# GROUND WATER IN BEACH DEPOSITS OF GLACIAL LAKE AGASSIZ

# NEAR MOUNTAIN, PEMBINA COUNTY, N.DAK.

BY

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North Dakota Ground Water Studies No. 2

Prepared in Cooperation Between the Geological Survey,
U. S. Department of the Interior; the North Dakota
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North Dakota State Beological Survey.

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CONTENTS



ILLUSTRATIONS



All illustrations attached.

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## INTRODUCTION

The study described in this report was restricted to a small area in the immediate vicinity of the village of Mountain. The area is a typical unit in a belt of beach and delta deposits that extend all along the shores of the ancient glacial Lake Agassiz in North Dakota. The study indicates that, in the aggregate, comparatively large quantities of water of good quality are available from these deposits . The development of water supplies from these sources may be of considerable importance to the future economy of the State and it is planned eventually to make a detailed study of the ground-water conditions in these deposits over a much wider area.

The village of Mountain is located in the southwestern part of Pembina County, on State Highway No. 32, about 5 miles south of the junction of State highway 32 and State highway No. 5. The population of the village at present is about 250. Many of the people of the village and surrounding area are of Icelandic origin or descent and the Icelandic Lutheran Church has had under consideration the building in this locality of a home for its aged members.

It was estimated that the proposed home would require approximately 5,000 gallons of water a day as a maximum, but the village of Mountain was also interested to learn if there might be sufficient water in the beach sands to furnish adequate water for a municipal water supply and a modern sewage system. Assuming the addition of the old folks' home and making allowances for normal population increases, it was estimated that the total population to be expected in the near future would be about 500 and that the total water requirements for a modern community of this size would be between 30,000 and 50,000 gallons a day.

The area covered by this investigation includes less than three square miles. It extends from the village of Mountain on the east to the foot of Pembina Mountain on the west. It is bounded on the south by Cart Creek and on the north by Can Creek which is tributary to Willow Creek. The eastern part of the area is shown in Figure 1, attached to this report.

## INVESTIGATIONAL PROCEDURE

The investigation was made as a part of the program to investigate the ground-water resources of North Dakota, through cooperation by the State Water Conservation Commission and the State Geological Survey with the Geological Survey, U.S.Department of the Interior.

P. D. Akin, hydraulic engineer for the U. S. Geological Survey was assigned to proceed with the investigation of the water resources of the shallow sands in the area. During the latter part of July and the early part of August, 1945, Mr. Akin and Sidney M. Thorstad, laborer, did field work in connection with the investigation. Mr. H. J Hallgrimson, of the village of Mountain, also assisted in putting down hand-auger wells in the area.

In making the field study, all available information was obtained from 19 existing wells in the area and 25 additional hand-auger wells were put down. Samples of the cuttings from all of the hand-auger wells were preserved for study. Ten samples were taken from the auger wells for the purpose of making permeability tests on the sands. Water levels were measured in all wells, and instrumental levels were run to them for the purpose of determining the shape of the water table. Estimates were made of discharge at various points on Can Creek and Cart Creek.

## PHYSIOGRAPHIC FEATURES

The area covered by this investigation was at one time occupied by the glacial Lake Agassiz, the escarpment at Pembina Mountain, which marks the western shore of the glacial lake at its highest stage, is about three miles west of the village of Mountain. The village is situated on a shore line formed at a lower stage of the ancient lake, marked by an eastward-facing escarpment that rises about 30 feet above the lake plain in a distance of 400 feet. The escarpment is a wave-cut cliff and is part of a prominent shore line formed during the Campbell 1/ stage of the glacial lake.

From the village of Mountain (elevation 1,068 feet) the land surface rises westward about 70 feet in the first mile and thence about 45 to 50 feet per mile for the next two miles to the foot of the Pembina Mountain (elevation about 1,225 feet). The creeks are entrenched 30 to 40 feet below the general level of the land surface between them.

The village of Mountain is about 3½ miles southeast of the southernmost reach of the Pembina Delta as mapped by Upham. 2/

## WATER BEARING FORMATIONS

The area is underlain by silty sand and shale-gravel derived from the erosion of the formations comprising the Pembina Mountain. The sand and gravel were deposited as beaches in glacial Lake Agassiz. The deposits range in thickness up to 25 feet and are the principal source of water for stock and domestic purposes in the area west of the village (wells 15-19, figure 1).

The sands and gravels are immediately underlain by glacial till composed chiefly of blue or yellow clay mixed with sand, gravel and boulders. The till is exposed in the escarpment at the village and is very near the surface all along the east side of the village (figure 5). Boulders derived from the till outcrop along a northwest-southeast line across the area west of the village as shown in Figure 1.

The till is not generally a good producer of water in North Dakota although many stock and domestic wells and some municipal wells derive their water

1/ Upham, Warren. The glacial Lake Agassiz: U. S. Geological Survey, Monograph 25, 1896, Pl. 30.

2/ Upham, Warren, Op cit., Pl. 30.

from sand and gravel lenses within it. The chief disadvantage of such supplies generally lies in the small size of the aquifer and its location within relatively impermeable material where it receives recharge very slowly. Large withdrawals frequently exhaust such aquifers. The wells on the east side of the village of Mountain obtain water from sands in the till (wells 4-8, figure 1), and it is likely that wells in the west side of the village (wells 9-14, figure 1) also obtain water from sands in the till. Unsuccessful attempts have been made to obtain water from wells in the till in the extreme southern part of the village.

Possibilities of obtaining potable water from formations underlying the till in this area are remote. The till is immediately underlain by shales of Cretaceous age - - the Pierre shale, Niobrara formation, and Benton shale - - all of which are very impervious and yield little or no water. In some localities, small amounts of highly mineralized water are obtained from weathered parts of the Pierre shale or from sandy layers in the upper portion of the formations. The Dakota sandstone, also of Cretaceous age, and the underlying rocks (older Mesozoic and Paleozoic) produce good quantities of highly mineralized water which, in this area, generally is not fit for human consumption.

A well 575 feet deep was drilled in 1926 on thewest side of the main street in the south end of the village of Mountain. No log is available for this well, but it is reported that no water was encountered above 575 feet. From this depth the water level rose to within 180 feet of the surface and was pumped with a windmill. The water is reported to have been soft and adequate in quantity but too highly mineralized for human consumption. The well has been abandoned for some time.

Inasmuch as existing data on the water-bearing formations indicated that the shallow water in the beach sands was of the best quality, was the most easily available, and gave promise of being the most permanent ground-water supply in the area, the present study was essentially confined to a quantitative investigation of this source.

## HYDROLOGY OF THE BEACH SANDS

### RECHARGE

The sands and gravels in the area between the village of Mountain and Pembina Mountain constitute a distinct hydrologic unit. There is little possibility of ground-water underflow entering the sands from the west through the shales which form the Pembina escarpment. The streams on both the south and north are cut through the sands and are entrenched deeply into the underlying till. The streams do not add water to the sands but rather act as channels to dispose of seepage from the sands. The ground-water flow in the sands is in general toward the east and there is no possibility of water being added to the sands from that direction.

It follows that all of the water in the sands is derived from the precipitation on an area of less than three square miles, bounded by Pembina Mountain on the west, the Campbell escarpment on the east, Can Creek on the north and Cart Creek on the south.

No definite figure can be placed upon the percentage of the precipitation on the area that will reach the water table. The precipitation is disposed of in many ways: by direct runoff into the streams, especially from melting shows while the ground is still frozen at depth; by evaporation from show in the winter and from the soil surface in the summer; by transpiration from plants;and by downward percolation to thewater table and thence into the streams or into other areas where transpiration and evaporation may dispose of it. Only that part of the water which escapes runoff and the other disposing agents can percolate downward and become part of the ground-water body and thus a potential ground water supply. This part generally will be only a small percentage of the total precipitation (in the area considered) and will vary from year to year according to the amount and character of the precipitation and the condition of the soil.

The soil over most of the area is quite sandy and affords good opportunity for recharge from moderate rainfall and from melting snows if the ground is not entirely frozen.

No precipitation records are available for Mountain. Records for Walhalla, about 17 miles north of Mountain, are available from January 1904, to April 1928 except 1924, 1925, and 1926 and for Cavalier about 13 miles northeast of Mountain, since April 1928. Climatic conditions at Mountain will be approximately the same as at Walhalla and Cavalier.

The monthly precipitation at Walhalla and Cavalier since 1904 as published by the U. S. Weather Bureau is given in the table on page five of this book.

About 68 percent of the mean annual precipitation is received during the five months from May to September inclusive. During the 37-year record, 17 years have had precipitation below normal and 13 years have had less than 16 inches. During the 37-year period, below normal precipitation has occurred for 4 consecutive years one time, for 3 consecutive years one time and for 2 consecutive years three times. Twice during the period of record the precipitation for 2 consecutive years has been less than 16 inches but at no time has the annual precipitation been less than 16 inches for 3 consecutive years. In the period immediately preceding thepresent investigation, the precipitation was above normal in 1940, 1941, and 1942, below normal in 1943, and above normal in 1944. During the first half of 1945 the precipitation was only slightly below normal, and heavy rainfall during July brought the total for the year to about 23 percent above normal.

The area over which the precipitation is likely to be effective in replenishing the ground-water supply in the beach sands is approximately 2½ square miles. The average annual precipitation is 18.86 inches. The average yearly amount of water reaching the area is thus about 800,000,000 gallons.

As will be shown later, the natural discharge from the area is estimated to have been about 80,000 gallons a day or 30,000,000 gallons a year at the time of the investigation. If the estimated natural discharge at the time of the investigation can be taken as the average annual replenishment to the ground-water body, then the recharge to the sands is only 3.7 percent of the average annual precipitation. This represents only 0.70 inch of precipitation a year that is effective in replenishing the ground-water supply. This is probably a conservative figure considering the relatively permeable character of the sands from the land surface to the water table.

Monthly Precipitation at Cavalier, North Dakota, in inches, 1904-1945
(Record for January 1904 to April 1928, inclusive is for Walhalla)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1904 | 0.29 | 0.70 | 2.24 | 1.09 | 3.42 | 8.05 | 7.65 | 3.11 | 1.86 | 1.52 | 0.11 | 0.20 | 30.24 |
| 1905 | 1.10 | T | 1.81 | T | 3.67 | 6.43 | 0.86 | 3.14 | 1.97 | T | 1.98 | 1.10 | 21.96 |
| 1906 | 0.71 | 0.40 | T | 0.69 | 3.36 | 5.36 | 3.16 | 0.34 | 1.10 | 0.54 | 2.49 | 1.80 | 19.95 |
| 1907 | 1.95 | T | 0.18 | 0.30 | 1.05 | 2.39 | 2.85 | 2.78 | 1.30 | 0.39 | T | 0.20 | 13.39 |
| 1908 | 0.13 | 0.93 | 0.08 | 1.77 | 3.99 | 3.29 | 1.83 | 3.15 | 0.98 | 1.84 | 0.72 | 0.82 | 19.53 |
| 1909 | 0.75 | 0.26 | 0.50 | 0.70 | 3.70 | 4.33 | 2.66 | 3.91 | 0.62 | 1.28 | 0.22 | 3.20 | 22.13 |
| 1910 | 0 | T | 1.00 | 2.14 | 1.00 | 0.37 | 0.94 | 0.86 | 4.48 | 1.04 | 0.35 | 0.80 | 12.98 |
| 1911 | 0.45 | 1.43 | 0.20 | 2.63 | 4.37 | 1.68 | 2.74 | 5.36 | 1.73 | 1.30 | 0.90 | 0.85 | 23.64 |
| 1912 | 0.20 | 0.30 | 0.25 | 2.08 | 5.36 | 0.51 | 8.87 | 3.05 | 3.00 | 1.60 | T | 0.75 | 25.97 |
| 1913 | 0.65 | 0.20 | 1.20 | 0.50 | 0.50 | 1.82 | 1.73 | 3.11 | 1.80 | 1.50 | 0.05 | 0.02 | 13.08 |
| 1914 | 1.80 | 0.80 | 0.40 | 1.60 | 2.65 | 2.52 | 2.44 | 1.67 | 1.97 | 1.01 | 0.60 | 1.60 | 19.06 |
| 1915 | 0.60 | 1.00 | 0.15 | 1.91 | 2.44 | 3.10 | 2.09 | 0.80 | 3.39 | 0.04 | T | 0.85 | 16.37 |
| 1916 | 2.20 | 0.30 | 1.30 | 0.63 | 1.50 | 2.18 | 3.84 | 2.66 | 1.13 | 1.13 | 0.10 | 2.80 | 19.77 |
| 1917 | 1.10 | 0.80 | 0.25 | 2.20 | T | 2.26 | 1.55 | 0.79 | 0.54 | 0.99 | 0.10 | 0.30 | 10.88 |
| 1918 | 0.40 | 0.65 | 0.05 | 2.81 | 3.39 | 1.43 | 3.67 | 2.59 | 1.13 | 1.14 | 1.69 | 1.50 | 20.45 |
| 1919 | 0.50 | 0.25 | 0.80 | 0.93 | 2.60 | 1.49 | 1.25 | 1.65 | 0.62 | 1.84 | 1.00 | 0.60 | 13.53 |
| 1920 | 1.40 | 0.70 | 0.95 | 0.32 | 1.97 | 1.64 | 1.92 | 1.32 | 3.35 | 0.27 | 1.00 | 0.66 | 15.50 |
| 1921 | 0.80 | 1.30 | 0.75 | 1.39 | 1.53 | 1.97 | 5.12 | 3.32 | 3.55 | 0.71 | 0.83 | 0.24 | 21.51 |
| 1922 | 0.79 | 0.38 | 1.24 | 0.32 | 5.63 | 4.01 | 0.60 | 0.74 | 4.69 | 0.44 | 3.16 | 2.43 | 24.43 |
| 1923 | 0.48 | 1.30 | 1.04 | 0.84 | 1.13 | 1.53 | 2.18 | 2.55 | 1.56 | 0.87 | 0.83 | 0.30 | 14.61 |
| 1927 | 0.26 | 0.14 | 0.44 | 2.01 | 5.40 | 4.30 | 1.83 | 4.69 | 0.94 | 2.28 | 0.81 | 0.15 | 23.25 |
| 1928 | 0.27 | 0.01 | 0.50 | 0.65 | 1.30 | 5.77 | 3.30 | 2.00 | 0.19 | 0.55 | 1.34 | 0.52 | 16.40 |
| 1929 | 0.85 | 0.30 | 0.77 | 1.63 | 1.47 | 1.07 | 1.19 | 0.44 | 1.95 | 1.76 | 0.09 | 1.85 | 13.37 |
| 1930 | 0.18 | 2.45 | 0.10 | 0.13 | 3.66 | 2.50 | 1.38 | 0.32 | 2.80 | 2.21 | 1.47 | 0.45 | 17.65 |
| 1931 | 0.27 | 0.35 | 0.95 | 0.27 | 2.05 | 1.46 | 3.00 | 2.33 | 3.81 | 2.89 | 0.76 | 0.10 | 18.24 |
| 1932 | 0.92 | 0.53 | 0.21 | 2.33 | 1.43 | 4.97 | 2.82 | 2.97 | 1.12 | 3.77 | 1.69 | 0.37 | 23.13 |
| 1933 | 1.08 | 0.27 | 0.09 | 0.38 | 3.36 | 0.92 | 0.68 | 0.80 | 0.86 | 0.41 | 0.97 | 1.72 | 11.54 |
| 1934 | 0.54 | 0.21 | 0.25 | 0.89 | 0.23 | 3.15 | 3.33 | 1.49 | 1.54 | 1.91 | 0.38 | 0.44 | 14.36 |
| 1935 | 0.63 | 0.06 | 1.41 | 2.08 | 1.41 | 3.89 | 4.10 | 2.48 | 1.70 | 0.45 | 0.83 | 0.33 | 19.37 |
| 1936 | 0.63 | 0.82 | 0.55 | 0.07 | 0.43 | 1.43 | 0.85 | 3.89 | 4.12 | 0.12 | 0.16 | 0.61 | 13.68 |
| 1937 | 0.93 | 0.33 | 0.05 | 3.66 | 1.96 | 3.09 | 4.07 | 4.01 | 1.07 | 0.36 | 0.85 | 0.61 | 20.99 |
| 1938 | - | - | - | - | - | - | - | - | - | - | 0.48 | 0.64 | --- |
| 1939 | 0.42 | 0.77 | 0.24 | 0.72 | 2.41 | 2.86 | 0.75 | 3.77 | 0.92 | 0.49 | T | T | 13.35 |
| 1940 | T | 1.15 | 0.99 | 2.11 | 1.25 | 1.50 | 5.49 | 0.82 | 3.00 | 0.98 | 0.87 | 0.73 | 18.89 |
| 1941 | 1.36 | 0.30 | 1.36 | 2.48 | 1.90 | 5.29 | --- | 2.21 | 9.34 | 2.39 | 0.25 | 0.12 | 27.17 |
| 1942 | 0.22 | 0.42 | 3.49 | 1.41 | 2.17 | 1.22 | 3.34 | 8.48 | 0.57 | 0.19 | 0.44 | 1.01 | 22.96 |
| 1943 | 0.66 | 0.46 | 1.42 | 1.19 | 3.01 | 3.71 | 1.90 | 1.03 | 0.67 | 0.27 | 0.83 | 0.34 | 15.49 |
| 1944 | 0.15 | 0.27 | 2.41 | 0.12 | 1.17 | 4.74 | 4.53 | 7.11 | 2.20 | 0.40 | 4.92 | 0.17 | 28.19 |
| 1945 | 0.70 | 0.11 | 1.51 | 2.59 | 1.74 | 1.77 | 5.50 | 1.43 | 3.24 | 0.61 | -- | -- | ----- |
| Mean | 0.67 | 0.51 | 0.76 | 1.39 | 2.26 | 3.08 | 2.64 | 2.51 | 2.32 | 1.29 | 0.74 | 0.69 | 18.86 |

## DISCHARGE

One of the most useful means of estimating the yield of an aquifer is to estimate the natural discharge from the aquifer. In the area considered thenatural ground-water discharge will be the sum of the underflow eastward and downward, the seepage into the streams, the water transpired by plants in the area, and the water evaporated directly from the soil in those areas where the water table is sufficiently near the land surface to permit the water to reach the surface through capillary action.

Figure 2 is a map of the water table in the area studied. As the motion of the ground water is in a direction at right angles to the water table contours, the map shows that in general the motion of the ground water is toward the east and downward through the till of the escarpment at the village. The ground water also discharges into the streams through seeps and springs all along their course, and the motion of the groundwater toward the streams is indicated by a bending of the water table contours upstream toward the creeks in their vicinity. One of the most notable springs derived from the ground-water body is located on the south side of Can Creek, between wells D-1 and E-1. This spring has the largest flow in the spring of the year after the snow has melted. The contours of the water table bend rather sharply toward the stream in this locality, indicating considerable discharge into the stream there.

There is also some percolation of water downward from the sands into the underlying till and thence laterally out of the area. The downward percolation of water into the till probably occurs over the entire area but the amount of water lost from the sands to the till in this manner is probably insignificant except in the Campbell escarpment and in the immediate vicinity of the streams.

Figure 3 is a section from north to south, along the line of auger wells lettered "A", from well A-7 to well A-2. This diagram shows in profile the slope of the water table toward the streams but it also indicates the limited thickness of the saturated sand near the streams.

No accurate estimates can be made of the water discharged into the stream valleys through stream discharge measurements because of the transpiration losses in the stream valleys and because of water entering the streams through seepage and springs from areas north of Can Creek and south of Cart Creek. However, estimates of the flow of the creeks were made at two points in line with the auger wells numbered "C" and "D" respectively. The estimated stream flows are shown in the following table.

| Station | Creek | Estimated flow (gallons per day) August 2, 1945 | Gain in flow (gallons per day) |
|---|---|---|---|
| "D" line | Cart | 65,000 | |
| "C" line | Cart | 23,000 | |
| | | | 42,000 |
| "D" line | Can | 14,000 | |
| "C" line | Can | 0 | |
| | | | 14,000 |
| | | Total gain | 56,000 |

Thus there was an apparent total gain in flow of about 56,000 gallons per day in the two creeks between the "C" line and the "D" line. If half of this total gain comes from ground-water discharge on the area between the creeks, then the ground-water discharge into the creeks from the area studied was about 30,000 gallons a day.

In order to estimate the amount of ground-water underflow out of the area, permeability measurements were made on sand samples collected from auger wells.

Permeability is that property of a material by virtue of which it permits the passage of a fluid through it. In other words, the relative ease with which a fluid, such as water, may be transmitted through a given material is measured by the permeability of that material. Different units of permeability have been used in the various branches of engineering and science, the coefficients being defined in a manner most useful to the particular application. For the purpose of this report, the coefficient of permeability considered will be that used in the hydrologic work of the U. S. Geological Survey for field conditions. This coefficient is called the "field coefficient of permeability" and is expressed in terms of the discharge of water in gallons a day through a section of the aquifer one foot high and one mile wide under a hydraulic gradient of one foot to the mile. The "field coefficient of permeability" depends upon the properties of the fluid being used as well as upon the properties of the material being considered. For the case at hand, the hydraulic gradient is approximately the slope of the water table.

Measurements of the coefficient of permeability were made on nine samples taken from the various auger wells and on one sample taken from the material dug out to make a stock pit about 300 feet west of well 15 (figure 1.) The measurements were made in the laboratory on disturbed field samples collected in glass jars, using a variable-head permeameter of the U. S. Geological Survey.

Results of the permeability tests are shown in the following table:

| Sample No. | Location or Well No. | Field coefficient of Permeability $P_f$, gpd/ft.$^2$ (Water temp. 50° F) |
|---|---|---|
| 1 | [illegible] stock pit, 300 ft. west of well #15 | 95 |
| 2 | A-3 | 163 |
| 3 | A-4 | 60 |
| 4 | A-8 | 77 |
| 5 | C-1 (depth 3-5½) | 155 |
| 6 | C-2 (depth 2-6½) | 228 |
| 7 | C-2 (depth 6½-8) | 121 |
| 8 | C-3 (depth 1-6½) | 232 |
| 9 | B-3 | 197 |
| 10 | B-10 | 160 |
| | SUM | 1,488 |
| | Average $P_f$ = | 149 |

Using data from Figure 2 and Figure 3 and an average coefficient of permeability of 149 gpd per sq. ft, a computation was made of the underflow eastward across the line of "A" wells between well A-6 and well A-2. This indicates that the underflow across this line was about 50,000 gallons a day at the time of the investigation (July-August 1945). The detailed estimate of the underflow is shown in the following table. Ground-water underflow through the till underlying the sands is assumed to be negligible in this section.

Estimate of ground-water underflow from west to east along section from test well A-6 to test well A-2

| 1<br>From To<br>Sta.Sta. | 2<br>Width of sub-sec (ft.) | 3<br>Average saturated thickness of sands (ft.) | 4<br>Area of sub-sec (sq.ft.) | 5<br>Equivalent depth for sub-sec one mile wide(ft) | 6<br>Average slope of water table in sub-sec (ft/mi) | 7<br>Coeffic. of permeability ($P_f$) gpd/ft$^2$ | 8<br>Gallons of water per day crossing sub-sec. (5x6x7) |
|---|---|---|---|---|---|---|---|
| A-6 3+00 | 240 | 0.20 | 48 | 0.009 | 90 | 149 | 121 |
| 3+00 6+00 | 300 | 0.90 | 270 | 0.051 | 92 | 149 | 699 |
| 6+00 9+00 | 300 | 2.40 | 720 | 0.136 | 79 | 149 | 1600 |
| 9+00 12+00 | 300 | 6.32 | 1896 | 0.359 | 63 | 149 | 3370 |
| 12+00 15+00 | 300 | 11.75 | 3525 | 0.668 | 61 | 149 | 6070 |
| 15+00 18+00 | 300 | 14.50 | 4350 | 0.824 | 62 | 149 | 7610 |
| 18+00 21+00 | 300 | 13.93 | 4179 | 0.792 | 67 | 149 | 7910 |
| 21+00 24+00 | 300 | 11.80 | 3540 | 0.671 | 82 | 149 | 8200 |
| 24+00 27+00 | 300 | 8.63 | 2589 | 0.491 | 99 | 149 | 7240 |
| 27+00 30+00 | 300 | 4.75 | 1425 | 0.270 | 116 | 149 | 4670 |
| 30+00 A-2 | 120 | 1.80 | 216 | 0.041 | 129 | 149 | 788 |
| | | | | | | Total | 48,278 or |

about 50,000 gallons a day

The total natural discharge through eastward underflow and spring discharge and seepage into the streams from the area is thus estimated to have been about 80,000 gallons a day at the time the study was made. While the figure of 30,000 gallons a day is probably somewhat high on the average the year around for the quantity discharged into the streams, no account has been taken of evaporation and transpiration losses. It is concluded that the natural discharge from the area is at least 80,000 gallons a day and perhaps more due to the losses not estimated.

## STORAGE

The water contained in the sands is in motion toward the east and toward the streams, but the rate of movement is relatively low when compared with surface stream velocities. The quantity of water passing out of the sands each day is only a small fraction of the total quantity of water contained in the sands. The water may be said to be in a state of "transient storage".

The amount of water in transient storage in the area between the "B" line of wells and the "D" line of wells was estimated in the following manner: The volume of saturated sands was determined from a map similar to Figure 4. The volume of saturated sands was then multiplied by an effective porosity factor to obtain an estimate of the volume of free water contained in the sands. The effective porosity, or specific yield, of sands varies between wide limits.

A specific yield of 20 to 40 percent is common in this type of material 3/. No measurements were made to determine the specific yield of the sands in the area but a specific yield of 15 percent was chosen for computation purposes.

It is thus computed that at the time of the investigation the amount of water in transient storage in the sands between the "B" line of wells and the "A" line was about 78,000,000 gallons and the amount in storage between the "A" line and the "D" line was about 63,000,000 gallons, or a total of about 141,000,000 gallons between the "B" line and the "D" line.

## WATER AVAILABLE FOR DEVELOPMENT

It has been estimated that under natural conditions at the time of the investigation (July, August, 1945) the discharge from the sands was about 80,000 gallons a day. During dry periods or during the winter when the ground is frozen so that recharge to the ground-water body cannot occur, the natural discharge is supported by the water stored in the sands and the water table is consequently lowered. As the water table is lowered, the rate of natural discharge decreases. In the spring when the soil thaws, water from melting snow percolates downward to the water table and more water is added to the ground-water body. Water levels then rise and natural discharge increases. During the warmer part of the year when the ground is not frozen, recharge to the ground-water body occurs intermittently and in a varying amount from the rainfall.

Withdrawal of water by means of wells will represent an additional discharge from the water stored in the sands. As a result, the water levels will be lowered and the natural discharge will be decreased. A considerable part of the water formerly discharged naturally will be discharged through the wells. The most efficient use of the ground-water body would occur if the water levels could be so lowered by pumping that all natural discharge would be stopped and if at the same time there would be left a sufficient thickness of saturated sands to support the production from the wells. Practically this ideal condition cannot be realized in the sands in this area because of the very steep slope of the water table and the initially small thickness of the saturated sands.

It has been estimated that the amount of free water in storage between the "D" line of wells and the "B" line of wells is approximately 141,000,000 gallons. About 85 percent of the water in storage (about 120,000,000 gallons) is contained in the upper 5 feet of the saturated zone.

If the water level over the entire area were lowered 5 feet, the eastward underflow across the "A" line of wells would be reduced to about 20,000 gallons a day due to a decrease in the saturated area along this line, assuming that the average permeability of the sands and the eastward slope of the water table remained about the same as at the present time. Also if the water levels over the area were lowered 5 feet, the natural seepage into the streams would be virtually stopped. It is therefore estimated that if the water level were lowered 5 feet over the entire area, the total natural discharge would be about 20,000 gallons a day or approximately 30 percent of the present natural discharge.

If no recharge occurred, as during an extended drought, the time required for the water level to drop 5 feet can be calculated in the following manner: Assume that the rate of natural discharge Q will vary directly as the saturated thickness of the sands , H. Then

3/ Meinzer, O.E. The occurrence of groundwater in the United States. U.S. Geological Survey Water-Supply Paper 489, pp. 50-76 1923.

(1) $Q = KH$

where K is a proportionality constant involving the permeability of the sands, the width of the section and the slope of the water table. The numerical value of K may be found as follows:

(2) $Q_o = 80{,}000 = KH_o$

(3) $Q_1 = 20{,}000 = KH_1$

where $Q_o$ is the natural discharge in gallons a day, $H_o$ is the initial saturated thickness of the sands, $Q_1$ is the natural discharge after the water level has dropped 5 feet and $H_1$ is the saturated thickness of the sands after the water level has dropped 5 feet. Subtracting (3) from (2) gives

(4) $80{,}000 - 20{,}000 = 60{,}000 = K(H_o - H_1)$

(5) $K = \frac{60{,}000}{5} = 12{,}000$

since $H_o - H_1 = 5$ feet. Also from (2), (3) and (5)

(7) $H_o = \frac{80{,}000}{12{,}000} = 6.66$ feet and

(8) $H_1 = \frac{20{,}000}{12{,}000} = 1.66$ feet

The figures for $H_o$ and $H_1$ given in equations (7) and (8) have no particular significance in the hydrologic unit. For example, $H_o$ does not represent the average saturated thickness of the sands over the entire area. This figure does however represent what the average saturated thickness would be if the rate of change of storage were strictly proportional to the average saturated thickness. This willl be approximately true for the upper 5 feet of the saturated sands, which is the part of the unit now under consideration.

The lowering of the water level through natural discharge should follow approximately the law

(9) $-\frac{dH}{dt} = \frac{Q}{A}$

where Q is the rate of natural discharge in gallons a day, t is the time in days and A is a proportionality factor involving the area of the hydrologic unit. Substituting in (9) the value of Q given in (1), we have

$-\frac{dH}{H} = -\frac{KH}{A}$ and

(10) $\frac{dH}{H} = -\frac{K}{A}\,dt$

Integrating both sides of this equation gives

$\ln H = -\frac{K}{A}t + C$ or

$$(11) \quad H = e^{-\frac{K}{A}t} + C = C_o e^{-\frac{K}{A}t}$$

To evaluate $C_o$, let $H = 6.66$ when $t = 0$. Then

$$(12) \quad C_o = 6.66$$

The factor A is determined by dividing the estimated quantity of water stored in the upper 5 feet of saturated sands by 5 or

$$A = \frac{120,000,000}{5} = 24,000,000$$

$$(13) \quad \text{and } \frac{K}{A} = \frac{12,000}{24,000,000} = 0.0005$$

Substituting the values of $C_o$ and $\frac{K}{A}$ from (12) and (13) into equation (11) this equation becomes

$$(14) \quad H = 6.66 e^{-0.0005t}$$

If H is now made 1.66 when

$$(15) \quad 1.66 = 6.66e^{-0.0005t} \text{ or}$$

$$(16) \quad e^{-0.005t} = 0.249$$

Taking natural logarithms of both sides of equation (16)

$$(17) \quad -0.0005t = -1.38$$

$$(18) \quad t = \frac{1.38}{0.0005} = 2760 \text{ days or about 7.6 years.}$$

If an additional development were made by withdrawal by means of wells, the time required to lower the water level 5 feet can be calculated in a similar manner. Under this condition, the equation corresponding to equation (11) will be

$$(19) \quad KH + W = C_w e^{-\frac{K}{A}t}$$

where W is the withdrawal of water by wells in gallons a day. The constant $C_w$ must be evaluated anew for each value of W.

The estimated time required to lower the water table 5 feet for various developments under the conditions outlined above is shown in the following table.

| Discharge rate of withdrawal by wells. (gallons a day) | Time required to lower water level 5 feet (years). |
|---|---|
| 0 | 7.6 |
| 10.000 | 6.0 |
| 20,000 | 5.0 |
| 30,000 | 4.3 |
| 40,000 | 3.8 |
| 50,000 | 3.4 |

It should be remarked that the above figures are estimated from the available data and that the actual performance of the aquifer may be somewhat at variance with the figures tabulated. The most important item not considered in the computations is the natural discharge through transpiration and evaporation. On the other hand the ground-water storage was estimated for only a part of the area. These two factors tend to offset each other and it is believed that the above figures will represent approximately the performance of the aquifer under the specified conditions.

It is not probable that there will be any year so dry that no recharge will occur to the ground-water body. Inspection of the precipitation records, however, indicates that during the period of record, 4 consecutive years of below normal precipitation have occured one time but at no time during the period of record have there been 3 consecutive years with less than 16 inches of precipitation.

The above discussion would apply to a development in which wells would be spaced strategically over the entire area. Inasmuch as the slope of the water table could not be increased materially except in the immediate vicinity of the wells by any one well or by a line of wells extending from south to north across the area, it would not be expected that production from a single well or line of wells could greatly exceed for any long period the natural underflow at that point or along that line. Consequently, the production from a single well or line of wells across the area could be expected to produce not more than about 50,000 gallons a day when the water levels are as high as atpresent and not more than about 20,000 gallons a day when the water levels have been lowered 5 feet.

## Conclusions

From the foregoing data it is concluded that there is sufficient water available in storage in the sands and that the replenishment of the groundwater through precipitation is sufficient to support indefinitely a development of 30,000 gallons a day. It is further concluded that a development of 50,000 gallons a day would be supported except possibly during the most severe drought periods.

Production of 20,000 gallons a day from a line of wells extending across the area from north to south is feasible. Wells should be constructed in the areas of greatest saturated thickness. The area in which the saturated thickness of sands is greater than 10 feet at the present time is shown by hatching on Figure 4.

The beach deposits are continuous for considerable distances both to the north and south of the area investigated except locally where the streams have cut through the sands and into the underlying till. Ground-water conditions all along the reach of these deposits are similar to conditions in the area investigated and it is possible that additional supplies, if needed, can be obtained from adjacent areas to the north and to the south.

## Well logs

Following are logs obtained for wells during the investigation. The locations of these wells are shown in Figure 1. Well numbers preceded by a letter indicate a hand auger well drilled during the investigation. All other numbers indicate existing wells.

Well No. E-2
H. Olafson
NE¼NE¼SE¼
Sec. 16, T. 160 N., R. 56 W.

| Depth | Material |
|---|---|
| 0-3 | Loam, sandy brown |
| 3-7½ | Sand, fine, silty, yellow |
| 7½-11½ | Sand, fine, silty, grey |
| 11½-15 | Clay, yellow, with sand and gravel mixed |
| 15-16 | Clay, blue, with sand and gravel mixed. |

Well No. 9
H. Olafson
NW¼SE¼NW¼
Sec. 16, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-4 | Topsoil |
| 4-11 | Sand |
| 11-18½ | Clay, blue |

Well No. E-1
Torfi Gudmundson
NE¼SE¼SE¼
Sec. 9, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-1 | Loam, clay, black |
| 1-11 | Clay, yellow |
| 11-14 | Sand with yellow clay |
| 14-15 | Sand, clayey, brown |
| 15-19½ | Silt, sandy; clay, brown |

Well No. 14
H. T. Hjaltalin
NW¼NE¼NE¼
Sec. 16, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-2 | Loam |
| 2-6 | Clay, soft, grey |
| 6-7 | Loam, soft, sticky grey |
| 7-17 | Sand |

Well No. D-4
B. A. Bjornson
NW¼NW¼SE¼
Sec. 16, T. 160 N., R. 56 W.

| Depth | Material |
|---|---|
| 0-4 | Sand, fine, silty, brown |
| 4-6 | Sand, fine, silty, grey to red. |
| 6-8 | Sand, fine, silty, brown; shale gravels |
| 8-11 | Sand, fine, silty, grey; shale gravels |
| 11-12 | Clay, blue andyellow mixed |

Well No. D-2
S. J. Hallgrimson
NW¼NW¼NE¼
Sec. 16, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-2 | Loam, sandy, black |
| 2-6 | Sand, fine, silty grey |
| 6-9 | Sand, medium, silty brown and red mixed |
| 9-9½ | Clay, blue |

Well No. D-3
H. Olafson
NW¼SW¼NE¼
Sec. 16, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-2 | Loam, black |
| 2-6 | Sand, fine, grey |
| 6-6½ | Sand, fine, dark; streaked yellow sand at bottom |
| 6½-7 | Clay, blue |

Well No. 16
J. Anderson
SW¼SW¼SE¼
Sec. 9, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-2 | Topsoil |
| 2-13 | Sand |
| 13-18 | Clay, blue |

Well No. D-1
J. Anderson
NW¼SW¼SE¼
Sec. 9, T. 160 N., R. 56 W.

| Depth | Material |
|---|---|
| 0-1 | Loam, sandy, black |
| 1-2 | Silt, sandy, brown |
| 2-4 | Clay, sandy, yellow |
| 4-8 | Sand, fine, silty, brown |
| 8-10 | Sand, fine, silty, grey |
| 10-12½ | Sand and gravel, glacial |
| 12½ | Clay, blue |

Well No. F-2
H. T. Hjaltalin
SE¼SE¼NW¼
Sec. 16, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-1 | Loam, black |
| 1-3 | Silt, sandy, brown |
| 3-8 | Sand, fine, silty; gravels, shale, brown |
| 8-9½ | Clay, yellow |
| 9½-15 | Sand, fine, silty, brown to red. |
| 15-15½ | Clay, blue |

Wel No. F-3
H . T. Hjaltalin
Sec. 16, T . 160 N., R. 56 W.

| | |
|---|---|
| 0-1 | Loam, sandy, black |
| 1-3 | Sand, fine, silty, brown |
| 3-7 | Sand, fine, grey to brown |
| 7-10 | Clay,yellow |
| 10-11½ | Sand, fine, silty, dark, to red |
| 11½-12 | Clay, yellow |
| 12-12½ | Clay, blue |

Well No. F-1
Pembina County
SE¼SE¼SW¼
Sec. 9, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-4 | Sand, fine grey; gravel, shale |
| 4 | Large boulder |

Well No. A-7
H. T. Hjaltalin
SW¼SE¼NW¼
Sec. 16, T. 160 N., R. 56 W.

| Depth | Material |
|---|---|
| 0-2 | Loam, sandy, black |
| 2-6 | Sand, fine, silty, brown |
| 6-8 | Sand, fine, silty, grey |
| 8-8½ | Clay, yellow |
| 8½-9 | Clay, blue |

Well No. A-5
Paul B. Olafson
SE¼NW¼NW¼
Sec. 16, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-2 | Loam, sandy, black |
| 2-3½ | Sand, fine, brown; gravel and shale |
| 3½-4½ | Clay, white; gravel, shale |
| 4½-5½ | Sand, fine to coarse, brown to red |
| 5½-7 | Clay, yellow |
| 7-8 | Clay, blue |

Well No. A-6
H. T. Hjaltalin
NE¼SE¼NW¼
Sec. 16, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-1½ | Loam, sandy, black |
| 1½-3 | Sand, fine, silty, brown |
| 3-3½ | Clay, white, with sand and shale gravels mixed |
| 3½-4½ | Clay, brown and yellow mixed |
| 4½-5 | Clay, blue |

Well No. A-8
Paul B. Olafson
NW¼NW¼NW¼
Sec. 16, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-1½ | Loam, sandy, black |
| 1½-4 | Sand, fine, silty, brown |
| 4-8 | Sand, fine to medium; gravel, shale; caving |

Well No. A-4
aul B. Olafson
¼NW¼NW¼
ec. 16, T. 160 N., R. 56 W.

| epth | Material |
|---|---|
| 0-2 | Loam, sandy, black |
| 2-3½ | Sand, fine, tab |
| 3½-7 | Sand, medium, brown; gravel, shale |
| 7-18 | Sand, fine, silty, brown |

Well No. A-2
Jim Enis
SE¼SW¼SW¼
Sec. 9, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-2½ | Loam, sandy, nrown |
| 2½-4 | Sand, fine, silty, brown |
| 4-7 | Sand, fine to medium, brown |
| 7-8½ | Sand, brown; gravel, shale |
| 8½ | Clay streak, sandy, grey |
| 8½-11½ | Sand, fine, brown, gravel shale |
| 11½-14 | Sand, fine, silty, brown with red streaks |
| 14-15½ | Sand, fine, clayey, blue |
| 15½-16 | Sand, fine, clayey, yellow |
| 16-16½ | Clay, blue |

Well No. A-1
Jim Enis
SW¼NW¼SW¼
Sec. 9, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-1 | Clay, loam, black |
| 1-8 | Clay, mixed yellow and blue |
| 8-11½ | Clay, black with red stained pebbles |
| 11½ | Boulder? |

Well No. C-3
Paul B. Olafson
SE¼NE¼NE¼
Sec. 16, T. 160 N., R. 56 W.

| Depth | Material |
|---|---|
| 0-1 | Loam, sandy, black |
| 1-6½ | Sand, fine, silty, grey |
| 6½-8.8 | Sand, medium, clean, grey with streaks of red |
| 8.8 | Boulder |

Well No. C-2
Pembina County
NE¼NE¼NE¼
Sec. 17, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-6½ | Sand, fine, silty, brown |
| 6½-8 | Sand, medium to coarse, silty, brown |
| 8 | Streak sand, clayey, yell-ow-red. |
| 8-8½ | Clay, blue |

Well No. C-1
Pembina County
NE¼SE¼SE¼
Sec. 8, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-1 | Loam, sandy, black |
| 1-3 | Sand, fine, silty, brown |
| 3 | Streak clay, white, sandy |
| 3-5½ | Sand, medium, brown; gravel, shale |
| 5½-6 | Clay, banded blue and yellow |

Well No. B-5
S. Hjaltalin
SE¼NE¼NW¼
Sec. 17, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-1 | Loam, sandy, black |
| 1-3 | Sand, fine, silty, brown |
| 3-7½ | Sand, medium, brown; gravel, shale |
| 7½-8 | Coarse sand and gravel, red; clay, yellow |
| 8-8½ | Clay, blue |

Well No. B-4
S. Hjaltalin
NE¼NE¼NW¼
Sec. 17, T. 160 N., R. 56 W.

| Depth | Material |
|---|---|
| 0-1½ | Loam, sandy, black |
| 1½-7 | Sand, fine to coarse, brown; gravel, shale |
| 7-9 | Sand, fine to coarse, grey; some gravel |
| 9-11 | Sand, fine to coarse, brewn |
| 11-11½ | Clay, blue |

Well No. B-2
Paul B. Olafson
NE¼SW¼SW¼
Sec. 8, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-2 | Loam, sandy, brown |
| 2-9½ | Sand, fine to coarse, brown; gravel and shale |
| 9½-11 | Sand, coarse, with yellow clay & granite cobbles |
| 11-11½ | Clay, blue |

Well No. B-3
Paul B. Olafson
SW¼SW¼SE¼
Sec. 8, T. 160 N., R. 56 W.

| Depth | Material |
|---|---|
| 0-2 | Sand, fine, silty, brown |
| 2-10½ | Sand, coarse, brown; gravel, medium to fine; shale gravels |
| 10½-11 | Clay, blue |

Well No. B-1
Omar Soli
SE¼NE¼SW¼
Sec. 8, T. 160 N., R. 56 W.

| | |
|---|---|
| 0-2 | Silt, sandy, brown |
| 2-8½ | Sand, medium to coarse, brown; gravel, brown |
| 8½ | Streak glacial pebbles mixed with yellow clay |
| 8½-9 | Clay, blue |

## Well records

The following tables show locations of wells, depths, diameters, uses, water levels, elevations, saturated sand thickness and other pertinent data for wells studied during the investigation.

| Well No. | Owner | Location in T. 160 N., R 56 W. | Elev of land surface | Depth to water below L.S. | Elev of Water Table | Depth of Well | Depth to Till |
|---|---|---|---|---|---|---|---|
| 1 | Oscar Bryon | NE¼SW¼NE¼ Sec. 16 | 1038-01 | 10.37 | 1027.64 | 20 | ? |
| 2 | Oscar Bryon | NE¼SW¼NE¼ Sec. 16 | 1038.35 | 10.31 | 1028.04 | ? | ? |
| 3 | S.J.Hanson | NE¼NE¼NE¼ Sec. 16 | 1035.31 | 6.66 | 1028.65 | 12 | ? |
| 4. | Walter Hollison | NE¼SW¼NE¼ Sec 16 | 1065.96 | 10.58 | 1055.38 | 18 | 0 |
| 5 | H.Olafson | NE¼SW¼NE¼ Sec 16 | 1066.64 | 12.14 | 1054.50 | 22 | 0 |
| 6 | Paulson | SW¼NE¼NE¼ Sec 16 | 1067.08 | 17.37 | 1049.71 | 40? | |
| 7 | Gritherun Thorstenson | NE¼NE¼NE¼ Sec 16 | 1067.96 | 22.28 | 1045.68 | 25 | |
| 8 | Torfi Gudmundson | NE¼SE¼SE¼ Sec 9 | 1063.27 | 14.20 | 1049.07 | 20 | 0 |
| E-2 | H.Olafson | NE¼NE¼SE¼ Sec 16 | 1070.49 | 7.87 | 1062.62 | 16 | 11½ |
| E-1 | Torfi Gudmundson | NE¼SE¼SE¼ Sec 9 | 1067.26 | 14.35 | 1052.91 | 19½ | 1 |
| 9 | H Olafson | NW¼SE¼NE¼ Sec 16 | 1074.10 | 7.58 | 1066.52 | 18½ | 11 |
| 10 | School Property | SW¼NE¼NE¼ Sec. 16 | 1074.79 | 6.76 | 1068.03 | 16 | ? |
| 11 | S.J. Hallgrimson | NW¼NE¼NE¼ Sec 16 | 1073.06 | 8.86 | 1064.20 | 22 | ? |
| 12 | Parsonage Lutheran Church | NW¼NE¼NE¼ | 1073.16 | 8.96 | 1064.20 | 27 | ? |
| 13 | H. J. Hallgrimson | NW¼NE¼NE¼ Sec. 16 | 1072.21 | 8.11 | 1064.10 | 19½ | ? |
| 14 | H. T. .. Hjaltalin | NW¼NE¼NE¼ Sec . 16 | 1072.61 | 9.02 | 1063.59 | 17 | ? |
| D-4 | B. A. Bjornson | NW¼NW¼SE¼ Sec. 16 | 1088.47 | 7.81 | 1080.66 | 12 | 11 |
| 15 | H Olafson | SW¼SW¼NE¼ Sec 16 | 1086.46 | 3.56 | 1082.90 | 10 | 9? |
| D-3 | H Olafson | NW¼SW¼NE¼ Sec. 16 | 1087.71 | 3.30 | 1084.41 | 7 | 6.5 |
| D-2 | S. J. Hallgrimson | NW¼NW¼NE¼ Sec. 16 | 1079.65 | 3.24 | 1076.41 | 9½ | 9 |
| 16 | J. Anderson | SW¼SW¼SE¼ Sec. 9 | 1082.81 | 5.10 | 1077.71 | 18 | 13 |
| D-1 | J.Anderson | NW¼SW¼SE¼ Sec. 9 | 1077.73 | 8.73 | 1069.00 | 13 | 12½ |

| Sat. Thick-ness of sands | Use a/ | Type | Date Comp-leted | Diam | Adequacy | Log given | Remarks |
|---|---|---|---|---|---|---|---|
| | DS | Bored | 1936 | 20" | Adeq. | No | Equipped with centrifugal pump Produces about 10 gpm |
| | U | Dug | | 4' | | No | |
| | DS | Dug | 1940 | 36" | Adq. | No | Aquifer reported as fine sand from 10½-12' on top og blue clay Water temp. 48oF |
| | D | | | | Adeq | | |
| | D | | | | | | |
| | D | | | | | | |
| 0 | DS | Dug | 1930 | 4x6' | Adeq.for farm | No | Log reported as yellow clay all the way |
| 3.6 | A | Hand Auger | 1945 | 6" | | Yes | |
| | A | Hand Auger | 1945 | 6" | | | |
| 3.4 | DS | Dug | 1940 | 4x4' | Inad. | Yes | |
| ? | D | Dug | 1940 | 4' | Adwq. | No | Aquifer, sand. May bottom in clay |
| ? | D | Dug | 1919 | | Adeq. | No | |
| ? | D | Dug | | 4' | | No | |
| ? | D | Dug | | 3' | Adeq. | No | Was necessary to deepen about 1 ft during dry years Not down to clay. |
| ? | D | Dug | 1944 | 5' | Adeq. | Yes | Water reported good, soft |
| 3.2 | A | Hand Auger | 1945 | 6" | | Yes | |
| 5.4? | DS | Dug | 1940 | 6x6' | Adeq. | No | Water reported good, hard. |
| 3.2 | A | Hand Auger | 1945 | 6" | | Yes | |
| 5.8 | A | Hand Auger | 1945 | 6" | | Yes | |
| 7.9 | DS | Dug | 1930 | 3½' | Adeq. | Yes | Water reported good, hard, water level reported 4 of 5' lower during dry years than nc |
| 3.8 | A | Hand Auger | 1945 | 6" | | Yes | |

| Well No. | Owner | Location in T 160 N., R. 56 W. | Elev. of land surface | Depth to water below L.S. | Elev. of water table | Depth of Well | Depth to Tilll |
|---|---|---|---|---|---|---|---|
| F-3 | H.T. Hjaltalin | SE¼SE¼NW¼ Sec 16 | 1100.0 | ? | ? | 12½ | 7? |
| F-2 | H.T. Hjaltalin | SE¼SE¼NW¼ Sec. 16 | 1098.92 | 10.20 | 1088.72 | 15½ | 15 |
| 17 | H.T. Hjaltalin | NE¼SE¼NW¼ Sec. 16 | 1098.75 | 6.02 | 1092.73 | 16 | ? |
| F-1 | Pembina County | SE¼SE¼SW¼ Sec. 9 | 1094.35 | 0.60 | 1093.75 | 4 | 4 |
| A-7 | H. T. Hjaltalin | SW¼SE¼NW¼ Sec 16 | 1108.96 | 7.11 | 1101.85 | 9 | 8 |
| A-6 | H. T. Hjaltalin | NE¼SE¼NW¼ Sec. 16 | 1111.12 | 3.58 | 1107.54 | 5 | 3.5 |
| A-5 | Paul B. Olafson | SE¼NW¼NW¼ Sec. 16 | 1111.17 | 4.10 | 1107.07 | 8 | 5½ |
| A-8 | Paul B. Olafson | NW¼NW¼NW¼ Sec. 16 | 1110.53 | 5.63 | 1104.90 | 8 | 15 b/ |
| A-4 | Paul B. Olafson | NW¼NW¼NW¼ Sec. 16 | 1109.62 | 5.27 | 1104.35 | 18 | 20 b/ |
| A-3 | Jim Enis | SE¼SW¼SW¼ Sec. 9 | 1108.68 | 5.68 | 1103.00 | 16½ | 16 |
| A-2 | Jim Enis | NE¼SW¼SW¼ Sec. 9 | 1105.11 | 7.29 | 1097.82 | 10 | 8 |
| A-1 | Jim Enis | SW¼NW¼SW¼ Sec. 9 | 1084.62 | 8.62 | 1076.00 | 11½ | - |
| 18 | Jim Enis | NW¼SW¼SW¼ Sec. 9 | 1125.98 | 3.53 | 1122.45 | 8 | ? |
| C-3 | Paul B. Olafson | SE¼NE¼NE¼ Sec. 17 | 1132.46 | 2.16 | 1130.30 | 8.8 | 8.8 |
| C-1 | Pembina County | NE¼SE¼SE¼ Sec. 8 | 1127.44 | 4.52 | 1122.92 | 6 | 5.5 |
| C-2 | Pembina County | NE¼NE¼NE¼ Sec. 17 | 1134.50 | 3.03 | 1131.47 | 8½ | 8 |
| 19 | Paul B. Olafson | NE¼SW¼SE¼ Sec. 8 | 1143.66 | 1.54 | 1142.12 | 10 | 10 |
| B-5 | S. Hjaltalin | SE¼NE¼NW¼ Sec. 17 | 1158.84 | 7.98 | 1154.86 | 8½ | 8 |
| B-4 | S. Hjaltalin | NE¼NE¼NW¼ Sec. 17 | 1160.44 | 7.48 | 1152.96 | 11½ | 11 |
| B-3 | Paul B. Olafson | SW¼SW¼SE¼ Sec. 8 | 1158.99 | 4.13 | 1154.86 | 11 | 10½ |
| B-2 | Paul B. Olafson | NE¼SW¼SW¼ Sec. 8 | 1158.99 | 6.98 | 1150.75 | 11½ | 11 |
| B-1 | Omar Soli | SE¼NE¼SW¼ Sec. 8 | 1156.62 | 6.10 | 1150.52 | 9 | 8½ |

b/ estimated.

| Sat. thickness of sands | Use (a) | Type | Date completed | Diam. | Adequacy | Log Given | Remarks |
|---|---|---|---|---|---|---|---|
| 0 | A | Hand Auger | 1945 | 6" | | Yes | Did not get water. |
| 4.8 | A | Hand Auger | 1945 | 6" | | Yes | |
| 19 + | DS | Dug | 1941 | 4' | Adeq | No | Well dug to 16' but prospected with auger to 25'. Reported sand all the way. Water temperature 51° F. |
| 3.4 | A | Hand Auger | 1945 | 6" | | Yes | Well in borrow pit. |
| 0.9 | A | Hand Auger | 1945 | 6" | | Yes | |
| 0 | A | Hand Auger | 1945 | 6" | | Yes | |
| 1.4 | A | Hand Auger | 1945 | 6" | | Yes | |
| 9.4 b/ | A | Hand Auger | 1945 | 6" | | Yes | Bottomed at 8' because of caving |
| 14.7b/ | A | Hand Auger | 1945 | 6" | | Yes | Caving sand. Augered to 18' by casing. |
| 10.4 | A | Hand Auger | 1945 | 6" | | Yes | Required casing to complete. |
| 0.7 | A | Hand Auger | 1945 | 6" | | Yes | |
| | A | Hand Auger | 1945 | 6" | | Yes | In coulee about 50' south of Can Creek |
| ? | DS | Dug | 1939 | 4' | Adeq | No | |
| 6.6 | A | Hand Auger | 1945 | 6" | | Yes | |
| 1.0 | A | Hand Auger | 1945 | 6" | | Yes | In right of way west side of road |
| 5 | A | Hand Auger | 1945 | 6" | | Yes | In borrow pit south of road |
| 8.5 | DS | Dug | 1915? | 4' | Adeq. | No | Well is equipped with rotary pump. Discharge rate estimated at 25 g.p.m. Will pump dry in about 2 hrs. and water level will recover again in about 2 hours (reported). Water reported good and quite soft. |
| 0 | A | Hand Auger | 1945 | 6" | | Yes | |
| 3.5 | A | Hand Auger | 1945 | 6" | | Yes | |
| 6.4 | A | Hand Auger | 1945 | 6" | | Yes | |
| 4 | A | Hand Auger | 1945 | 6" | | Yes | |
| 2.4 | A | Hand Auger | 1945 | 6" | | Yes | |

a/ A- Hand auger test well; not used. DS- Domestic-Stock
D - Domestic. U - Not used.

b/ Estimated.

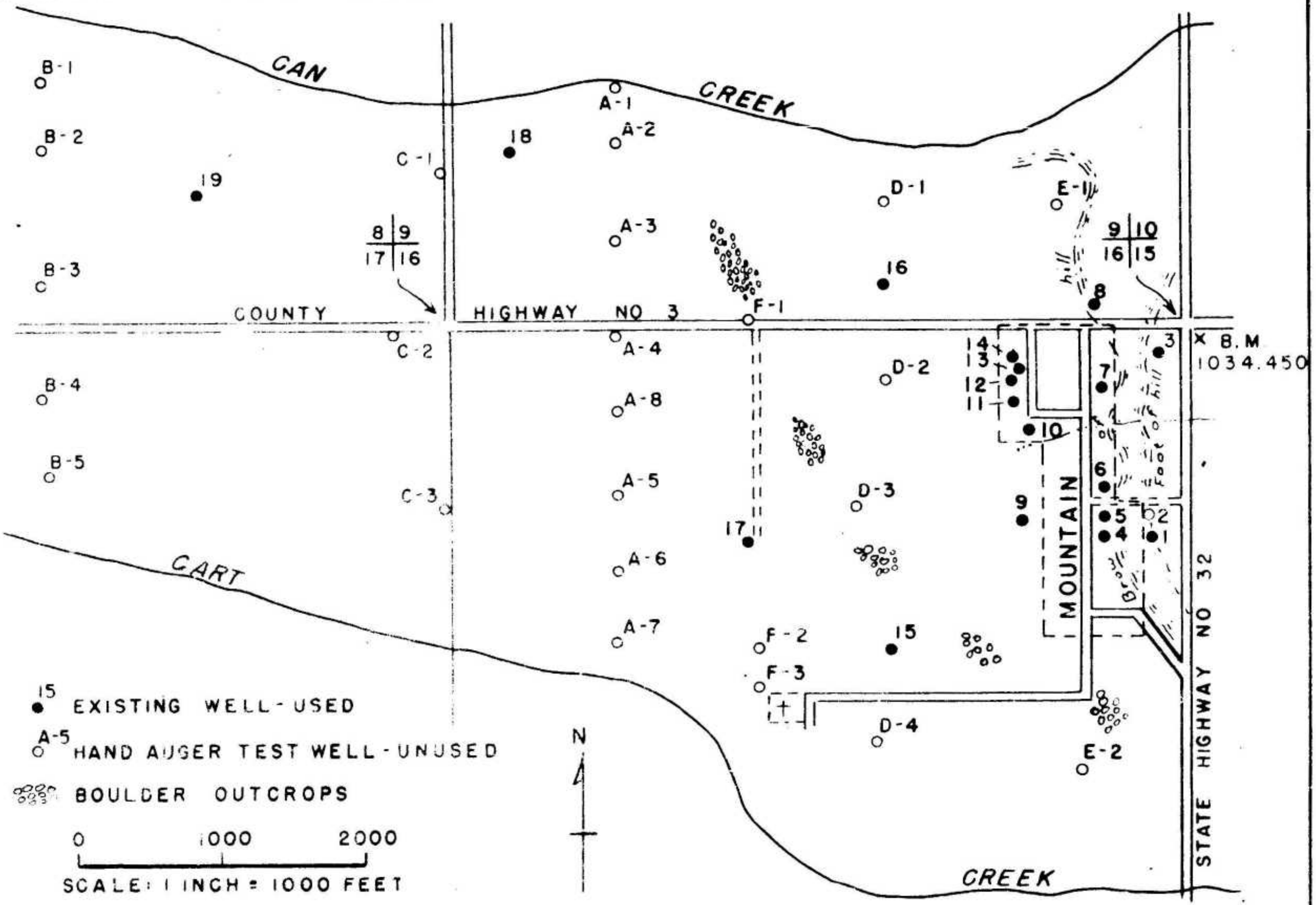


FIGURE 1. MAP SHOWING LOCATIONS OF WELLS STUDIED DURING INVESTIGATION OF SHALLOW WATER RESOURCES NEAR MOUNTAIN, NORTH DAKOTA.

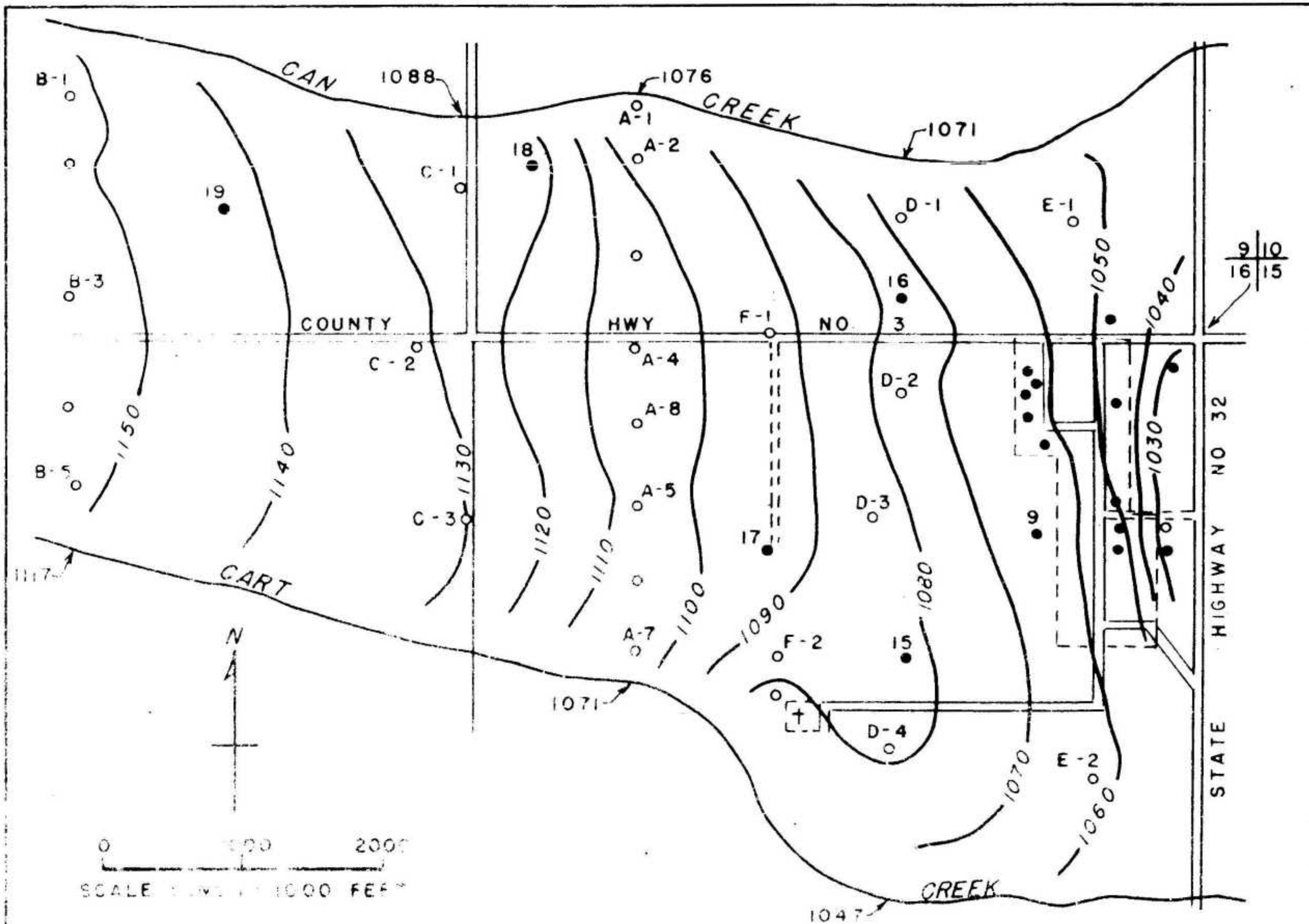


FIGURE 2. MAP SHOWING CONTOURS ON THE WATER TABLE
IN AREA NEAR MOUNTAIN, NORTH DAKOTA
JULY 1945

772

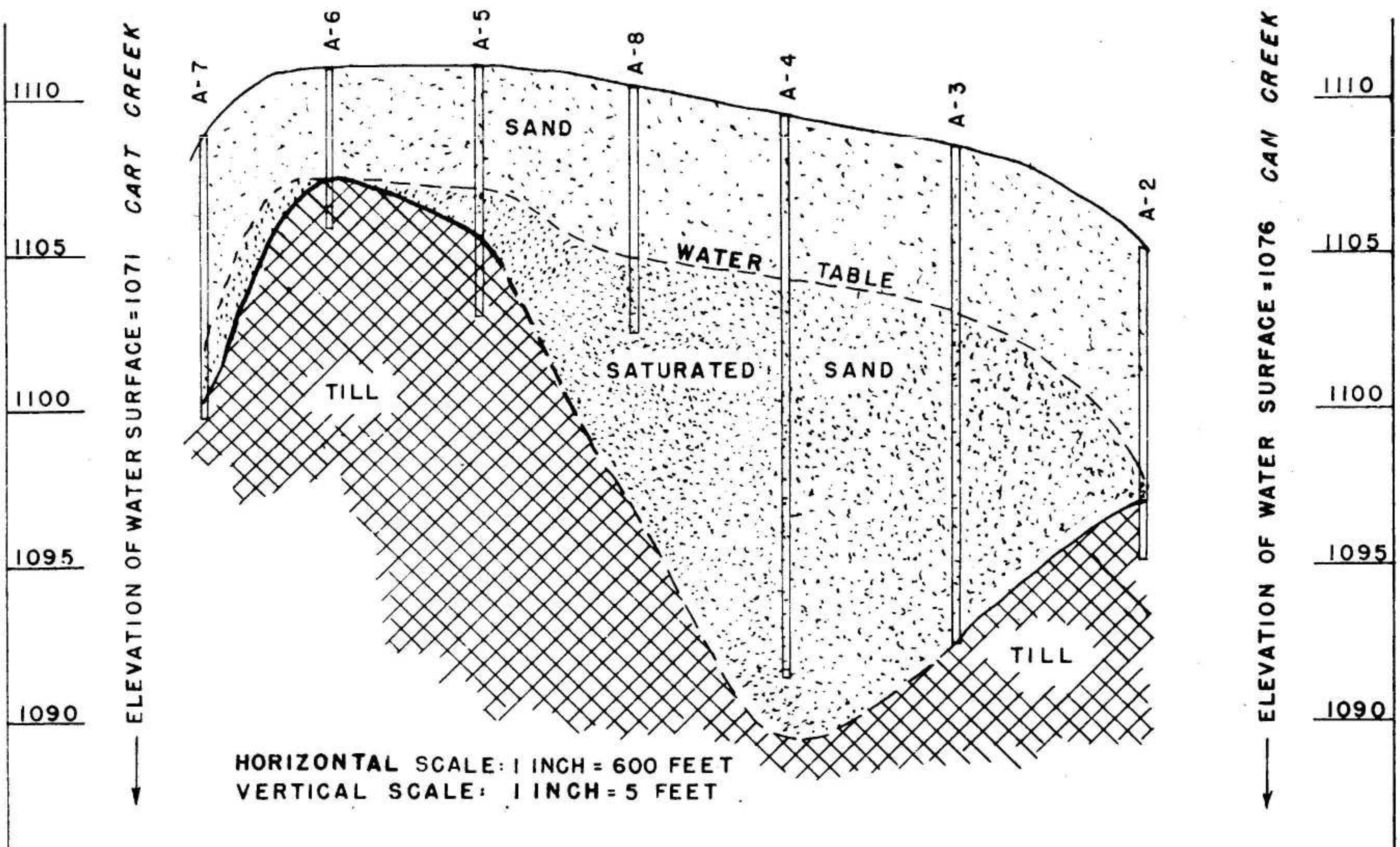


FIGURE 3. CROSS SECTION FROM TEST WELL A-7 TO TEST WELL A-2
NEAR MOUNTAIN, NORTH DAKOTA
JULY 1945

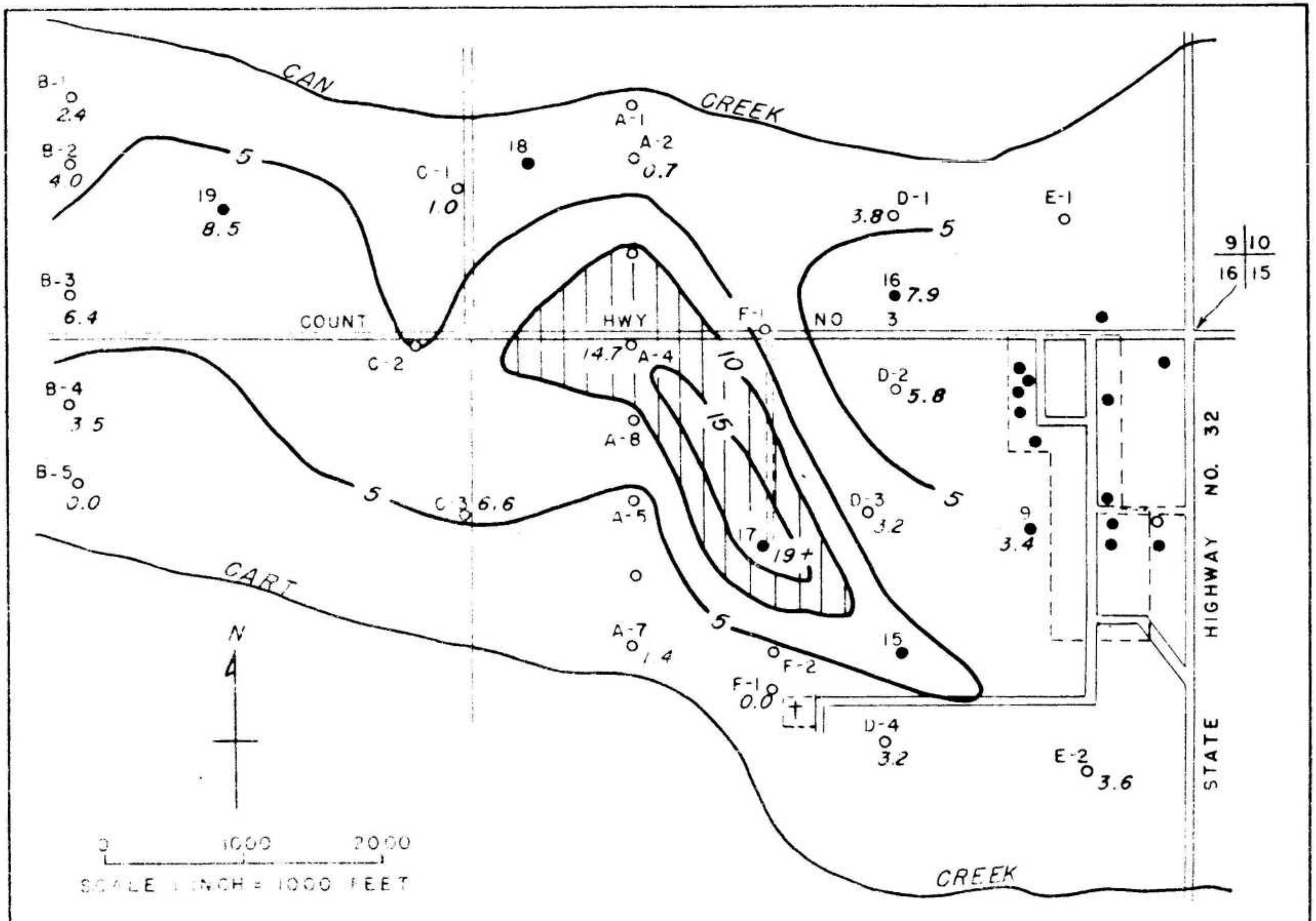


FIGURE 4. MAP SHOWING SATURATED THICKNESS OF SANDS
IN AREA NEAR MOUNTAIN, NORTH DAKOTA
JULY 1945

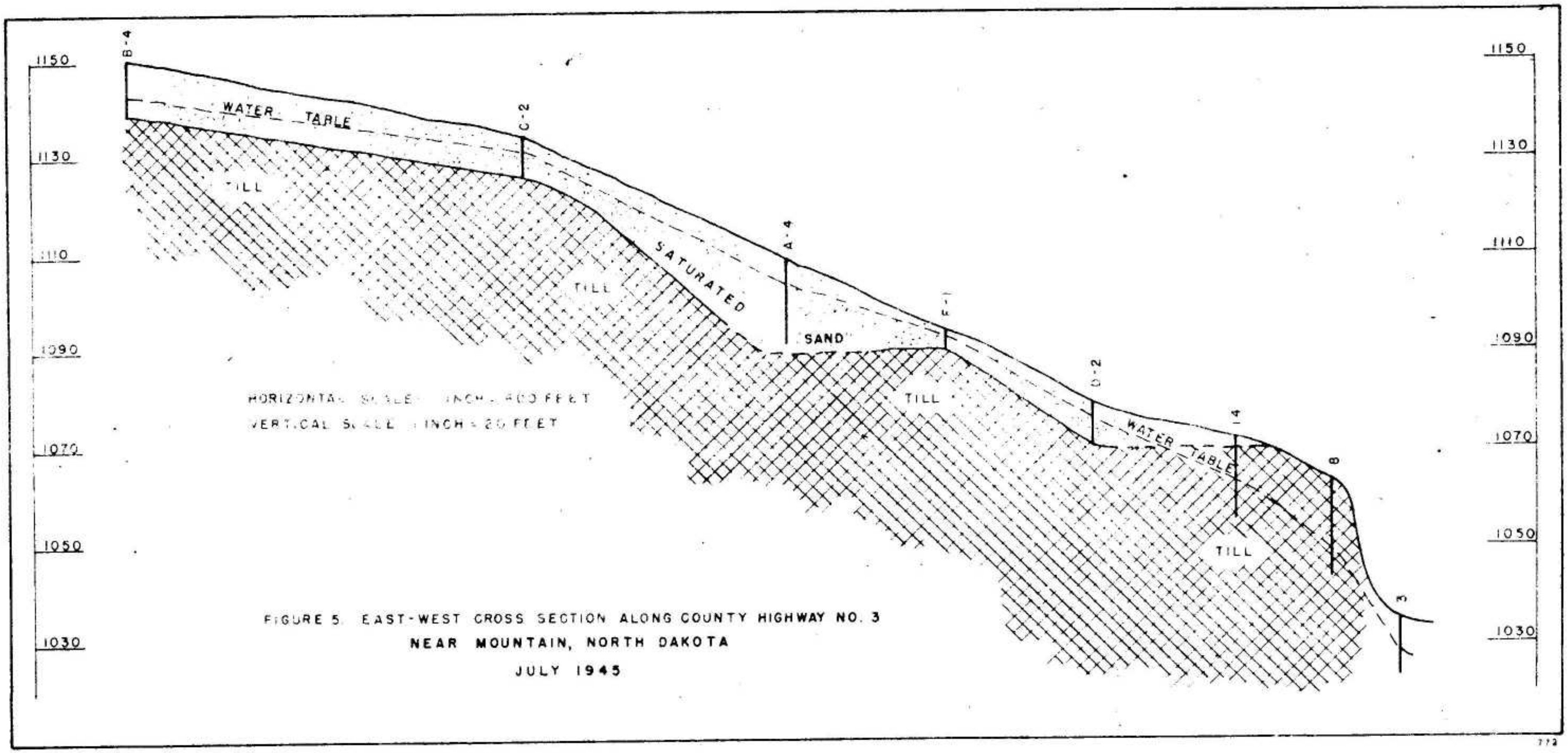


FIGURE 5. EAST-WEST CROSS SECTION ALONG COUNTY HIGHWAY NO. 3
NEAR MOUNTAIN, NORTH DAKOTA
JULY 1945