seasonal fluctuations at wells 139-48-7acb and 18aba can be correlated with the pumping schedules of the Fargo and Moorhead wells (fig. 3). The nature of the fluctuations leads to the conclusion that the water level at well 139-48-18aba is more strongly affected by the Fargo pumping than is the water level at well 139-48-7acb, though the latter well is nearer the Fargo well. On the other hand, the magnitude of the fluctuations during seasons when the Fargo well is not pumped suggests that the water level at 139-49-7acb is more strongly affected by pumping from the Moorhead area than is the water level at well 139-48-18aba.

For example, in 1940, the water level at well 139-48-18aba began to decline noticeably before pumping of the Fargo well began in July. The water level continued to decline until after the Fargo pumping was stopped in September, whereas in well 139-48-7acb the water level rose somewhat about the middle of August and subsequently followed a pattern roughly parallel to the pumping at Moorhead. Also, in 1941, when the seasonal pumping from the Fargo well was the heaviest for any season during the entire period of record, there was a general decline in the water level in well 139-48-18aba, closely related to the pumping period of the Fargo well, whereas the decline of the water level in well 139-48-7acb was interrupted about the middle of August, or about 45 days before pumping at the Fargo well was stopped. During this period also the pattern of the water-level fluctuations at well 139-48-7acb can be roughly correlated with the pumping regimen of the Moorhead city wells.

There is little direct evidence in the seasonal fluctuations to indicate that the water level at well 139-48-7acb is affected by the Fargo pumping. However, a part of the seasonal fluctuations at well 139-48-18aba are due to the pumping in the Moorhead area. Because the Moorhead pumping affects the water levels seasonally at both wells and because pumping effects from the Fargo well are apparent at well 139-48-18aba, the water level at well 139-48-7acb must also be affected by pumping the Fargo well.

Fluctuations at well 139-49-1ccd2 during the latter parts of 1943, 1944, and 1945 and the first part of 1946 lead to the conclusion that the water level in this well is affected by pumping from the Union Stockyards well. The general trend of the water level during this period can be correlated with the general trend of the water levels in the stockyards well during the same period. The same general trend of the water levels is found in wells 139-48-6ccd and 6cdd, but the fluctuations are much smaller in magnitude and the rate of lowering during the latter part of 1944 and during 1945 was much less than at well 139-49-1ccd2. The fluctuations at well 139-49-1ccd2 during this period are not particularly well correlated with fluctuations at wells 139-48-7acb and 18aba, probably because at the latter wells the effects of pumping from the West Fargo aquifer were more or less masked by the effects of pumping from the Moorhead area.

On the basis of water-level fluctuations and their response to pumping from the Moorhead, Fargo, and West Fargo aquifers, there appears to be little doubt that the aquifers are hydrologically interconnected so that pumping from any one of them eventually affects the water levels in all the others.

West Fargo area

A hydrograph of well 139-49-6ad, which is approximately 700 feet east of the Union Stockyards Co. supply well in West Fargo, is shown in figure 3. Also shown is the estimated monthly pumpage from the Union Stockyards Co. well. The principal water-level fluctuations at well 139-49-6ad as illustrated in the hydrograph are due to pumping from the Union Stockyards Co. supply well. The more or less cyclic fluctuations, generally covering about a week's time, are due to the variations in water demand during the week.. The more general trend of the water levels is the result of the seasonal pumping demands. There are, undoubtedly, fluctuations due to barometric-pressure changes, as at the wells in the Fargo area, but these are masked by the greater variations due to the daily pumping regimen at the supply well. There

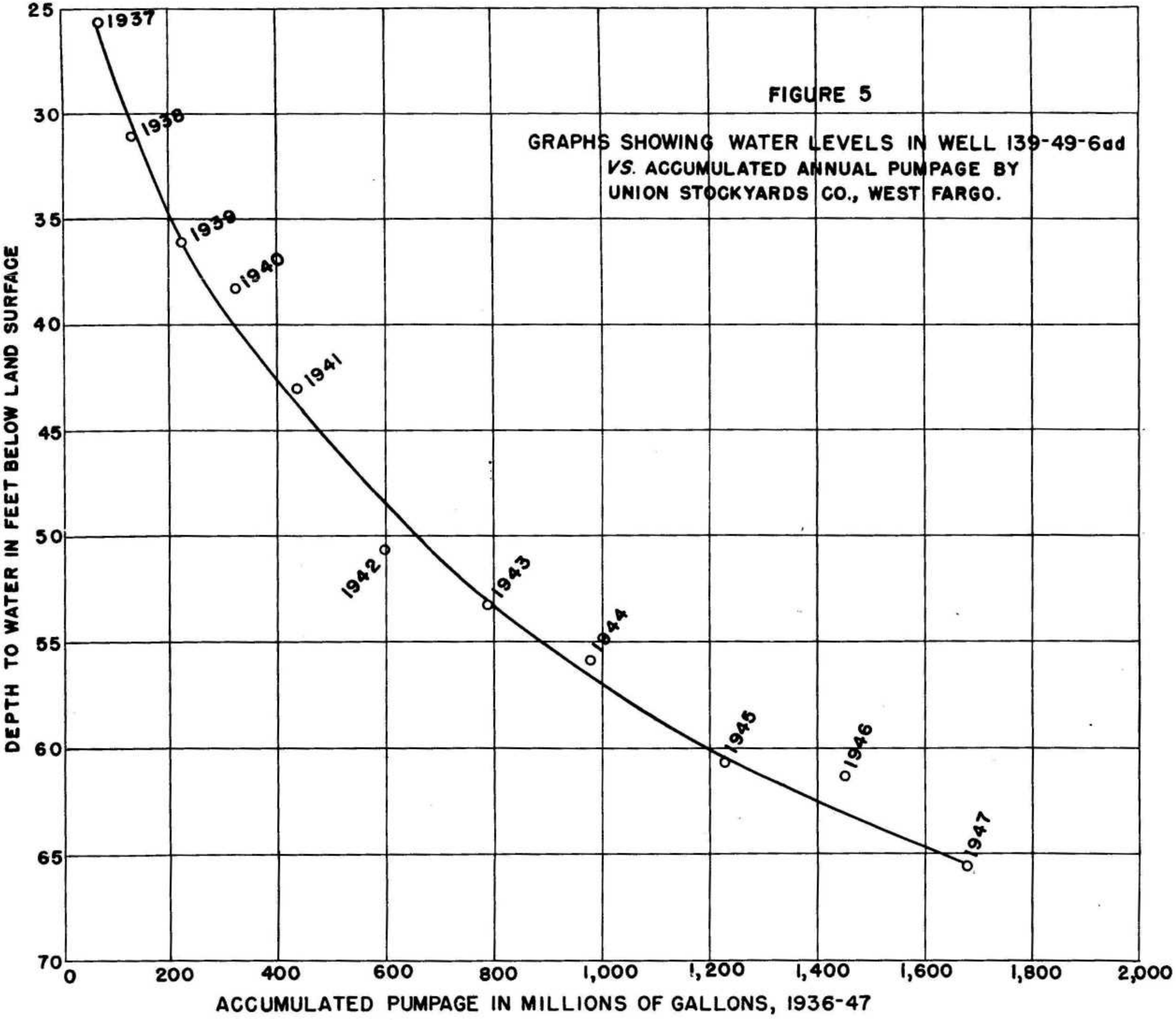


FIGURE 5

GRAPHS SHOWING WATER LEVELS IN WELL 139-49-6ad
VS. ACCUMULATED ANNUAL PUMPAGE BY
UNION STOCKYARDS CO., WEST FARGO.

probably are effects from pumping the Ferch well in Southwest Fargo and perhaps effects due to the pumping in Fargo and Moorhead, but fluctuations due to these causes are not distinguishable.

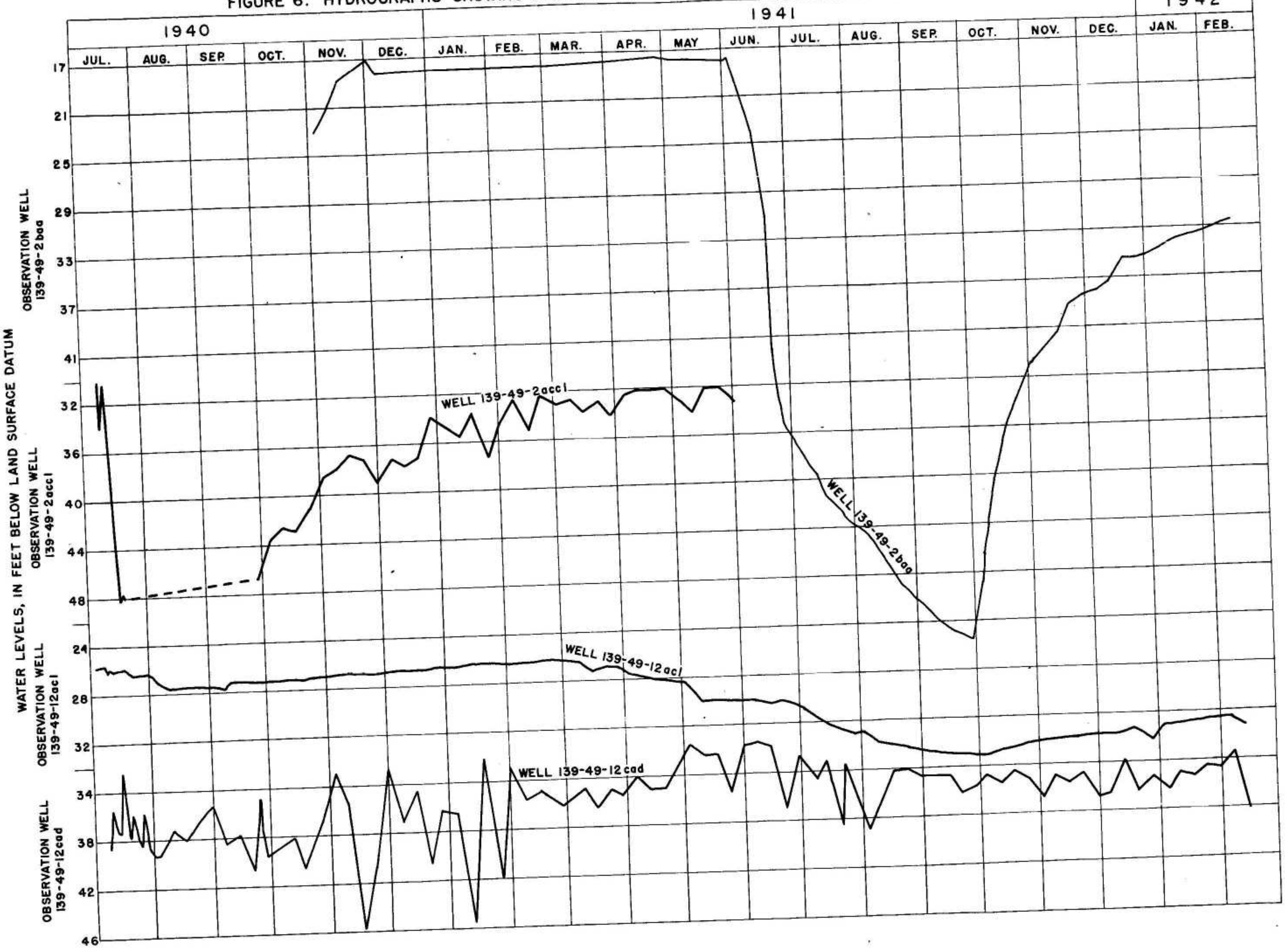
Figure 5 is a graph showing accumulated yearly pumpage from the Union Stockyards well plotted against water levels in well 139-49-6ab2. The water levels represent lowest stages on December 31 of each year or on days nearest the December 31st date for which data are available. This graph indicates a decreasing rate of lowering of water levels with continued pumping such as would be expected as the result of pumping from a relatively large aquifer. The present rate of lowering of water levels is about 11 feet for each billion gallons of water pumped, but it is likely that this rate will be somewhat reduced with continued pumping.

Marginal areas

During the latter part of 1940, during 1941, and during the early part of 1942, water-level measurements were made at approximately weekly intervals in a number of wells other than those already discussed. Hydrographs of four of these wells in Cass County near Fargo are shown in figure 6 and hydrographs of four of the wells in the Clay County, Minnesota, portion of the area are shown in figure 7. The locations of these wells are shown in figure 1. Except for two wells in the Fargo area (139-49-2acc1 and 139-49-12cad), which are used for domestic and stock purposes, all were unused at the time the water levels were measured. The hydrographs indicate the presence or absence of pumping effects from the larger ground-water developments, and the natural fluctuations in the aquifers in the till if pumping effects are not present.

The water levels in well 139-49-2baa, approximately 0.70 mile

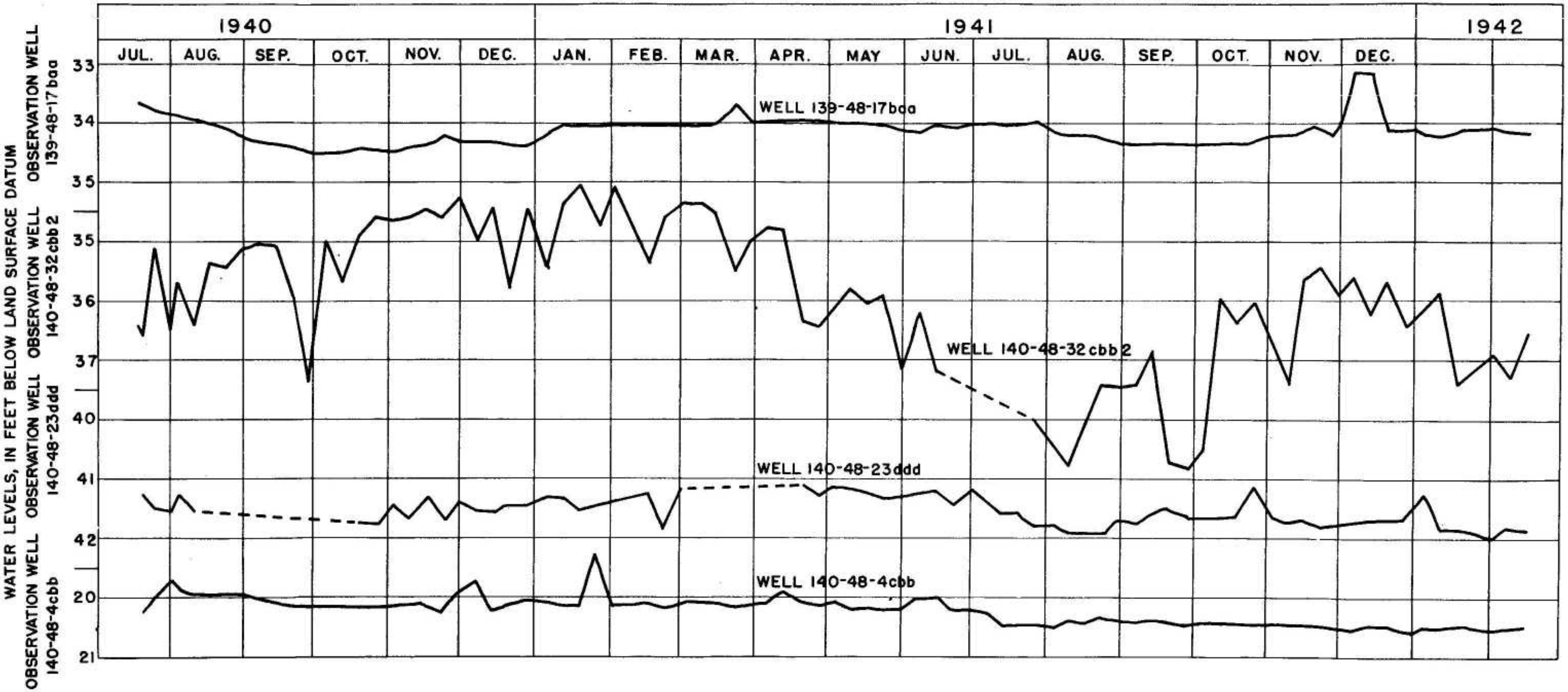
FIGURE 6. HYDROGRAPHS SHOWING WATER-LEVEL FLUCTUATIONS IN FOUR WELLS NEAR FARGO.



west-northwest, and 139-49-2acc1, approximately 0.75 mile northwest of the Fargo municipal well, are strongly affected by pumping of the Fargo well. Well 139-49-2acc1, 140 feet deep, is a domestic well serving about six families, and the effects of use from the well are apparent as relatively minor variations from the general trend of the water level. The sharp drop in water level during the first part of July 1940 and the relatively rapid and continued general rise in the water level during the latter part of September and during subsequent months are readily correlated with the pumping of the Fargo well during the 1940 season. Well 139-49-2baa is an unused well 156 feet deep. The decline and subsequent recovery of the water level in this well due to the pumping of the Fargo well during the 1941 season is apparent.

Well 139-49-12ac1, approximately 0.60 mile south and east of the Fargo well, is an unused well 175 feet deep. The fluctuations in this well are not readily correlated with pumpage from any aquifers or with water-level fluctuations in any of the other observation wells in the area, although the rising trend of the water level during the latter part of 1940 may be related to recovery from the pumping of the Fargo well. The water level in this well reached a peak in the latter part of February 1941, and then began a decline until the latter part of the following September. It then began a slow rise broken by minor fluctuations which persisted until the end of the record. The decline beginning during the latter part of February is not correlated with any known pumpage in the area or with water-level fluctuations at any of the other observation wells. The rise during the latter part of the year, however, began at about the same time that pumping from the Fargo well was stopped and has the general form of a recovery curve. Therefore, it is thought likely that the seasonal water-level fluctuations are affected to some

FIGURE 7. HYDROGRAPHS SHOWING WATER-LEVEL FLUCTUATIONS IN FOUR WELLS NEAR MOORHEAD



extent by pumping from the Fargo well and that the water level is affected over longterm periods by pumpage from the other areas.

Well 139-49-12cad, approximately 1 mile south-southeast of the Fargo well, is 142 feet deep and is used for domestic and stock purposes. The principal water-level fluctuations in this well appear to be caused by withdrawals from the well itself. However, the general trend can be correlated roughly with the pumping from the Fargo well during 1940 and 1941. It is thought that the water level in this well is affected seasonally also by the pumping from the Fargo well and in the long run by pumping from other areas.

The depth to water in all these wells indicates that approximately the same amount of lowering occurred in them during the period 1910-40 as in other observation wells in the area. Inasmuch as a considerable part of this decline in other observation wells can be attributed to pumping from the Moorhead area, it is assumed that a considerable part of the decline in these wells also resulted from pumping the Moorhead wells, even though seasonal correlations to establish the relationship are not apparent during the period for which water-level measurements are available.

Hydrographs of four wells in the Clay County portion of the area are shown in figure 7, and the location of these wells is shown in figure 1. Well 139-48-17baa is an unused well 133 feet deep, approximately 1 mile east of well 139-48-18aba and about 1 mile south of the 12th Street well field in Moorhead. The depth to water in this well during the period shown was about the same as at wells 139-48-7acb and 18aba, but seasonal fluctuations due to pumping from the area were not as great as at the latter wells. Small seasonal declines during August, September, and October of 1940 and 1941 likely were due to the increased summer pumpage in the Moorhead area. The lowest seasonal water levels occurred considerably later than the peak summer pumpage from the area, however, indicating that considerably more time was required for the pumping effects to influence the water level significantly in this well than in wells 139-48-7acb and 18aba. The longer time required for the effects of seasonal pumping changes to influence the water level may indicate a relatively poor connection between this well and the producing wells. The unusual rise in December 1941 cannot be explained on the basis of available data, but it is apparent that no permanent rise in water level resulted.

Well 140-48-32cbb2 is an unused well 131 feet deep, 1½ miles north of the Moorhead well fields. The hydrograph of this well shows fluctuations which undoubtably are due to interference caused by pumping from a nearby well. The fluctuations are of considerable magnitude and tend to mask fluctuations due to other causes. There is, however, good correlation between the seasonal fluctuations of the water level in this well during 1941 and the seasonal pumping changes at the Moorhead city wells, and it is quite probable that a considerable part of the seasonal fluctuation is caused by the heavy pumping in the Moorhead area.

Well 140-48-23ddd is an unused well about 4½ miles northeast of Moorhead. Here again the general trend of the water level during 1941 is very closely parallel to the general trend in well 139-48-7acb, though on a considerably reduced scale. This may indicate an extension of the Moorhead aquifers in this direction, or at least a relatively permeable interconnection of the aquifers between the two locations. It is possible, however, that the seasonal water-level trend noted may be due to withdrawals for domestic and stock purposes from local farm wells. More geologic and hydrologic evidence is needed to establish whether the Moorhead aquifers extend into this area.

Well 140-48-4cbb is an unused well approximately 6½ miles north of Moorhead. The general trend of the water level is characterized by a slow decline during the entire period of record. This decline probably was caused partly by pumping at Moorhead and partly by pumping from stock and domestic wells.

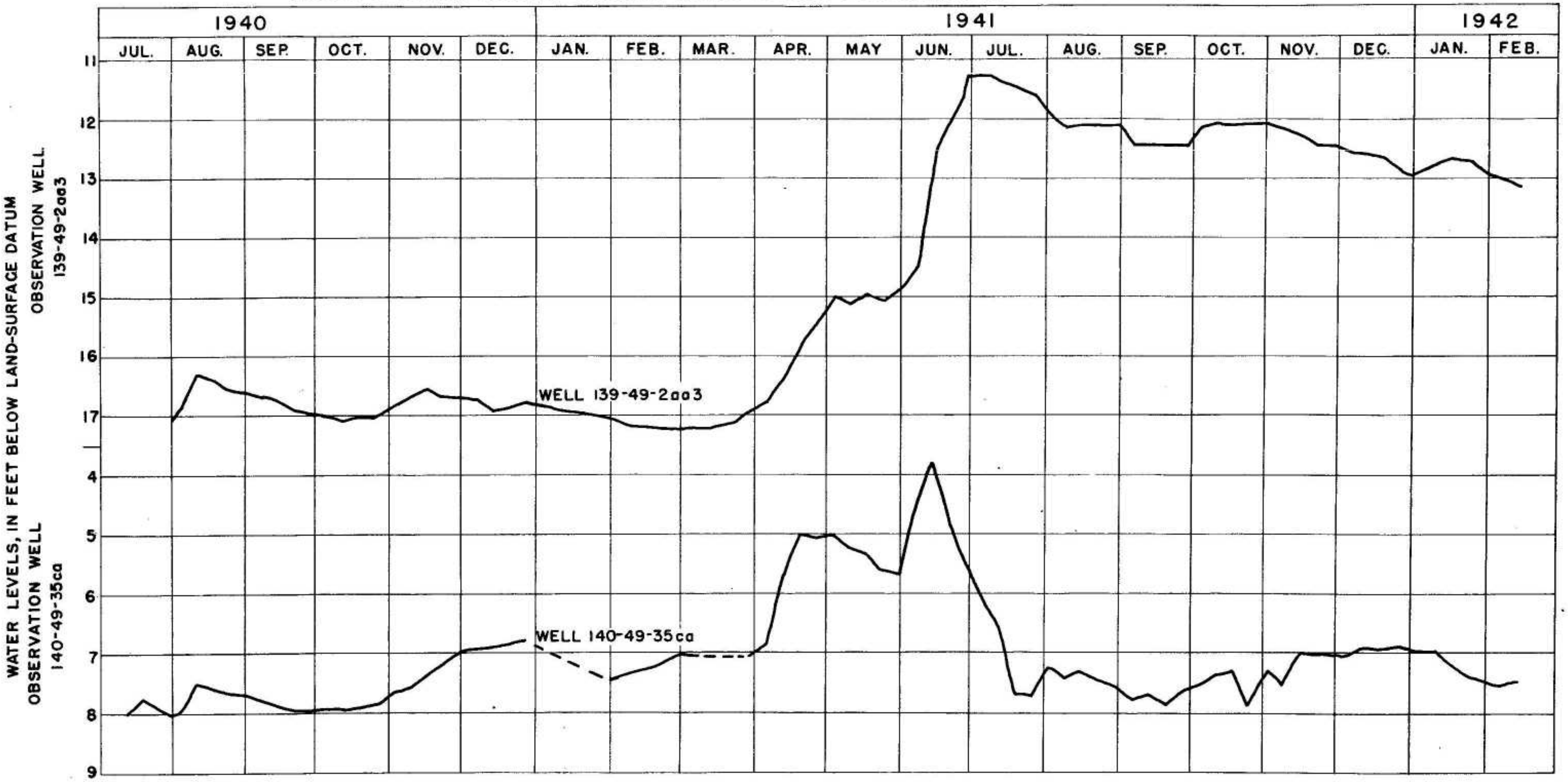
It is significant that none of the eight wells discussed in this section showed water-level fluctuations during the period of observation that would indicate any significant amount of recharge to the aquifers in the till.

Water-level fluctuations in shallow wells in the silt unit of the Lake Agassiz deposits

In connection with the investigation of the ground-water resources of the Fargo area begun by Byers and Wenzel in 1940, water-level measurements were made at approximately weekly intervals in two shallow wells near Fargo during the latter part of 1940, during 1941, and during the first part of 1942. Hydrographs of these two wells are shown in figure 8. Well 139-49-2aa3 is an unused well 35 feet deep and well 140-49-35ca is an unused well 75 feet deep. Both these wells penetrate the silt unit of the Lake Agassiz deposits and enter the clay unit of the Lake Agassiz deposits but do not reach the till and associated glaciofluvial deposits. The principal aquifers are the coarser materials in the silt, the parts of the wells below the silt serving only for storage.

The hydrographs of these wells illustrate clearly the response of

FIGURE 8. HYDROGRAPHS SHOWING WATER-LEVEL FLUCTUATIONS IN TWO SHALLOW WELLS IN AREA.



the water levels in the shallow aquifers to recharge. Recharge to shallow aquifers in the area during the spring thaw is common. As the ground thaws, the water from melted snow, which collects in poorly drained areas, has ample opportunity to soak into the ground and seep down to the water table. Fluctuations due to recharge of this type are illustrated by the water-level rise which began about the middle of March 1941 in well 139-49-2aa3 and during the first part of April in well 140-49-35ca. The rises continued until the last part of April in the latter well and until the first part of May in well 139-49-2aa3. During the first part of June the water levels in both wells began to rise as a result of recharge from rains during that period. This rise continued until about the last of June in well 139-49-2aa3 but only until about the middle of June in well 140-49-35ca.

After the full effects of the recharge were culminated, the water level in well 140-49-35ca declined rather steadily until it reached a level lower than before the rise in April began. The water level in well 139-49-2aa3 began to decline after reaching a peak in June, but the decline took place at a much slower rate, and the water level at the end of 1941 was still several feet higher than before the spring rise began. Also, the total 1941 fluctuation at well 140-49-35ca was considerably less than at well 139-49-2aa3. The difference in the magnitude of the fluctations was due principally to the difference in depth to water in the two wells and is explained as follows: The water level in well 140-49-35ca was less than 4 feet below the land surface, so that in this area the ground water was disposed of by capillary movement upward from the water table and subsequent transpiration by plants and evaporation from the soil surface. On the other hand, the water level in well 139-49-2aa3 was never less than 11 feet below the surface, and therefore was deep enough to escape surface discharge by transpiration and evaporation for the most part.

Coefficients of transmissibility and storage

As used in this report, the coefficient of transmissibility is defined as the number of gallons of water, at the prevailing temperature, that will pass in 1 day through a vertical strip of the aquifer 1 foot wide under a unit hydraulic gradient. As the rate of ground-water flow is proportional to the hydraulic gradient, it is also equal to the number of gallons of water that will pass in 1 day through a vertical strip of the aquifer 1 mile wide under a hydraulic gradient of 1 foot per mile. The coefficient of transmissibility is equal to the average field coefficient of permeability, at the prevailing temperature (gallons per day per square foot under unit hydraulic gradient) multiplied by the thickness of the aquifer in feet.

The coefficient of storage is the amount of water in cubic feet that will be released from storage in a vertical column of the aquifer having a base of 1 square foot when the water level falls 1 foot. For nonartesian or water-table aquifers the coefficient of storage is nearly identical with the specific yield of the material of the aquifer (amount of water, in cubic feet, that will drain by gravity from 1 cubic foot of the saturated material). In artesian aquifers the coefficient is much smaller and depends essentially upon the compressibility of the aquifer or of included or stratigraphically adjacent materials.

Byers and Wenzel[57] give results of computations for permeability

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[57] Byers, A. C., Wenzel, L. K., and others, op. cit., pp. 35-39.

as follows: Based upon the difference in water levels in wells 139-49-1ccd2 and 1cbd1 (985 feet and 8 feet respectively from the Fargo supply well) when the Fargo supply well was pumping and an aquifer 100 feet thick, the average coefficient of permeability is 720 gpd/ft^2, correspinding in this instance to a coefficient of transmissibility of 72,000 gpd/ft; Based upon the difference in water level in well 139-49-1ccd2 and well 139-49-2baa, which is 3,700 feet from the Fargo supply well, the average coefficient of permeability is 57 gpd/ft^2, corresponding to a coefficient of transmissibility of 5,700 gpd/ft.

Computations of the coefficient of transmissibilty were made by the writers from semilog plots of drawdowns in individual wells against time,[58] using drawdowns in wells 139-48-6ccd, 6cdd, and 139-49-1ccd2 during the period of pumping the Fargo well in 1940, and in wells 139-48-6ccd and 139-48-6cdd during the period of pumping the Fargo well in 1941. Computations were also made from plots of residual drawdowns in individual wells against $\log \frac{t}{t'}$,[59] using water-level data from wells 139-48-6ccd, 6cdd, 139-49-1ccd2, and 1cbd1 during the period subsequent to pumping the Fargo well in 1940. In $\log \frac{t}{t'}$ above, t is the time since pumping began in the 1940 season and t' is the time since pumping stopped, both referring to the time coordinate corresponding to the particular value of residual drawdown being considered. The discharge rate of the Fargo well used in these computations was an average obtained by dividing the total pumpage during the period considered by the total time involved. The values for the coefficient of transmissibility

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[58] Jacob, C. E., Drawdown test to determine effective radius of artesian well: Am. Soc. Civil Engr. Trans., p. 1047, 1947.

[59] Theis, C. V., The relation between the lowering of the peizometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., 1935, p. 522.

computed from these plots ranged from a high of 6,180 gpd/ft to a low of 1,190 gpd/ft. The average of the computed values for the coefficient of transmissibility is 3,700 gpd/ft.

A short pumping test was made on wells in the West Fargo aquifer during July 7 to July 9, 1945. The test was made by officials of the Union Stockyards Co., and data were obtained by the writers during the test. Because of the necessity for supplying water to stock and to business establishments connected with the stockyards, it was difficult to arrange a satisfactory pumping schedule which could be maintained for more than 1 or 2 days at a time. Because of the usual intermittent and unequal pumping periods, it was decided that best results could be obtained by allowing the supply well to remain idle for a period of 24 hours over a week-end, during which time water-level measurements would be made. The well would then be pumped steadily for as long a time as was convenient (actually about 22 hours), and drawdowns could be calculated as the differences in the recovery curves as extrapolated over the subsequent pumping period and the water levels during pumping.

Accordingly, water-level measurements were made throughout the test in the Union Stockyards Co. supply well (139-49-6ad), which was the source or pumped well for the test, and in six observation wells ranging from 715 feet to 4,210 feet distant from it. A few water-level measurements were made in all the wells while the supply well was pumping and prior to the first 24-hour shut-down. Computations of the coefficient of transmissibility were made from data obtained during both the shut-down period and subsequent pumping period. Computations were made using type curves[60] for the Theis formula, using data from individual

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[60] Wenzel, L. K., Methods for determining permeability of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 887, pp. 87-91, 1942.

wells. The pumping rate of the well was checked roughly during the test, but an accurate determination could not be obtained because of certain unmeasureable losses. For purposes of computation the pumping rate was taken to be 900 gpm.

The coefficients of transmissibility as computed from these graphs ranged from a high of 125,000 gpd/ft to a low of 33,000 gpd/ft. The average of the computed values for the coefficient of transmissibility is 71,100 gpd/ft.

The wide range in the computed values of the coefficient of transmissibility is, perhaps, to be expected because of the relatively heterogeneous character of the material comprising the glaciofluvial deposits, both as to assortment and extent. The higher average values of about 72,000 gpd/ft for the Fargo aquifer and about 71,100 gpd/ft for the West Fargo aquifer probably represent the order of magnitude of the local transmissibility in these two aquifers, inasmuch as the first value was computed from the difference in water level in two wells relatively near each other and penetrating the permeable section of the aquifer, and the latter value was computed from a pumping test covering a relatively short period of time. On the other hand, the lower average transmissibility of 3,700 gpd/ft computed for the Fargo aquifer probably represents the order of magnitude of the transmissibility in a much larger area than is occupied by the highly permeable portion of the aquifer.

It is doubtful whether the coefficient of transmissibility of the till and included glaciofluvial materials considered as a whole on a regional basis would be represented by the figure of 3,700 gpd/ft, as there is some evidence to indicate that this figure may be too high.

Byers and Wenzel[61] give a table of physical properties of earth materials from the vicinity of Fargo showing, among other data, laboratory permeability determinations of materials obtained from wells in the Fargo area. Listed samples which are from the till can be identified by the depth from which the material was obtained and the mechanical analysis given. Permeabilities of the till samples listed range from 0.01 to 3 gpd/ft^2. Considering the heterogeneous vertical distribution of much of the glaciofluvial material associated with the till and the rather poor interconnection of these deposits as indicated by the well logs and by water-level fluctuations in some of the observation wells, it is apparent that at least locally the transmissibility may be very low, perhaps not greater than 1 or 2 gpd/ft where "dry" holes are encountered.

The small yields of some farm wells in this and other areas where water is obtained from lenses of glaciofluvial deposits in the till also attest to the very low permeabilities and transmissibilities that may be encountered. Results of a pumping test on a well near Minnewaukan, North Dakota, which penetrated about 3 feet of glaciofluvial material in the till indicated a coefficient of transmissibility at that location of about 600 gpd/ft. This well yielded about 15 gpm during the pumping test and would be considered a "strong" well in comparison with many of the farm wells tapping similar deposits.

On the other hand, there is evidence to indicate that there is a larger percentage of glaciofluvial materials in the till in the Fargo area than there is generally in some other areas in North Dakota, probably due to differences in the mode of deposition of the till and included

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[61] Byers, A. C., Wenzel, L. K., and others, op. cit., p. 56.

deposits. Filaseta[62/] estimated that in the area near Fessenden, North Dakota, only about 12 percent of the material of the glacial drift encountered in wells was of such a nature as to be water-bearing, whereas in the Fargo area an average of 27 percent of the material represented by the till and associated glaciofluvial deposits in 44 representative wells and test holes was water-bearing.

It is apparent that many more data regarding the transmissibility of the till and associated glaciofluvial deposits are needed in order to estimate accurately the value of this coefficient in a regional sense. However, it is the opinion of the writers that a coefficient of transmissibility of 1,000 gpd/ft, comparable to the lower values of this coefficient computed from the water-level fluctuations in the Fargo observation wells, would be more nearly of the order of magnitude of the regional transmissibility of the till and associated glaciofluvial materials than the higher computed average coefficient of 3,700 gpd/ft.

Computations of the coefficient of storage were made from the water-level fluctuations in the Fargo aquifer and from the pumping test on the West Fargo aquifer, using the methods previously referred to in connection with the computations for the coefficient of transmissibility. Computed values for the coefficient of storage of the Fargo aquifer ranged from a high of 0.00083 to a low of 0.000075 and averaged 0.00058. Values for this coefficient computed from the pumping test on the West Fargo aquifer ranged from a high of 0.018 to a low of 0.00046, the average value being 0.0037.

As for the computed values of the coefficient of transmissibility,

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62/ Filaset, Leonard, Ground water in the Fessenden area, Wells County, North Dakota, U. S. Geol. Survey mimeo. report, Mar. 1946.

the wide range in the computed values for the coefficient of storage probably is due principally to the relatively heterogeneous character of the glaciofluvial deposits. In the case of the computations made for the Fargo aquifer, no attempt was made to correct for interference effects from pumping of the Moorhead and West Fargo aquifers. These effects probably were sufficiently large over the period of time used in the computations to affect the computed values of the coefficient of storage materially and may account for the relatively low values obtained. On the other hand, the higher values of the coefficient of storage obtained in the computations for the West Fargo aquifer appear to be out of line with values of this coefficient ordinarily associated with artesian conditions, and also with the values computed for the Fargo aquifer.

In the absence of more general and better data, it is the opinion of the writers that a coefficient of storage of about 0.0005, which is comparable to the average coefficient computed for the Fargo aquifer, would represent reasonably well the order of magnitude of the coefficient of storage of the till and associated glaciofluvial materials when considered as a whole and on a regional basis. This coefficient of storage would be representative only so long as the water level remained above the till and associated glaciofluvial materials, so that the water is derived from compression of the aquifers and by expansion of the water, rather than from drainage of sands and gravels. Once the water levels are drawn below the clays of the Lake Agassiz deposits, it may be assumed that some water will be derived by gravity drainage of the glaciofluvial materials. If the effective porosity or specific yield of the water-bearing materials is assumed to be 0.25 and if the percentage of these materials in the till and associated deposits is about 27 (as indicated by the logs of wells and test holes), it is estimated that the effective coefficient of storage when the water level is drawn below the clay of Lake Agassiz would be about 0.07. Locally, where the water levels are drawn below the tops of the relatively large aquifers, as in Moorhead, the full specific yield of the water-bearing material will be effective in supplying water to the wells. In the long run, this specific yield may be considerably higher than the 0.25 taken above.

Recharge and natural discharge

The water in the silt unit of the Lake Agassiz deposits is derived principally from local precipitation. Water-level fluctuations in two shallow wells in the silt showing reactions to recharge from melting snow in the spring and to rainfall have been described on pages 82-84 and are illustrated in figure 8. In areas where the artesian head of the aquifers in the till is higher than the water table in the silts, there is also upward percolation of water through the till and the clay unit of the Lake Agassiz deposits to the shallow water body. In the past, when the artesian head of the aquifers in the till was considerably higher than at present, the upward percolation of water in this manner may have been the principal method of natural discharge for the artesian aquifers, and the amount of water discharged in this way probably was of considerable magnitude. At the present time, however, the artesian head is much lower than the water table in the eastern half of the area and upward percolation no longer occurs. In the western half of the area the artesian head ranges up to 15 feet or more above the water table, and upward percolation of water still occurs in this area, although the quantity must be much less than originally.

Natural discharge of water from the silt unit of the Lake Agassiz deposits occurs through evaporation from shallow water-table ponds and slough areas, through evaporation from the soil surface, through transpiration by plants, through seeps and small springs along the streams, through artificial drains in the area, and by downward percolation to the aquifers in the till in the area where the artesian head is lower than the water table. It is likely that evaporation and transpiration are the principal natural discharge agencies although there are no data to evaluate the amount being discharged into the streams and drainage ditches. The amount of water discharged through downward percolation to aquifers in the till depends upon the difference in elevation between the water table and the artesian head, and is becoming more important as the artesian head is lowered.

There appear to have been only two possible sources of recharge to the aquifers in the till prior to the construction of wells in the area: (1) water derived from precipitation on the upland areas along both the east and west margins of the valley, where the till is exposed over large areas at higher elevation than the central part of the valley; and (2) water from the Dakota sandstone which could move laterally and upward into the till along the western part of the valley. The water from these sources moved laterally through the till toward the central part of the valley. Natural discharge occurred through upward percolation of water into the silts, probably over the greater part of the valley. Considerable natural discharge must also have occurred by upward percolation into the shallow-lying gravel aquifer[63] east of Dilworth, which

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[63] Dennis, P. E., and Morgan, A. M., op. cit.; Dennis, P. E., and Akin, P. D., op. cit. (press releases).

extends entirely through the lake deposits and rests directly upon the underlying till.

With the development of ground water, water levels declined in the valley area. Hydraulic gradients from the areas of natural recharge toward the valley were increased, and as a consequence the amount of water reaching the valley areas from the original recharge sources was increased. In the areas where the artesian head of the aquifers in the till was drawn below the shallow water level in the silts, natural discharge through upward percolation was stopped, the water formerly discharged naturally being diverted to the wells. As the water levels were lowered further, opportunity was developed for downward percolation of water from the silts into the aquifers in the till, reversing the original arrangement of recharge and discharge between these two formations, and excellent opportunity was afforded for recharge from such sources as the shallow gravel aquifer east of Dilworth.

On the basis of the data available at present, it is not possible to estimate accurately the amount of recharge that may be reaching the area from the sources mentioned above. However, the following discussion will serve to give an idea of the quantities involved:

The transmissibility of the till and associated glaciofluvial deposits as a whole has been estimated as of the order of 1,000 gpd/ft. In the western half of the area, available data indicate that the piezometric surface of the till (surface defined by the water levels in wells) sloped generally from west to east at about 5 feet/mile at the present time. This indicates that about 1,000 x 5 x 12 = 60,000 gallons a day is entering the areas of heavy pumping through the 12-mile strip represented in the area of this report. East of the area the piezometric surface of the till slopes generally from east to west. The available water-level data indicate that the slope is about 10 ft/mile in Ranges 46 and 47 West, just east of the area of this report. This indicates that about 1,000 x 10 x 12 = 120,000 gallons a day is entering the area through underflow from the east. The total amount of water entering the area through underflow across the east and west boundaries then is about 180,000 gallons a day. Actually, the movement of water from the recharge areas in the uplands toward the areas of heavy pumping probably takes place over a strip much wider than the 12 miles considered, and water enters the areas of heavy pumping from all directions rather than simply from the east and the west. It is likely, therefore, that at least 250,000 gallons a day is entering the area of heavy pumping through underflow. A part of this water is being taken from storage in the areas between the area of the report and the upland recharge areas, but some water is moving into the valley from the recharge areas.

The amount of water reaching the aquifers in the till through downward percolation of water from the silt unit of the Lake Agassiz deposits depends upon the difference in elevation between the water table in the silts and the artesian head in the aquifers in the till, and upon the permeability of the material through which the water must pass - the silt and clay units of the Lake Agassiz deposits and the relatively impermeable till - in order to reach glaciofluvial materials that will yield water to wells.

Available water-level data indicate an area of approximately 140 square miles surrounding the areas of heavy pumping in which the depth to water in the till aquifers is 20 feet or more below land surface, the water levels ranging down to 195 feet or more in the Moorhead and

Fairmont Creamery Co. well fields. It is estimated that over this area the average depth to water in the glaciofluvial aquifers in the till is about 35 feet below land surface at the present time. Water-level measurements in wells in the silt unit of the Lake Agassiz deposits indicate that the water table will average about 15 feet below land surface in the area, so that the artesian head of the aquifers in the till, is, on the average, about 20 feet lower than the water table.

The average thickness of the Lake Agassiz deposits is estimated from section A-A'-A" (figure 2) to be about 80 feet in the area and the average thickness of the till and associated glaciofluvial deposits is estimated to be about 170 feet. If it is assumed that water in passing downward from the water table to the aquifers in the till will pass on the average through 80-15 = 65 feet of lake deposits and through one-half the thickness of the till ($\frac{170}{2}$ = 85 feet) before reaching permeable deposits in which wells could be constructed, the average hydraulic gradient causing downward percolation of the water would be $\frac{20}{85 + 65} = \frac{20}{150}$ ft/ft.

The available data on the permeability of the Lake Agassiz deposits and the relatively impermeable till is insufficient to derive a reliable average permeability for these materials. Byers and Wenzel[64/] published a table of physical properties of earth materials form the vicinity of Fargo showing laboratory permeability determinations of material obtained from wells in the Fargo area. Permeabilities of the Lake Agassiz deposits and the till range between 0.006 and 3 gpd/ft^2. However, tests on materials from other areas which are similar in character to the lake deposits indicate that the average permeability may be lower than

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[64/] Byers, A. C., Wenzel, L. K., and others, op. cit., p.56.

indicated above. For example, a sample form the Escalante Valley in Utah containing 24.7 percent very fine sand and 65 percent silt and clay had a permeability of only 0.0002 gpd/ft2[65]. The samples from the Lake Agassiz deposits and till from the Fargo area listed by Byers and Wenzel contain from 36 to 99 percent silt and clay.

Assuming, for purposes of computation, an average coefficient of permeability of 0.001 gpd/ft^2, which appears to be conservative from the standpoint of available information, the average quantity of water moving downward to the till aquifers would be $0.001 \times \frac{20}{150} \times 43{,}560 \times 640 \doteq 3{,}717$ gallons a day per square mile, and would amount to more than 500,000 gallons a day over the 140-square-mile area considered.

In addition to the water entering the area through underflow and through downward seepage from the silts of the Lake Agassiz deposits, considerable recharge may be derived by percolation from such sources as the shallow-lying gravel aquifer east of Dilworth. There is no way to estimate the quantity of water which may be recharging the till aquifers from these sources. However, the average westward hydraulic gradient west of the shallow aquifer near Dilworth is considerably greater than the westward gradient east of the aquifer, and this is fair evidence that recharge from that aquifer is occurring.

It is likely, therefore, that the present recharge to the aquifer in the till in the areas of heavy pumping may be of the order of 1 million gallons a day. This is only about 40 percent of the estimated 2½ million gallons a day now being produced from the area. Recharge to the glaciofluvial aquifers in the till will be increased as the water levels are lowered, and there is a possibility that ultimately the

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[65] Wenzel, L. K., Methods for determining permeability of water bearing materials: U. S. Geol. Survey Water-Supply Paper 887, pp. 13-14, 1942.

recharge would amount to as much as the present use. However, further lowering of water levels in order to increase the recharge will not be practicable at locations where pumping water levels are already about as low as can be attained, so that it can be achieved only by placing new developments as to spread the pumping and the lowering of water levels over a wider area. The extent to which this can be done practicably is a matter of economics, and considerable test drilling and careful planning will be necessary if the water needed is to be developed at reasonable cost.

Those who are interest in utilizing ground water in preference to surface water for cooling and other purposes should not overlook the possibility of artificially recharging the aquifers with surface water in areas where local overdevelopment of the ground-water supplies has occurred. Surface water, usually filtered and chlorinated, can be directed underground through the supply wells during times when they are not in use or through especially constructed recharge wells.

The relatively constant temperature of the ground water, which is lower than that of the surface water in the summer, would be reduced still further, and the chemical character of the ground water, which though relatively constant is somewhat poorer than that of the surface water might be improved, by artificially recharging the aquifers during the winter months when the temperature of the surface water is the lowest. An economic advantage would also result, because of the higher water levels and consequent smaller pumping lift which would be made possible by artificial recharge.

Storage

A very large amount of water is stored in the glaciofluvial aquifers in the till. Using a coefficient of storage of 0.07 for the till as a whole, as given on page 101, and an average thickness of 170 feet for the till and associated glaciofluvial deposits, the amount of water in storage in the 360-square-mile area covered by this report and which theoretically could be removed through complete drainage of the aquifers by means of wells would be 43,560 x 640 x 360 x 170 x 7.5 x 0.07, or about 900 billion gallons. However, only a fraction of this could be recovered by economical means.

So long as the water levels in the aquifers are above the base of the clays of the Lake Agassiz deposits, no gravity drainage of the aquifers can occur, and water taken from storage through pumping is derived by compression of the aquifers and adjacent materials or from expansion of the water, both due to the decrease in hydrostatic pressure when the water levels are lowered. The following computation will illustrate this point: Prior to the development of municipal and industrial supplies in the area (about 1905-10), the water levels in the aquifers in the till ranged from well above land surface in the western part of the area to about 6 feet below land surface in the eastern part of the area. Assuming that, on the average, the water level over the whole area was at land surface, that the effective coefficient of storage is 0.0005 so long as the water levels are above the base of the clay unit of the Lake Agassiz deposits and that the average thickness of the lake deposits is 80 feet over the area of 360 square miles, the amount of water that theoretically could be removed from storage by lowering the water levels to the base of the clays would be 43,560 x 360 x 80 x 7.5 x 0.0005, or about 3 billion gallons. This represents only about 0.3 percent of the total amount of water in storage in the glaciofluvial deposits.

Complete drainage of the glaciofluvial deposits by means of wells would not be feasible from a practical standpoint, but if wells are distributed uniformly over the area and pumping rates are kept low enough to avoid local short-term overdevelopment, it should be possible to recover a considerable amount of the water in storage. Furthermore, it would be impossible to recover the water stored in the area of the report without removing water from storage in surrounding areas. The amount of water that could be taken from storage in the surrounding areas by developments in the area of the report will depend upon the ground-water developments made in the surrounding areas. If there were no developments of magnitude in the surrounding areas, the amount of water that theoretically could be removed from storage by developments within the area would amount to considerably more than the amount stored within the area. On the other hand, if the surrounding areas were more highly developed than the area of the report, the amount of water theoretically available to the developments within the area would be less than the estimated amount.

In addition to the water that can be removed from storage there is also the water furnished to the area through recharge. It has been estimated that present recharge to the area may be of the order of 1 million gallons a day. At the present time, however, a part of the recharge to the area through underflow is water derived from storage in the surrounding areas.

The significance of storage and recharge can be illustrated by a practical example. It has been estimated that approximately 13 billion gallons of water has been produced from the area during the period

1906-47 (p. 59. Using available water-level data and the coefficients of storage given on page 90 , it is estimated that only about 5 billion gallons has been taken from storage within the area, while the remaining 8 billion gallons has been derived from storage in the surrounding areas and from recharge. The 5 billion gallons estimated as already having been removed from storage within the area amounts to a little over half of 1 percent of the 900 billion gallons estimated as stored in the glaciofluvial deposits within the area.

SECURITY OF PRESENT DEVELOPMENTS AND POSSIBILITIES FOR FUTURE DEVELOPMENTS

General

It has been estimated that the rate of recharge to the glaciofluvial aquifers in the till in the area at the present time is of the order of 1 million gallons a day, which amounts to approximately 40 percent of the water now being produced in the area. The rate of recharge will be increased as the water level in the area is lowered, possibly to as much as 2 or 2½ million gallons a day. This is the ultimate rate at which water could be produced from the area with full development, after removal of water from storage in the aquifer as completely as practicable and assuming no introduction of water into the aquifers by artificial means. On the other hand, the amount of water that can be removed from storage in the area itself is a small but substantial fraction of the estimated 900 billion gallons within the area plus an additional amount from the surrounding areas. The storage in and adjacent to the area, then, would support a development of several million gallons a day for many years.

The maximum production of the water stored in the aquifers could be accomplished only by means of a large number of wells spaced over the entire area. With such an arrangement many of the wells would have comparatively small yields, perhaps of the order of a few gallons a minute or less, and in the long run the yields of wells which were originally large producers would be decreased to only a fraction of the original yields. Yet, even so, it would be possible to recover a large part of the water available from storage through wells having sufficient yields for irrigation, municipal, and industrial purposes. Such wells could be developed only in the more permeable aquifers and it would be necessary to adjust pumping rates and limit the number of large producing wells that could be constructed in any locality so as to prevent short-term local overdevelopment.

Six glaciofluvial aquifers in the till have been named and described individually in this report. These aquifers are named as follows: (1) the Dilworth; (2) the east Moorhead; (3) the west Moorhead; (4) the Fargo; (5) the West Fargo; and (6) the Maple Ridge. The possibilities for present and future developments in these aquifers are discussed in the following pages.

Dilworth aquifer

Little is known of the extent and character of the Dilworth aquifer. Although the Dilworth wells apparently do not penetrate the entire thickness of the glaciofluvial deposits, the yields of these wells are reported to be 50 and 100 gpm. The drawdown in these wells due to pumping is not known. The nonpumping water level is reported to have been about 120 feet below the surface in 1948. This low water may indicate a rather good connection between the Dilworth aquifer and the east Moorhead aquifer, but is is more likely that the low water level is the result of pumping from an aquifer of small areal extent or of relatively low transmissibility, or both. In any event, there appears to be little opportunity for additional ground-water development of magnitude in this area. The 1946 pumpage by the village of Dilworth is estimated to have been of the order of 13 million gallons, and it is estimated that the total withdrawals during the 1907-47 period have amounted to about 400 million gallons. It is quite likely that this aquifer will produce sufficient water for the needs of the village of Dilworth for several years to come. Nevertheless, the water levels already have been drawn below the bottom of the lake deposits and undoubtedly water is already being drained from storage in the glaciofluvial deposits. It would seem to be worth while for the village of Dilworth to institute a systematic program for obtaining water-level data in the village wells and in other wells in the area, along with adequate production records, so that they would have advance warning of the possibility of failure of the present supply through local overdevelopment, and of the consequent necessity for obtaining water from another source.

Moorhead aquifers

So far as can be determined from available logs and records of wells in the Moorhead area, the more permeable sand and gravel deposits of the Moorhead aquifers are not extensive in any direction. The combined areas of these aquifers, for instance, appear to be very small as compared to the known extent of the West Fargo and Maple Ridge aquifers. Yet they have yielded more than 8 billion gallons of water during the past 40 years and, despite lowering water levels and decreasing pumping rates, it has been possible to increase progressively the annual yields from these aquifers. From 1940 to 1947 the annual production from the Moorhead aquifers increased from about 350 million gallons to about 570 million gallons, which amounts to an increase of over 60 percent during this 7-year interval.

It has been indicated that the present rate of lowering of water levels in the Moorhead aquifers is of the order of 5 or 6 feet for every billion gallons of water produced. The depth to the bottom of the west Moorhead aquifer ranges from 218 to 240 feet below land surface in the present city and Fairmont Creamery wells and the present water levels at these locations are 195-196 feet below land surface. The depth to the bottom of the east Moorhead aquifer ranges from 240 to 269 feet in the present city wells in the Moorhead 22nd Street field and present water levels are 184 feet below land surface. Inasmuch as it will not be possible to unwater the aquifers completely by means of wells with pumping rates as high as at present, it appears that it will be necessary to reduce pumping rates more and more in order to continue production from these aquifers as the water levels continue to lower.

There is, therefore, no opportunity for additional development of ground-water supplies of magnitude from the Moorhead aquifers under present conditions, and little hope that present developments can be maintained at present production rates for many more years. On the other hand, it seems quite likely that much more water can be withdrawn from these aquifers if pumping rates and annual production rates are lowered. For instance, it appears reasonable that another 8 to 10 billion gallons of water, or perhaps even more, could still be pumped from these aquifers if the production rate were reduced to the order of 250 to 300 million gallons a year and at the same time the pumping rates of individual wells were kept as low as feasible.

At the present time the City of Moorhead is developing a new ground-water supply from the shallow-lying gravel aquifer east of Dilworth. It is anticipated that this aquifer will supply the entire needs of the city for many years. Furthermore, it appears likely that the Fairmont Creamery Co. will switch to city water for their needs as soon as the new development is put into use. If this entire load is then switched to the newly developed aquifer for a time, it will leave the Moorhead aquifers practically without use. Observations on the rate of recovery of the water levels in these aquifers at that time would be of great value in evaluating the amount of water that could be produced from them in the future. It is reasonable to assume that the city will wish to continue to use water from the Moorhead aquifers insofar as it is practical, because the aquifers are near to the place of use and because of the investment already made in wells and pumping equipment. However, if the use of these aquifers is discontinued by the city and by the Fairmont Creamery Co., there would then be opportunity for limited use by others who might be interested.

The specific capacities and actual pumping water levels of the wells in the Moorhead aquifers are not known. The present pumping rates of city wells 5 and 6 in the east Moorhead aquifer are reported[66] as 500 gallons a minute each. The present pumping rates of city wells 2 and 3 in the west Moorhead aquifer are reported as 150 gallons a minute each. The present yields of the Fairmont Creamery Co. wells in the west Moorhead aquifer are reported by Mr. J. H. Deems, plant superintendent, as 75, 125, and 150 gallons a minute.

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[66] Young, J. E., Moorhead City Water & Light Supt., oral communication, Dec. 1947.

Fargo aquifer

The Fargo City well is the only ground-water development of magnitude that has been made in the Fargo aquifer. This well is used only to supplement the Fargo City supply from the Red River in summers when the flow in the river is inadequate or when water demands are unusually high. About 142 million gallons of water has been pumped from the well since it was put into service in 1938. The maximum pumpage during any season was 52 million gallons in 1941.

According to estimates of Byers and Wenzel[67] in 1941, the pumping rate of the Fargo City well was 850 gallons a minute. The following table showing maximum depth to water during the 1941 pumping season in wells influenced by pumping of the Fargo well is adapted from information given by Byers and Wenzel[68] and other available water-level data.

Maximum depth to water, in feet below land surface, and maximum seasonal drawdowns in wells in Fargo area during the 1941 period of pumping the Fargo city well

Well No.	Distance from Fargo well (feet)	Direction from Fargo well	Depth to water (feet)	Maximum seasonal drawdown (feet)
139-49-1cbd2 (Fargo City well)	0	----------	159 +	127 +
139-49-1cbd1	8	Southwest	138.68	106.73
139-49-1ccd2	985	South	125.10	94.04
139-49-baa	3,700	West-northwest	66.50	49.24
139-48-6ccd	4,830	South of east	42.39	13.69
139-48-6cdd	5,910	South of east	40.74	11.7
139-48-7acb	7,770	Southeast	38.78	1.7
139-48-18aba	10,400	Southeast	35.05	2.5

These figures indicate the large drawdowns in and near the Fargo

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[67] Byers, A. C., Wenzel, L. K., and others, op. cit., p. 35.
[68] Op. cit., pp. 35-39.

city well and demonstrate the necessity for locating new developments as far from this well as possible so as to avoid large interference effects. Also, it is indicated that actual drainage of the glaciofluvial materials of the aquifer has not yet begun even during pumping, although drainage of some of the materials in the till may occur in the vicinity of the well during pumping. Any such drainage, however, has been temporary in nature up to the present time, as the water levels rapidly rise to levels above the top of the till once pumping is stopped.

The Fargo aquifer, as such, appears to cover not more than about one-half as much area as the combined Moorhead aquifers, and the thickness of the highly permeable material is generally less than at the Moorhead well fields. These considerations would indicate that it would not be feasible to withdraw as much water from the Fargo aquifer as has been taken from the Moorhead aquifers over a corresponding period of time. However, there is good geologic and hydrologic evidence to indicate a permeable connection between the Fargo aquifer and the comparatively large West Fargo aquifer. On a comparative basis, it appears probable that at least 4 to 5 billion gallons could be taken from the aquifer over a period of 40 years or more. This would represent an average daily pumpage of the order of 250,000 to 350,000 gallons a day during the entire period. Best results, of course, would be obtained by using wells of lowest feasible yield and operating them continuously throughout the period.

West Fargo aquifer

From the standpoint of areal distribution and thickness of permeable water-bearing materials, the West Fargo aquifer appears to offer more promising opportunities for additional ground-water development than any of the other aquifers in the area. Present information regarding this aquifer is inadequate to permit an estimate of the amount of water that could be withdrawn from it under a given set of pumping conditions, but it is to be expected that this aquifer will yield many times as much water as either the Fargo or the Moorhead aquifers and, incidentally, will support wells of higher yield.

At present, supplies have been developed in this aquifer for both municipal and industrial purposes, and it is estimated that approximately 1.7 billion gallons of water has been recovered for these purposes during the past dozen years. The supply well at the Union Stockyards produces at a rate in excess of 900 gallons a minute, and it is estimated from pumping tests that the 1-day specific capacity of this well is approximately 90 gpm/ft; that is, the well will produce approximately 90 gallons a minute for each foot of drawdown after pumping continuously for 1 day.

To date, the water levels have not been lowered sufficiently to cause drainage of the glaciofluvial materials in the area, and the water pumped has been derived from storage under artesian conditions and through replenishment by recharge .

Maple Ridge aquifer

The Maple Ridge aquifer appears to offer good opportunity for additional ground-water supplies in the area. To date no large developments for municipal or industrial purposes have been made in this aquifer, and the present geologic and hydrologic data are insufficient to permit an estimate of its potential yield. Present information indicates, however, that the aquifer may have a comparatively large areal extent and may be sufficiently permeable to support wells of comparatively large yields.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report is based upon the location of the well with respect to the land-survey divisions used in North Dakota. The first number is the township north of the base line running along the Kansas-Nebraska State line. The second number is the range west of the 6th principal meridian. The third number is the section within the designated township. The letters a, b, c, and d, designate, respectively the northeast, northwest, southwest, and southeast quarter sections, the quarter-quarter sections, and of the quarter-quarter-quarter sections. If more than one well occurs within a 10-acre tract, consecutive numbers are given to them as they are scheduled. This number follows the letters. Thus, well 139-48-1ccc2 is in Township 139 North, Range 48 West, section 1. It is in the southwest quarter of the southwest quarter of the southwest quarter of that section and was the second well scheduled in that 10-acre tract. Similarly well 140-51-34daa (see figure 1) is in the northeast quarter of the northeast quarter of the southeast quarter of sec. 34, T. 140 N., R. 51 W. Numbers for wells not accurately located within the section in the field may contain only one or two letters following the section number, indicating that the locations of such wells are accurate only to the quarter section or the quarter-quarter section, respectively.

The following diagram, showing the method of numbering the tracts within the section, may be helpful in determining locations of wells not shown in figure 1.

bbb	bba	bab	baa	abb	aba	aab	aaa
(b)		(a)		(b)		(a)	
bbc	bbd	bac	bad	abc	abd	aac	aad
		b				a	
bcb	bca	bdb	bda	acb	aca	adb	ada
(c)		(d)		(c)		(d)	
bcc	bcd	bdc	bdd	acc	acd	adc	add
cbb	cba	cab	caa	dbb	dba	dab	daa
(b)		(a)		(b)		(a)	
cbc	cbd	cac	cad	dbc	dbd	dac	dad
		c				d	
ccb	cca	cdb	cda	dcb	dca	ddb	dda
(c)		(d)		(c)		(d)	
ccc	ccd	cdc	cdd	dcc	dcd	ddc	ddd

Many of the wells used in this report were also reported by Byers and Wenzel.[69] The following tabulation shows the well numbers for these wells as given in the two reports:

Well number in this report	Well number (or numbers) used by Byers and Wenzel	Well number in this report	Well number (or numbers) used by Byers and Wenzel
139-48-4dcc1	M15	139-49-1dca	L8
4dcc2	M16	1dcc	L6
4dcc3	M17	2aa5	F154
5cab	L3	2dbb	F127; T12
5ddd1	M12	3ad2	F170
5ddd2	M13	6ab2	57
5ddd3	M14	6ac	56
6ccd	F3	6ad	58
7acb	F4	12acb	L1
11aaa1	M21	12bab	T6
18aba	67; T9	12cac	L2
139-49-1cbc	T5	12cad	F6; T8
1cbd1	28; T4	12dcb	T7
1cbd2	F14	22ba	F86
1cca	T3	140-48-31cbd	L4
1ccd1	T2	140-49-20aaa2	F24
1ccd2	12; T1	25dcd	F63
1cdc	L5		
1cdd	L7		

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[69] Byers, A. C. Wenzel, L. K., and others, op. cit., pp. 28-31 and 57-68, 1946.

QUALITY OF THE GROUND WATER

Analyses of waters from 17 representative wells in the Cass-Clay Counties area are given in the following table. All ground waters in the area are rather highly mineralized and hard. However, those listed in the table of analyses are used or have been used for domestic purposes. Waters from the glaciofluvial deposits were somewhat lower in mineral content than waters from wells producing from the Lake Agassiz deposits or the Dakota sandstone (?). Water from some wells in the shallow silt unit of the Lake Agassiz deposits is reported to have been too highly mineralized for domestic use, but analyses of waters from such wells are not available.

ANALYSES OF GROUND WATERS IN THE NORTH DAKOTA AND

Location	Name of owner	Date of analysis	Source of analysis	Aquifer	Dissolved solids	Silica (SiO_2)	Iron (Fe)
139-48-4dcc3	City of Moorhead	9/19/46	(a)	East Moorhead h/	629	22	1.0 i/
139-48-5ddd2	...do...	9/19/46	(a)	West Moorhead h/	683	26	.7 i/
139-48-6b	S. B. Steeves	6/25/21	(b)	Silt of the Lake Agassiz deposits	1,340	27	.27
139-48-11aa1	Village of Dilworth	1908	(c)	Dilworth h/	562	..	...
139-48-11aa2	...do...	7/25/46	(d)	...do... h/	.....	..	.35 i/
139-49-1cbd1	City of Fargo	....	(e)	Fargo h/	746	26	.43
139-49-2aa5	Paul Baker	....	(e)	Silt of the Lake Agassiz deposits	.....	..	17
139-49-3ad2	Ernest Fricke	....	(e)	...do...	.....	..	...
139-49-6ab2	Union Stockyards	....	(e)	West Fargo h/	1,090	26	.39
139-49-22ba	Mrs. P. J. Welsh	....	(e)	Glaciofluvial deposits h/	.....	..	3.6
139-53-10bba	USGS test hole	5/27/46	(f)	Dakota sandstone(?)	2,582	..	3.0
140-49-20aaa2	Louis Thorson	....	(e)	Glaciofluvial deposits h/	.....	..	...
140-50-31	Northern Pacific R.R.	....	(g)	Silt of the Lake Agassiz deposits	2,570	21	...
140-50-31	School Dist. #7 Mapleton	....	(g)	Glaciofluvial h/ deposits	870	30	1.8
140-52-35	City of Casselton, E. well	6/19/36	(g)	Dakota sandstone(?)	2,770	13	.4
140-52-35	City of Casselton N. well	6/25/36	(g)	...do...	1,140	26	.6
140-52-35a	Mrs. Grovenor	7/ 1/2/	(b)	...do...	2,770	12	.48
140-52-35c	Public School Casselton	7/1/2/	(b)	Glaciofluvial h/ deposits	915	30	1.6

a/ Infilco, Inc., Chicago, Ill.

b/ Simpson, H. E., Geology and ground-water resources of North Dakota; U. S. Geol. Survey Water-Supply Paper 598, pp. 280-281, 1929.

c/ Water plant superintendent, Dilworth.

d/ Minnesota Dept. of Health.

CASS-CLAY COUNTIES AREA,
MINNESOTA (PARTS PER MILLION)

Alumina (Al_2O_3)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Flouride (F)	Nitrate (NO_3)	Total hardness as $CaCO_3$
....	55	22	142	331	140	84	...	....	227
....	61	24	147	326	184	81	...	....	252
....	186	145	46	644	244	110	...	....	1,060
....	...	...	...	...	...	47	...	....	.....
....	...	...	...	...	210	42	.2	....	160
....	45	15	206	324	161	132	.6	3	178
....	...	...	...	670	733	7	.3	5.4	1,155
....	...	...	...	774	3,730	405	...	.5	2,475
....	57	21	325	412	90	355	.6	5.2	228
....	...	...	...	448	676	368	.8	9.2	135
....	...	...	831	...	980	488	...	....	60
....	...	...	...	314	146	148	.6	2.3	156
11	251	214	282	1,079	1,098	53	....	31	1,512
7.4	98	53	142	727	2.9	141	1	1.8	497
6.4	12	1.3	964	351	1,086	487	5	3.5	335
8.1	49	11	367	386	288	250	1	.18	171
....	12	7.3	938	344	1,091	492	....	9.5	60
....	126	30	148	464	301	40	....	1.5	438

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e/ Byers, A. C., Wenzel, L. K., and others, Ground water in the Fargo-Moorhead area, North Dakota and Minnesota, U. S. Geological Survey Mimeo. report, p.49, 1946.

f/ State Laboratories Department, Bismarck, North Dakota.

g/ Abbott, G. A., and Voedisch, F. W., The municipal ground water supplies of North Dakota: North Dakota Geol. Survey Bull. 11, pp. 52-53, 1938.

h/ Of the till and associated glaciofluvial deposits.

i/ Iron and manganese.

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
139-48						
1bcb	W. B. Houge	Carl Larson	1913	Drilled	147	5
1cccl		....	....	....	320	..
1ccc2	John Miley	....."....	1938	...do..	200	4
1ccc3	....do....	.....do....	....	...do..	158*	1½
1dcc	Anthon Olsen	.....do....	....	...do..	....	3
2bbc1	A. Helgren	Ole Felton	1940	...do..	140	2
2bbc2	....do....	Carl Larson	1900	...do..	165	2
2ccc	Mrs. Kramer	....	....	...do..	145	..
2ccd	Lyle St. John	....	....	...do..	...	..
2ddd	P. G. Houge	....	....	...do..	200	4
3cac	R.J. Sluggett	G.A. Griffen	1936	...do..	157	2
3cccl	John Lamb	Carl Larson	1941	...do..	169	3
3ccc2	Buetler	Larson Bros.	....	Jetted	183	3
3ccd	John Lamb	Carl Larson	....	Drilled	152	2
4dcb	City of Moorhead	....	1926	...do..	...	..
4dccl	...do...	McCarthy Well Co.	....	...do..	242	20
4dcc2	...do...	.....do....	....	...do..	265	20.
4dcc3	...do...	.....do....	....	...do..	281	20 20.
4dcc4	...do...	.....do....	....	...do..	242	..
4dcc5	A.T. Nelson	G. Haaland	....	...do..	158	2
4dcd	City of Moorhead	....	....	...do..	245	..
4ddd	...do...	....	....	...do..	300	..
5cab	City of Fargo	....	....	...do..	241	..
5cccl	Moorhead Laundry	....	1906	...do..	153	3
5ccc2	...do...	Carl Larson	1918	...do..	150	4

Principal Aquifer

Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	108	...	...	...	DS	
...	...	...	...		D	El Rancho well, Dilworth. See log.
...	...	...	...	...	DS	
...	...	...	99.90	6-30-41	A	Measuring point, top of casing, 1.0 foot above surface.
...	...	...	12.72	7- 2-41	DS	Measuring point, top of coupling on casing, 1.3 feet above surface.
...	...	...	...	...	DS	
...	...	...	5.50	7-22-46	DS	Measuring point, top of plank cover, 0.5 foot above surface.
...	...	...	...	...	DS	Water temperature 46° F.
...	...	...	...	...	D	
...	...	...	...	...	DS	
...	...	...	...	...	DS	
145	...	Sand	...	...	DS	
...	...	...	157.37	3-29-46	D	Measuring point, top of casing, 1.5 feet above surface.
145	...	....do....	...	...	DS	
...	...	...	80-83	1926	A	City test well.
142	108	....do....	...	...	M	City supply well 4. See log. Screen set, 209-240 feet.
154	109	Sand, gravel, and boulders	...	...	M	City supply well 5. See log. Screen set 223-263 feet.
155	114	Sand	...	...	M	City supply well 6. See log and chemical analysis. Screen set 233-273 feet.
...	...	...	...	...	A	City well. Abandoned when drilled. See log.
152	6	Pebbles and sand	...	7-29-40	A	Water level below 152 feet.
...	...	...	...	...	T	Moorhead City test hole. See log.
...	...	...	...	...	T	Do.
...	...	...	...	...	A	Old Fargo City well. See log.
...	...	...	...	...	I	
...	...	...	...	...	I	

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
5cdd1	Fairmont Creamery	McCarthy Well Co.	....	Drilled	230	16
5cdd2	...do...	....do....	....	...do..	240	8
5cdd3	...do...	....do....	....	...do..	230	20
5ddd1	City of Moorhead	....do....	....	...do..	198	10
5ddd2	...do...	....do....	....	...do..	219	12
5ddd3	...do...	....do....	....	...do..	223	12
6b	S.B. Steeves	....	....	Bored	23	16
6cab	St. Johns Orphanage	....	....	Drilled	...	..
6ccd	Pierce Printing Co.	....	1923	...do..	403	6
6cdd	Gardner Hotel	....	....	...do..	382	18 to 6
7acb	City of Fargo	....	....	...do..	228*	10
7acc	...do...	....	....	...do..	262	..
7daa	....	....	1912	...do..	250	6
8aaa	....	....	....	...do..	300	..
8baa	....	....	1888	...do..	1,901	..
9acc1	John Young	Marchland	....	Bored	90	24
9acc2	Clifford Hansen	....	....	Drilled	...	..
10aaa	Ida Carlson	M.E. Steffins	1940	Dug	26	8
10baa1	T.E. Gullengs	M. Baker	1925	Drilled	180	..
10baa2	T.E. Gullengs	....	....	...do..	.do.	..
10daa	Union Central Life Insurance Co.	....	....	....	176	..
11aaa1	Village of Dilworth	McCarthy Well Co.	1906	...do..	154	10

COUNTIES, NORTH DAKOTA AND MINNESOTA (con't)

Principal Aquifer						
Depth to top	Thickness	Material	Depth to water 2/	Date of measurement	Use 3/	Remarks
...	...	....	....	....	I	Fairmont Creamery well 1. See log. Screen set 195-222 feet
...	...	....	....	....	I	Creamery well 2. See log. Screen set 188-240 feet.
...	...	....	....	....	I	Creamery well 3.
180	18	Sand	....	....	M	City supply well 1. See log. Screen set 168-198 feet.
155	64	....do.....	....	....	M	City supply well 2. See log and chemical analysis. Screen set 166-218 feet.
158	65	....do....	....	....	M	City supply well 3. See log. Screen set 171-223 feet.
...	...	Sandy clay	13	6-25-21	DS	See chemical analysis.
...	...	....	....	....	A	
...	...	....	28.01	7- 3-40	A	Measuring point, top of coupling on well casing, 5.0 feet below surface. Equipped with water-stage recorder. See log.
...	...	....	28.37	7- 5-40	A	Measuring point, edge of plank floor over well, 7.1 feet below surface.
...	...	....	37.40	7- 3-40	A	Measuring point, top edge of coupling on casing, 2.8 feet above surface. Equipped with water stage recorder.
95	10	Gravel	.....	....	T	Old City test well, (Island Park,) See log.
100	4	Gravel and sand....		....	T	Moorhead City test hole. See log.
...	...	....	.....	....	T	Moorhead City test hole. See log.
...	...	....	.....	....	T	Old Moorhead City test hole. See log.
...	...	....	.....	....	DS	
...	...	....	.....	....	D	
...	...	Sand	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	......	....	DS	
...	...	....	.....	....	DS	
138	16	Sand and gravel	.....	....	M	See log and chemical analysis.

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
11aaa2	Village of Dilworth	Ole Johnson	1931	Drilled	154	10
11baa	Harry Seaburg	....	....	....do..	165	..
11bbb	Mrs. J. W. Garron	Larson Bros.	1918	...do..	200	..
11bcc	Louie Anderson	....	1938	...do..	210	3
11daa	John Shapland Est.	....	....	...do..	80	3
12bca	....	Carl Larson	1925	...do..	205	3
12cbb	Angelo Fiandaca	....	....	...do..	150	..
13bbb1	William Tovolt	....	.....	...do..	130	..
13bbb2	.....do.....	G. Haaland	1939	...do..	183	3
13cdc	Fred Anstett	....	.....	...do..	200	..
14aaa	E.E. Ulness	....	.....	...do..	130	2
14baa	Fred Anstett	....	.....	...do..	300	..
14cdd	S.J. Provan	....	....	...do..	...	..
15bbb	Ida LeVitre	E. Clemenson	1936	...do..	180	2
15cdd	Olof Safgren	....	....	...do..	145	3
16aab	H.E. Stevenson	....	1939	Bored	50	14
16ccb	Fred Meyers	....	1915	Drilled	150	..
16dcc	Bert Wear	Carl Larson	1933	...do..	170	3
17add	Station KVOX	....do....	1937	...do..	334	..
17baa	William Bailey	....	1917	...do..	133*	3
17bcd1	F.W. Bosshard	Savageau	1931	Bored	98	12
17bcd2	A. Oldsberg	....do....	1928	...do..	98	12
17bcd3	Herman Bosshard	....	1916	...do..	98	16
17bcd4	J.C. Marchand	Fugere	1940	...do..	100	18
17cc	Fairmont Creamery Co.	....	....	Drilled	220	6
18aaa	Leo Marsh	....	....	Jetted	162	..
18aad	Nels H. Overboe	....	....	Dug	28	..
18aba	City of Fargo	....	....	Drilled	242	8
18cd	Riverside Cemetery	....	....	...do..	220	..
18da	City of Fargo	....	....	...do..	...	..
19ad	Fargo Country Club	Carl Larson	....	...do..	120	3
19ba1	Harry Baker	Frank O'Neil	1919	...do..	164	3

Principal Aquifer

Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	....	.....	....	M	See chemical analysis.
...	...	....	.....	....	D	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	D	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
169	14	Gravel	105	12-39	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	D	
...	...	....	.....	....	DS	
...	...	....	8	9-41	Cooling	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	I	
...	...	Sand (?)	34.19	7-17-40	A	Measuring point, top of casing, 0.6 foot above surface.
...	...	....	.....	....	D	
...	...	....	.....	....	D	
...	...	....	32	9-45	DS	
...	...	....	15	1944	D	
...	...	....	.....	....	DS	
...	...	....	.....	....	D	
...	...	....	25	8-19-46	S	
100	70	Gravel and sand	32.47	7-10-40	T	City test hole. Measuring point, top of casing flush with surface. See log.
...	...	....	.....	....	D	
...	...	....	.....	....	D	Supplies municipal tourist camp.
...	...	....	.....	....	D	
...	...	....	.....	....	DS	

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
19ba2	D.G. Radcliffe	Frank O'Neil	1923	Drilled	165	3 to 2
19bd	Fargo Country Club	Carl Larson	1917	...do..	165	4
19ca	J.J. Scouler	....	....	...do..	165	2
19cc	M.T. Moen	....	....	...do..	...	..
20cac	Mrs. Esther Ogren	Savageau	....	Drilled and Bored	230	18 to 2
20dca	Mrs. Mabel Belsly	....	....	Drilled	...	2
21aad	Concordia College	....	....	...do..	167	2
21ccc	Alfred Johnson	....	1906	...do..	147	2
22ccc1	Larson Bros.	....	1885	...do..	190	3
22ccc2	....do....	Chris Miller	1946	Jetted	183	3
23aaa	Rudolph Peterson	....do....	1927	Drilled	182	3
23dcc	Roy Martin	....do....	1928	...do..	100	..
24bab	H.J. Quick	....	....	...do..	300	..
24cbb	Lloyd Kreps	....	....	...do..	...	..
25aaa	W.H. MacGregor	....	....	...do..	280	2
25bbb	Ben Holm	....	....	...do..	196	2
26bda	Oscar Olsen	....do....	1922	...do..	205	..
28abb	N.E. Roberts	Carl Larsen	1921	...do..	180	..
29dbb	Mrs. Videen	Chris Miller	1940	Jetted	290	2
30add	Geo. Menrik	Hansen	1914	Drilled	180	4
30ba	Gus Lemke	Carl Larsen	1938	...do..	280	4 to 3
30bc	Mrs. Tom Hansen Est.	....	1925	...do..	80	15
30bd	Gus Lemke	....	....	...do..	...	$3\frac{1}{2}$
30daa	A.M. Melgard	G. Haaland	1940	Jetted	146	3
31ccc	Frank Johnson	Savageau	1920	Bored	117	20
32abb	P.O. Johnson	....	1911	Drilled	162	3 to 2
32caa	Mabel Edlund	....	....	Jetted	160	..
34bbc	Emil Lambert	Chris Miller	1923	Drilled	182	$2\frac{1}{2}$
36baa	Merle Allen	G. Haaland	1941	...do..	143	3
139-49						
1acc	USGS test hole	....	1947	...do..	190	5
1bab	Great Northern R.R.	....	....	....	365	..
1bad	USGS test hole	....	1947	Drilled	200	5

Principal Aquifer						
Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	....	.....	....	DS	
...	...	....	.....	....	D	
...	...	....	.....	....	DS	
...	...	....	.....	....		
...	...	....	45.6	8-20-46	DS	Measuring point, pump base on top of 2-inch plank cover, 1.0 foot above land surface.
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	A	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	....	.....	....	DS	
...	...	Sand	30	1940	DS	
...	...	....	.....	....	DS	
...	...	Gravel	24	1939	DS	
...	...	.....do.....	15	1939	DS	
...	.....	....	23.35	7-23-40	DS	Measuring point, top of casing west side, 0.8 foot above surface.
...	....	....	50	1940	D	
...	...	....	.....	....	DS	
...	...	....	60	7-45	DS	
...	...	....	.....	....	DS	
...	...	....			DS	
133	10	Gravel	12	1-41	DS	
...	...	....	.....	....	H	See log.
...	...	....	.....	....	A	Do.
...	...	....	.....	....	H	Do.

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
1bb	Davis Lewis	....	1940	Bored	25	8
1bbb	USGS test hole	....	1947	Drilled	190	5
1bcd	.....do.....	....	1947	...do..	220	5
1bdd	.....do.....	....	1947	...do..	190	5
1cb	Peter Swanson	....	....	Dug	26	18
1cbb	USGS test hole	....	1947	Drilled	225	5
1cbc	Fargo City test hole	....	....	....	202	...
1cbd1	City of Fargo	....	....	...do..	192*	2
1cbd2	.....do.....	....	....	...do..	200	24
1cc	Mrs. Julie Smith	Marchand	1924	Bored	45	18
1cca	Fargo City test hole	....	....	Drilled	201	...
1ccd1	.....do.....	....	....	...do..	417	...
1ccd2	.....do.....	....	....	...do..	196	8
1cd	Cass County	....	....	...do..	150	...
1cdc	.....do.....	....	....	....	251+	...
1cdd	Old well	....	....	....	252	...
1dca	.....do.....	....	....	....	250	...
1dcc	.....do.....	....	....	....	240	...
2aa1	David Bossart	Carl Larson	1933	...do..	140	3
2aa2	....	....	....	...do..	140	3
2aa3	Leonard Hobbs	....	....	Dug	22*	42
2aa4	R. Kirkevold	Marchand	1933	Bored	45	18
2aa5	Paul Baker	....	....	...do..	28	18
2aa6	Albert Hoiland	....	....	....	...	...
2aa7	Pauline Moe	....	....	....	...	...
2aa8	Alpha Bjerken	....	....	...do..	22*	18
2aa9	Mrs. Maleock	....	....	Dug	17*	36
2aa10	Kenneth Olson	....	....	...do..	12*	...
2aa11	L.R. Valley	....	1928	Bored	35	8

Principal Aquifer						
Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	....	....	....	A	
...	...	....	....	....	H	See log.
...	...	....	....	....	H	Do.
...	...	....	....	....	H	Do.
...	...	....	....	....	A	
...	...	....	....	....	H	Do.
...	...	....	....	....	T	Do.
...	...	....	26.68	7- 8-40	T	Measuring point, top of casing, 3.2 feet above surface. See log, water-level data and chemical analysis.
...	...	....	....	....	M	City supply well.
...	...	Sand	....	....	S	
...	...	....	....	....	T	See log.
...	...	....	....	....	T	Do.
...	...	....	29.04	7- 8-40	T	Measuring point, top of casing flush with surface. Equipped with water-stage recorder. See log.
...	...	....	....	....	D	
...	...	....	....	....	A	See log.
...	...	....	....	....	A	Do.
...	...	....	....	....	A	Do.
...	...	....	.....	....	A	Do.
...	...	....	30.29	7- 8-40	D	Measuring point top of casing.
...	...	....	....	....	D	Supplies about 20 families.
...	...	....	17.06	7-31-40	A	Measuring point, top of 2 by 8-inch plank on west side, 0.5 foot above surface.
...	...	....	....	....	S	
...	...	....	....	....	D	See chemical analysis.
...	...	....	....	....	D	
...	...	....	....	....	A	
...	...	....	12.59	6-20-41	A	Measuring point, top of wood cover, at surface.
...	...	....	11.36	6-20-41	A	Measuring point, top of curbing at surface.
...	...	....	10.00	6-20-41	A	Measuring point, top of wood cover, 1.0 foot above surface.
...	...	....	....	....	D	

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth1/	Diameter (inches)
2aal2	Carl Moen	....	....	Bored	19*	6
2aal3	Thomas Thompson	....	....	Dug	30	24
2aal4	O.L. Dahley	Dahley and Beauchamp	1941	...do..	28*	9
2aal5	L.D. Benson	....	1929	...do..	...	...
2aal6	Olaf Kvitte	....	1922	Bored	20	7
2aal7	Fred Bossart	....	....	Drilled	160	...
2adl	Elmer Boddy	....	....	Dug	...	...
2ad2	Geo. E. Fowler	....	1930	...do..	22	10
2ad3	A.R. Sutter	....	....	...do..	...	...
2ad4	H.R. Kollman	Savageau	....	Drilled	115*	5½
2addl	Brudevald	Julius Fugere	1947	Jetted	168	3
2aad2	Sam Clemenson	.....do..	1947	...do..	162	3
2baa	USGS test hole	....	1947	Drilled	292	5
2bd	Pederson Bros.	....	1931	Dug	20	36
2ca	Clifford J. Johnson	....	....	...do..	20*	48
2dbb	Fargo City test hole	Layne-Western Co. of Minn.	1940	Drilled	155*	1½
3aa	John Preboske	Marchand	1941	Bored	35	24
3adl	Roland Tougas	...do...	1941	...do..	30*	24
3ad2	Ernest Fricke	...do...	1941	...do..	34	18
3ccc	USGS test hole	....	1946	Drilled	367	5
4aa	Gus Torkelson	....	....	...do..	120	2
4ac	.....do.....	....	....	...do..	119	2
4ccc	USGS test hole	....	1946	...do..	260	5
4dcl	E.W. Benton	....	....	...do..	115	2
4dc2	F. Fuller	Carl Larson	....	...do..	...	...
4dc3	Geo. Thoemke	....do....	1931	...do..	145	3
4dc4	Oscar Euren	....do....	1936	...do..	135	3
4dcc	Dahl	....do....	....	....	145	...
4ddl	E.W. Trapp	....	1938	Dug	18	42
4dd2	Joe Pearl	....	....	Drilled	135	...
4dd3	W.D.A.Y., Inc.	Savageau	1932	...do..	94	4
5aaa	USGS test hole	....do....	1947	...do..	240	5
5cc	Armour & Co.	....do....	1922	Bored	100	24 to 18

Principal Aquifer

Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	....	12.63	6-20-41	A	Measuring point, top of curbing, 0.4 foot above surface.
...	...	....	......	....	D	
22	2	Sand	11.19	6-20-41	A	Measuring point, top of curbing, 1.5 feet above surface.
...	...	....	......	....	A	
...	...	....	......	....	S	
...	...	....	......	....	DS	
...	...	....	......	....	A	
...	...	Gravel	......	....	A	
...	...	....	......	....	D	
...	...	....	36.63	10- 8-40	A	Measuring point, top of cast iron pipe, 2 feet above surface.
140	28	Sand and sandy gravel	40	5-47	D	
150	12	Sand	42	5-47	D	
...	...	....	......	....	H	See log.
...	...	....	......	....	S	
...	...	Sand	12.79	6-23-41	S	Measuring point, top of wood curbing, 0.5 foot above surface.
133	23	Medium to coarse sand	17.06	11-30-40	T	Measuring point, top of casing, 1.3 feet above surface. See log.
...	...	Sand	......	....	D	
...	...	.....do....	9.55	6-23-41		Measuring point, top of curbing, 0.3 foot below surface.
...	...	.....do....	......	....	D	See chemical analysis.
...	...	....	......	....	H	See log.
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	H	Do.
...	...	....	35	1941	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	12	1941	DS	
...	...	....	......	....		Do.
...	...	....	......	....	D	
....	...	....	......	....	DS	
...	...	....	......	....	D	
...	...	....	......	....	H	Do.
100	...	Sand	......	....	M	

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth1/	Diameter (inches)
5dcd	USGS test hole	....	1947	Drilled	220	5
6ab1	Balthauser & Mayer	....	1934	...do..	112	2
6ab2	Union Stock-yards	McCarthy Well Co.	1935	...do..	240	24
6ac	.....do.....	.....do.....	1935	...do..	236	8
6ad	.....do.....	.....do.....	....	...do..	230	8
6baa	Union Stockyards test well A	.....do.....	1945	...do..	227	8
6bcc	Union Stockyards test well B	.....do.....	1945	...do..	192	8
6cd	Union Stockyards	.....do.....	1935	...do..	200	6
7aa1	John Rausch	Frank McCumber	1938	...do..	106	2
7aa2	G.R. Taylor	Carl Larson	1939	...do..	105	3
7aa3	Fred Cederberg	.....do.....	1940	...do..	161*	3
7aa4	W.A. Francis	Savageau	1920	Drilled and Bored	150	18 to 8
7ab	G.R. Taylor	Geo. Griffin	1939	Drilled	126	2
7ad1	Neal Rausch	Frank MCCumber	1940	...do..	258	2
7ad2	L.R. Leopard	....	1935	Bored	...	18
7da1	Wm. Greison	Carl Larson	1940	Drilled	175	3
7da2	Harold Peterson	.....do.....	1938	...do..	190	3
7da3	H.O. Mannes	.....do.....	1939	...do..	195	4
7da4	Joe Schekall	.....do.....	1940	...do..	276	3
8ba1	West Fargo School Dist. 6	Marchand	1939	...do..	162	6
8ba2	Sukut	....	....	...do..	87*	3½
8ba3	Joe Marlow	....	....	Bored	70	14

Principal Aquifer						
Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	....	......	....	H	See log.
...	...	....	......	....	S	
...	...	....	35.60	7-17-40	DS	Measuring point, bottom edge of pump base 17.5 feet below surface. See log and chemical analysis.
...	...	....	21.55	12-25-37	S	Measuring point, concrete shoulder of pump base, 7.4 feet below surface See log.
...	...	....	37.32	7-17-40	T	Measuring point, top of casing, 0.4 foot above surface. Equipped with water-stage recorder. See log.
...	...	....	......	....	T	See log.
...	...	....	......	....	T	Do.
...	...	....	36	9-26-40	DS	Measuring point, land surface.
...	...	....	......	....	D	
...	...	Sand	......	....	D	
...	...	Gravel and sand	36.32	7-27-40	D	Measuring point, top of extended iron casing, 3.0 feet above surface.
...	...	Gravel	30	1941	DS	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	26	9-38	D	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	30.35	7-27-40	A	Measuring point, top of casing, 0.7 foot above surface.
...	...	....	......	....	I	Used for automobile radiators only.

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
8ba4	Mrs. Margaret Forsberg	McCumber & Stafford	1939	Drilled	85	4
8bba1	C.J. Ferch	Dakota Artesian Well Co.	1937	...do..	132	10
8bba2	.....do.....	McCarthy Well Co.	1940	...do..	136	10
8bb1	Elmer Sukut	....	....	...do..	100	4
8bb2	Floyd Sumpter	Carl Larson	1939	...do..	119	4
8bb3	Joe Hanisch	Savageau	1927	Bored	100	15
8bb4	Floyd Sumpter	Carl Larson	1940	Drilled	...	4
8bb5	....	....	....	...do..	76*	...
8bb6	Lyman Stafford	Frank McCumber	1937	...do..	106	2
8bb7	Eugene Loberg	McCumber & Stafford	....	...do..	84	4
8bb8	Daniels	....	....	...do..	...	...
8bb9	Axel Anderson	Frank McCumber	1940	...do..	96	4
8bb10	Helmer Berger	.....do.....	1936	...do..	82	4
8bb11	Mrs. Celia Nelson	.....do.....	1932	...do..	102	4
8bb12	Wm. Pierson	.....do.....	1940	...do..	...	...
8bc	O.N. Enger	.....do.....	1935	...do..	108	4
8ccc	H.C. Berger	.....do.....	1941	...do..	107	2
8dd	A.H. Meyer	Marchand	1938	...do..	160	6
9dd	Car Robanus	....	....	...do..	120	2
10bbb	R. A. Barfuss	Julius Fugere	....	Jetted	...	...
10bc	Mrs. C.H. Perritt	....	.....	Drilled	...	...
10ccc	Tom McDermott	....	1938	...do..	123	...
11aaa	Northern Pacific R.R.	....	1947	...do..	170	...
11abb	M.C. Hawn	Marchand	1941	Bored	90	18
11ba	Aaron Kenward	Carl Larson	....	Drilled	160	3
11cd	Carl Ostwald	.....do.....	1937	...do..	309	4
11dc1	Albin Olson	....	1939	Bored	14*	12
11dc2	Solomon Heldt	....	1939	Dug	17*	36 x 48
11dc3	F. Palm	....	....	...do..	13*	36 x 36
12ac1	H. Benson	....	....	Drilled	175	4

Principal Aquifer						
Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	....	....	....	D	
95	37	Coarse sand	41	9-17-41	M	
95	41	.....do.....	41	9-17-41	M	
...	...	....	....	....	D	
...	...	....	....	....	D	
95	...	Sand	36	....	D	
...	...	....	34.64	7-27-40	D	Measuring point, top of extended casing, 2.25 feet above surface.
...	...	....	32.61	7-27-40	D	Measuring point, top of sheet iron casing north side, level with surface.
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	Sand	......	....	D	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	D	
...	...	....	......	....	DS	
...	...	....	......	....	D	
...	...	....	......	....	I	See log.
...	...	....	12	1941	D	
...	...	....	......	....	A	
...	...	Sand and gravel	28	1939	DS	
...	...	....	10.96	7-10-40	S	Measuring point, top of wood cover, 1.4 feet above surface.
...	...	Quicksand	12.46*	7-10-40	DS	Measuring point, top of curb, north side, 1.5 feet above surface.
...	...	....	10.50*	7-10-40	S	Measuring point, top edge at wood curb, east side 0.9 foot above surface.
...	...	....	27.18	7- 3-41	A	Measuring point, top of casing, 0.72 foot below surface.

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
12ac2	H. Benson	....	....	Drilled	152*	2
12acb	Fargo City old well	....	....	...do..	210	...
12bab	Fargo City test hole	....	....	...do..	190	...
12bb	Anna C. Pederson	Carl Larson	1931	...do..	154	4
12ca1	Charles Roberts	....	1922	...do..	192	3
12cac	Fargo City old well	....	....	...do..	216	...
12cad	Merchants Nat. Bank & Trust Co.	McCarthy Well Co.	1937	...do..	205	8
12cc	A.C. Rose	....	1928	...do..	100	3½
12cd	Ellen Shinn	Frank O'Neil	1926	...do..	176	3 to 2
12dcb	Fargo City test hole	....	....	...do..	232	...
13aa1	G.R. Addyman	Carl Larson	1940	...do..	163	4
13aa2	T.O. Strand	Hildreth	....	...do..	173	...
13abc	USGS test hole	....	1947	...do..	200	...
13ba	R.D. Chowning	Carl Larson	1940	...do..	110	3
13bc1	Hilma C. Johnson	Beckstrom	....	...do..	221*	3
13bc2	.....do.....	.....do.....	....	...do..	...	...
13bc3	.....do.....	Frank O'Neil	....	...do..	...	...
13da	C. Bohnsack	....	....	...do..	...	3
14ad	M.A. Wilks	....	....	...do..	...	...
14bb	Geo. Fowler, Inc.	....	....	...do..	140	3
17aa	Max C. Tyler	Carl Larson	1939	...do..	130	3
17cc	Frank Beaton	McCumber	....	...do..	172	4
18aa	Reuben Simpson	Marchand	1938	...do..	196	6
18cdc	Mrs. Malley Beaton	Frank O'Neil	1923	...do..	150	3
19ad	Milton Loberg	....	1924	...do..	112	4 to 3
19da	Herman Heiden	....	1939	...do..	108	4
20ba	Almklov	McCumber	....	...do..	83*	4
20bb	Ole Rustad	.....do.....	1934	...do..	180	4 to 3
20cc	Henry Loberg	.....do.....	1935	...do..	107	4

COUNTIES, NORTH DAKOTA AND MINNESOTA (con't)

Principal Aquifer						
Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	....	32.4	7- 3-41	A	Measuring point, top of casing, 0.2 foot above surface.
...	...	....	......	....	A	See log.
...	...	....	......	....	T	Do.
...	...	....	......	....	D	
...	...	....	......	....	DS	
...	...	....	......	....	A	Do.
...	...	....	38.72	7- 8-41	DS	Measuring point, top of concrete rim, west side, 1.8 feet above surface. See log.
...	...	....	......	....	W	Used only for garden.
...	...	....	......	....	DS	
...	...	....	......	....	T	See log.
145	18	Sand	......	....	D	Water temperature 47° F.
...	...	....	......	....	D	
...	...	....	......	....	H	See log.
...	...	....	......	....	DS	
...	...	....	21.04	7-22-40	A	Measuring point, top of casing, 1.0 foot above surface.
...	...	....	......	....	S	
...	...	....	......	....	A	
...	...	....	......	....	D	
...	...	....	......	....	Ds	Water temperature 45° F.
...	...	....	......	....	DS	
...	...	....	......	....	D	
...	...	....	......	....	D	Water temperature 48° F.
...	...	Sand	30	1938	DS	Water temperature 45° F.
...	...	....	......	....	DS	
...	...	Gravel	14	1939	D	
...	...	....do.....	14	1939	D	
...	...	....	40.74	7-25-41	A	Measuring point, top of casing west side, 1.3 feet above surface. Inadequate water supply.
...	...	....	18	1939	D	
...	...	Gravel	14	1939	DS	

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
21aa	A.H. Barnes	Carl Larson	1936	Drilled	148	3
21cd	Axel Johnson (tenant)	....	1938	...do..	170	3
22aa	E.G. Clapp	Carl Larson	....	...do..	117	...
22ba	Mrs. P.J. Welsh	McCarthy Well Co.	....	...do..	207	8
23ba	Roy Smith	....	1925	...do..	160	4
24aa	W.W. Wallwork	....	....	...do..	...	2
24ba	E.F. Alford	....	1930	...do..	...	3
24cb	Sandford Johnson	Carl Larson	1919	...do..	155	3
24da	Sam Chessley	....	....	...do..	...	3
25ba	Willy Lemke	....	1927	...do..	154	3
26aa1	Wm. Horstman	Carl Larson	1935	...do..	130	4
26aa2	.....do.....	....	....	Dug	...	...
27aad	Mrs. Emerson Smith	....	....	Drilled	176	...
29bdd	Ole Loberg	Hagman	1924	...do..	235	4 to 3
29cba	O.T. Lawton	McCumber	1936	...do..	100	3
29cca	Carl Houkom	.....do.....	1933	...do..	109	4
29ccd	W.F. Kreiselmaier	.....do.....	1934	...do..	96	4
30bad	Kiel Bros.	Selvig	1920	...do..	90	4
31ddd	A.P. Martin	Carl Larson	1925	...do..	106	...
32aca	John Beach	....	....	...do..	140	3
32bba	C.C. Furnberg	Frank O'Neil	....	...do..	185	...
34da	A.A. Albertson	Carl Larson	1938	...do..	135	3
35baa	Mrs. Mary C. Casler	Frank O'Neil	1920	...do..	140	2
36aad	Don Burritt	....	....	...do..	115	3
36dab	Frank Bergmann	....	....	Bored	87	18
139-50						
1ddd	USGS test hole	....	1946	Drilled	260	5
2aaa	August Swanson	John Larson	1910	...do..	250	2
2ddb	A.P. Gress	Julius Fugere	1940	Jetted	170	20 to 4
2ddc	.....do.....	.....do.....	1939	...do..	265	20 to 4
3ddd	Archie Libbrecht	Independent Drilling Co.	1945	...do..	126	3
4ddd	Chas. Thompson	....	....	Bored	60	42

Principal Aquifer						
Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	Gravel	20	1939	DS	
...	...	....	20	1939	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	See chemical analysis.
...	...	Gravel	35	1939	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	32.29	7-23-40	DS	Measuring point, top of casing, north side, 0.5 foot above surface.
...	...	Sand	24	1939	DS	
...	...	....	....	....	DS	
...	...	....	....	....	A	
...	...	....	....	....	DS	
...	...	....	6	9- 1-41	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	D	
...	...	....	....	....	D	
...	...	....	....	....	S	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	D	
...	...	....	....	....	D	
...	...	....	....	....	H	See log.
...	...	....	....	....	DS	
...	...	....	12	- 1940	S	
...	...	....	34.55	4- 2-46	DS	Measuring point, base of pump, 5.82 feet below surface.
...	...	Fine sand	15.29	4- 9-46	D	Measuring point, casing, 0.4 foot above surface.
...	...	....	20.50	4- 9-46	DS	Measuring point, top of plank at top of casing, 1.5 feet above surface.

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1/]	Diameter (inches)
5ccc	USGS test hole	....	1946	Drilled	329	5
5cda	Wayne Cross	Marchand	....	Bored	63	18 to 8
5cdd1	.....do.....	....	....	Jetted	450	3
5cdd2	.....do.....	....	....	...do..	150	...
5cdd3	.....do.....	....	....	Bored	65	18
6bbb	USGS test hole	....	1947	Drilled	314	5
8cbb	E. Gauffin and Thompson	....	....	Dug	45	...
8dcc	A.R. Utke	....	....	Bored	...	20
9abb	Gladys Moe	....	....	....	...	...
11bba	Archie Libbrecht	Julius Fugere	1936	Jetted	177	3 to 2½
11bbb	USGS test hole	....	1946	Drilled	309	5
13baa	Kenneth Pyle	....	....	...do..	80	2
17abb	Lester Morris	Hildreth	1939	Jetted	76	...
18bcc	Albert Lindsey	Marchand	....	Bored	67	36
24dd	J.E. Gaard	....	1931	Drilled	115	3
25bbb	Margaret Skicke	Savageau	1926	Bored	60	24
25ddc	E.W. Hartman		1923	Drilled	100	...
31bbb	Laurence Kraft	....	....	Bored	50-60	...
36bdd	Minnie Miller Foltz	Rean	1923	Drilled and bored	93	15 to 6
139-51						
1ddd	H.J. McGuire	....	....	....	...	...
4cdd	USGS test hole	....	1946	Drilled	419	5
5abb	J.R. Askew	....	....	Dug	40	48
6ddc	USGS test hole	....	1946	Drilled	402	5
7cbb	J.S. Dalyrymple	....	1925	Jetted	320-330	...
8baa	.....do.....	....	....	Dug	70-80	36
10cad	Arnold Gohdes	....	....	...do..	25	3
10daa	Ralph Gibson	....	....	Jetted	100-200?	3
11bbb	USGS test hole	....	1946	Drilled	349	5
12ada	A.L. Eggert	....	....	....	...	...
14ada	John Ellison	....	....	....	...	...
14bbb	Jack Waltz	....	....	Jetted	420	...
15bab	D.A. Malstrom	Dakota Artesian Well Co.	....	Drilled	382	...
18cbb	J.S Dalrymple	....	1927	Jetted	120	4
19add	John Yunker	....	....	...do..	100	3

Principal Aquifer

Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	....	......	....	H	See log.
...	...	....	14	4- 9-46	DS	
...	...	Sand	14	4- 9-46	A	
...	...	....	......	....	A	
...	....	....	14	4- 9-46	A	
...	...	....	......	....	H	Do.
...	...	....	4	4- 45	DS	
...	...	....	12-14	4-15-46	DS	
...	...	....	......	....	DS	
...	...	Sand	17	1936	DS	
...	...	....	......	....	H	Do.
...	...	....	......	....	S	
...	...	....	18.26	4-15-46	DS	Measuring point, top of casing, 1.5 feet above surface.
...	...	....	......	....	S	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	S	
...	...	....	......	....	DS	
...	...	....	......	....	..	
...	...	....	......	....	H	See log.
...	...	....	20	11- 6-46	S	Do.
...	...	....	......	....	H	Do.
...	...	....	2	11- 5-46	DS	
...	...	....	......	....	D	
...	...	....	14.97	4-10-46	DS	Measuring point, top of concrete reservoir, level with surface.
...	...	Quicksand	40	10-31-46	DS	
...	...	....	......	....	H	See log.
...	...	....	......	....	..	
...	...	....	......	....	DS	
...	...	....	2	10-31-46	DS	
...	...	....	2	10-31-46	DS	
...	...	....	2	10-23-46	DS	
...	...	....	13	10-30-46	DS	

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
19ccd	Ed Olson	....	1937	Jetted	400	...
20abb	Frank Lynch Co.	....	....	...do..	300	...
22baa	D.A. Malstrom	Dakota Artesian Well Co.	....	Dug	58	42
26aaa	Glen Simpson	....	....	Jetted	85	48
27ccc	C.E. Gust	......do....	1946	...do..	186	3 to 2
29cbc	R.A. Reynold	....	....	....	84	...
30cbd	H.A. Miller	....	1925	...do..	400	...
30daa	Dennis Schultz	Adair	....	...do..	87	6
31bbd	Richard Baumgarten	Dakota Artesian Well Co.	1936	...do..	312	3 to 1½
31ccb	Evald Bucholtz	....	....	Dug	75-100	...
34dda	Carl Gust	Tim Hicks	1933	Jetted	340	2
35aaa	R.F. Miller	Savageau	....	Bored	...	24 to 18
36cbb	.....do.....	....	....	Dug and jetted	90	...
139-52						
1cbb	Dalrymple	....	....	Jetted	400	...
2aba	Ed. Wohnar	....	....	...do..	200	3
2baa	E.W. Bautz	....	1936	Bored and jetted	180	...
2ccc	USGS test hole	....	....	Drilled	400	5
3baa	Dalrymple	....	....	Jetted	300-350	...
4aaa	Joseph F. Langer	....	....	...do..	300	2
9daa	Ed. Neisemeyer	May	1893	...do..	290	2
10adc	G.F. Weber	Mike Crutkon	1917	...do..	400	2
11bcc	Joe King	....	....	Bored and jetted	250	24
12cbb	J.S. Dalrymple	....	1931	Jetted	330	3
13bcb	Ernest Pietsch	....	1934	...do..	300-400	...
14ada	Edwin Pietsch	....	....	...do..	...	...
15aaa	Edward Sellant	....	....	...do..	...	...
15abb1	E.L. Weber	....	....	...do..	400	2½

Principal Aquifer

Depth to top	Thickness	Material	Depth to water 2/	Date of measurement	Use 3/	Remarks
...	...	....	......	....	DS	
...	...	....	......	....	D	
...	...	....	40	10-31-46	DS	
...	...	....	20	10-31-46	D	
...	...	....	9	1946	DS	
...	...	....	15	10-24-46	DS	
...	...	....	......	....	DS	
...	...	....	28	1945	DS	
...	...	....	2	10-23-46	DS	
...	...	....	19.2	10-23-46	DS	Measuring point, top of wood cover, 1.5 feet above surface.
...	...	Quicksand	......	....	DS	Water level, reported 1.0 foot above surface 10-30-46.
...	...	....	35.40	10-31-46	DS	
...	...	....	20	10-31-46	S	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	H	See log.
...	...	....	3	11-31-46	S	
...	...	....	4	11-13-46	DS	
...	...	....	4	10-17-46	DS	
396	4	Medium sand, coarse	3	10-17-46	DS	
...	...	....	......	....	DS	
...	...	....	2	11- 6-46	DS	
...	...	....	2	10-23-46	DS	
...	...	....	......	....	DS	
...	...	....	9.27	10-21-46	S	Measuring point, top of wood platform, level with surface.
...	...	....	3.5	10-21-46	DS	

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
15abb2	E.L. Weber	Dakota Artesian Well Co.	....	Drilled	300	3
15abb3	.....do.....	Meinke	....	Bored	53	18
22daa	Victor Roesler	....	1942	Jetted	150	3
23bbb	Paul Schultz	Dakota Artesian Well Co.	....	...do..	417	...
25ddc	J.S. Dalrymple	Hachberger	1944	...do..	400	4
26bcc	Frank Nilles	Dakota Artesian Well Co.	1932	...do..	380	...
27daa1	Clayton Runck	....	....	....	40-50	...
27daa2	.....do.....	....	....	...do..	...	...
33aaa	Donald Mc-Intire	....	....	...do..	400-450	...
34bbc	Carl Statsman	Lockhart	....	...do..	60	6
36bdd	Herbert Bucholtz	....	....	Dug	18	...
36cba	Richard Hildebrand	Dakota Artesian Well Co.	1933	Jetted	350	2
36dcd	Geo. Bucholtz	....	....	Driven	30	1½
139-53						
10bba	USGS test hole	....	1946	Drilled	608	5
140-48						
2aba	A. Bergland	Carl Larson	1930	...do..	163	3
3aab	L.F. Sinner	John Sorby	....	Jetted	132	...
3bab	Norman Sorby	Carl Larson	1933	...do..	152	...
4aaa1	John Sorby	John Sorby	....	Drilled	200	...
4aaa2	.....do.....	Mike Steen	....	...do..	150	...
4cbb	....	....	....	....	...	3
6caa	Ingri Stansland	.....do...	1917	...do..	132	2
8bbb	Charles Peterson	....	1933	...do..	144	3
10add	Herman Jorgenson	....	....	...do..	125	2
10ccb	C.R. Jacobson	.....do.....	....	....	...	3
11ccc	Carl Wiederick	....	....	Jetted	84	...

COUNTIES, NORTH DAKOTA AND MINNESOTA (con't)

Principal Aquifer

Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	....	3	10-21-46	S	
...	...	....	......	....	S	
...	...	....	50	10-22-46	DS	
...	...	....	4	10-22-46	DS	
...	...	Fine sand	6	10-23-46	DS	
...	...	....	4	10-22-46	DS	
...	...	....	......	....	D	
...	...	....	3	10-22-46	DS	
...	...	....	2	11-13-46	DS	
...	...	....	20	10-22-46	DS	
...	...	Quicksand	16	10-23-46	S	
...	...	....	20	10-23-46	S	
...	...	Fine sand	18	10-23-46	DS	
...	...	....	Flow	....	H	Outside of area of report. See log.
...	...	....	......	....	DS	
...	...	....	16	8- 7-46	DS	
...	...	....	......	....	DS	
...	...	....	......	....	D	
...	...	....	......	....	S	
...	...	....	20.25	7-19-40	A	Measuring point, top of casing, 0.9 foot above surface.
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
12ccc	Gilbert Kassenborg	....	....	Drilled	136	3
13cdc	M.F. Tex	Carl Larson	...	...do..	125	...
14bcc	Albert Johnson	....	...	Jetted	152	...
15bcb	Edwin Melby	....	...	....	...	4
15daa	Litz	Larson Bros.	...	...do..	165	3
16aba	Mrs. Fred Knuth	Hansen	...	Drilled	207	2
17dcc	Acme Dairy	....	...	...do..	180	3
17ddc	Lew Stensland	....	...	...do..	...	...
18bab	Wm. Speers	Carl Larson	...	...do..	133	3
18bcb	A.S. Larson	.....do.....	1932	...do..	150	...
18ccd	Alfred Bekkerus	A.T. Bekkerus	1917	...do..	137	3
19abd	Fred Fischer	....	1933	...do..	...	...
19ad	Paul Utke	....	....	Dug	33*	60
19baa	Olaf Hokonson	Pete Stoberg	1941	Drilled	200	2
20ad1	City of Fargo	....	1937	...do..	160	2½
20ad2	.....do.....	....	....	...do..	160	1½
20bba	Almer Rice	Carl Larson	1940	...do..	148	3
20bbb1	N.E. Anderson	.....do.....	1938	...do..	114	3
20bbb2	T.A. Gallagher	Joe Macott	1936	Bored	110	18
21bbb	McCann Bros.	....	....	...do..	106	18 to 12
21cac	Ray Gasell	Larson Bros.	....	Jetted	140-148	...
21cbb	Geo. Anderson	Olsen	1936	Drilled	94	2
21cca1	E.M. and J.I. Probstfield	Carl Larson	....	...do..	200	...
21cca2	Ray Gasell	Larson Bros.	....	Jetted	180	...
21cdb	.....do.....	Carl Larson	....	Drilled	210	...
22aaa	R.A. Rice	....	....	...do..	150	2
22ccc	John Lamb	.....do.....	....	...do..	160	3
22ddd	Dora Martin	....	....	...do..	150	2
23add	T.H. Hegland	....	....	...do..	...	...
23bcb	T. Bekkerus	....	....	...do..	150	2
23ddd	Andrew Gunderson	....	....	...do..	...	3
24ccc	A.S. Nelson	Hansen	....	...do..	160	6
25ccc	John Beatler	G. Haaland	1939	...do..	148	3
26cc	Vaughan Wagner	....	....	...do..	185	2
26dcc	John Lamb	Carl Larson	....	...do..	142	2
27ccc	John Filing	.....do.....	1938	...do..	209	3
27cdd	Frank Kimm Est.	....	....	...do..	200	...
29ab	F.H. Peterson	.....do.....	....	...do..	160	6
29dcd	Geo. Seastream	Severson	1937	...do..	240	2
30bc	Mrs. S.L. Yunker	....	1933	...do..	196	6

Principal Aquifer						
Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	....	....	....	DS	
...	...	....	....	....	D	
...	...	Fine sand	40	12- 45	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	S	
...	...	....	....	....	DS	
...	...	....	30.67	7-16-40	DS	
...	...	....	....	....	DS	
...	...	....	....	....	D	
...	...	....	....	....	D	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	76	1940	DS	
...	...	....	....	....	D	
...	...	....	....	....	S	
...	...	....	....	....	D	
...	...	....	....	....	D	
...	...	....	....	....	D	
...	....	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	41.27	7-19-41	A	Measuring point, top of casing, 1.1 feet above surface.
...	...	....	....	....	DS	
128	20	Sand	30	7- 39	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	....	....	DS	
...	...	....	60	1939	DS	
...	...	....	....	....	D	
...	...	....	18	1939	DS	

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth1/	Diameter (inches)
30cd	C.P. Vogel	....	1922	Drilled	150	6
31cbd	Fargo City old well	....	....	....	338	...
31cdb	Leonard Steeves	....	....	Bored	23	16
32aaa	American Crystal Sugar Co.	....	....	Drilled	265	...
32acc	J. Hall and C. Overby	Carl Larson	1945	Jetted	125	...
32bab	Amon Thorson	....	1929	Drilled	135	2
32bac	Mrs. S.O. Camp	....	1915	...do..	135	3
32bb	Mrs. Minnie Hector Smith	....	....	...do..	197	3
32bdd	P.C. Van Vlissingen	Matschenbacher	1913	...do..	137	2
32caa	John McCann	Carl Larson	1926	...do..	144	3
32cad	Oscar Christensen	....	....	Dug	15	48
32cbb1	City of Moorhead	McCarthy Well Co.	....	Drilled	190	6
32cbb2	.....do.....	....	....	...do..	131*	3
32daa	Norman Van Raden	....	....	Bored	20	12
32dab1	Mike Lamm	Carl Larson	1937	Drilled	110	3
32dab2	.....do.....	....	1931	Bored	109	...
32dbb	Norman Van Raden	....	1930	Dug	...	...
32dd	Ray Gasell	.....do.....	....	Drilled	368	...
34ccc1	Henry Olsen	....	....	...do..	...	3
34ccc2	T. and R. Grosz	Larson Bros.	....	Jetted	...	...
34ddd	Mrs. Ivy Ayler	....	....	Drilled	...	3
35ccc	Euland Mortgage Co.	Gus Haaland	....	...do..	105	3
36abb	F.W. Bolmeier	....	....	...do..	185	2
140-49						
1ddc	John Westlund	Frank O'Neill	1924	...do..	164	3 to 2

Principal Aquifer						
Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	....	20	1939	DS	
...	...	....	......	....	A	See log.
...	...	....	13	1941	A	
...	...	....	......	....	T	Do.
...	...	....	......	....	DS	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	A	Reported not enough water, very hard. Found snail and clam shells all the way down.
172	18	Sand	......	....	D	
...	...	....	36.44	7-17-40	A	Measuring point, top of concrete pump base 1.4 feet above surface.
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	......	....	S	
...	...	....	5.0	4-12-46	D	Measuring point, top of casing, level with surface.
...	...	....	......	....	D	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
99	6	Sand	20	9- 38	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
2acc	John Westlund	....	1911	Drilled	130	3 to 2
3daa	E.T. Conmy	....	....	...do..	300	...
5adb	Mickelson	Higman	....	Jetted	190	...
5add	Mrs. Wm. Shepherd	....	....	Drilled	200	3
5cab	A.W. Storley	....	1905	Bored and jetted	...	...
7ada	Henry Robanus	.....do.....	....	Jetted	60	2
7daa1	Arthur Waa	Albert Johnson	1940	Drilled	140	3
7daa2	.....do.....	John Larson	1902	...do..	142	2
9cdc	W.H. Shure	....	....	...do..	190	...
10bab	John Westlund	Albert Johnson	1911	...do..	110	2
11aad	Mrs. Auty	....	....	Dug	20	12 x 72
12acc	A.P. Harris	Carl Larson	1933	Drilled	148	6
13abc	Peter Sway	....	....	Dug	30	36 x 36
14ddd	Travelers Ins. Co.	Mike Steen	....	Drilled	...	...
15ddd	M.F. Steele	Marchand	1937	Bored	112	24 to 18
16cdd	USGS test hole	....	1947	Drilled	180	5
16daa	M.J. McGregor	....	....	...do..	130	3
17add	Olaf Quandt	Higman	....	Jetted	150	3
17ddd	Roy Landblom	Beckstrom	1900	Drilled	130	3
18ccc1	A. Selstedt	H. Hagmann	1923	...do..	180	3
18ccc2	Roy Landblom	Beckstrom	1900	...do..	136	3
19baa	Cora S. Hoglund	H. Hagmann	1928	...do..	140	3
19bcc1	Elmer Johnson	.....do.....	1938	...do..	124	3
19bcc2	Mrs. E.M. Nystrom	.....do.....	....	...do..	121	...
19caa	C.R. Landblom	A. Beckstrom	1914	...do..	165	...
20aaa1	USGS test hole	....	1947	...do..	154	5
20aaa2	Louis Thorson	....	....	...do..	129	5
20ddd	A.J. Anderson	.....do.....	....	...do..	135	2
21bba	USGS test hole	....	1947	...do..	165	5
21ccc	.....do.....	....	1947	...do..	180	5
21ddd	E. Olson and C.O. Bolgren	....	....	...do..	...	...
22cd	C. Hale	.....do.....	1925	...do..	...	...
23cd	Nels Johnson	....	1933	...do..	195	4 to 3
23dd	Axel Gustafson	....	....	...do..	...	3½

Principal Aquifer						
Depth to top	Thickness	Material	Depth to water2/	Date of measurement	Use3/	Remarks
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	Fine sand	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	12	9- 5-46	DS	
...	...	....	......	....	DS	
...	...	....	......	....	S	
...	...	....	39.77	9- 3-46	DS	Measuring point, top of casing, 2.0 feet above surface.
...	...	....	......	....	A	
...	...	....	......	....	S	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	......	....	DS	
...	...	....	30	1939	DS	
...	...	....	......	....	H	See log.
...	...	Sand	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	25	1939	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	A	
...	...	....	......	....	D	
...	...	....	......	....	H	Do.
...	...	....	......	....	DS	See chemical analysis.
...	...	....	......	....	DS	
...	...	....	......	....	H	See log.
...	...	....	......	....	H	Do.
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	Sand	3	1939	DS	
...	...	....	......	....	DS	

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
24cd	William Selck	Carl Larson	....	Drilled	142	4
24dd	Florence Gole (tenant)	....	....	Bored	...	24
25ab	Holy Cross Cemetery Assn.	.....do.....	1939	Drilled	...	...
25dcd	City of Fargo	Marchand	1936	...do..	105	6
26aa	K.F. Knopp	....	....	...do..	...	...
26ba	N.E. Brentzel	Carl Larson	1932	...do..	176	2
26dd1	Geo. Merrin	....	....	...do..	150	4
26dd2	.....do.....	....	....	...do..	150	3
27ad	Wayne Cockrill (tenant)	....	....	...do..	...	...
28ccc	USGS test hole	....	1947	...do..	200	5
28cc	Tessier Bros.	Marchand	....	...do..	...	...
28dd	Ancient Order United Workman	.....do.....	1939	...do..	126	4
29dcd	Tescher	J. Fugere	1941	...do..	130	4
30ab	F. Selberg	H. Hagmann	1933	...do..	120	3
30ba	Herman Rust	....	....	...do..	150	3
30dd	Nystrom Bros.	A. Beckstrom	1890	...do..	145	2
31aa	O.B. Quam	....	....	...do..	120	2
31ab1	Dr. A.J. Kaess	....	....	...do..	130	2
31ab2	Ed. Ornberg	....	1938	Dug	20	36 x 36
31ac1	Eugene Loberg	....	....	...do..	...	...
31ac2	Mrs. Ide Ostrom	Johnson Bros.	1918	Drilled	183	2
31db	C.E. Larsen	....	....	...do..	175	...
31dc	Oluf Kyllo	....	1906	...do..	172	3
32ad	O.B. Quam	H. Hagman	1932	...do..	110	3
32add	USGS test hole	....	1947	...do..	180	5
32bb	Mrs. Anna Quam	....	....	...do..	130	2
32cd	Goldberg Seed & Grain Co.	Carl Larson	....	...do..	98	4
32daa	Hector Estate	....	....	....	...	...
33cc	Carol Barnes	....	....	...do..	172	...
33ddd	USGS test hole	....	1947	...do..	173	5
34ca1	Harold Massey	....	....	Dug	19*	36 x 36

COUNTIES, NORTH DAKOTA AND MINNESOTA (con't)

Principal Aquifer

Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	Fine sand	......	....	DS	
...	...	....	......	....	S	
...	...	....	......	....	W	
...	...	....	......	....	D	See log. Hector airport well.
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	D	
...	...	....	......	....	H	See log.
...	...	....	......	....	DS	
...	...	....	......	....	DS	
110	20	Sand and gravel	42	1941	D	
...	...	Sand	20	1939	DS	
...	...	....	......	....	DS	
...	...	....	......	....	A	
...	...	....	......	....	DS	
...	...	....	......	....	D	
...	...	....	......	....	S	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	Sand	30	1939	DS	Water temperature 45° F.
...	...	....	......	....	H	See log.
...	...	....	......	....	DS	
...	...	....	......	....	D	
...	...	....	53.75	6-21-47	A	Measuring point, top of well casing, .5 foot above surface.
...	...	....	60	1944	DS	
...	...	....	......	....	H	See log.
...	...	....	17.00	7-11-40	S	Measuring point, top of wood curbing, east side, 0.8 foot above surface.

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth1/	Diameter (inches)
34ca2	Henry Palm	....	1926	Dug	18*	48 x 48
34cad1	.....do.....	J. Fugere	1942	Drilled	132	5
34cad2	Devenor	.....do.....	1942	...do..	142	5
34cd1	Adolph Guldrick	....	1939	Bored	...	...
34cd2	Lena Lund	Carl Larson	1934	Drilled	100	3
34cdd	USGS test hole	....	1947	...do..	210	5
35ba	A.L. Upperman	....	....	...do..	150	2
35ca	North Dakota State College	....	....	Bored	70*	36
140-50						
12cbb	Oscar Johnson	H. Hagmann	1920	Drilled	160	...
13cdd	Maple-Sheyenne Lutheran Church	.....do.....	....	...do..	...	3
19cbb	Nellie Dale	....	....	Bored	60	18
24add	Emil Bjorkmen	Beckstrom	1898	Drilled	227	2
24bcc	Mrs. G.P. Twitchell	....	....	...do..	...	...
24dcc	Mrs. W.O. Olsen	Marchand	1939	...do..	135	4
25aaa	S.P. Swisher	.....do.....	1938	...do..	134	4
25cdd1	G.W. Parmenter	.....do.....	1938	...do..	100	4
25cdd2	.....do.....	.....do.....	1924	Bored	85	18
26daa	Margaret Forsberg	H. Hagmann	1936	Drilled	208	3
31	Northern Pacific R.R.	....	....	Dug	20	48 x 48
31	School Dist. No. 7	....	....	Drilled	182	4
35ddd	Hagenwalker (tenant)	....	1937	...do..	110	...
36dcc	Ed Swanson	Anstedt Bros.	1935	...do..	120	2
140-51						
6ccc	Elmer Mallow	....	....	Dug	90-100	...

COUNTIES, NORTH DAKOTA AND MINNESOTA (con't)

Principal Aquifer						
Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	....	16.55	7-11-40	S	Measuring point, edge of wood curbing, east side, 0.5 foot above surface.
130	2	Gravel	41.40	6-13-47	D	Measuring point, top of casing, 7 feet below surface.
142	...	Gravel	36	1942	D	About 10 feet of sand above gravel.
...	...	....	......	....	S	
...	...	....	......	....	DS	
...	...	....	......	....	H	See log.
...	...	....	......	....	DS	
...	...	....	7.85	7-16-40	A	Measuring point, top of 2 x 12-inch board cover, 1.0 foot above surface.
...	...	....	......	....	DS	
...	...	....	......	....	D	
...	...	....	......	....	S	
...	...	....	18	1939	DS	
...	...	....	......	....	DS	
...	...	....	......	....	D	
...	...	....	12	1941	DS	
...	...	....	......	....	DS	
...	...	....	60	1939	DS	
...	...	....	20	1939	DS	
...	...	Sand	15	....	D	See chemical analysis.
...	...	Sand	16	....	D	Do.
...	...	....	......	....	DS	
...	...	....	20	1939	DS	
...	...	....	10.93	11- 6-46	DS	Measuring point, 1.0 foot above surface.

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
8ccc	George Howes	....	.....	Jetted	80-100	...
12cdd	Fred G. Walen	....	....	Dug	60	36
13dda1	H.S. Waxler	Marchand & Savageau	....	Bored	75	...
13dda2	.....do.....	.....do.....	....	...do..	100	...
17bbb	George Howes	....	....	Jetted	70-80	...
19ddd	.....do.....	....	....	...do..	80-100	...
22ccc	Lloyd Roden	Vern Honeyman	....	...do..	90	...
24dcd	Ralph Ruliffson	....	....	...do..	...	...
26ccd	O. Nelson	....	1945	Dug	35	...
27caa	John Cosler	J. Fugere	....	Bored	60	24
28ccb1	Leo Sinner	Marchand & Fugere	....	Bored and jetted	...	...
28ccb2	.....do.....	.....do.....	1946	Bored	68	24
29cbb	Ralph Grommesch	Ashton Lockhart	....	Jetted	40-50	...
30dcc	.....do.....	Savageau & Marchand	....	Bored	70	24
32ccc	Howard Nelson	....	1935	Jetted	290	...
33abb	Joe Kasowski	Ashton Lockhart	....	...do..	92	...
34ccd	USGS test hole	....	1947	Drilled	330	5
34cdd	J.S. Dalrymple	....	....	Dug	30	36
34daa	USGS test hole	....	1947	Drilled	350	5
35bba	Melvin Scherweit	....	1946	Dug	30	22
140-52						
3baa	Henry Woel	H.F. Chaffes	....	Jetted	350	3
10cdd1	Tobias Bender	....	....	...do..	...	...
10cdd2	.....do.....	....	....	Bored	...	18
10ddd	Wm. Radermacker	Savageau	....	...do..	80	24
12dbb	Roy Johnson	....	....	Jetted	360	6
13bdb	Ed Nesemeyer	....	....	...do..	300	...
14ada	Mrs. Anderson	O'Neil	1942	...do..	280	...
14dda	Art Hale	....	....	...do..	150	...
15dcc	Dayton Byram	Ashton Lockhart	....	Bored and jetted	...	...
22add1	John Sinner	....	....	Jetted	360	2
22add2	.....do.....	Albert Herber	1935	...do..	196	3

COUNTIES, NORTH DAKOTA AND MINNESOTA (con't)

Principal Aquifer						
Depth to top	Thickness	Material	Depth to water[2]	Date of measurement	Use[3]	Remarks
...	...	....	......	....	S	
...	...	....	......	....	S	
...	...	....	2	11-13-46	D	
...	...	....	3	11-13-46	S	
...	...	....	......	....	S	
...	...	....	......	....	D	
...	...	....	......	....	S	
...	...	....	......	....	DS	
...	...	....	......	....	S	
...	...	....	......	....	S	
...	...	....	......	....	DS	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	......	....	D	
...	...	....	2	11-12-46	DS	
...	...	....	12	11-12-46	D	
...	...	....	......	....	H	See log.
...	...	....	8.45	4-10-46	S	Measuring point, top of 2-inch board over well, 1.0 foot above surface.
...	...	....	......	....	H	See log.
...	...	....	......	....	S	
...	...	....	......	....	S	
...	...	....	......	....	D	
...	...	....	......	....	S	
...	...	....	25	11-13-46	DS	
...	...	....	20	11- 5-46	DS	
...	...	....	3	11- 6-46	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	16	11-13-46	DS	
...	...	....	......	....		
...	...	....	0.0	11-13-46	DS	

(See footnotes at end of table)

Location number	Owner or name	Driller	Year completed	Type	Depth[1]	Diameter (inches)
25ddd1	A.F. Sinner	....	....	Jetted	184	3
25ddd2	.....do.....	....	....	...do..	200	3
26ddd	Paul Bucholtz	....	....	Bored	140	...
27dcc1	Henry Woel	....	....	Jetted	110	3
27dcc2	.....do.....	A. Hawley	1914	...do..	310	2
30ddb	Eugene Kiefer	....	....	...do..	300-400	...
32bbd	L.J. Langer	....	....	...do..	300-375	...
34ccd	Wm. Johnson	....	....	...do..	...	...
35	City of Casselton (east well)	....	....	Drilled	298	16 to 6
35	City of Casselton (north well)	....	....	...do..	300	12 to 5
35a	Mrs. Grovenor	....	....	...do..	430	2
35c	Public School	....	....	...do..	70	4
36ddd	J.S. Dalrymple	Dakota Artesian Well Co.	1936	Jetted	330	3

COUNTIES, NORTH DAKOTA AND MINNESOTA (con't)

Principal Aquifer						
Depth to top	Thickness	Material	Depth to water2/	Date of measurement	Use3/	Remarks
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	......	....	DS	
...	...	....	8	11-14-46	DS	
...	...	....	......	....	S	
...	...	....	3	11-14-46	DS	
...	...	....	3	11-14-46	DS	
...	...	....	3	11-12-46	DS	
...	...	Fine Sand	24	....	M	See chemical analysis.
...	...	Sand	24	....	M	Do.
...	...	Sandstone	1	7- 1-21	DS	Water level above surface, was originally 30 feet above surface. See chemical analysis.
...	...	....	1	7- 1-21	D	See chemical analysis.
...	...	....	15	11- 6-46	DS	

1/ Depth given in feet below land surface. Asterisks (*) indicate measured depths to nearest foot; all others reported.

2/ Depth to water given in feet below land surface. Water levels given to tenths or hundreths of a foot are measured water levels; those given to unit feet are reported water levels.

3/ A-Filled in, or unused except, in some cases, for observation purposes; D-Domestic; DS-Domestic and Stock; H-USGS test holes; I-Industrial; M-Municipal; S-Stock; T-Test wells or test holes, not drilled by USGS; W-Irrigation.

Logs of test holes and wells

Logs of test holes drilled under the supervision of the Geological Survey and logs of other test holes and wells collected during the course of the investigation are given here in order of the location number of the well or test hole.[70] Most of these logs are also shown graphically on cross sections (fig. 2). The descriptions of the Geological Survey test holes are composite logs based on the driller's log and upon laboratory examination of ditch samples and cores. Logs of other wells are chiefly those of the driller although these were supplemented by examination of samples when available. The stratigraphic correlations are those of the authors in all cases and are considered reliable for the Geological Survey test holes but considerably less reliable for other test holes and wells. The term "granite" is used in the correlations, as well as elsewhere in this report, to include all of the pre-Cambrian crystalline rocks.

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[70] See page 108 for a description of the well numbering system.

139-48-1ccc
El Rancho well, Dilworth

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
	Clay	80	80
Till and associated glaciofluvial deposits			
	Clay and hardpan	60	140
	Sand	3	143
	"Hardpan"	37	180
	Sand and gravel	8	188
	Sand	12	200
	Clay, dark blue-gray to brown	68	268
	Clay and sand, hard	1	269
Older lake clay and drift deposits			
	Sand, very fine to medium	6	275
	Clay, greenish-gray	10	285
	Clay, sticky, dark blue	12	297
"Granite"			
	Clay, white, and sand	3	300
	Clay, blue-green, with quartz grains and granite fragments	20	320

139-48-4dcc1
Moorhead City supply well 4

Lake Agassiz deposits			
Silt unit			
	Clay, yellow	16	16
Clay unit			
	Clay, blue	74	90
Till and associated glaciofluvial deposits			
Till			
	"Hardpan"	13	103
Glaciofluvial deposits			
	Gravel	4	107
Till			
	"Hardpan"	35	142
Glaciofluvial deposits			
	Sand, fine	66	208
	Gravel and sand, clayey, and clay	5	213
	Sand, fine	5	218
	Sand, coarse	22	240
	Clay, blue	2	242

139-48-4dcc2
Moorhead City supply well 5

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Clay, yellow	10	10
Clay unit			
	Clay, blue	86	96
Till and associated glaciofluvial deposits			
Glaciofluvial deposits			
	Gravel and sand	4	100
Till			
	"Hardpan"	54	154
Glaciofluvial deposits			
	Sand, fine	16	170
	Sand, hard	20	190
	Sand, fine	9	199
	Sand, hard	16	215
	Sand	10	225
	Gravel and sand	9	234
	Gravel, coarse	29	263
	Clay	2	265

139-48-4dcc3
Moorhead City supply well 6

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Clay, yellow	15	15
Clay unit			
	Clay, blue	67	82
Till and associated glaciofluvial deposits			
Till			
	"Hardpan"	73	155
Glaciofluvial deposits			
	Sand, clayey	15	170
	Sand, coarse	60	230
	Gravel	39	269
Till			
	Clay	12	281

139-48-4dcc4
Moorhead City well

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Clay, yellow	15	15
Clay unit			
	Clay, blue	81	96
Till and associated glaciofluvial deposits			
Till			
	Gravel, clay, and "hardpan"	9	105
	Clay, blue	27	132
	"Hardpan"	33	165
	Gumbo	30	195
	"Hardpan"	47	242

139-48-4dcd
Moorhead City test hole

Lake Agassiz deposits			
	Clay, blue	110	110
Till and associated glaciofluvial deposits			
Till			
	Sand, hard, and blue clay	25	135
	Gravel and clay	20	155
	Clay, blue	90	245

139-48-4ddd
Moorhead City test hole

Lake Agassiz deposits			
Silt unit			
	Clay, yellow	15	15
Clay unit			
	Clay, blue	82	97
Till and associated glaciofluvial deposits			
Till			
	"Hardpan"	60	157
	Gravel and sand, clayey	11	168
	Clay, sandy	12	180
	Clay, blue, and "hardpan"	35	215
	Clay, blue	85	300

139-48-5cab
Old Fargo City well

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Clay, yellow	8	8
	Clay, blue	30	38
Clay unit			
	Clay, blue, and very fine sand	5	43
	Clay, blue	51	94
Till and associated glaciofluvial deposits			
Till			
	Clay, blue, and very fine sand	3	97
	Clay, blue, sand, and fine gravel	2	99
Glaciofluvial deposits			
	Sand, coarse, and gravel	3	102
	Clay, blue	1	103
	Sand and gravel	4	107
Till			
	Clay and coarse gravel	19	126
	Gravel, coarse, with little clay	1	127
Glaciofluvial deposits			
	Sand, medium	5	132
	Sand, coarse	8	140
Till			
	Clay, sand, and gravel	10	150
	Clay, blue, and fine sand	40	190
	Sand, fine, "light", gray	2	192
	Sand, fine, blue, and clay	8	200
Glaciofluvial deposits			
	Sand, fine, gray	23	223
	Sand, fine, gray, with trace of clay	3	226
	Sand, medium, gray	2	228
	Sand, medium to coarse, and gravel	3	231
	Sand, medium, with trace of clay	2	233
	Sand, fine, with trace of clay	2	235
Till			
	Sand, fine, and clay	6	241

139-48-5cdd1
Fairmont Creamery well 1

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Clay, yellow	30	30
Clay unit and underlying till, undifferentiated			
	Clay, blue	100	130
Till and associated glaciofluvial deposits			
Glaciofluvial deposits			
	Sand	30	160
Till			
	Clay	38	198
Glaciofluvial deposits			
	Sand	24	222

139-48-5cdd2
Fairmont Creamery well 2

Lake Agassiz deposits and underlying till, undifferentiated			
	Clay	136	136
Till and associated glaciofluvial deposits			
Glaciofluvial deposits			
	Sand	19	155
Till			
	Clay	28	185
Glaciofluvial deposits			
	Gravel and sand	57	240

139-48-5ddd1
Moorhead City supply well 1

Lake Agassiz deposits and underlying till, undifferentiated			
	Clay	180	180
Till and associated glaciofluvial deposits			
Glaciofluvial deposits			
	Sand	18	198

139-48-5ddd2
Moorhead City supply well 2

Formation	Material	Thickness	Depth
Lake Agassiz deposits and underlying till, undifferentiated			
	Clay	155	155
Till and associated glaciofluvial deposits			
Glaciofluvial deposits			
	Sand	64	219

139-48-5ddd3
Moorhead City supply well 3

Lake Agassiz deposits			
	Clay, blue	108	108
Till and associated glaciofluvial deposits			
Till			
	"Hardpan"	50	158
Glaciofluvial deposits			
	Sand	65	223

139-48-6ccd
Pierce Printing Co.

Lake Agassiz deposits			
	Soil and clay, yellow and blue	105	105
Till and associated glaciofluvial deposits			
Glaciofluvial deposits			
	Sand	55	160
	Sand and gravel, water-bearing	20	180
Till			
	Sand and clay	100	280
"Granite"			
	"Sandstone" (decomposed granite?), green	115	395
	"Sandstone" (decomposed granite?), red	5	400
	"Sandstone" (granite?), gray	3	403

139-48-7acc
Old Fargo City test well (Island Park)

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil	3	3
	Clay, yellow and white	50	53
Clay unit			
	Clay, dark	42	95
Till and associated glaciofluvial deposits			
Glaciofluvial deposits			
	Gravel	10	105
Till			
	"Hardpan", gravel, and boulders	115	220
	Shale (clay?), soft, blue	32	252
"Granite"			
	Coarse sand rock (granite?)	6	258
	Soapstone (decomposed granite?)	4	262

139-48-7daa
Moorhead City test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
	Clay, blue	100	100
Till and associated glaciofluvial deposits			
Glaciofluvial deposits			
	Gravel and sand	4	104
Till			
	Clay and "hardpan"	146	250

139-48-8aaa
Moorhead City test well

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
	Clay	103	103
Till and associated glaciofluvial deposits			
	Sand	7	110
	Clay	12	122
	Sand	3	125
	Clay	55	180
	Sand	7	187
	Clay	83	270
Older lake clay and drift deposits			
	Clay	30	300

139-48-8baa
Old Moorhead City test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil	5	5
	Clay, yellow	50	55
Clay unit			
	Clay, very fine, tough, blue-gray	55	110
Till and associated glaciofluvial deposits			
Till			
	Gravel with some blue clay	5	115
Glaciofluvial deposits			
	Gravel, coarse, much limestone (struck water at 120 feet which rose to near the top)	20	135
Till			
	Gravel, coarse, sand, and blue clay	60	195
	Clay and gravel with boulders	25	220
	Clay, sandy, blue-gray	20	240
Older lake clay and drift deposits			
	Clay, sandy, bluish	60	300
	Quicksand, rounded quartz grains	45	345
	Quicksand, some subangular quartz grains, with some clay	20	365
"Granite"			
	Clay, light green, gritty, decomposed gneiss	110	475
	Chlorite-granite or gneiss, soft, red, feldspathic	290	765
	Gneiss, mostly feldspar and quartz, chloritic, fine-grained	355	1,120
	Felsite (?), soft, greenish but finely red-mottled, fissile, chloritic	85	1,205
	Other granite rock	696	1,901

139-48-11aaa1
Dilworth Village well

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Clay, yellow	20	20
Clay unit			
	Clay, blue	75	95
Till and associated glaciofluvial deposits			
Till			
	Clay, boulder	33	128
	Sand, fine	1	129
	Clay, boulder	9	138
Glaciofluvial deposits			
	Sand and gravel	16	154

139-48-18aba
Fargo City test hole

Lake Agassiz deposits			
Silt unit			
	Silt and clay, tan	25	25
Clay unit			
	Clay, gray; yellow-gray in upper part	70	95
Till and associated glaciofluvial deposits			
Till			
	Clay, gray, and some sand and gravel	5	100
Glaciofluvial deposits			
	Silt, gray, and considerable gravel and sand	52	152
	Gravel, fine, and coarse sand, silty	3	155
	Sand, coarse	5	160
	Gravel and coarse sand	5	165
	Gravel	5	170
Till			
	Clay, gray, pebbly, and some sand	15	185
	Clay, gray	5	190
	Clay, silty, gray	10	200
	Clay, buff	5	205
	Clay, silty, gray, and some gravel	10	215
	Sand and silt, buff	15	230
"Granite"			
	Clay, white, and some sand	12	242

139-49-1acc
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	1	1
	Clay, yellow and gray and fine gravel	24	25
Clay unit			
	Clay, light gray	67	92
Till and associated glaciofluvial deposits			
	Clay, gray, with sand and gravel	41	133
	Gravel, fine to medium	3	136
	Clay, blue-gray, and some fine gravel	36	172
	Clay, blue and brown, and fine gravel	6	178
"Granite"			
	Granite, decomposed	12	190

139-49-1bab
Great Northern R.R. well, Fargo

Lake Agassiz deposits			
Silt unit			
	Clay, yellow	20	20
Clay unit			
	Clay, blue-gray	70	90
Till and associated glaciofluvial deposits			
Till			
	"Lime rock" (?)	45	135
	Clay, sandy	3	138
	"Lime rock" (?), white	5	143
	"Shale" (clay?), blue	2	145
Glaciofluvial deposits			
	Boulders	20	165
Till			
	Clay, blue	25	190
Glaciofluvial deposits			
	Boulders	5	195
Till			
	Clay, blue	5	200
"Granite" (?)			
	"Marl" (?), hard, white	50	250
	Sand, dry, sharp, white and gray	115	365

139-49-1bad
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	4	4
	Clay, yellow, and a few fine gravel	14	18
Clay unit			
	Clay, greenish-gray	75	93
Till and associated glaciofluvial deposits			
Till			
	Clay, blue, and some fine gravel	19	112
Glaciofluvial deposits			
	Gravel, fine and medium, and some gray clay	20	132
Till			
	Clay, hard, sandy, gray, and considerable gravel	59	191
	Clay, light brown, and some fine gravel	6	197
"Granite"			
	Granite, decomposed, reddish-brown	3	200

139-49-1bbb
USGS test hole

Lake Agassiz deposits			
Silt unit			
	Soil, black	3	3
	Clay, yellow, and a few pebbles	15	18
	Clay, gray, and some sand and gravel	16	34
Clay unit			
	Clay, gray	55	89
Till			
	Clay, blue-gray, gravel and boulders	51	140
Glaciofluvial deposits			
	Gravel, fine to coarse, clean	22	162
Till or glaciofluvial deposits			
	Gravel and sand, fine, and some brown clay	22	184
"Granite"			
	Granite, decomposed, white	6	190

139-49-1bcd
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	1	1
	Clay, yellow, and some fine gravel	15	16
	Clay, light gray, silty	14	30
Clay unit			
	Clay, dark gray	52	82
Till			
	Gravel, medium, sand, and clay	18	100
	Clay, gray, and some gravel and sand	32	132
	Clay, brown and blue-gray, and some fine gravel	20	152
Glaciofluvial deposits			
	Gravel, fine, and fine to coarse sand	5	157
Till			
	Clay, sandy gray, and fine sand and gravel	41	198
"Granite"			
	Granite, decomposed	22	220

139-49-1bdd
USGS test hole

Lake Agassiz deposits			
Silt unit			
	Soil, black	4	4
	Clay, yellow, and a few fragments of fine gravel	14	18
Clay unit			
	Clay, gray	70	88
Till and associated glaciofluvial deposits			
	Gravel, fine, and gray clay	21	109
	Clay, sandy, gray, and some fine gravel	12	121
	Gravel, fine to medium	3	124
	Gravel, fine, and gray clay	32	156
	Clay, very light gray, sandy, and some fine gravel	22	178
"Granite"			
	Granite, decomposed, white	12	190

139-49-1cbb
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	2	2
	Clay, yellow, and some fine gravel	18	20
	Clay, brown, sandy	5	25
	Clay, light gray	3	28
	Sand, fine to medium, and some gravel and clay	24	52
Clay unit			
	Clay, gray	42	94
Till and associated glaciofluvial deposits			
Till			
	Clay, gray and sand and gravel	58	152
Glaciofluvial deposits			
	Sand and gravel	6	158
Till			
	Gravel, fine, and blue and brown clay	30	188
"Granite"			
	Granite, decomposed	37	225

139-49-1cbc
Fargo City test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	No record	20	20
	Silt, clayey, gray	35	55
Clay unit			
	Clay, gray to blue	40	95
Till and associated glaciofluvial deposits			
Till			
	Sand, silty, gray and gravel	15	110
	Clay, gray, and sand and gravel	47	157
Glaciofluvial deposits			
	Sand, medium to coarse, loose, clean	4	161
	Gravel and sand, fine to medium, clean	32	193
	Gravel, coarse	6	199
	Sand, medium to coarse, brown	1	200
"Granite"			
	Sand, white	2	202
	Clay, light green	(?)	(?)

139-49-1cbd1
Fargo City test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	No record	25	25
	Silt, brown, sandy	10	35
Clay unit			
	Clay, gray, laminated (varved?)	50	85
	Clay, gray, and some gravel	10	95
Till and associated glaciofluvial deposits			
Till			
	Clay, gray, silty, and some sand and gravel.	50	145
Glaciofluvial deposits			
	Sand, loose, medium, rounded, clean	2	147
	Sand, medium, and medium gravel, clean	8	155
	Sand, coarse, clean	15	170
	Sand, medium to coarse, and coarse gravel, clean	22	192

139-49-1cca
Fargo City test hole

Lake Agassiz deposits			
Silt unit			
	No record	20	20
	Silt, yellow	35	55
	Sand, fine to medium, silty	5	60
Clay unit			
	Clay, gray	45	105
Till and associated glaciofluvial deposits			
Till			
	Clay, silty, gray, and some gravel	5	110
	Silt, sandy, gray and some gravel	41	151
Glaciofluvial deposits			
	Sand, fine to coarse, and some gravel, clean	9	160
	Sand, fine to coarse, and gravel, clean	29	189
Till			
	Clay and silt, carbonaceous, black, and some gravel	10	199
"Granite"			
	Clay (kaolin?), white, and some angular sand	2	201

139-49-1ccd1
Fargo City test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	No record	20	20
	Silt, buff	15	35
	Sand, fine to medium, silty, buff	5	40
	Silt, clayey, gray	5	45
	Sand, silty, fine to medium, buff	17	62
Clay unit			
	Clay, gray	33	95
Till and associated glaciofluvial deposits			
	Silt, sandy, and some clay and gravel, gray	30	125
	Gravel, coarse, clayey	2	127
	Silt, sandy and gravelly and blue clay	38	165
	Silt, sandy, gray, and some clay	25	190
	Silt, sandy, gray, and some gravel and clay	35	225
	Clay, blue to gray	22	247
	Gravel, fine, clean	2	249
"Granite"			
	Clay, green, and fragments of quartz and granite	5	254
	Sand, coarse, angular, white	6	260
	Clay, green, and some angular granite pebbles	5	265
	Clay (kaolin?), green, and pebbles of schist and granite	152	417

139-49-1ccd2
Fargo City test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	No record	50	50
	Sand, medium, clean	12	62
Clay unit			
	Clay, blue, silty in lower part	28	90
Till and associated glaciofluvial deposits			
Till			
	Clay, blue, and fine silty sand	35	125
	Gravel, silty sand, and blue clay	15	140
	Gravel, coarse sand, and blue clay	10	150
	Clay, sandy, gray, and some gravel	5	155
Glaciofluvial deposits			
	Gravel and sand, fine to medium, water rose to 25 feet	3	158
	Gravel, fine, and sand, coarse	7	165
	Sand, medium to coarse	15	180
	Sand and some gravel, clean	15	195
Till			
	Clay, silty, black	1	196

139-49-1cdc
Cass County well

Lake Agassiz deposits			
Silt unit			
	Soil and yellow clay	20	20
Clay unit			
	Clay, blue	70	90
Till and associated glaciofluvial deposits			
Till			
	"Hardpan" and gravel	60	150
	Sand	½	150½
	Gravel and clay	94½	245
	Sand, fine	6	251
"Granite"			
	Granite	(?)	251+

139-49-1cdd
Old well, Fargo

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
	Soil and clay	89	89
Till and associated glaciofluvial deposits			
	Sand and boulders	47	136
	Gravel and sand	20	156
	Sand and soapstone(?)	11	167
	Sandstone, soft	13	180
	Sand	70	250
"Granite"			
	Granite	2	252

139-49-1dca
Old well, Fargo

Lake Agassiz deposits			
Silt unit			
	Clay, yellow	20	20
Clay unit			
	Clay, blue	105	125
Till and associated glaciofluvial deposits			
	Clay, gray	65	190
	Clay, blue	37	227
	Sand and gravel	19	246
	Clay	4	250

139-49-1dcc
Old well, Fargo

Lake Agassiz deposits			
	Soil and clay	93	93
Till and associated glaciofluvial deposits			
	Gravel and sand	57	150
	Sand, soft, and gravel	90	240

139-49-2baa
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	3	3
	Silt and clay, buff to yellow	12	15
	Sand, fine, yellow	1	16
	Clay and silt, buff	14	30
Clay unit			
	Clay, gray; yellow in upper 15 feet	75	105
Till and associated glaciofluvial deposits			
	Gravel, medium to coarse, gray, clayey	6	111
	Clay, blue-gray, and considerable fine to coarse gravel	43	154
	Clay, light gray, and considerable sand and fine gravel	80	234
	Clay, gray, considerable fine gravel, and some sand	28	262
Glaciofluvial deposits			
	Gravel, fine to medium, considerable sand, and a little clay	23	285
"Granite"			
	Granite, decomposed	7	292

139-49-2dbb
Fargo City test hole

Lake Agassiz deposits			
Silt unit			
	Soil	2½	2½
	Clay, yellow	12½	15
Clay unit			
	Clay, blue	7	22
	Sand, very fine, dirty; (no water)	2	24
	Clay, soft, blue	88	112
Till and associated glaciofluvial deposits			
Till			
	Boulder, clay	21	133
Glaciofluvial deposits			
	Sand, medium and coarse, and some gravel; (water)	23	156
Till			
	Boulder, clay	12	168

139-49-3ccc
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	5	5
	Clay, silty, buff	14	19
	Sand, brown	10	29
Clay unit			
	Clay, gray	60	89
Till and associated glaciofluvial deposits			
Till			
	Clay, gray, and some gravel and sand	30	119
Glaciofluvial deposits			
	Gravel, and some sand and clay	5	124
Till			
	Clay, gray, and considerable gravel and sand	15	139
	Gravel, sand, and gray clay	10	149
Glaciofluvial deposits			
	Gravel and sand, and a little clay	20	169
Till			
	Gravel, sand, and clay	25	194
	Clay, gray, and considerable gravel and sand	5	199
	Gravel and sand, and some clay	10	209
	Gravel, sand, and clay	15	224
Glaciofluvial deposits			
	Sand, and considerable gravel and clay	15	239
Till			
	Gravel and sand, and a little clay	20	259
	Gravel, sand, and clay	10	269
	Gravel, sand, and considerable clay	5	274
	Gravel, sand, and clay	45	319
Glaciofluvial deposits			
	Gravel and some sand, clean	5	324
Till			
	Gravel, sand, and clay	15	339
"Granite"			
	Granite, decomposed, greenish gray	28	367

139-49-4ccc
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	3	3
	Clay, yellow	6	9
	Sand, fine to medium, loose	9	18
Clay unit			
	Clay, blue	56	74
Till and associated glaciofluvial deposits			
Till			
	Cobbles and blue clay	25	99
Glaciofluvial deposits			
	Gravel	16	115
	Sand	4	119
Till			
	Cobbles and clay	5	124
Glaciofluvial deposits			
	Gravel and sand	10	134
	Gravel and fine sand	10	144
Till			
	Sand, clay, and gravel	15	159
Glaciofluvial deposits			
	Gravel and sand	20	179
	Gravel and fine sand	20	199
Till			
	Gravel, sand, and clay	20	219
Glaciofluvial deposits			
	Gravel and sand	25	244
"Granite"			
	Gravel and sand (decomposed granite pebbles)	5	249
	Granite, decomposed, white	11	260

139-49-4dcc
Dahl well

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
	Clay	70	70
Till and associated glaciofluvial deposits			
Till			
	"Drift" and "rocks" (boulder clay?)	24	94
	Clay, blue	5	99
	"Drift" and "rocks" (boulder clay?)	12	111
	"Hardpan"	17	128
Glaciofluvial deposits			
	Gravel and sand	2	130
	Sand	7	137
	Gravel	2	139
	Sand	6	145

139-49-5aaa
USGS test hole

Lake Agassiz deposits			
Silt unit			
	Soil, black	4	4
	Clay, yellow, and a few pebbles	7	11
	Sand, fine to medium	11	22
	Clay, light gray	2	24
	Sand, fine to medium	10	34
Clay unit			
	Clay, gray	48	82
Till and associated glaciofluvial deposits			
Till			
	Gravel and sand, fine, and gray to blue clay	21	103
Glaciofluvial deposits			
	Gravel, fine, and coarse sand, clayey	16	119
	Gravel, medium to coarse, clean	65	184
Till			
	Clay, blue-gray, and some fine gravel and sand	18	202
	Clay, dark brown to black, and a little fine gravel	9	211
	Clay, light gray, and a little fine gravel	4	215
"Granite"			
	Clay, white	10	225
	Clay, reddish brown (decomposed granite?)	9	234
	Granite, decomposed, white	6	240

139-49-5dcd
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	1	1
	Clay, yellow, weathered	9	10
Clay unit			
	Clay, gray to blue	65	75
Till and associated glaciofluvial deposits			
Till			
	Gravel, fine to medium, sand, and blue clay	16	91
Glaciofluvial deposits			
	Gravel, fine to medium, and fine to coarse sand	89	180
Till or glaciofluvial deposits			
	Sand, fine to coarse, some fine gravel, and clay	20	200
"Granite"			
	Granite, decomposed, white	14	214
	Granite, decomposed, greenish (Core sample 214 to 220 feet)	6	220

139-49-6ab
Union Stockyards

Lake Agassiz deposits			
	Soil and alluvium	3	3
	Clay, gumbo	6	9
	Silt(?)	76	85
Till and associated glaciofluvial deposits			
Till			
	Boulder, clay	15	100
Glaciofluvial deposits			
	Gravel and sand	110	210
	Sand	30	240

139-49-6ac
Union Stockyards

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
	Soil and alluvium	3	3
	Clay, gumbo	5	8
	Silt(?)	65	73
Till and associated glaciofluvial deposits			
Till			
	Boulder, clay	15	88
Glaciofluvial deposits			
	Gravel and sand	135	223
Till(?)			
	"Shale" (clay?), black	5	228
	"Shale" (clay?), black and gray streaked	8	236

139-49-6ad
Union Stockyards

Lake Agassiz deposits			
	Soil and alluvium	2	2
	Clay, gumbo	3	5
	Silt(?)	65	70
Till and associated glaciofluvial deposits			
Till			
	Boulder, clay	33	103
Glaciofluvial deposits			
	Gravel and sand	112	215
Till(?)			
	"Shale" (clay?), light gray	15	230

139-49-6baa
Union Stockyards, test well A

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
	Soil, black clay loam	5	5
	Clay, yellow	55	60
	Clay, blue	20	80
Till and associated glaciofluvial deposits			
Till			
	Clay, sandy, blue, and boulders	5	85
	Sand, silty, fine, brown, water-bearing	9	94
	Clay, sandy, blue (hardpan), and some boulders	18	112
	Sand, silty, fine, brown, water-bearing	6	118
Glaciofluvial deposits			
	Sand, fine, flowing, brown, water-bearing	4	122
	Gravel, fine, and sand, clean	18	140
	Sand, fine to medium	10	150
	Gravel, fine, and coarse sand	18	168
	Sand, fine to medium, clean	4	172
	Gravel, fine, and coarse sand	20	192
	Gravel, coarse, and some coarse sand	11	203
	Sand, fine, white, clean	6	209
	Gravel, coarse, and sand	6	215
	Sand, fine, hard, white	12	227

139-49-6bcc
Union Stockyards, test hole B

Lake Agassiz deposits			
	Soil	6	6
	Clay, gray	54	60
	Silt and clay, gray, with some pebbles	16	76
Till and associated glaciofluvial deposits			
Till			
	Silt, sandy, gray	19	95
	Clay, gray, and some gravel	8	103
	Silt, gray	24	127
Glaciofluvial deposits			
	Gravel and fine sand	7	134
	Gravel, fine to coarse, and a little sand	13	147
	Sand, medium, rounded, clean	20	167
	Gravel and sand, dirty	9	176
	Gravel and sand, fine, clean	3	179
	Sand, medium to coarse, clean	3	182
	Gravel, dirty	3	185
	[illegible] silty, buff		[illegible]

139-49-11aaa
Northern Pacific well

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil and yellow clay	5	5
	Clay, yellow	15	20
	Clay, yellow and gray	5	25
Clay unit			
	Clay, gray, and a few scattered pebbles	70	95
Till and associated glaciofluvial deposits			
Till			
	Clay, gray, silt, and gravel	40	135
	Clay, gray, silt, and loose gravel	5	140
Glaciofluvial deposits			
	Sand and gravel	25	165
Till			
	Gravel, sand, and clay	5	170

139-49-12acb
Fargo City old well

Lake Agassiz deposits			
	No record; to "hardpan" at 96 feet	96	96
Till and associated glaciofluvial deposits			
Till			
	"Hardpan" at top and at 100 feet; (bad water)	4	100
	No record	56	156
Glaciofluvial deposits			
	Sand	50	206
"Granite"(?)			
	"Rock," white, chalky	4	210

139-49-12bab
Fargo City test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	No record	20	20
	Clay, yellow (silt or sandy clay?)	20	40
Clay unit			
	Clay, gray	55	95
Till and associated glaciofluvial deposits			
Till			
	Silt, sandy, gray, and a little gravel	40	135
	Silt, sandy, gray, and considerable fine gravel	20	155
	Silt, sandy, gray, and a little gravel	35	190

139-49-12cac
Fargo City old well

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
	Soil	7	7
	Clay, yellow	15	22
	Sand, fine	4	26
	No record	121	147
Till and associated glaciofluvial deposits			
Glaciofluvial deposits			
	Gravel, water	8	155
	Sand and gravel	61	216

139-49-12cad
Merchant's Nat. Bank Trust Co.
Fargo City test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Silt, white	20	20
Clay unit			
	Clay, gray	70	90
Till and associated glaciofluvial deposits			
Till			
	Silt, sandy, gray clay, and some gravel	40	130
	Sand and some gravel, silty, and some gray clay	20	150
Glaciofluvial deposits			
	Sand, fine to coarse, fairly clean	20	170
	Sand, fine, silty, dark gray	10	180
	Sand, fine, clean	5	185
Till			
	Clay, dark gray, hard	10	195
	Clay and silt, dark gray, hard	10	205

139-49-12dcb
Fargo City test hole

Lake Agassiz deposits			
Silt unit			
	Clay, grayish-tan	20	20
Clay unit			
	Clay, dark gray	70	90
Till and associated glaciofluvial deposits			
Till			
	Clay, gray, and some gravel	5	95
	Sand, silty, fine to medium gray	25	120
Glaciofluvial deposits			
	Gravel, fine to medium	6	126
Till			
	Silt, sandy, gray	9	135
	Silt, sandy, gray, and coarse gravel	15	150
Glaciofluvial deposits			
	Sand, fine to medium, loose, clean	25	175
Till			
	Clay, dark gray	3	178
	Silt, sandy, dark gray	12	190
	Sand, silty, dark brown	15	205
	Clay, carbonaceous, black and gray streaks	5	210
"Granite"(?)			
	Clay (kaolin?), marly(?), white	22	232

139-49-13abc
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	1	1
	Silt, yellow to light gray	29	30
Clay unit			
	Clay, gray	71	101
Till and associated glaciofluvial deposits			
Till			
	Clay, gray, considerable fine to coarse gravel, and sand	44	145
Glaciofluvial deposits			
	Gravel, fine to coarse, some sand, and a little clay	10	155
Till			
	Clay, blue, black, brown, and some gravel and sand	20	175
	Clay, dark gray to brown, and some gravel and sand	14	189
"Granite"			
	Granite, decomposed, light greenish gray	11	200

139-50-1ddd
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	4	4
	Clay, yellow	15	19
Clay unit			
	Clay, blue-gray	5	24
Clay, dark gray		45	69
Till and associated glaciofluvial deposits			
Till			
	Gravel, sand, and blue clay	10	79
	Gravel, coarse, and blue clay	10	89
	Cobbles and blue sandy clay	10	99
	Gravel, coarse, sand, and clay	10	109
	Clay, blue	10	119
	Clay, blue-gray	10	129
	Clay, sandy, blue-gray	5	134
	Clay, sandy, blue-gray; and gravel	10	144
	Gravel, sand, and blue clay	5	149
Glaciofluvial deposits			
	Gravel and sand	10	159
Till			
	Gravel, sand, and clay	20	179
	Gravel, sand, and clay(?)	55	234
Glaciofluvial deposits			
	Gravel and sand	15	249
"Granite"			
	Granite, decomposed	11	260

139-50-5ccc
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	3	3
	Clay, buff	16	19
	Clay, brown	5	24
Clay unit			
	Clay, brown and gray	5	29
	Clay, dark gray	5	34
	Clay, gray	15	49
Till and associated glaciofluvial deposits			
Till			
	Sand and gray clay	3	52
	Silt, gray, and some sand and gravel	11	63
	Clay, silty, gray, and some sand and gravel	6	69
	Gravel, fine; coarse sand; and gray silty clay	5	74
	Silt, gray, and some sand and gravel	35	109
	Silt, gray, and considerable sand and gravel	5	114
	Silt, gray, and some sand and gravel	95	209
	Silt, gray, and some dark gray clay, sand, and gravel	5	214
Older lake clay and drift			
	Clay, black, and some sand and gravel	5	219
	Gravel, sand, silt, and gray clay	5	224
	Clay, silty, light and dark gray	5	229
	Clay, gray	5	234
	Clay, gray, and considerable sand and gravel	15	249
	Clay, silty, gray, and considerable sand and gravel	5	254
	Clay, silty gray	5	259
	Clay, white and black, and some sand and gravel	5	264
	Clay, micaceous, black and brown	5	269
	Clay, light gray and black	5	274
	Clay, silty white	5	279
	Clay, light to dark gray, in part black carbonaceous	5	284
	Clay, white and gray	5	289
	Clay, silty gray	5	294
	Clay, gray and orange	5	299
"Granite"			
	Clay, white (kaolin)	5	304
	Clay, white and light gray (kaolin)	5	309
	Clay, light greenish-gray (kaolin)	5	314
	Sand, quartz, angular, and light greenish-gray clay (kaolin)	10	324
	Clay, light green (kaolin) and rock (granite?)	5	329

139-50-6bbb
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	2	2
	Silt, yellow, and a little fine gravel	20	22
Clay unit			
	Clay, blue-gray	30	52
Till and associated glaciofluvial deposits			
Till			
	Clay, gray, and some fine gravel and sand	24	76
Glaciofluvial deposits			
	Gravel, medium to fine, and sand; fairly clean	18	94
Till			
	Clay, sandy, gray, and some gravel	86	180
	Clay, blue-gray, and a little gravel and sand	15	195
Older lake clay and drift deposits			
	Clay, very hard, blue, and some gravel and sand	43	238
	Clay, hard, gray, and some gravel and sand	62	300
	Clay, sandy, gray, and considerable gravel; struck "rock" at 314 feet	14	314

139-50-11bbb
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black, and brown clay	4	4
	Clay, buff	15	19
	Clay, sandy, buff	10	29
Clay unit			
	Clay, brown and gray	5	34
	Clay, gray	5	39
	Clay, light gray and black streaked	5	44
	Clay, dark gray	20	64
	Clay, light and dark gray streaked	2	66
Till and associated glaciofluvial deposits			
Till			
	Clay, silty, light gray, and sand	3	69
	Clay, silty, light and dark gray, and some sand and gravel	5	74
	Clay, silty, gray, and some sand and gravel	10	84
	Gravel, sand, and gray silt	25	109
	Silt, gray, and some sand and gravel	20	129
	Silt, gray, and some black clay, sand, and gravel	5	134
	Silt, gray, and some sand and gravel	80	214
	Silt and clay, gray, and some sand and gravel	5	219
Older lake clay and drift deposits			
	Clay, gray, and some silt, sand, and gravel	5	224
	Clay, dark gray	5	229
	Clay, gray, and some silt, sand, and gravel	5	234
	Clay, gray to black and some red, and sand and gravel	5	239
	Clay, gray and white, and sand and gravel	10	249
	Clay, gray and olive drab, and sand and gravel	5	254
"Granite"			
	Clay, gray and white (kaolin?)	3	257
	Clay, dark greenish-gray and white (kaolin?)	2	259
	Clay, white, gray, and reddish brown, and considerable sand and gravel	5	264
	Clay, reddish brown, and rock fragments	1	265
	Clay, white, and rock fragments	4	269
	Rock, white or light buff	10	279
	Rock, buff and black, and red clay	10	289
	Rock, buff and black, and red and white clay	10	299
	Rock, buff and black, and red and blue kaolin		

nd red and white c

139-51-4cdd
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black and gray	5	5
	Clay, yellow	19	24
	Sand, coarse	10	34
	Sand, coarse, gray	5	39
	Sand, fine	5	44
Clay unit			
	Clay, blue, and some fine gravel and sand	5	49
	Clay, blue, and some fine gravel	15	64
Till and associated glaciofluvial deposits			
Undifferentiated			
	Gravel and blue clay	5	69
	Gravel, fine, and sand	5	74
	Gravel, coarse	5	79
	Gravel, coarse and fine, and blue clay	5	84
	Gravel, coarse	1	85
	Gravel, coarse and fine	4	89
	Gravel and blue clay	15	104
	Gravel, sand, and blue clay	10	114
Glaciofluvial deposits			
	Gravel and sand, coarse	20	134
	Gravel, sand, and blue clay	35	169
	Gravel, coarse, and fine sand	10	179
	Gravel, fine sand, and clay	15	194
	Gravel and very fine sand	15	209
Undifferentiated			
	Sand, fine, and brown clay	10	219
	Sand, fine	30	249
	Gravel, coarse, and fine sand	10	259
	Gravel, fine sand, and some brown clay	10	269
	Gravel and fine sand	5	274
	Gravel and sand, fine	25	299
Older lake clay and drift deposits			
	Gravel and sand, fine, and gray clay	15	314
	Clay, light gray, and some fine gravel	25	339
	Clay, light and dark gray	5	344
	Clay, black, and some gravel	8	352
	Gravel, fine, and gray clay	17	369
	Gravel, fine, and gray and green clay	5	374
	Gravel and gray and white clay	5	379
	Gravel, fine, and gray clay	10	389
"Granite"			
	Clay, yellow and gray	10	399
	Granite, decomposed; gray clay, and fine gravel	13	412
	Granite, decomposed (less decomposed than above)	7	419

139-51-6ddc
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil	4	4
	Clay, yellow	20	24
Clay unit			
	Clay, gray	10	34
	Clay, blue-gray	5	39
Till and associated glaciofluvial deposits			
Till			
	Gravel and blue clay	20	59
	Gravel, coarse, sand, and blue clay	5	64
	Gravel, fine sand, and blue clay	5	69
Glaciofluvial deposits			
	Sand, fine	5	74
	Gravel, coarse, and fine sand	5	79
	Sand, fine, and cobbles at base	10	89
Till			
	Gravel, fine, and blue-gray clay	15	104
	Clay, blue-gray, and some fine gravel	50	154
	Gravel, fine, and some blue clay	5	159
	Gravel, fine, and gray clay	10	169
Older Lake clay and drift deposits			
	Gravel, fine, coarse sand, and gray clay	30	199
	Clay, blue-gray, and some fine gravel	20	219
	Gravel, fine, sand, and gray clay	10	229
	Gravel and blue and brown clay	10	239
	Gravel, sand, and blue and brown clay	10	249
	Gravel, sand and blue clay	20	269
	Clay, blue	5	274
	Gravel, sand, and blue clay	25	299
	Gravel, fine sand, and blue clay	30	329
	Gravel, fine, and blue and yellow clay	10	339
	Gravel, fine, and blue and yellow clay; some decayed granite pebbles	10	349
	Gravel, fine, and blue and yellow clay	20	369
	No record	7	376
"Granite"			
	Granite, decomposed	26	402

139-51-11abb
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	4	4
	Clay, gray	15	19
	Clay, yellow	5	24
Clay unit			
	Clay, gray	5	29
	Clay, gray, and some very fine sand	10	39
Till and associated glaciofluvial deposits			
Till			
	Gravel, coarse, and blue clay	5	44
	Gravel, coarse, sand, and blue clay	5	49
	Gravel, coarse, and blue clay	45	94
	Gravel, fine, sand, and blue clay	5	99
Glaciofluvial deposits			
	Gravel, fine, coarse sand, and some blue clay	10	109
	Gravel, fine, and some blue clay	30	139
Till			
	Gravel, fine to coarse, and blue and gray clay	5	144
	Clay, blue, and some gravel	5	149
	Clay, blue, and some coarse gravel	10	159
	Gravel, fine, and grayish-blue clay	10	169
Older lake clay and drift deposits			
	Clay, dark gray	25	194
	Clay, blue, and some sand	10	204
	Gravel, sand, and blue clay	45	249
	Gravel and blue clay	15	264
	Gravel and gray clay	10	274
	Clay, dark gray	5	279
	Clay, gray	50	329
"Granite"			
	Granite pebbles and gray clay (kaolin?)	10	339
	Granite, white, and gray clay (kaolin?)	5	344
	Granite, decomposed	5	349

139-52-2ccc
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil	1	1
	Clay, yellow	18	19
	Clay, yellow and blue	5	24
Clay unit			
	Clay, blue	30	54
Till and associated glaciofluvial deposits			
Till			
	Gravel, fine to coarse, and blue clay	80	134
	Gravel, sand, and blue-gray clay	5	139
	Gravel, coarse, and blue-gray clay	15	154
	Gravel, sand, and blue clay	32	186
	Gravel and blue clay	4	190
Older lake clay and drift deposits			
	Gravel, sand, and sandy clay	19	209
	Clay, blue, and some gravel	40	249
	Gravel, sand, and blue clay	40	289
	Gravel, fine, and blue-gray clay	45	334
	Gravel and sand, fine	5	339
	Gravel, fine, and blue-gray clay	10	349
	Gravel, fine, and light gray and blue clay	10	359
	Gravel and sand, fine, and white and blue clay	25	384
"Granite"			
	"Granite", decomposed, white	16	400

139-53-10bba
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil	1	1
	Clay, yellow and brown	8	9
	Clay, yellow, and some sand	5	14
	Gravel, fine, sand, and yellow clay	5	19
	Gravel, fine, and yellow and blue clay	5	24
Clay unit			
	Clay, blue and some fine gravel	65	89
Till and associated glaciofluvial deposits			
	Gravel, sand, and blue clay	38	127
	Boulders	2	129
	Gravel, sand, and clay; cobbles near base	19	148
	Cobbles, gravel, and sand	1	149
	Sand and blue clay	10	159
	Gravel, fine, sand, and blue clay	10	169
Older lake clay and drift deposits			
	Clay, blue-gray, and some fine gravel	25	194
	Gravel, fine, sand, and blue-gray clay	25	219
	Gravel, fine, and blue-gray clay	10	229
	Clay, blue-gray, and some fine gravel	20	249
	Clay, gray-black, and some fine gravel	10	259
	Clay, blue, and some fine gravel	30	289
	Clay, blue, and some fine to coarse gravel	5	294
	Clay, blue, and some fine gravel	65	359
	Clay, blue-gray, and some fine gravel, occasional cobbles or boulders	20	379
	Clay, gray, and some fine gravel	10	389
	Clay, gray-blue, and some fine gravel	5	394
	Clay, brown and blue, and some fine gravel	5	399
	Clay, brown to white and blue, and some fine gravel	5	404
	Clay, blue and brown, and some fine gravel	5	409
	Gravel, sand, and gray clay	5	414
	Gravel, sand, and gray and black clay	5	419
	Clay, gray-black	5	424
	Clay, gray to brown	5	429
	Sand and gray clay	20	449
	Clay, gray, and some black shale	5	454
Dakota ? sandstone:			
	Sandstone, silty, soft, interbedded with gray to black shale in part mecaceous	111	565
"Granite"			
	Sand, quartz, angular, and some black clay	10	575
	Sand, quartz, angular, and black and white (kaolin?) clay	10	585
	Sand, quartz, angular, and red and white (kaolin?) clay; some shale (hard clay?) and rock (granite) fragments near bottom of hole	23	608

140-48-31cbd
Fargo City old well

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Clay, yellow	30	30
Clay unit			
	Clay, blue	78	108
Till and associated glaciofluvial deposits			
Till			
	Clay and sand	82	190
	Clay, blue	21	211
	"Rocks"	4	215
	Clay, blue	97	312
"Granite" (?)			
	Sand and clay	12	324
	Sand	14	338

140-48-32aaa
American Crystal Sugar Co. test hole

Lake Agassiz deposits			
Silt unit			
	Soil	4	4
	Clay, buff	36	40
Clay unit			
	Clay, gray	66	106
Till and associated glaciofluvial deposits			
Till			
	Silt, gray, sandy, occasional pebbles	22	128
	Clay and silt, gray, with numerous pebbles	8	136
	Clay and silt, buff, with numerous pebbles	9	145
	Clay, gray, with occasional pebbles	25	170
	Sand and clay, gray, with numerous pebbles	20	190
	Silt and clay, gray, with some sand and pebbles	70	260
"Granite"			
	Sand, coarse and gravel with some clay and many chips of pink granite and black schist	2	262
	Granite, pink and schist black, angular chips	3	265

140-49-16cdd
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	4	4
	Clay, gray	4	8
	Silt, yellow	7	15
Clay unit			
	Clay, gray to blue-gray	69	84
Till and associated glaciofluvial deposits			
Till			
	Clay, gray, sandy, and some fine gravel and sand	31	115
Glaciofluvial deposits			
	Gravel, medium to coarse, and some sand; clean	61	176
"Granite"			
	"Granite," decomposed, greenish gray	4	180

140-49-20aaa1
USGS test hole

Lake Agassiz deposits			
Silt unit			
	Soil, black	1	1
	Clay, gray	3	4
	Silt, yellow	12	16
Clay unit			
	Clay, blue-gray to gray	57	73
Till and associated glaciofluvial deposits			
Till			
	Clay, sandy, light gray, hard, and some gravel	33	106
	Clay, dark gray, and considerable fine gravel	41	147
"Granite"			
	Granite (?), decomposed, dark to greenish gray	7	154

140-49-21bba
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	4	4
	Silt, buff to light brown	16	20
	Sand, fine	3	23
	Intraformational conglomerate. Pebbles of yellow clay in gray clay	7	30
Clay unit			
	Clay, gray	52	82
Till and associated glaciofluvial deposits			
Till			
	Clay, gray, and a little gravel and sand	18	100
	Clay, sandy, gray, and some fine gravel	22	122
	Gravel, fine, sand, and gray clay	8	130
Glaciofluvial deposits			
	Gravel, fine to medium, and sand; clayey	15	145
	Gravel, fine, and sand, very clayey	10	155
Till			
	Clay, light gray, and considerable gravel	3	158
"Granite"			
	Granite, decomposed, green to gray	7	165

140-49-21ccc
USGS test hole

Lake Agassiz deposits			
Silt unit			
	Soil, black	1	1
	Silt, light gray	8	9
	Sand, fine to medium, clayey, brown	24	33
Clay unit			
	Clay, dark gray	39	72
Till			
	Clay, gray, and considerable fine gravel and sand	95	167
Glaciofluvial deposits (?)			
	Gravel, fine, fine sand, and a little gray clay	8	175
"Granite"			
	Granite, decomposed, greenish gray	5	180

140-49-25dcd
City of Fargo
Hector Airport well

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
	Clay	75	75
Till and associated glaciofluvial deposits			
	Sand	2	77
	"Hardpan"	25½	102½
	Sand	2½	105

140-49-28ccc
USGS test hole

Lake Agassiz deposits				
	Silt unit			
		Soil, black	1	1
		Clay, sand, greenish gray	4	5
		Silt, buff to light gray	8	13
		Sand, fine, buff	13	26
	Clay unit			
		Clay, dark gray	51	77
Till and associated glaciofluvial deposits				
	Till			
		Clay, gray, and considerable gravel and sand	27	104
	Glaciofluvial deposits			
		Gravel and sand, clayey	22	126
	Till			
		Gravel, fine, and gray sandy clay	14	140
	Glaciofluvial deposits			
		Gravel, fine to coarse, sand, and little clay	54	194
"Granite"				
		Granite, decomposed, gray to green	6	200

140-49-32add
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	4	4
	Silt, yellow	9	13
	Sand, fine, buff	7	20
	Sand, fine, and brown clay	9	29
Clay unit			
	Clay, gray	45	74
Till and associated glaciofluvial deposits			
Till			
	Clay, blue, and some fine to coarse gravel and sand	6	80
	Clay, sandy, gray, and considerable fine gravel	27	107
Glaciofluvial deposits			
	Gravel, medium, and some sand; clean	8	115
	Gravel, coarse, and a little sand; clean	5	120
	Gravel, fine to medium, and cobbles	39	159
Till			
	Clay, light gray, and some sand and fine gravel	6	165
"Granite"(?)			
	Slate(?), red and green, decomposed	7	172
	"Granite"(?), decomposed, very light gray	8	180

140-49-33ddd
USGS test hole

Lake Agassiz deposits			
Silt unit			
	Soil, black	4	4
	Silt and clay, buff	18	22
Clay unit			
	Clay, gray	60	82
Till and associated glaciofluvial deposits			
Till			
	Clay, sandy, blue to gray, and fine to medium gravel	63	145
Glaciofluvial deposits			
	Gravel, fine to coarse, clean	24	169
	Cobbles, gravel, sand, and some clay	4	173

140-49-34cdd
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	3	3
	Silt and clay, buff	9	12
	Clay, blue	4	16
	Sand, fine and medium	6	22
Clay unit			
	Clay, gray	66	88
Till and associated glaciofluvial deposits			
Till			
	Gravel, sand, and gray clay	15	103
Glaciofluvial deposits			
	Gravel, medium, clean	9	112
	Gravel, fine to coarse, sandy, clayey	3	115
Till			
	Clay, sandy, gray, and some coarse gravel	45	160
"Granite"			
	"Granite", decomposed, greenish gray	50	210

140-51-34ccd
USGS test hole

Lake Agassiz deposits			
Silt unit			
	Soil, black	3	3
	Silt, yellow, and a few pebbles	23	26
	Sand, medium, clayey, brown	9	35
Clay unit			
	Clay, light gray	20	55
Till and associated glaciofluvial deposits			
Till			
	Clay, light gray, and a little sand and gravel	15	70
	Gravel, fine to coarse, sand, and light to dark gray clay	84	154
Glaciofluvial deposits			
	Cobbles and gravel	1	155
	Gravel and sand, fine, and a little gray clay	15	170
Older lake clay and drift deposits			
	Clay, hard, blue, with considerable gravel	40	210
	Clay, very hard, dark gray, with very little gravel	53	263
	Clay, dark brown, and very little gravel	30	293
	Clay, light gray	12	305
	Clay, dark brown	11	316
	Clay, light brown to gray	3	319
"Granite"			
	"Granite," decomposed, white	11	330

140-51-34daa
USGS test hole

Formation	Material	Thickness	Depth
Lake Agassiz deposits			
Silt unit			
	Soil, black	4	4
	Clay, sandy, gray	4	8
	Silt, buff to light brown	17	25
	Sand, medium to coarse, and some fine gravel	10	35
	Gravel, fine to coarse, and some sand; clean	6	41
Clay unit			
	Clay, gray	9	50
Till and associated glaciofluvial deposits			
Till			
	Clay, gray, and some gravel and sand	32	82
Glaciofluvial deposits			
	Gravel and sand, fine to medium, clayey	8	90
	Gravel and sand, fairly clean	5	95
Till			
	Clay, gray, and a little gravel and sand	5	100
Glaciofluvial deposits			
	Gravel and sand, clayey	5	105
	Gravel, fine, and sand, fairly clean	50	155
	Gravel and sand, clayey	6	161
Till			
	Clay, gray, with some sand and little gravel	9	170
Older lake clay and drift deposits			
	Clay, hard, blue, some gravel and sand	25	195
	Silt and clay, hard, gray, and a little gravel	45	240
	Clay, hard, blue to gray, and a few pebbles	22	262
	Clay, hard, dark brown	5	267
	Clay, alternating light and dark gray	65	332
	Clay, hard, gray, and some gravel and sand	6	338
"Granite"			
	"Granite," decomposed, light gray	12	350

(Core sample 170 to 190 feet)