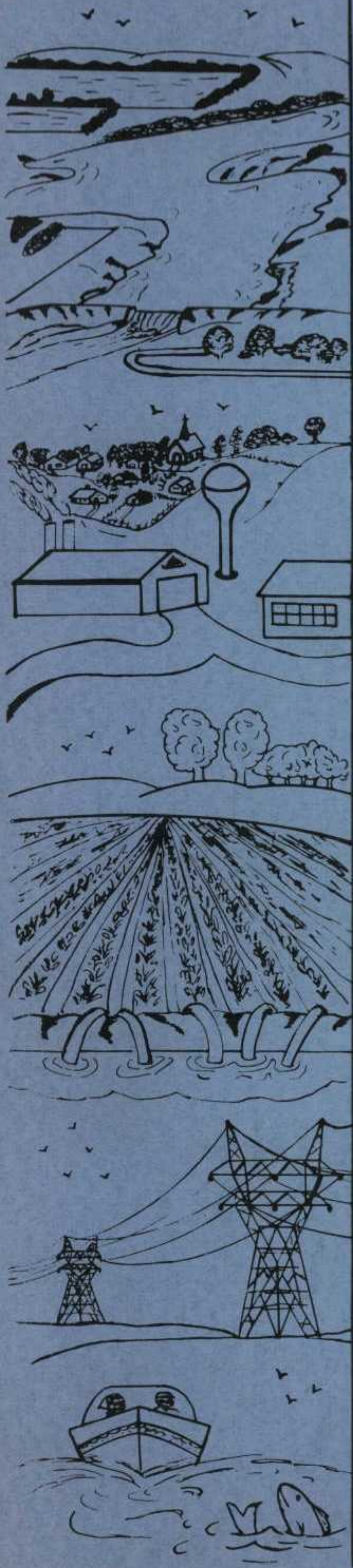
GROUND WATER IN THE DEPOSITS OF ANCIENT LAKE DAKOTA DICKEY COUNTY, NORTH DAKOTA



By

William C. Rasmussen

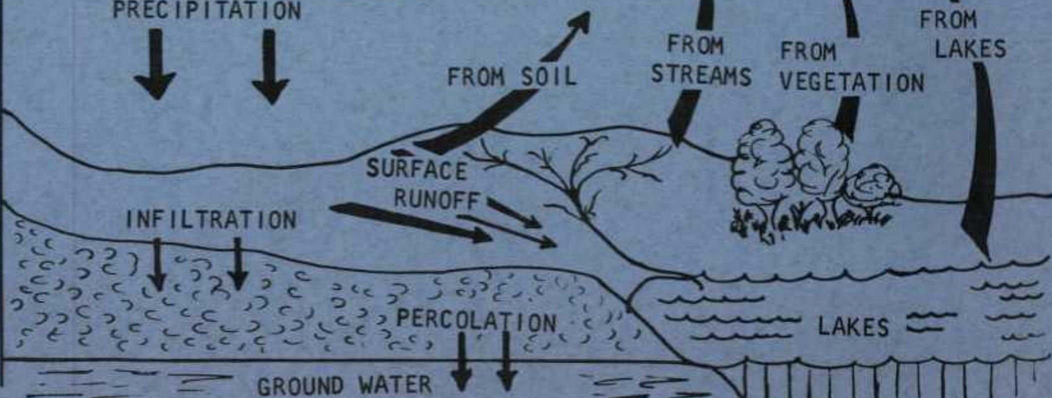
NORTH DAKOTA GROUND WATER STUDIES

NO. 4

Prepared by the United States Geological Survey in cooperation with the North Dakota State Water Conservation Commission, and the North Dakota Geological Survey

PUBLISHED BY
NORTH DAKOTA STATE WATER CONSERVATION COMMISSION
1301 STATE CAPITOL, BISMARCK, NORTH DAKOTA

Originally published - 1947 Republished - 1962



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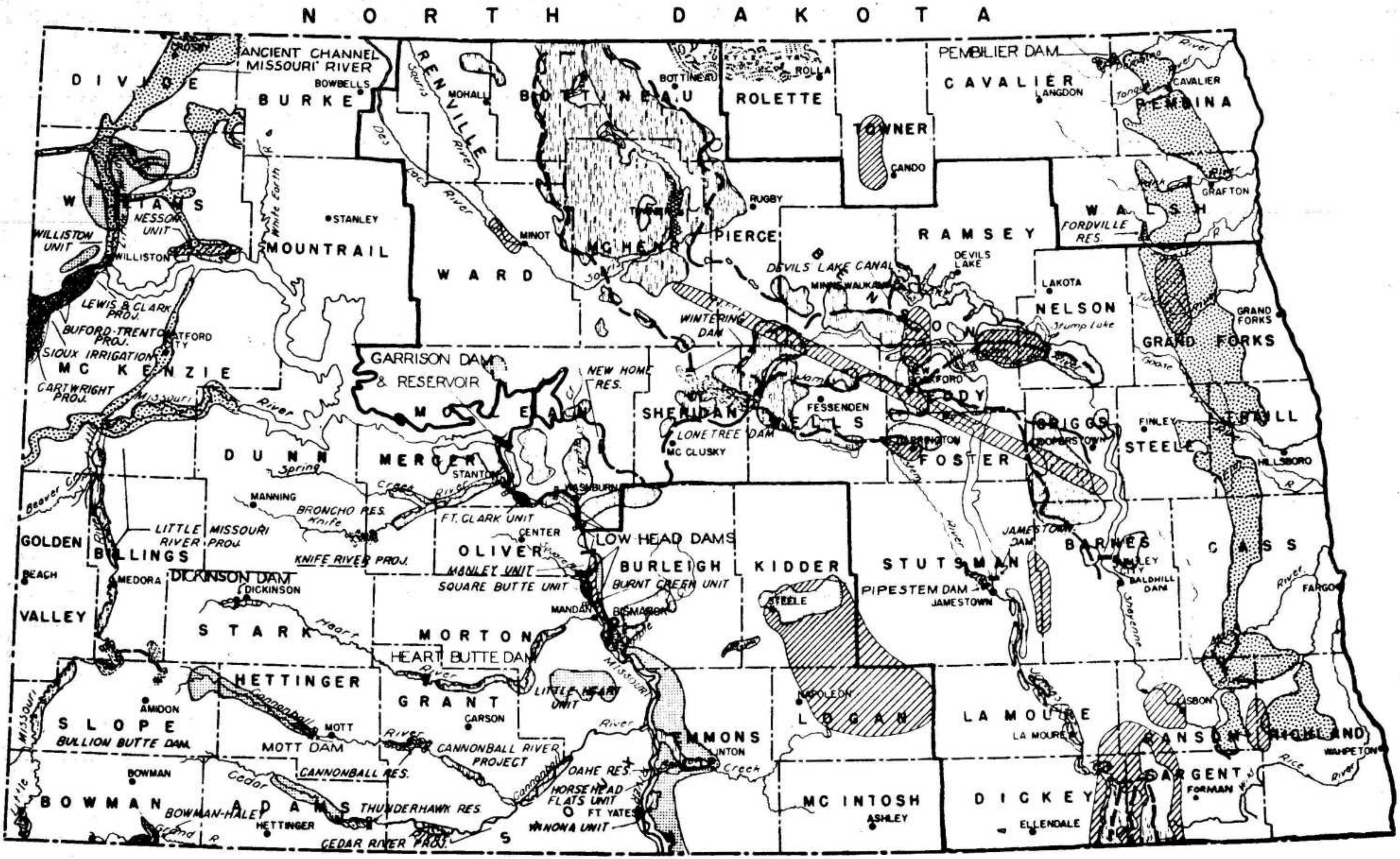

NORTH DAKOTA STATE WATER CONSERVATION COMMISSION

WATER RESOURCES DEVELOPMENT PLAN

LANDS UNDER IRRIGATION
AREAS CONSIDERED IRRIGABLE
AREAS BEING INVESTIGATED
PROPOSED FOR INVESTIGATION

EXISTING
UNDER CONSTRUCTION OR PROPOSED
DAM & RESERVOIR SITES

PROPOSED CANALS

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GROUND WATER IN THE DEPOSITS OF ANCIENT LAKE DAKOTA

DICKEY COUNTY, NORTH DAKOTA

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C O N T E N T S

ILLUSTRATIONS

GROUND-WATER RESOURCES OF THE OAKES AREA, NORTH DAKOTA

By

William C. Rasmussen

June 1946

INTRODUCTION

Purpose of the investigation and field operations

This report relates to the occurrence of ground water in the sand deposits beneath the plain south of Oakes, North Dakota (the site of glacial Lake Dakota), and the availability of the water for agricultural, industrial, military, and other uses.

The area was chosen for detailed investigation after a reconnaissance of several areas in the State.1/

In a previous investigation covering several thousand square miles, of which the Oakes plain is a small part, the water supply of the Dakota sandstone was studied, and it was concluded that further decline in artesian pressure would be slight if the rate of withdrawal remained constant.2/

The Dakota sandstone underlies the Oakes plain at a depth of about 850 feet and furnishes water to about 50 wells within the plain. The water is highly mineralized and, although suitable for stock, it is unsatisfactory for domestic use or for irrigation. The geology and water resources of part of the Oakes plain have been discussed by Hard.3/ Soil surveys including this area have been made for

1/ Rasmussen, W. C., A reconnaissance of possible well irrigation areas: N. Dak. Geol. Survey Bull. 20, 1945.

2/ Wenzel, L. K., and Sand, H. H., Water supply of the Dakota sandstone in the Ellendale-Jamestown area, North Dakota: U.S. Geol. Survey Water-Supply Paper 889-A, pp. 1-81, 1942.

3/ Hard, H. A., Geology and water-resources of the Edgeley and LaMoure Quadrangles North Dakota: U.S. Geol. Survey Bull. 801, p. 35, 1929.

Dickey and Sargent Counties.[4]

The field investigation in the Oakes area was made by the writer during parts of 1940 and 1941. The work included an inventory of existing wells; a level survey; borings with a hand auger at almost every section corner; pumping tests on four groups of wells; drilling of 12 test holes; sampling of sediments for mechanical analyses; and sampling of well water for chemical analyses. D. I. Swanson, W. W. Handy, A. A. Volland, and O. E. Cotton served as rodmen and laborers in the field. Drilling was done under contract with Fred Sletvold and Sons, of the Dakota Artesian Well Company.

The investigation was under the supervision of L. K. Wenzel, engineer, in the United States Geological Survey. The chemical analyses of the water were made by G. J. Petretic and the mechanical analyses and permeability tests on the samples of sediment were made by V. C. Fishel, both of the United States Geological Survey.

The writer is indebted to N. A. Devick, of the Forest Service, and George Wilhelm, chairman of the Park Board, City of Oakes, for permitting pumping tests on three irrigation wells at the tree nursery and on the wells of the Oakes swimming pool, respectively.

Location and general features of the area

The area covered by this investigation is in southeastern North Dakota, in the eastern part of Dickey County and the western part of Sargent County (see index map, figure 1). The area is underlain by deposits of sand and silt comprising the bed of glacial Lake Dakota, which existed during the last ice age. These deposits were laid down in a basin that extends along the James River valley

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4/ Bushnell, T. M., and others, Soil survey of Dickey County, North Dakota: U. S. Dept. Agr., Bur. Soils, Report, pp. 1-59, 1916.
Hutton, F. Z., and others, Soil survey of Sargent County, North Dakota: U. S. Dept. Agr., Bur. Soils, Report, pp. 1-41, 1920.

from a point about 3 miles north of Oakes, North Dakota, southward to Mitchell, South Dakota, a distance of about 170 miles. The basin has a maximum width of 30 miles near Aberdeen, South Dakota. The approximate position of the shore of the ancient lake is shown by the heavy dashed line on plate 1.

The Oakes investigation is concerned only with the 17-mile stretch of the lake deposits in North Dakota. In this stretch the lake deposits consist chiefly of coarse- to medium- grained sand in the northern part but grade into fine-grained sand and silt toward the south.

According to the records of the U. S. Census Bureau, the population of the area was about 2,370 in 1940. There are two towns in the area, Oakes, the principal trading center, and Ludden. The area is served by four railways, the Chicago and Northwestern; the Northern Pacific; the Minneapolis, St. Paul, and Sault Ste. Marie; and the Great Northern. State Highways 1 and 11 cross the area from north to south and west, respectively.

The area was settled in the eighties, mostly by naturalized Scandinavians. It is devoted to agriculture; corn, wheat, and hay are the principal crops. The farms range in size from 160 to 1,280 acres. In general the soil ranges from about half a foot to 2 feet in thickness, and both the soil and subsoil are sandy. The area is mostly prairie, but here and there small patches of land are timbered. A 60-acre tree nursery, 1 mile south of Oakes, is operated by the Forest Service, U. S. Department of Agriculture, to provide seedling trees for the shelterbelt program. This is the only tract of farm size in the area that has been irrigated.

The topography of the Oakes plain is shown in plate 2. It is a nearly featureless plain, 1,300 to 1,315 feet above sea level, and is bounded on the east by rugged hills of bouldery clay and on the west by gently rolling land of like material. The James River, a sluggish stream with a natural gradient of half a foot per mile, has cut a narrow channel to a depth of about 20 feet along the west margin of the plain. A low earth and rock fill dam in the river south of Oakes, near the State line, constructed by the Federal Government in 1937, forms a lake that extends upstream about 23 miles when the water reaches the spillway level of 1,290 feet. This lake is shallow and averages about 500 feet wide, not much wider than the original stream channel. The flood plain of the river, a strip in most places less than a mile wide, is marshy in wet seasons. Bear Creek, the only tributary in the area, joins the river at the north end of the plain.

The surface drainage of the plain is poorly developed and ground water is found from 0 to 20 feet below the land surface. In the spring and early summer water stands in depressions that occur chiefly in the southern part of the area.

Sand dunes, now partly stabilized, dot the southeastern part of the plain. According to local legend, many blowouts and dunes were formed during the period of settlement when the thin sod was plowed too deeply and the fine-grained sand began to blow. The dunes surmount and obscure the clay hills at the southeastern boundary of the plain, where many acres of waste land now exist.

CLIMATE

The area is in a zone of relatively infrequent rainfall, with short, hot summers and cold winters. Table I gives the mean temperature, total precipitation, and number of rainy and clear days at the Oakes substation of the U. S. Weather Bureau each year from 1929 to 1945. Table II shows mean temperature, total precipitation, and number of cloudy and clear days by months during 1941, a year of above-normal precipitation. The mean annual precipitation during the 17 years was 17.90 inches, of which an average of about 13 inches occurred during the growing season. In years when the rain has occurred at favorable intervals, the moisture has proved adequate for farming. However, long dry spells have occurred even during years of average precipitation. The year 1940, for example, was one of almost normal precipitation (17.76 inches), yet for 30 days, from late May until late June, no rain fell. A light irrigation during such periods of deficient rainfall may mean the difference between the success or failure of a crop.

Only June, July, and August are warm enough for rapid plant growth. During the period 1929-45, the monthly mean temperatures from May to September at Oakes were as follows, in degrees Fahrenheit: May 56°; June 65°; July 72°; August 69°; and September 59°. The growing period between killing frosts was 146 days in 1940 and 128 days in 1941.

Evaporation from a free water surface has averaged 33.6 inches from April to September, inclusive, for the 31 years of record at Mandan, the nearest official station in North Dakota.

USE OF GROUND WATER IN 1941

It is estimated that the water requirements of the Oakes area averaged about 590,000 gallons a day in 1940 and 1941. The water was used for the municipal supply, a swimming pool, a creamery, and two railroads at Oakes; for the public supply of Ludden; for domestic and stock uses on the farms; and to some extent for tree and garden irrigation. The types of wells and the quantities of water used are discussed below.

Years ago, the City of Oakes obtained water from wells in the Dakota sandstone at depths of 900 to 1,100 feet, but the wells were abandoned because the highly-mineralized water corroded pipes and was unsatisfactory for public supply. In 1940 the public supply for the city, which then had a population of 1,665, was obtained from fourteen 3-inch driven sand-point wells in the southwestern part of town. The water was withdrawn with a centrifugal pump at the rate of about 300 gallons a minute, and the average daily demand during 1941 was about 200,000

TABLE I

Mean annual temperature, total annual precipitation, and number of rainy and clear days at Oakes, N. Dakota, 1929-45

Year	Mean temperature °F.	Snowfall (inches)	Total precipitation (inches)	Number of rainy days	Number of clear days
1929	40.0	49.7	17.31	76	116
1930	44.1	19.3	17.39	82	130
1931	46.3	24.8	18.71	86	122
1932	42.2	23.4	17.36	90	123
1933	43.9	18.2	13.38	66	123
1934	45.7	11.4	12.60	67	111
1935	42.1	38.0	21.81	80	94
1936	41.1	31.8	9.14	56	122
1937	39.2	58.3	16.41	79	190
1938	43.5	23.5	12.84	77	174
1939	43.0	23.0	17.32	75	197
1940	42.2	25.1	17.76	83	170
1941	43.4	15.3	23.07	95	166
1942	41.6	28.6	25.13	78	157
1943	39.8	66.5	22.42	78	189
1944	41.6	19.0	27.78	75	159
1945	40.2	33.7	13.89	84	125
Average	42.3	30.0	17.90	78	145

TABLE II

Mean temperature, total precipitation, and number of rainy and clear days by months in 1941 at Oakes, North Dakota

Month	Mean temperature °F.	Snowfall (inches)	Total precipitation (inches)	Number of rainy days	Number of clear days
Jan.	12.0	8.0	0.71	5	11
Feb.	11.4	1.3	.12	2	16
Mar.	25.8	3.0	.41	7	13
Apr.	46.0	0	4.03	17	7
May	59.4	0	2.33	9	9
June	65.5	0	6.06	11	14
July	72.4	0	1.26	10	22
Aug.	69.5	0	2.37	9	20
Sept.	56.9	T.	3.82	12	16
Oct.	45.9	T.	1.61	8	14
Nov.	31.8	2.2	.26	3	13
Dec.	23.8	.8	.08	2	11
Totals	43.4	15.3	23.07	95	166

gallons. The Oakes Park Board obtained water for the municipal swimming pool from six 3-inch driven sand-point wells in the southeastern part of town. In a 17-hour pumping test made during the investigation, the combined yield of the Park Board wells was 297 gallons a minute at the start and gradually decreased to 239 gallons a minute toward the end of the test.

The Oakes Creamery had 20 driven sand-point wells, and it is estimated that the creamery used an average of about 200,000 gallons a day.

The railroads had two dug wells at Oakes, each 12 feet in diameter and about 22 feet deep, in the lake deposits. It is estimated that the railroads used about 35,000 gallons a day.

The village of Ludden had a population of about 150 in 1940. The public supply was derived from a well 3 inches in diameter and about 900 feet deep in the Dakota sandstone. The well had a flow of 10,000 gallons a day of highly-mineralized water. In addition to the municipal supply, water was obtained from seven privately-owned wells, of which three were shallow driven sandpoints and three were drilled. The drilled wells derived water from depths of 100 to 140 feet. The log of one of these wells, recorded by the writer in August 1940 while the well was being drilled, is given below:

	Thickness (feet)	Depth (feet)
Lake Dakota quicksand	20	20
Blue Clay (lake clay or glacial till)	67	87
Hardpan (boulder in till)	2	89
Blue Clay (glacial till)	47	136
Water-bearing sand	1	137

Ludden could obtain less highly-mineralized water for public supply from the shallow lake deposits at the east side of town, but the water would be more expensive to produce than the present supply because it would have to be pumped.

The chief irrigation project in the area, begun in 1938, is that of the Oakes Tree Nursery of the Prairie State Forestry Project of the United States Department of Agriculture, about 1 mile south of Oakes. At this nursery 60 acres of seedling trees are irrigated for shelterbelt planting. In 1940 and 1941 three irrigation wells, 39 to 43 feet in depth, were used. The wells were provided with 12-inch perforated casing and were gravel packed around the bottom. They furnished 200 to 400 gallons a minute each when pumped by 4-inch centrifugal pumps powered by tractors. The cost of each well was about $750 plus the cost of pumping equipment. It is reported that an average of 166,000 gallons a day was pumped for 120 days during the growing season in 1941.

Elsewhere in the area irrigation has been limited to the watering of gardens. The largest plot investigated was the 3-acre garden of W. J. Shaefer, at the east edge of Oakes. Mr. Shaefer has a 4- to 6-inch sand-point well,28 feet deep, with a centrifugal pump powered by a gasoline engine.

Most of the farm wells in the Oakes area are used for watering stock and for domestic purposes. The location of the wells is shown on the map, (plate 3). On this map and in table 3 the number of each well indicates its location, in miles, with respect to the southwestern corner of the area, a point called the origin. The first figure gives the distance east, and the second figure (after the hyphen), gives the distance north of the origin. For example, well 4-3 is four miles east and 3 miles north of the origin.

As shown in table 5 and 6, pages 64-79, the shallow wells range in depth from 10 to 128 feet. About 85 percent of these wells are driven sand-point wells, and the others are dug, bored, or drilled. The sand-point wells range in depth from 10 to 42 feet and average 18.5 feet; the dug wells range in depth from 14 to 50 feet and average 25 feet; the bored wells range in depth from 30 to 68 feet and average 44 feet; and the drilled wells range in depth from 35 to 128 feet and average 73 feet.

Wells drilled 90 to 140 feet deep near the James River penetrate gravels in glacial till. These wells, of which the well at Axel Daniels' farm in the SW¼SE¼ sec. 34, T. 129 N., R. 60 W. is representative, are known as valley artesian wells. They are artesian because the water rises above the gravel source and in the lower parts of the valley the head is sufficient to produce small flows.

Most of the driven wells are 1¼ inches in diameter. The few dug wells are generally 3 or 4 feet in diameter, the bored wells 1½ to 3 feet, and the drilled wells 1¼ inches to 12 inches.

The altitudes of the measuring points of the wells for which the depth to water level is given to a tenth of a foot were determined during the level survey, and are considered to be accurate to the nearest hundredth of a foot. The altitudes of the wells that were not tied in with the level survey were determined from the topographic map of the area, plate 2, which is drawn with a contour interval of 5 feet, and the altitudes are considered to be accurate to about the nearest 2 feet.

Estimates of the quantities of ground water used for different purposes in the Oakes area are given below:

Estimated quantities of ground water used in the Oakes are
(Average in gallons a day)

	Average
Shallow water	
City of Oakes	200,000
Oakes swimming pool	3,000
Oakes creamery	200,000
Railroads	35,000
Oakes tree nursery	55,000
Domestic supply and stock	3,000
Sub-total	496,000
Deep artesian water	
Village of Ludden	10,000
Domestic supply and stock	84,000
Sub-total	94,000
Total for the area	590,000

HYDROLOGY OF THE LAKE DAKOTA BASIN

The Lake Dakota basin functions both as an underground reservoir and as an underground conduit. As a reservoir it has a large quantity of water in storage. As a conduit it periodically receives recharge from rains and melting snows and continuously releases water at a rate that increases as the water table rises and decreases as the water table declines. Indeed, the reservoir is analogous to a large lake with a small overflow, which increases as the level of the lake rises and decreases as it falls. The natural discharge represents a loss of water, for the most part, because it produces sloughs that lose water by evaporation, transpiration of watergrasses, and by seeps and springs that discharge into the river.

The discussion that follows is concerned with the recharge of the ground water, the dimensions of the underground reservoir, the permeability of the sediments as indicated by pumping tests, the slope and shape of the water table in the late summer of 1941, and the discharge of ground water during 1941.

Recharge of ground water

The source of recharge to the ground-water reservoir in the Oakes area is the precipitation. Evidence of this is shown by the fact that the water levels in wells rise in seasons of abundant rainfall or melting snow and decline in seasons of scanty precipitation (see hydrographs in figure 2). The recharge is limited almost entirely to infiltration from precipitation on the surface of the plain itself. Some water is contributed, however, by the runoff from the narrow range of bouldery clay hills to the east of the plain during periods of heavy rainfall or melting snow. The runoff from the plain itself is slight, as shown by lack of a developed drainage system, tributary gullies to the James River being rare. Therefore, most of the precipitation enters the soil zone where it is lost by evaporation and transpiration of plants or penetrates to the water table.

Little or no water is received from the James River. Water-level measurements made late in the summer of 1941 throughout the area show that the water table, with a few exceptions, was above the level of the river. Even at the highest reported stage of the river, about 1,300 feet during a spring flood, the water table was probably above the stream. Moreover, the river bed is covered with alluvial deposits of silt and clay of low permeability, which partially seal off the ground water in the lake-basin sediments. Underground recharge from the bouldery clay hills to the east is probably negligible.

During the investigation bore holes from 5 to 25 feet in depth were dug with hand augers at almost every section corner on the Oakes plain. The logs of these holes are given in table 5, pp.64-75. The number of each bore hole shows its location, in miles, with respect to the extreme southwestern corner of the area (see page 9, paragraph 3). There is no correlation of beds from one hole to another; the usual sequence is about 1 foot of black topsoil, about 10 feet of yellow sand, and 1 or 2 feet of gray sand or silt with water. The yellow sand shows the oxidation of a small amount of iron, which stains and cements the quartz grains. The oxidation presumably takes place in the zone of aeration above the water table, for below the water table the sands are gray. The sands are usually calcareous, with occasional layers of marl at depths of 2 to 4 feet, derived from surface leaching and concentration. The sandy character of the soil, subsoil, and the underlying deposits of the lake basin is favorable for recharge from precipitation.

On the basis of comparatively rapid rises in water levels in wells during periods of rainfall, it is estimated by the writer that as much as 20 per cent of the precipitation in the Oakes area may percolate down through the soil and lake sediments to the water table. This recharge would amount to 3.6 inches a year, on the average, over the entire area. The actual amount of water that reaches the water table annually depends on the total precipitation, on the condition of the soil, the intensity of the rainfall, and other factors. In some years of normal or almost normal precipitation the recharge may be practically negligible. If the annual recharge amounted to 3.6 inches, the lake sediments have an average specific yield of 25 percent, and all the water remained in storage, the water table would show a net rise of 14.4 inches, or about 1.2 feet. Actually, however, the water table does not show an appreciable net rise from year to year because, over a period of years, the ground-water recharge is approximately balanced by natural ground-water discharge.

Dimensions of the underground reservoir

In order to determine the thickness and water-bearing properties of the sediments of Lake Dakota, 12 test holes were put down along and across the Oakes plain. The locations of the test holes are shown on the geologic map, plate 4, and the logs are given on pages 76 to 79. Eleven of the holes were drilled by the jetting method and the logs of these holes are subject to the inaccuracies of interpretation inherent in that method. One test hole, number 6-11, 1 mile east and 3 miles south of Oakes, was drilled by the cable-tool method, and the log is considered to be fairly accurate. Cuttings from test hole 6-11 were collected at each significant change in material. The physical properties of these samples are given in the table, p. 81. A north-south cross-section, along the line A-A' through eight of the test holes, is shown in figure 3 and three east-west cross-sections, along the lines B-B', C-C', and D-D', are shown in figure 4. These cross-sections indicate the occurrence of thick fairly permeable sands in the northern part of the basin, sands and thick layers of silt from Oakes southward beyond Ludden, and chiefly silt near the State line. The deepest part of the basin shown by the test drilling was about 5 miles south of Bear Creek, where 90 feet of lake sediment was penetrated, the bottom 1,220 feet above sea level. Section C-C' shows that the lake sediments are thicker at the east side of the plain than at the west side.

The lake sediments rest on boulder clay and the contact between them was easy to determine. The clay is, on the whole, of extremely low permeability. Moreover, the silt at the south end of the area, near the State boundary, may represent a barrier of low permeability. Hence, the lake basin in North Dakota may be practically enclosed by relatively impermeable material. Additional test drilling, however, would reveal more accurately the thickness and character of the lake deposits beneath the Oakes plain.

Movement of ground water

The movement of water in the ground is subject to natural laws. Water absorbed at the surface from precipitation or from surface streams moves downward through the sand or rock to the zone of saturation, where all the spaces are filled with water. The top of this zone is called the water table. In this zone water moves laterally, under the influence of gravity, from the areas of intake or recharge to lower points of discharge in seeps, springs, and sloughs.

The movement of water underground through the tiny interstices between the sand grains is very slow in comparison to the movement of water in surface streams. For example, the average velocity of water in a typical medium-grained sand (grains 0.25 to 0.5 mm. in diameter) under a hydraulic gradient of 1 percent (53 feet to the mile), at a temperature of 60° F., is only about 400 feet per year. Under a gradient of 10 feet to the mile the rate of movement is only about 80 feet per year.

During the field operations a level survey was made along every section line in the area, using for reference the United States Coast and Geodetic Survey bench marks that are located at intervals of 2 miles along the railway tracks. From this survey the topographic map, plate 2, was constructed with a 5-foot contour interval. This map is not accurate in detail within each section, but it does show where the contours cross each section line.

In the progress of the survey the elevations of the measuring points of the bore holes and the key wells were determined to the nearest hundredth of a foot. From these elevations and the measurements of depth to water at each of these points, the elevation of the water table was then determined. Although the water-level measurements were made during the period from July 12 to September 2, 1941, the levels were adjusted to represent a short period of time by remeasurement of key wells and certain bore holes during the last week in July 1941. These adjusted measurements were plotted on a map and from them and the topographic control the map of the water table, plate 5, was prepared, with a 2-foot contour interval.

The position of the water table, thus shown in late summer at the end of a 10-year period of below-normal precipitation, was probably considerably below the average position. This is indicated by measurements made in two wells, Dickey well 101 (coordinate 3.4-5) at Ludden and Dickey well 128 (coordinate 5.4-14) at Oakes. The former showed a net rise of 7 feet and the latter a net rise of 4 feet from August 1941 to May 1945. (See hydrographs, figure 2.) However, the water level throughout the Oakes plain probably did not rise that much, for both of these wells are on the lower slopes of the water table within a mile of the zone of ground-water discharge.

A ground-water contour map shows the direction of the movement of the ground water which is approximately at right angles to the lines of equal elevation (contours) of the water table.

The water-table map of the Oakes area indicates that, in general, the ground water is moving under a gradient of 2 to 4 feet to the mile from the hills on the east to the James River valley on the west. The only important ground-water "high" is at the extreme north. This high is probably due as much to the occurrence of relatively impermeable boulder clay at shallow depth beneath the lake deposits as to ground-water recharge from the high hills to the east.

The steepening of the contours between 1,290 and 1,300 feet at the north end of the area is due to the abrupt drop in the land surface from the Lake Dakota plain to the flood plain of the James River, which results in discharge of ground water in a spring and seep zone. Moreover, the permeability of the flood-plain silt or "blue clay" is low. Water-table depressions adjacent to the rivers are caused, it is believed, by the consumption of ground water by the grasses and marsh vegetation.

The flow of g round water, even under gradients as low as 2 or 3 inches per mile, has been found to conform to a physical law, first discovered experimentally by Darcy, 5/ which states that the apparent velocity is directly proportional to the permeability and gradient of the head. This relation is proportional to the permeability and gradient of the head. This relation is commonly expressed as

$$Q = P\ I\ A \quad (1)$$

where Q is the quantity or volume of a fluid flowing in a given unit of time through a cross-sectional area A, under a hydraulic gradient I (loss of head per unit length), controlled by the density and viscosity of the fluid; the shape and size of the openings, all summed as a constant, P, called the coefficient of permeability.

<u>Permeability and storage capacity as determined by pumping tests</u>

Developments within recent years have made it possible to determine the rate of percolation of water underground and he amount of available water,stored in the voids by means of pumping tests of wells. A well is pumped at a measured rate of flow while measurements are made of the water level in the well itself and, where possible, in surrounding wells, at regular intervals of time. These measurements reveal the drawdown of the water level during the test. When pumping

5/ Darcy, H., Les fontaines publiques de la ville de Dijon, Paris, 1856.

is stopped, measurements of the water levels are continued during the period of recovery.

The calculations involved are unavoidably technical. A complete explanation of the methods used is beyond the scope of this report, but definitions and references are given so that a person already familiar with ground-water hydrology may follow the discussion. The reader who is not familiar with this type of treatment may wish to pass over this section to the summary on p. 45.

In ground-water hydrology, permeability is often expressed in field terms as the gallons of water at 60° Fahrenheit that is conducted laterally in one day through each mile of rock (measured at right angles to the direction of flow) which is 1 foot thick and under a gradient of 1 foot per mile. The corresponding unit of permeability is gallons per day per square foot, abbreviated gpd per sq.ft.

The coefficient of storage is the volume of water released from storage within a vertical prism of the aquifer of unit cross-section by a unit decline of head. In an unconfined aquifer, such as that of the Oakes plain, the coefficient of storage generally increases with time because of the slow draining of water above the declining water table. Its ultimate value is the same as the specific yield.

The field methods of determining the permeability and storage coefficient are described by Wenzel. 6/ The Thiem formula, the limiting formula, the gradient formula and the so-called "non-equilibrium formula" are all fundamentally related, and only the "non-equilibrium method" is applied here. This formula was first developed by Theis 7/ by analogy to the non-steady flow of heat, and later derived directly from hydrologic premises by Jacob.8/

6/ Wenzel, L. K., Methods for determining permeability of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 887, pp. 77-117, 1942.
7/ Theis, C. V., The relation between the lowering of the piezometric surface and the rate and duration of the discharge of a well using ground-water storage: Am. Geophys. Union Trans., pp. 520-524, 1935.
8/ Jacob, C. E., On the flow of water in an elastic artesian aquifer: Am. Geophys. Union Trans., pp. 574-586, 1940.

The integrated equation for radial flow towards a steadily discharging well in an infinite homogeneous aquifer is:

$$s = (Q/4\pi T) : W(u) \qquad (2)$$

where s is the drawdown in multiples of the length unit (the foot is used in this paper)

Q is the discharge, or volume per unit time (gallons per day)

T is the transmissibility, defined as the product of the permeability, P and the saturated thickness, m. The dimension of transmissibility is volume per unit time per unit length (gallons per day per foot).

and W(u), called the "well-function" of u, is computed from the infinite series:

$$W(u) = -0.5772 - \log_e u + u - \frac{u^2}{2.2!} \; . \; . \; . - \frac{(-u)n}{n \; . \; n \; !}$$

Here

$$u = (r^2 S)/4Tt \quad ; \qquad (3)$$

where r is the radial distance from the pumped well (feet)

S is the coefficient of storage (expressed as a decimal fraction)

and t is the time since pumping started (days)

This equation is not soluble algebraically for T or S, but it has been solved graphically by Theis 9/ by a procedure since justified by Hubbert.10/ Moreover, Theis 11/ has shown that for small values of u (small r or large t) all but the first two terms of the infinite series may be neglected. The equation for radial flow reduces to

$$s = (Q/4\pi T) \quad (\log_e (4Tt/r^2 S) - 0.5772) \qquad (4)$$

This is the equation of a straight line, where for any given time the drawdown, s, is plotted against the logarithm of the radial distance, r, from the pumped well, or where, for any given radial distance, the drawdown is plotted against the logarithm of the time of measurement, t. From the slope of this line the transmissibility, T, may be calculated and then from any selected point the storage

9/ Wenzel, L. K., op. cit., p. 88.
10/ Hubbert, M. K., Discussion: Am Geophys. Union Trans., pp. 560-564, 1943.
11/ Op. cit., p. 522.

coefficient, S, may be determined.

Because these straight-line graphs are simpler than the curves obtained in the Theis graphical method, they are applied here. As a check the recovery, s', has been plotted on the same graph against the time since pumping stopped, and the straight line adjusted for the combined data. Recovery is defined as the difference between the drawdown that would have occurred had the well continued pumping and the "residual drawdown" at any time after shut-down. In other words, it is the difference between the extrapolated drawdown and the observed water level during the period of recovery following the drawdown.

The recovery, thus defined, follows the same equation as the drawdown (equation 2). That is,

$$s' = (Q/4\pi T)W(u') \quad (5)$$

where u' is determined at t', the time since pumping stopped.

Pumping tests were run on four separate well systems: three at the Forest Service Nursery, located 1 mile south of Oakes, and the fourth on a battery of six wells at the swimming pool of Oakes. Because in all cases the pumped wells had not been pumped for a week prior to the tests, the initial water levels are assumed to have been subject only to natural fluctuations.

The three wells of the U. S. Forest Service are located in sec. 33, T. 131 N., R. 59 W. The wells have been assigned the State well numbers Dickey 107, 108, and 109, so they are discussed below in that order. The three wells are located on the vertices of a triangle about a quarter of a mile to the side. A test well drilled in May 1941 at 6 - 13 (see log, p. 76), about 1 mile northeast of the well group, showed 85 feet of lake sand and silt and had a static water level about 10 feet below the land surface. This is about 2 feet higher than the water level at the end of the preceding summer, when the tests were run, and the saturated thickness used in the calculations is 73 feet.

Test of Dickey well 107

Dickey well 107 (coordinate number 5.0-12.5) is in the SW¼SW¼NW¼ sec. 33, T. 131 N., R. 59 W. The well is 41.7 feet deep and consists of a pit 12 feet square to a depth of 10.5 feet and a 24-inch hole from there to the bottom. The well was completed by inserting a 12-inch galvanized iron casing, perforated with ¼-inch slots, and by packing the annular space between the casing and sides of the hole with ¼ to 3/4-inch gravel. The casing was closed at the bottom with a concrete shoe. A 4-inch centrifugal pump, belt-driven by a 20-horsepower gasoline engine, was used in the test.

The well was pumped for 8 hours, beginning at 6:44 a.m. on August 30, 1940, at an average rate of 306 gallons per minute as determined with a standard weir in the discharge ditch. During the pumping period 21 tape measurements were made of the water level in the well. From the time of shut-down until 3:00 p.m. on September 2, 1940, 40 water-level measurements were made to determine the rate and amount of recovery in the pumped well. An unusually rapid fall of the water level was noted between 8:58 a.m. and 9:32 a.m. This was probably due to an increased rate of pumpage, as the gasoline engine sputtered and slowed, making it necessary to reset the throttle. Toward the end of the test the motor was particularly refractory.

The water level in the well was lowered several feet during the test; the saturated zone did not remain 73 feet in thickness as it was initially. Therefore the observed drawdowns, s_o, have been corrected for this decrease in depth of flow by subtracting the factor $(s_o^2/2m)$ as suggested by Jacob.[12]

The plot of these corrected drawdowns against time on semi-logarithmic paper is shown in figure 5. A straight line fits the data fairly well, conforming to the theory, and the change in drawdown, Δs, is 1.16 feet over one log cycle, from whence

12/ Jacob, C. E., Notes on determining permeability by pumping tests under water table conditions: U.S. Geol. Survey (multilithed), June, 1944.

$T = 2.30 \quad Q/4\pi\Delta s = 2.30 \times 305 \times 1440/4 \times 3.14 \times 1.16 = 69{,}200$ gallons per day per foot.

However, the pumped well only penetrates the saturated thickness of 73 feet for a distance of 30 feet (initial water level was 1.49 feet below the top of the casing) and therefore the true transmissibility must be considerably greater than that obtained.

Following a method outlined by Jacob,13/ which he credits to Kozeny14/ and Muskat 15/ the following empirical adjustment is made for partial penetration, assuming the bed to be homogeneous.

$$T/T' = C/\partial$$

where ∂ is the partial penetration (here = 30 ft./73 ft. = 0.41) and C is Kozeny's empirical correction factor 16/ which approximates the results of Muskat's analysis.

For this well C = 0.583, whence T = 1.42 x 69,200 = 98,300 gpd per foot or the average permeability, P = T/m = 98,300/73 = 1,350 gpd per sq. foot.

Theoretically it is possible to compute the coefficient of storage, S, from any point on the curve, once T is determined. However, the observed drawdowns of the pumped well are several feet too large because the well penetrates only a fraction of the saturated zone, and because of uncalculated well losses. As S is calculated from the anti-log of the drawdown, each additional foot of drawdown becomes an exponent of the base ten, and without correcting the drawdown for the well losses the apparent storage coefficient becomes absurdly low.

The departure of the recovery from the straight line in the early part of the period is due partly to the departure of the curve, W(u) from its asymptote,

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13/ Jacob, C. E., Partial penetration of pumping well, adjustments for: U.S. Geol. Survey (mimeographed), pp. 169-175, Aug. 1945.
14/ Kozeny, Wasserkraft and Wasserwirtschaft, Vol. 28, P. 101, 1933.
15/ Muskat, M., The flow of homogeneous fluids through porous media, New York, McGraw-Hill, pp. 263-286, 1937.
16/ $1/C = 1 + 7\ (r_w/2\partial m)^{\frac{1}{2}} \cos\ (\pi\partial/2)$
r_w is the well radius, here one foot to the outside of the gravel wall.
m is the saturated thickness, here 70 feet.

$\log_e$ (1/u) - 0.5772, and partly to the variation of the storage coefficient, S, because of hysteresis of the capillary fringe overlying the water table.

Test of Dickey well 108

Dickey well 108 (coordinate number 5.3-12.6) is in the NE$\frac{1}{4}$SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 33, T. 131 N., R. 59 W. It was drilled in 1939 to a depth of 39 feet below the land surface by the sand-bailer method. The well has a perforated galvanized iron casing 12 inches in diameter, with a 6-inch radial pack of $\frac{1}{4}$ to 3/4-inch gravel outside the casing. A pit 12 by 6 by 12 feet deep has been dug around the well, so that the casing now extends 29 feet below the bottom of the pit. The water level in October 1940 was about 2 feet below the top of the casing, or 12 feet from the land surface. A 4-inch centrifugal pump, belt-driven by a 20-horsepower gasoline engine, was used in the test.

The pumping test was of 8 hour's duration, beginning at 9:28 a.m. on October 7, 1940. The rate of flow was determined by two trials, one in the early and the other in the later part of the test. It took 40 and 41 seconds, respectively, to fill a 250-gallon horse trough, which correspond to flows of 375 and 366 gpm. The well pumped silt throughout the test. After pumping was stopped, at 5:29 p.m. on October 7, measurements of the water level were made until 7:52 a.m. on October 12, 1940, by which time the initial level was almost regained.

Four observation wells, each 1$\frac{1}{4}$ inches in diameter with a 3-foot copper gauze well screen and drive point at the lower end, were driven to depths of about 20 feet at the four major compass points, each 50 feet from the pumped well. The initial water-level readings were as follows, with the datum of the pumped well assumed to be 100.00 feet: north well 100.7 feet, west well 99.98 feet, south well 100.03 feet, and east well 100.16 feet. This indicates flow from the east-north-east, and a residual depression to the southwest, toward the natural discharge along the flood plain of the James River 1 mile to the west, and in the direction of wells 107 and 109, over ¼ mile away, neither of which had been pumping for several days.

Ninety-two wetted tape measurements were made in the pumped well and 53 in each observation well, for a total of 304 measurements. The water levels are plotted on the semi-logarithmic graph of drawdown against the logarithm of the time, figure 6. All drawdowns have been corrected for the decrease in depth of flow as discussed previously.

During the test the water level in the east observation well lagged both in drawdown and in recovery. When the well point was pulled after the test it was found to be clogged with sand. The graph indicates that this well was still far from the approximate equilibrium attained by the other wells and therefore data from this well have not been used in the calculations.

The transmissibility determined from drawdown measurements in the pumped well is:

$T = 2.30\ Q/4\pi\Delta s = 2.30 \times 370 \times 1440/4 \times 3.14 \times 2.10$ feet =

= 46,400 gpd per ft. = 46,400 gpd per ft./7.48 gals. per cu. ft.

= 6,210 sq. ft. per day;

The coefficient of storage is computed from the equation

$$S = 2.25\ T\ t_o/r^2 \qquad (6)$$

where t_o is the time at zero drawdown on the straight line. In this case by extrapolation it is found that $t_o = 4.2 \times 10^{-4}$ min, and r is assumed to be 1 ft. It is computed that $S = 4.1 \times 10^{-3}$. For water-table conditions that is absurdly low for reasons given previously.

From the graph it may be seen that many more points could be made to fit a straight line by choosing a straight line of lower slope. However, the lower slope would give lower extrapolated drawdowns, making the recovery a poor fit. The theory requires that W(u) approaches but never reaches a straight line on the semi-log graph.[17/] By choosing the asymptote to the lower end of the drawdown curve, the recovery is also made to fall close to the asymptote.

Asymptotes of the same slope have been drawn to the curves obtained for the observation wells. These lines give, therefore, the same transmissibility. However, entirely different values of the storage coefficient are obtained. Because screen losses of the pumped well are not present in the observation wells, and because the effect of partial penetration is reduced, these values come closer to the true storage coefficient. Substituting in equation (6): r= 50 feet, T = 6,210 $ft.^2$/day, t_o = 62, 43, and 50 min., respectively, for the north, south, and west wells, it is computed that S = 0.24, 0.17, and 0.19 for those three wells, the average being 0.20 or 20 percent.

The correction for partial penetration of the pumped well is figured as before. The ratio of true to apparent transmissibility is 1.51 in the case of well 108, for λ = 27/73 = 0.37 and C = 0.56. Therefore the corrected transmissibility

T = 46,400 x 1.51 = 70,200 gpd per ft.

and the permeability,

P = T/m = 70,200/73 - 961 gpd per sq. ft.

Test of Dickey well 109

Dickey well 109 (coordinate number 5.3-12.4) is in the NE¼NW¼SW¼ sec. 33, T. 131 N., R. 59 W. It was drilled in 1939 to a depth of 43 feet below the land surface by the sand-bailer method. The well has a perforated galvanized iron casing 12 inches in diameter with a 6-inch radial pack of ¼ to 3/4-inch gravel outside the casing. A pit, 12 feet square by 11 feet deep, has been dug around the well. The water level was about 4 feet below the bottom of the pit in

17/ See figure 3 of Jacob, C. E., Radial flow in a leaky artesian aquifer: Am. Geophys. Union Trans., p. 204, 1946.

October 1940, so that the well penetrated 28 feet of saturated sand. During the test the well discharged between 283 and 295 gallons a minute, as determined by timing the filling of a 250-gallon tank and by piezometer readings behind an orifice. The average flow was 290 gallons per minute. Only a small amount of silt was pumped.

Three observation wells, each 1¼-inch sandpoints driven about 20 feet deep, were located at distances of 50, 100, and 150 feet on a line north-northwest from the pumped well. This north-northwest line was at right angles to the ground-water flow as determined by the test on Dickey 108.

The pumping test lasted 8 hours and 4 minutes, beginning at 8:10 a.m. on November 3, 1940. After pumping stopped measurements were continued until noon on November 4, at which time the water levels were about 0.2 foot below their pre-pumping position.

The water levels at the recorded times are shown in figure 7. As plotted, the water levels are corrected for decrease in depth of flow, by subtraction of the factor $s_o^2/2m$. Values of recovery have been plotted for the recovery period by subtracting observed residual drawdown from the extrapolated drawdown of the pumping period.

The water levels are plotted against the log of time in figure 7. The points for the pumped well do not describe a smooth curve, probably because of variation in pumping rate. A line with a slope of 1.35 ft. over one log cycle has been drawn asymptotic to the lower end of the drawdown curve. The recovery computed from this asymptote fits the drawdown data. Asymptotes of the same slope have been drawn to the measurements for the observation wells 50, 100, and 150 feet distant. The recovery points fall close to the lines.

The water-level curves for wells farther from the pumped well show greater curvature at the time pumping ceased, and greater departure from the asymptote at that time.

The apparent transmissibility is

$T = 2.30\ Q/4\pi\Delta s = 2.30 \times 290 \times 1440/4 \times 3.14 \times 1.35$ feet =

56,700 per ft. = 7,600 sq. ft. per day.

The coefficient of storage may be calculated from the intercept on the zero-drawdown line. Assuming the effective radius of the pumped well to be 1.0 ft., with $t_o = 3.6 \times 10^{-2}$ min.

$S = (2.25 \times 7{,}600\text{ ft.}^2/\text{day} \times 3.6 \times 10^{-2}\text{ min.})/(1\text{ ft.}^2 \times 1440\text{ min./day}$

$= 0.43$

Similarly, for the 50-foot observation well, t_o = 46 min. and S = 0.22. For the 100-foot observation well t_o = 160 min. and S = 0.19. Finally for the 150-foot observation well, t_o = 310 min. and S = 0.16.

It is natural for the early period of pumping that the storage coefficient should be larger closer to the pumped well, because the dewatered sediments have been draining longer near to the well. However, it is well to consider that the apparent storage coefficient for the pumped well is almost 0.42, whereas the tests on wells Dickey 107 and 108 gave absurdly low coefficients of storage for the pumped wells. There it was concluded that the uncalculated screen loss, plus the exaggerated drawdown because of partial penetration, gave the low value of the storage coefficient. In the case of Dickey 109, however, it is apparent that the assumed effective radius, 1.0 foot, is too small. Through natural well development, or through the formation of a larger gravel envelope than that described, the effective radius of the well may have been increased beyond the normal diameter. Assuming that it is 2.0 feet (instead of 1.0 ft.) the recalculated coefficient of storage is .105. The effective radius is probably between 1 and 2 feet.

Applying Kozeny's empirical correction for partial penetration of the pumped well, ∂ = 28/73 = .384 and C = .565, and consequently

$T = T' \times C/\partial = 56,700 \times .565/.384 = 83,400$ gpd per ft.

and P = 1,140 gpd per sq. ft.

A plot of the drawdowns in the observation wells against their distance from the pumped well for a selected time is shown in figure 8. Instead of using the actual drawdowns that occurred in the test, drawdowns have been picked from the semi-log time-drawdown graph (figure 7) for the time 2,000 minutes. This was done because the steady-state drawdown needed to justify the straight-line approximation of the well-function curve had not been reached within the 484 minutes of the test at the 100 and 150-foot observation wells. A line with a slope of 2.30 ft. per log cycle has been drawn through the three points, from which a first approximation of the transmissibility may be made as follows:

$$T = 2.30\ Q/2\pi\Delta s = 2.30 \times 290 \times 1440/2 \times 3.14 \times 2.30$$

$$= 66,600 \text{ gpd per ft.} = 8.900 \text{ sq. ft. per day} \qquad (7)$$

The drawdowns have then been corrected for partial penetration from the curves given by Jacob,[18] and a second line, of slope 2.00 ft. per log cycle, has been drawn, making the transmissibility

T = 76,500 gpd per ft. = 10,200 sq. ft. per day

Further adjustment proves to be unnecessary. Therefore the permeability

P = 76,500/73 = 1,050 gpd per sq. ft.

The storage coefficient may be computed from the formula

$$S = 2.25\ T\ t/r_e^2 \qquad (8)$$

where r_e is the radial distance from the pumped well at which the drawdown is zero according to the straight-line extrapolation. From the graph, figure 8, r_e is determined to be 540 feet. Thus

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18/ Jacob, C. E., Partial penetration of pumping well, adjustments for: U. S. Geol. Survey (mimeographed), pp. 169-175, Aug. 1945.

$S = (2.25 \times 10{,}200 \text{ ft.}^2/\text{day} \times 2000/1440 \text{ days})/(540)^2 \text{ft.}^2 = .109$

This storage coefficient is low because it is the average computed for the entire dewatered section out as far as the virtuse radius of the "cone of depression," 540 feet.

Test of Oakes swimming pool wells

The swimming pool wells are in the NE¼NW¼ sec. 28, T. 131 N., R. 59 W., in the City of Oakes. There are six 3-inch gravel-packed sandpoint wells, spaced 8 feet apart in an east-west line. Each well is reported to be 25 feet deep, with a measured non-pumping water level about 10 feet below land surface in September 1940. From the two nearest test holes, one a mile northwest and the other a mile southeast of the swimming pool wells, it is estimated that the thickness of the lake deposits is 70 feet at the swimming pool, so that the saturated thickness is 60 feet. The degree of penetration of the wells is then ∂ = 15 feet/60 feet = 0.25, approximately.

The wells were pumped as a unit by an electrically-powered centrifugal pump, at an average rate of 260 gpm, determined by filling the swimming pool during the 16-hour 50-minute test begun September 14, 1940, at 3:54 p.m. Water-level measurements were made before, during, and for 2 days after the test on four observation wells. These were 1¼-inch sandpoints driven 20 feet deep, located at the center, 50 feet east, 100 feet east and 150 feet east, respectively, from the center of the battery of pumped wells. Just before the end of pumping, the drawdown of the central observation well was 2.68 feet, the drawdown of the 50-foot well was 1.60 feet, the drawdown of the 100-foot well was 0.95 foot, and the drawdown of the 150-foot well was 0.59 foot. By 3:50 a.m. on September 16, about 36 hours after pumping started and about 19 hours after pumping ceased, the original water level had virtually been regained by all wells.

Wenzel and Greenlee[19/] calculated the transmissibility of the Lake Dakota deposits in this test at Oakes as between 63,100 and 67,400 gpd per foot, and the coefficient of storage as 0.197. They did not consider the effect of the partial penetration of the pumped wells in their calculation. The interference among the six wells depends upon the degree of penetration, making it impossible to correct for that factor by the method used previously. It would appear that the entire saturated thickness has a transmissibility two or three times as great as the apparent transmissibility from this test.

The average temperature of the ground water in the lake deposits of the Oakes plain is 49.4° F. To convert all the permeabilities to Meinzer's units, which are determined for 60° F., it is necessary to multiply them by 1.17.[20/]

The corrected coefficients of transmissibility, permeability and storage are summarized in the following table.

Location	Transmissibility gpd/ft at 49° F.	permeability gpd/ft.^{2} at 49° F.	Permeability in Meinzer's units gpd/ft.^{2} at 60° F.	Coeff. of storage
Oakes Swimming Pool	65,000 a/			19.7
One mile south of Oakes Forest Service Nursery Well 107 (s:log t)	98,300	1,350	1,580	
Well 108 (s:log t)	70,200	960	1,120	20 (average)
Well 109 (s:log t)	83,400	1,140	1,330	25 (average)
(s:log r)	76,500	1,050	1,230	10.9

a/ Not corrected for partial penetration

Considering the heterogeneity of the lake deposits, as shown by the test hole logs, it is not unreasonable that the transmissibility and permeability should vary within distances of a quarter of a mile to a mile by the amounts indicated.

19/ Wenzel, L. K., and Greenlee, A. L., A method for determining transmissibility and storage-coefficients by tests of multiple well-systems: Am. Geophys. Union Trans., pp. 556-560, 1943.
20/ Wenzel, L. K., Methods for determining permeability of water-bearing materials: U.S. Geol. Survey Water-Supply Paper 887, p. 62, 1942.

However, the figures should be regarded as engineering approximations only. This is because the formulas are based on assumptions of ideal conditions, which are only approached in the field. The most important of these assumptions are: the water-bearing formation is homogeneous throughout and conducts water equally well in all directions, vertically, horizontally, and obliquely (that is, it is isotropic); the formation has an infinite areal extent; the formation has the same thickness throughout; the water surface is horizontal at the time pumping begins; there is no change in rate of net recharge during the test; the pumping rate is constant; and there is no discharge other than that of the pumped well during the test.

The coefficients of permeability listed in the table of physical properties, p. 81 , are radically lower than the coefficients determined by the pumping tests. Test hole 6-11 is only 1-3/4 miles southeast of the nursery well field, yet the highest permeability shown in the test-hole samples is only 330, and the weighted average permeability is 70 gpd per sq. ft. The reason for these low coefficients is the inadequate method of sampling the unconsolidated sediments. The hole was drilled by the sand-bailer method and the samples were bailed from the hole. Consequently, the natural sorting of the waterlaid strata was destroyed and the fine grains filled the voids between the coarse grains, resulting in a low average permeability. Thus these low sample permeabilities are meaningless, except insofar as they indicate the lack of homogeneity of the aquifer and give a general picture of relative permeabilities.

Discharge of ground water in 1941

One approach to the problem of the ground-water discharge from the Oakes plain has been afforded by the water-table map constructed in this study. The elevations of the measuring points of selected wells throughout the area were determined in the course of the level survey. The depths to water and the well locations are shown on plate 3, and the elevations and descriptions of the measuring points are given in the well tables, pp. 48-63. By periodic measurement of the water levels in these wells other water-table maps can be drawn. By comparing maps made during periods of drought and before and after periods of heavy rainfall, the magnitude of both the recharge and discharge can be estimated. For example, the ground-water discharge can be estimated during the period of drought by comparing the average drop in water level over the entire area during the interval in which there had been no recharge. Likewise, the recharge could be estimated by construction of water-table maps before and after a short period of intensive precipitation, during which the discharge could be assumed as continuing at the predetermined rate. Unfortunately, this method has not been applied because measurements of water level in the key wells were not made during the war.

Several methods have been used to solve similar problems of evaporation and transpiration from a shallow ground-water body. [21/] One method involved the daily measurement of water-level fluctuations with water-stage recorders, the determination of specific yield in undisturbed samples taken with driven cyclinders, and computation of the ground-water discharge by plants by a formula.[22/] In another method the evaporation was determined from pans, and the transpiration was taken as the loss of weight of the natural plants in the 15 minutes immediately after cutting, for which time the transpiration rate was assumed not to have been affected by the cutting.[23/] Other methods involve a comparison of the dry weight of plants grown in tanks which are given measured quantities of water with the dry weight of the same plant species growing in the field.[24/] None of these methods

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21/ Meinzer, O. E., Plants as indicators of ground water: U.S. Geol. Survey Water-Supply Paper 577, pp. 82-88, 1927.
22/ White, W. N., A method of estimating ground-water supplies based on discharge by plants and evaporation from soil: U.S. Geol. Survey Water-Supply Paper 659-A,1932.
23/ Lee, C. H., An intensive study of the water resources of a part of Owens Valley California: U.S. Geol. Survey Water-Supply Paper 294, pp. 48-63, 1912.
24/ See references in Tolman, C. F., Ground water, p. 93, New York, McGraw-Hill Book Co., 1937.

were applied in this investigation because the expense of the detailed work did not seem to be justified.

ESTIMATES FOR THE POTENTIAL DEVELOPMENT OF THE GROUND-WATER RESOURCES

Any development of the ground-water resources depends upon the quantities of water available and the economics of development. The safe yield of an underground reservoir may be considered as the rate at which water can be retrieved from the reservoir without continually diminishing the storage. On the other hand, it may become more profitable to deplete the storage - that is, to mine water - for a number of years, recognizing that the supply will eventually diminish to the point of uneconomical yield, and then discontinue the enterprise. Such overdevelopment might be justified, for example, during a series of drought years, when general irrigation could be practiced, followed by return to dry farming during succeeding wet years. Over a period of time the partially-emptied groundwater basin would refill, so that it could be used again in another cycle of development.

In 1941 the sum of the estimated natural discharge (525 million gallons) and the total well discharge (180 million gallons) from the ground-water reservoir beneath the Oakes plain was about 700 million gallons. Of this quantity only the natural discharge (about 525 million gallons per year) is available for further development. This amounts to 1,600 acre-feet per year, or the equivalent of 1 foot of water on 1,600 acres.

Continuous withdrawal at this rate would result in a permanent lowering of the water table beneath the plain. For a time the water would be taken almost entirely from storage. Steeper gradients would be developed gradually from the present areas of higher water table along the Oakes moraine to the well fields, and gradients from the areas of natural discharge would eventually be reversed toward the well fields. Theoretically, the natural discharge would finally cease, and the water table, sloping towards the well fields, would everywhere be below an elevation of 1290 feet above sea level.

It is estimated from the water-table map, plate 5, that a general lowering of the water table of 10 feet over 100 square miles will eliminate the present natural discharge. Using an average specific yield of 25 percent, as determined from the pumping tests, this amounts to a removal from storage of the volume:

$V = 10 \text{ ft.} \times (5{,}280 \text{ ft./mile})^2 \times 100 \text{ sq. miles} \times 0.25$

= 7 billion cubic feet of water

= 52 billion gallons of water

= 160,000 acre-feet of water

Thus it would take over 70 years of pumping at the rate of 700 million gallons a year before the areas of ground-water discharge would be eliminated. If this were to happen a condition of equilibrium would be reached in which the general decline would cease and the water table would again be subject only to seasonal fluctuations and the longer cycles of wet and dry years.

It is in order here to calculate what yield might be attained for a given period of enterprise, assuming that an industry or an irrigation project desired to overdevelop the water resources in the underground reservoir. First, however, the total quantity of water in storage should be estimated. Again assuming a specific yield of 25 percent and taking the average saturated thickness beneath 100 square miles of the Oakes plain as 45 feet, the total volume of water stored in the basin is:

$v = 45 \text{ feet} \times (5{,}280 \text{ ft./ mile})^2 \times 100 \text{ sq. miles} \times 0.25$

= 31.4 billion cubic feet of water

= 235 billion gallons of water

= 720,000 acre-feet of water

Obviously only a part of this water could be extracted without greatly increasing the pumping costs. But even if only half of the water, that is, 350,000 acre-feet, could be extracted economically, a huge reserve would be available. For example, if the withdrawal exceeded by 10 times the average yearly rate of natural discharge, that is, if 16,000 acre-feet were pumped annually, the enterprise could be continued for 24 years before the saturated thickness would drop to half the present amount. By way of illustration, this means that 25 square miles, or one-fourth of the entire area, could be irrigated yearly to a depth of 1 foot of water for 24 years before the general water level would decline 23 feet.

Because any such extensive ground-water development would permanently lower the water table and dry up the areas of natural discharge, the value of such a development would have to exceed the loss in hay and pasture yield in the areas affected.

The production of feed could probably be increased in areas where the water table is 5 to 15 feet below the surface by seeding a sub-irrigating crop like alfalfa, which sends its roots down to the water table. W. N. White has reported on successful development of sub-irrigated alfalfa in the Escalante Valley, Utah.[25/] A light irrigation is often necessary during the first season to get the plant roots down to the water table.

RECOMMENDATIONS FOR WELL SPACING AND WELL CONSTRUCTION

A rational well spacing has been assumed in making the estimates of regional drawdown resulting from the various rates of withdrawal. If the wells were concentrated in a small area, for example, 3 or 4 square miles, such as might seem desirable for an industrial development, and if the water demand were about 5 billion gallons a year, the local drawdown resulting from this overdevelopment would be so great that the rate of withdrawal could not be maintained for more

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25/ Meinzer, O. E., Plants as indicators of ground water: U. S. Geol. Survey Water-Supply Paper 577, pp. 89-91, 1927.

than a few years. Therefore, from the standpoint of utilizing the natural ground-water resources to the optimum extent, it is desirable to consider what well pattern would be most beneficial.

Proper well spacing depends upon the purpose of development, and whether or not it is planned to exceed the long-term yield. If it should be determined that the safe yield of the basin is not to be exceeded, the hydrologically preferable concentration of wells would be near the areas of natural discharge; that is, approximately in the area where the water table is within 5 feet of the surface, as shown on the map, plate 3. However, if it should be desirable to practice temporary overdevelopment, using many more wells, a more general spacing would be required, based on an analysis of the effect of the boundaries of the ground-water reservoir. Wells near the sides of the basin would have a lower yield for the same drawdown than similarly-constructed wells on the central axis of the basin. Consequently it would be desirable to locate wells closer together along the central axis, and to space them farther apart along the sides. Moreover, since the permeability decreases southward, it would be preferable to have a greater distance between wells in the southern part of the area. As a rule of thumb, wells of over 500-gpm capacity should be located at least a quarter of a mile apart.

In general, it has been found unprofitable to install irrigation wells with capacities less than 500 gpm, and it is desirable to have wells that can produce about 800 gpm. Where wells of smaller yield are developed, as would probably be the case in the southern part of the Oakes plain, irrigation can be accomplished by constructing large water-storage tanks, which can be filled by long pumping at a low rate, so that large quantities of water may be released when it is time to irrigate.

The quantity of water derived from a well depends to a considerable extent upon the construction of the well.[26/] As the water beneath the Oakes plain is under relatively low head, it would be desirable to construct wells at least 1 foot in diameter. The wells should penetrate the entire saturated thickness of the lake deposits, down to the boulder clay, and they should be screened opposite the sand. It is preferable to use turbine pumps in the wells because with the progress of development in the area, the drawdowns may become so great that the suction lift of centrifugal pumps would be exceeded. If centrifugal pumps are used they should be placed in pits in order to reduce the suction lift, such as is the practice at the Forest Service Nursery.

Well drillers rate the performance of a well in terms of the specific capacity, which is expressed as the discharge in gpm for each foot of drawdown. Because the drawdown increases during steady pumping, the specific capacity is not constant but decreases with time. This is demonstrated in table supplement 40a, which shows the specific capacities of the wells employed in the pumping tests calculated for a few minutes, for the duration of the tests (different periods for each test), and for one day (by means of the extrapolated, unadjusted drawdown). For purposes of comparison the only intelligible specific capacity is one related to a fixed period; for this purpose 1 day has found much favor among pump operators.

The method of using a battery of driven sandpoint wells, such as those now in use by the City of Oakes, at the Oakes creamery, and at the Oakes swimming pool, could be employed on the edges of the lake basin where the saturated deposits are not very thick (for example, thinner than about 25 feet), as the effective diameter of the well field would be considerably greater than that of a single well, permitting large yields at shallow depth. However, well batteries would not be satisfactory for extensive ground-water development of the basin because it is necessary to pump them with suction pumps and with the regional

26/ Rohwer, Carl, Putting down and developing wells for irrigation: U.S. Dept. Agr. Circ. 546, 1940.

TABLE OF SPECIFIC CAPACITY OF WELLS

Well	Draw-down S	Time T	Short-term specific capacity	Draw-down S	Time T	End of test specific capacity	Draw-down S	Time T	One-day specific capacity
	ft.	min.		ft.	hr.min.		ft.	days	
Dickey 107 (Q=305 gpm)	7.01	12	44	8.85	7:58	35	9.55	1	32
Dickey 108 (Q=370 gpm)	11.19	20	33	14.04	7:55	26	15.33	1	24
Dickey 109 (Q=290 gpm)	3.99	15	74	5.81	8:03	50	6.51	1	45
Oakes Swimming Pool, 6 wells (Q=260 gpm)	1.29	15	201	2.68	16:50	98			
Per Well			34			16			

decline in water level the suction lift (practically limited to 25 feet for most pumps) would be exceeded.

QUALITY OF WATER

Six samples of water for chemical analysis were taken from the wells in the Lake Dakota basin in North Dakota and were analyzed in the Geological Survey laboratory in Washington. The analyses are shown in Table 7, p. 80, in comparison with the analysis of a sample from the area that was made in 1921.[27]

Well 3.2-5, NW¼NW¼ sec. 7, T. 129 N., R. 59 W., in Ludden, is a drilled well, 97 feet deep, with a water level only 9 feet below the surface. It is a well of the valley artesian type, described on p. 48, which probably derives its water from a gravel layer within the boulder clay. Well 5-10.7, in the SW¼NW¼ sec. 9, T. 120 N., R. 59 W., which is only 14.5 feet deep, shows 30 ppm of nitrate and with 38 ppm of chloride, indirect evidence of fecal contamination. No bacterial tests were made on the waters, as this was not a sanitary survey, yet such an analysis is a reminder of the danger of surface contamination in shallow wells, and the necessity of locating such wells far from waste disposal if they are to be used for domestic supply. Well 5-1.8, SW¼SW¼ sec. 21, T. 130 N., R. 59 W., which is only 14.3 feet deep, had an unusually high nitrate content, 112 ppm, without high chloride. It is the opinion of W. D. Collins, chemist in charge of the Quality of Water Division of the U. S. Geological Survey, that it may have received drainage from land which had received nitrate fertilizer. Well 6-2.3, in the NW¼SW¼ sec. 22, T. 129 N., R. 59 W., is a bored well 42 feet deep that obtains water from fine-grained sand within the lake silt and clay, in the southern part of the area. Well 5.5-14, NE¼NW¼ sec. 28, T. 131 N., R. 59 W., is a driven sandpoint well 25 feet deep, in the baseball park near the grandstand, at Oakes. Well 9.4-9, NE¼NW¼ sec. 19, T. 130 N., R. 58 W., is a driven pitcher-pump well,

27/ Simpson, H. E., Geology and ground-water resources of North Dakota: U.S. Geol. Survey Water-Supply Paper 598, p. 282, 1929.

13.2 feet deep, near the hills along the east margin of the area. Further description of the wells may be found in the table p. 48.

The waters analyzed are all hard, and some would be classed as very hard. The hardness is a detriment where the waters are used with soap. The waters would all form considerable scale when heated. The hardness has no adverse effect on the potability of the waters.

Most of the waters had more iron than is desirable. The United States Public Health Service standard for drinking and culinery water suggests an upper limit of 0.3 ppm of iron. More than 1 part usually gives an objectionable reddish precipitate where the water is exposed to the air. The objection to iron is not because of any harmful effect on health, but because of the unpleasant taste of too much iron and the stains made on articles washed in a water that contains more than about 1 ppm.

The waters examined should be excellent for irrigation. Hardness is generally an advantage in water for irrigation.

GEOLOGIC HISTORY OF THE LAKE DAKOTA BASIN

The regional geology is illustrated by the cross-section, figure 10, and described by Todd, Darton, Leonard, Kline, and Laird.[28/]

The oldest known rocks below the Lake Dakota basin are granites, probably of pre-Cambrian age. A well drilled for the City of Oakes penetrated 2 feet of granite at a depth of 1,232 feet. 29/ The granite is not known to contain usable water.

This granite is overlain by about 380 feet of shaley sandstone, about 700 feet of blue shale, about 80 feet of glacial drift, and about 65 feet of lake sediment,

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28/ Todd, J. E., A preliminary report on the geology of South Dakota: S. Dak. Geol. Survey Bull. 1, 1894.
Darton, N. H., Geology and underground waters of South Dakota: U.S. Geol. Survey Water - Supply Paper 227, 1909.
Leonard, A. G., The geological history of North Dakota: Univ. N.Dak. Quart. Jour., vol. 7, pp. 228-235, 1917.
Kline, V. A., Stratigraphy of North Dakota: Am. Assoc. Petroleum Geologists Bull., vol. 26, pp. 336-379, 1942.
Laird, W. M.Stratigraphy and structure of North Dakota: N.Dak. Geol. Survey Bull. 18, 1944.

29/ Simpson, H. E., Geology and ground-water resources of North Dakota: U.S. Geol. Survey Water-Supply Paper 598, 1929, p. 117.

as shown in the log of another City well at Oakes, fig. 9. The sandstone has been named the Dakota sandstone, and from records of wells is known to underlie large areas of North Dakota, South Dakota, Nebraska, and Kansas, where it furnishes considerable quantities of highly mineralized artesian water. The blue shale, elsewhere subdivided into the Benton, Niobrara, and Pierre shales, is a tight, almost impermeable series of rock strata that forms an ideal confining cover for the Dakota sandstone. The sandstone and shale are of Cretaceous age.

Prior to the great glaciations, the surface of this region underwent considerable erosion. The major streams probably flowed in channels different from the present valleys. There is considerable controversy over whether the regional preglacial drainage was north to Hudson's Bay or south to the Mississippi River.[30/] However, it is believed that a major preglacial valley existed along the present axis of the James River. Although this valley was partly filled by the deposits of the glaciers, it remained as a sag in the land surface that became the basin of Lake Dakota. Sand and gravels in this old valley may be the aquifer for the valley artesian wells described on p. 60.

The Pleistocene or glacial epoch is believed by some geologists to have begun more than a million years ago, and it may still be in process.[31/] Large areas in the northern part of the European and North American continents have been covered

30/ Upham, Warren, Age of the Missouri River: Am. Geologist, Vol. 34, pp. 80-87, 1904.
Todd, J. E., The Pleistocene history of the Missouri River: Science, new ser., vol. 39, pp. 263-274, 1914.
Bauer, C. M., A sketch of the later Tertiary history of the upper Missouri River: Jour. Geol., vol. 23, pp. 52-58, 1915.
Leonard, A. G., Pleistocene drainage changes in western North Dakota: Geol. Soc. America Bull., vol. 27, pp. 295-304, 1916.
Todd, J. E., Is the channel of the Missouri River through North Dakota of Tertiary origin?: Geol. Soc. America Bull., vol. 34, pp. 469-494, 1923.

31/ Coleman, A. P., The duration and causes of the ice ages: The Last Million Years, pp. 196-207, 1941.

by great ice sheets at least four times, and each time the ice front receded for a long interval before advancing again. Each time the ice slowly accumulated in great snowfields until it was of immense thickness, possibly as great as 2 miles at the center. As it accumulated it spread laterally until it extended far beyond its area of accumulation.

The margins of the ice sheet were probably only a few hundred feet thick and were in the form of finger-like lobes whose movement was directed by preglacial valleys through which the lobes were pushed. The ice moved slowly, advancing perhaps only a few thousand feet a year. It scoured and plucked huge quantities of rock from the surface it overrode. This debris was carried within and on the ice, and was dragged along the bottom to be used as the abrasive for further erosion. Hills were planed off on their iceward side, V-shaped stream valleys were widened into U-shaped troughs, and the drainage system was completely disrupted. Streams were dammed, forming lakes that filled until they overflowed their divides and discharged into adjacent streamways or eroded new drainage channels.

The ice mass pushed down from northern climates into warmer ones, moving more rapidly under warmer conditions as it melted and diminished in size. Eventually equilibrium was established between yearly advance and summer melting, and the ice front became stationary. The large quantities of rock shoved ahead and carried within the ice mass were dropped at the ice margin to form long ridges of accumulated material, known as end moraines.

Large quantities of gravel, sand, silt, and clay were carried by great rivers running off the ice surface in the summertime and were deposited as large aprons at the foot of the glacier or were emptied into the glacial lakes where they settled out, the coarser sand and pebbles near the ice source and the silt and clay farther away.

The glacial deposits associated with Lake Dakota are all of the latest, or Wisconsin stage of glaciation. However, North Dakota was covered by at least one of the earlier glaciations.[32] Soil and pieces of wood have been reported within the drift in wells in Dickey County, and these probably represent an interglacial period between two invasions.[33]

Regardless of the effect of earlier glaciations, the James River Valley was profoundly affected by the last ice invasion. This invasion began an estimated 85,000 years ago.[34] The ice moved from the Keewatin gathering ground in north-central Canada up the course of the Red River valley. From there it spread across North Dakota almost to the Missouri River. One of its lobes, called the Dakota lobe, pushed down the axis of the present James River, and at its southern and western limits built the Altamont terminal moraine. After a long stand at its maximal extent, the active ice front receded northward several miles, presumably because of warmer weather. Here it built the Gary end moraine, the first recessional moraine.

These end moraines are rugged belts of hills and undrained hollows, strewn with boulders and composed of glacial till, mixed with deposits of sand, gravel, silt, and clay derived from the rocks which the glacier passed over. Gently rolling tracts known as ground moraines, also composed of glacial till, occur between the hilly end moraines. Glacial till usually does not yield large quantities of water to wells because the deposits are unsorted, the fine particles filling the pore spaces between the boulders and grains of sand.

Withdrawal of the ice front from the Gary moraine, near Mitchell, South Dakota, exposed the tip of the basin of Lake Dakota and a shallow lake was formed. The lake grew as the ice front withdrew north of Huron and Redfield, but the sedi-

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32/ Leonard, A. G., The pre-Wisconsin drift of North Dakota: Jour. Geol., vol. 24, pp. 521-532, 1915.
33/ Hard, H. A., Geology and water-resources of the Edgeley and LaMoure quadrangles, North Dakota: U.S. Geol. Survey Bull. 801, p. 19, 1929.
34/ Leverett, Frank, Relative length of Pleistocene glacial and interglacial stages: Science, new ser., vol. 62, pp. 193-195, 1930.

ments in this shallow basin appear as aprons of outwash in front of each recessional moraine. The lake did not reach its maximum extent nor achieve any considerable depth until the ice front withdrew to the moraine along the east boundary of the Oakes area. This moraine has been named the Oakes moraine by Hard.[35/]

The geological map of the Oakes area, plate 4, shows the ground moraine on the west side, the Oakes end moraine on the east side, and the lake sediments and recent alluvium in the center. The mapping is taken from Hard's report [36/] except for the southern 5 miles and the eastern 2 miles of the area, which were mapped by the author.

From the Oakes moraine the ice front retreated northeast to the morainal belt, in northern and eastern Sargent County, which has been called the Dovre moraine by Upham [37/] and the Bigstone morainic system by Leverett. [38/]

As the ice withdrew to this moraine, it uncovered a low area in western Sargent County, in which formed a glacial lake, continuous with glacial Lake Dakota, described first by Upham [39/] and named Lake Sargent by Willard. [40/]

The ice withdrew progressively from North Dakota, leaving recessional moraine bands at intervals of longer stand. In the Red River basin glacial Lake Agassiz formed as the ice retreated, and in the Souris River basin glacial Lake Souris formed. [41/] These lakes existed only so long as the ice presented a northern barrier to the escape of the water. After the ice disappeared they drained to the north.

35/ Hard, H. A., Geology and water resources of the Edgely and LaMoure quadrangles, North Dakota: U. S. Geol. Survey Bull. 801, p. 31, 1929.
36/ Hard, H. S., op. cit., Plate 2.
37/ Upham, Warren, The glacial Lake Agassiz: U.S. Geol. Survey Mon. 25, p. 147, 1896.
38/ Leverett, Frank, Quaternary geology of Minnesota and parts of adjacent states: U.S. Geol. Survey Prof. Paper 161, p. 107, 1932.
39/ Upham, Warren, op. cit., p. 148.
40/ Willard, D. E., The story of the prairies, 1st. ed., 1902, p. 120.
41/ Upham, Warren, The glacial Lake Agassiz: U. S. Geol. Survey Mon. 25, 1896.

Glacial Lake Dakota was first named by Todd[42/] after the Dakota River, a former name of the James River. The surface of the lake plain may be described as stony for 80 miles at the south end, from Mitchell to a point 12 miles below Redfield, S. Dak., and from thence northward as composed to cream-colored silt with patches of sand to the North Dakota boundary, north of which sand predominates.

Logs of wells in the plain show a considerable thickness of sand and silt beds but no boulders. The log of the Aberdeen city well shows 90 feet of sand. The mill well at Northville encountered 45 feet of fine-grained sand, [43/] and the log of the Oakes well, figure 9, shows 65 feet of sand and gravel.

Todd [44/] found beach lines near Aberdeen and mapped the upper limit of the lake sediment at about 1,315 feet in the Aberdeen-Redfield folio. Hard [45/] mapped the upper limit of the lake sediments at 1,320 feet in the northern end of the basin, except for the high area just north of Oakes, where the sand plain rises to 1,340 feet above sea level.

Todd [46/] also found varves, which are considered conclusive evidence of a glacial lake. He reported 19 cycles, representing as many years, in a section from Lager's brickyard at Aberdeen, S. Dak.[47/]

Glacial Lake Dakota passed through three phases: a period of formation and expansion as the ice front receded up the James River valley to the Oakes moraine; a period of sediment accumulation from meltwaters discharging from the glacier at its stand along the Oakes moraine; and a period of sediment accumulation from melt-

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42/ Todd, J. E., The Missouri Coteau and its moraines: Am. Assoc. Adv. Sci. Proc., vol. 33, map p. 393, 1884.

43/ Todd, J. E., U.S. Geol. Survey Geol. Atlas, Aberdeen-Redfield folio (no. 165), p. 12, 1909.

44/ Todd, J. E., The moraines of the Missouri Coteau and their attendant deposits: U. S. Geol. Survey Bull. 144, pp. 52-53, 1896.

45/ Hard, H. A., Geology and water resources of the Edgeley and LaMoure quadrangles, North Dakota: U. S. Geol. Survey Bull. 801, Plate 2, 1929.

46/ Todd, J. E., More light on the origin of the Missouri River loess: Iowa Acad. Sci. Prec., vol. 13, p. 188, 1906.

47/ Todd, J. E., U. S. Geol. Survey Geol. Atlas, Aberdeen-Redfield folio (no. 165) p. 6, 1909.

waters discharging down the James River and Bear Creek from another glacial lobe farther to the north, while the ice front withdrew from the Oakes moraine to the Dovre moraine in northwestern Sargent County and the Lake Dakota waters were confluent with the waters of Lake Sargent. These sediments constitute the shallow ground-water reservoir beneath the Oakes plain.

It is of interest here to speculate on the duration of glacial Lakes Dakota and Sargent. On the basis of his calculations of the rapid retreat of the ice, Upham 48/ estimated that the great glacial Lake Agassiz endured less than 1,000 years. Many other studies of ice movement have been made since that estimate and other geologists 49/ have accepted about 1 mile in 10 years as the rate of retreat of ice in Wisconsin time, on calculations from the correlation of varves by Antevs and De Geer in Europe and America.

Using this rate, the formational and depositional stages of Lake Dakota took about 1,700 years as the ice retreated 170 miles from Mitchell, South Dakota, to the position of the Oakes moraine. Another 300 years may be assigned for the formation and duration of Lake Sargent in the retreat to the Dovre moraine, 30 miles away. Therefore, Lake Dakota lasted about 2,000 years.

The final disappearance of the continental glaciers from North America has been generally estimated to have occurred only 10,000 years ago. On that assumption, it is estimated that glacial Lake Dakota existed approximately 20,000 years ago.

48/ Upham, Warren, The glacial Lake Agassiz: U. S. Geol. Survey Mon. 25, pp. 240-244, 1896.

49/ Kay, G. F., Classification and duration of the Pleistocene Period: Geol. Soc. America Bull., vol. 42, p. 461, 1931.

SUMMARY

The available supply of ground water of satisfactory quality for irrigation and other uses in the Oakes plain occurs in the sand and silt deposits of Lake Dakota, an ancient glacia' lake that occupied a narrow basin along the present valley of the James River in North Dakota and South Dakota. This ancient lake, with a shoreline elevation 1,320 feet above sea level, covered an area of about 120 square miles in North Dakota, extending from a locality about 3 miles north of Oakes southward 17 miles to the State line, and from the west boundary of the flood plain of the James River eastward an average of about 7 miles, to a range of boulder-clay hills. On the edges of the basin the lake deposits are thin, but in about 100 square miles of the area they average about 55 feet in thickness, of which an average of about 45 feet is saturated, as revealed by logs of 12 test holes drilled along and across the plain.

As shown by the topographic map (plate 2) the plain is relatively flat and ranges in elevation from about 1,340 feet at its northeastern corner to about 1,290 feet in the lowlands of the James River and in depressions in the plain near the South Dakota boundary.

The soils and subsoils of the plain are dominantly sandy and the opportunities for the infiltration of water into the underground reservoir are, therefore, good.

As shown by the water-table map (plate 5), compiled from data obtained in late July 1941, the movement of the ground water is westerly or southwesterly from the range of hills along the east side of the plain towards discharge areas along the James River and in depressions at the south.

The map showing depths to water in late July 1941 (plate 3) reveals that the water was within 5 feet of the surface beneath about 25 square miles of the plain, and within 20 feet beneath practically all of it. In general, these shallow ground-water areas support a heavy growth of grass, which often stands in several inches of water in the spring and early summer.

The quality of water, as determined by chemical analyses of samples from six wells, showed that the waters are hard, averaging 430 ppm hardness as $CaCO_3$, and relatively high in iron, 3.1 ppm on the average. All the water analyzed would be suitablefor irrigation but the hardness and iron content would be detrimental for some industrial uses.

Permeability and storage determinations were made from pumping tests of four well systems near Oakes. The permeability ranged from 1,120 to 1,580 gallons a day through a cross-sectional area 1 foot thick and 1 mile wide under a hydraulic gradient 1 foot per mile at 60° F. The storage coefficient ranged from 10.9 percent to 25 percent for 8-hour tests, from which it is estimated that the average coefficient of storage would be about 25 percent for long-term recharge or discharge.

The present use of shallow ground water in the Oakes plain in North Dakota is estimated to be 180 million gallons a year. The natural discharge of the ground water in the lake deposits is estimated to be 525 million gallons of water in addition. This discharge is now largely wasted through evaporation and transpiration, so that if it were recovered it represents a safe annual yield for further well development. The actual safe yield may be several times as large because of the large area in which the water table is within 5 feet of the surface, from which an undetermined amount of recharge is now rejected. Comparison of the rise of water level in two wells, one at Oakes and the other at Ludden, during the four years 1941-1944, inclusive, in which there was above-normal precipitation, indicate that possibly as much as 20 percent of the precipitation, which averages 17.9 inches a year, may be available for ground-water recharge.

If it were planned to overdevelop the ground-water resources, it is estimated that about 16,000 acre-feet, or 5.2 billion gallons, of water could be pumped each year for 24 years, using proper well spacing, to reduce the quantity of water in storage by one-half, with a consequent average lowering of the water table of about 23 feet.

It is recommended that in any large well development, the wells should be gravel packed to increase their effective diameter and reduce their drawdown, and that the wells penetrate the entire saturated thickness of the lake deposits. It is suggested that wells with capacities of 500 gallons per minute or more be placed not closer than a quarter of a mile apart, to reduce mutual interference.

In any program of ground-water development, water-stage recorders should be placed on key observation wells so that an accurate record of the water-table fluctuations can be kept, and a record should also be kept of the quantity of water pumped.

TABLE III

RECORDS OF THE SHALLOW WELLS IN THE

No.	Name or owner	Location: Quarter	Section	T. N.	R. W.	Date com-pleted	Altitude above sea level, ft.	Depth of Well
9.4-0	A. Clayes	SW	31	129	58	1899	1313	--
9.4-0	A. Clayes	SW	31	129	58	--	1313	--
9.4-0	A. Clayes	SW	31	129	58	--	1313	--
9.4-0	A. Clayes	SW	31	129	58	--	1313	--
9.4-0	A. Clayes	SW	31	129	58	--	1313	--
10.2-0	F. Coburn	SW	32	129	58	1909	1322	--
6.6-5	Esterby Estate	SE	3	129	59	1934	1306	13.2
6-5	A. Louma	SE	4	129	59	--	1305	--
6-5	A. Louma	SE	4	129	59	1914	1305	13
6-5	A. Louma	SE	4	129	59	--	1305	--
5-5.1	E. Stearns	SE	5	129	59	1915	1304	16
5-5.1	E. Stearns	SE	5	129	59	--	1304	--
3.4-5	D. C. Botts	NW	7	129	59	1941	1303	16.9
3.2-5	D. C. Botts	NW	7	129	59	1924	1299	97
4-4.4	Ed Hankel	SW	8	129	59	1934	1306	42
5.6-4.9	A. F. Hankel	NE	9	129	59	1925	1304	17
5.6-5	A. F. Hankel	NE	9	129	59	--	1304	--
5.6-5	A. F. Hankel	NE	9	129	59	1910	1304	15
6-4	--	SW	10	129	59	--	1303	--
7-5	Dickey County	NW	11	129	59	--	1307	--
8-4	A. Lizer	SE	12	129	59	--	1306	--
6.6-4	F. Wegner	NE	15	129	59	--	1303	--
6.6-4	F. Wegner	NE	15	129	59	--	1303	--
6-3.9	Scott Livestock Co.	NW	15	129	59	--	1302	--
6-3.9	Scott Livestock Co.	NW	15	129	59	--	1302	--
6-4	Scott Livestock Co.	NE	16	129	59	--	1302	--
4.6-4	R. Nichols	NE	17	129	59	--	1307	12
4.6-4	R. Nichols	NE	17	129	59	--	1307	--
4.1-4	S. Staley	NW	17	129	59	1915	1306	20
4-3	O. Porter	SW	17	129	59	--	1304	30
4.6-3	J. Schroeder	SE	17	129	59	1939	1304	50
3-2.4	Mrs. Koski	SW	19	129	59	1939	1295	14.8
3-2.4	Mrs. Koski	SW	19	129	59	1934	1295	18
5-2.9	J. C. Johnson	NE	20	129	59	--	1304	55

SAND PLAIN SOUTH OF OAKES, NORTH DAKOTA

Type of pump a/	Water level: Depth below land surface	Water level: Date	Water level: Elevation above sea level	Use b/	Temperature, °F.	Measuring point and remarks.
CL	22	1938	--	S	--	
CL	--	--	--	S	--	
CL	--	--	--	S	--	
CL	--	--	--	S	--	
P	--	--	--	D	--	
--	12	1938	--	D,S	--	
P	5.0	7-21-41	1300.69	G	--	Top casing, 1308.32, 2.6 feet above ground.
P	--	--	--	D	--	
CL	13	1939	--	D,S	--	
P	--	--	--	S	--	
CL	14	1939	--	D,S	--	
P	--	--	--	D	--	
P	11.3	7-28-41	1291.75	O	51	Top casing, 1304.44, 1.3 ft. above ground. Dickey well 101.
CS	8.9	8-21-40	--	D	49	Water sample analysed: See table 7, p. 86.
C	40	1939	--	D,S	--	
P	4.5	7-21-41	1299.38	S	--	Joint in pump, 1306.37, 2.5 feet above ground.
P	--	--	--	D	--	
CL	10	1939	--	S	--	
CL	--	--	--	S	--	
CL	--	--	--	S	--	
CL	--	--	--	D,S	--	
P	--	--	--	D	--	
P	--	--	--	S	--	
CL	--	--	--	S	--	
P	--	--	--	D	--	
CL	--	--	--	S	--	
CL	10	1939	--	S	--	
P	--	--	--	D	--	
CL	20	1939	--	D,S	--	
CL	30	1939	--	D,S	--	
CL	10	1939	--	D,S	--	
P	7.1	7-23-41	1288.37	S	--	Top pump, 1297.93, 2.5 feet above ground.
P	10	1939	--	S	--	
CL	--	--	--	D,S	--	

1/ CL - Cylinder lift.
P - Pitcher.
R - Rotary.
F - Flow.
C - Centrifugal.
CS - Cylinder suction.

2/ S - Stock.
D - Domestic.
DS - Domestic-Stock
G - Garden.
O - Observation
PS - Public Supply.

U-Unused.
RR-Railroad
CP-City Park.
AW-Auto Wash.
I-Irrigation.

RECORDS OF THE SHALLOW WELLS IN THE

No.	Name or owner	Location: Quarter	Section	T. N.	R. W.	Date com-pleted	Altitude above sea level, ft.	Depth of Well
6-2.3	E. Beck	SW	22	129	59	1934	1301	42
7-2.3	H. Ulman	SW	23	129	59	--	1298	--
7-1.6	H. Ulman	NW	26	129	59	--	1298	--
7-1.6	J. West	NE	27	129	59	--	1298	--
4-2	C. W. Whittier	NW	29	129	59	--	1304	100
3.1-2	E. G. Hyatt	NW	30	129	59	1930	1294	18
5-0.6	C. Kelly	NW	33	129	59	--	1297	--
6-0.3	--	SW	34	129	59	--	1298	--
2.7-4	H. Lucksinger	NE	13	129	60	1937	1300	18
2.7-4	H. Lucksinger	NE	13	129	60	--	1299	--
2-2.2	V. S. Doyen	SW	24	129	60	1928	1302	19.0
1-1.4	Stoldenben	SE	27	129	60	1910	1293	85-100
0.7-0	A. Daniels	SE	34	129	60	1918	1293	118
10-9.4	O. Burger	SE	18	130	58	1899	1313	27
9.4-9	Reko Realty	NW	19	130	58	1930	1314	13.2
9.4-9	Reko Realty	NW	19	130	58	--	1313	--
10.3-7.2	A. Thompson	SW	29	130	58	--	1320	--
9.8-7.2	Pitz	SE	30	130	58	--	1314	--
9.8-7.2	Pitz	SE	30	130	58	--	1314	20
8.7-11.4	B. Johnson	SE	1	130	59	--	1323	--
9-11.4	B. Johnson	SE	1	130	59	--	1320	--
9-11.4	B. Johnson	SE	1	130	59	--	1318	--
9-11.4	B. Johnson	SE	1	130	59	--	1325	--
7-11.8	D. Sjolin	NW	2	130	59	--	1314	--
7-11	A. Kliment	SW	2	130	59	1917	1312	20.9
7-11	A. Kliment	SW	2	130	59	1925	1312	17
6-11.3	M. J. Reinhart	NW	3	130	59	--	1311	14
5-11.7	Ulland Mortgage Co.	NW	4	130	59	1920	1308	15
5-11.7	Ulland Mortgage Co.	NW	4	130	59	--	1308	--
5-11.2	Travelers Ins. Co.	SW	4	130	59	1910	1309	16
5-11.2	Travelers Ins. Co.	SW	4	130	59	--	1309	--
6-11.4	B. Sonkup	SE	4	130	59	--	1311	12
5-11.8	Anderson	NE	5	130	59	--	1308	--
5-11.8	Anderson	NE	5	130	59	--	1308	--
3.7-11	H. Meyer	SE	6	130	59	--	1300	--
4.7-10.5	J. Severson	SE	8	130	59	1910	1311	20
4.7-10.5	J. Severson	SE	8	130	59	--	1311	--

SAND PLAIN SOUTH OF OAKES, NORTH DAKOTA

Type of pump	Water level: Depth below land surface	Water level: Date	Water level: Elevation above sea level	Use	Temperature, °F.	Measuring point and remarks.
CL	22	10-1940	--	D,S	47	Water sample analysed: See table 7, p. 86.
CL	--	--	--	D,S	--	
CL	--	--	--	D,S	--	
CL	--	--	--	D,S	--	
CL	--	--	--	D,S	--	
P	18	--	--	D	--	
CL	--	--	--	D,S	--	
P	--	--	--	D,S	--	
CL	12	1939	--	D,S	--	
P	--	--	--	D	--	
P	15.8	8-21-41	1286.05	D	--	Joint in pump, 1303.88, 2 feet above ground. Dickey well 135.
F	--	--	--	D,S	48	2.8 gpm Aug. 12, 1940
F	--	--	--	D,S	48	11.6 gpm, Aug. 12, 1940
CL	10	1939	--	D,S	--	
P	7.2	7-25-41	1306.35	D	48	Top pipe, 1315.75, 2.2 feet above ground. Water sample analysed: See table 7, p. 86.
CL	--	--	--	D,S	--	
CL	--	--	--	D,S	--	
CL	--	--	--	D	--	
CL	15	1939	--	S	--	
P	--	--	--	D	--	
P	--	--	--	S	--	
P	--	--	--	S	--	
CL	--	--	--	S	--	
P	--	--	--	D	--	
P	11.5	7-17-40	--	D,S	--	Dickey well 130.
--	15	1939	--	--	--	
P	8.5	7-25-41	1302.20	D	--	Top pump, 1314.01, 3.3 feet above ground.
CL	13	1939	--	S	--	
P	--	--	--	D	--	
CL	14	1939	--	S	--	
P	--	--	--	D	--	
--	10	1939	--	--	--	
CL	--	--	--	S	--	
P	--	--	--	D	--	
P	--	--	--	D,S	--	
CL	18	1939	--	S	--	
P	--	--	--	D	--	

RECORDS OF THE SHALLOW WELLS IN THE

No.	Name or owner	Location: Quarter	Section	T. N.	R. W.	Date completed	Altitude above sea level, ft.	Depth of Well
4.7-10.5	J. Severson	SE	8	130	59	--	1311	--
5-10.7	Martin Estate	NW	9	130	59	--	1312	--
5-10.7	Martin Estate	NW	9	130	59	1940	1312	14.5
5-10.7	Martin Estate	NW	9	130	59	1910	1312	14
7-10.9	R. A. Savage	NE	10	130	59	--	1313	--
7-10.9	R. A. Savage	NE	10	130	59	--	1313	--
6.2-11	Bond	NW	10	130	59	--	1313	--
6-10.4	L. Ball	SW	10	130	59	--	1311	--
7-10.1	M. Savage	SE	10	130	59	1920	1310	17
7-10.6	A. Holling	NW	11	130	59	--	1312	--
7-10.6	A. Holling	NW	11	130	59	--	1312	--
8.3-9.3	N. J. Nelson	SW	13	130	59	--	1310	--
7.6-9	P. Vetter	SE	14	130	59	--	1313	--
7.6-9	P. Vetter	SE	14	130	59	--	1313	--
6-9.4	A. Ross	SW	15	130	59	1900	1313	12
5.4-9.6	Nat. Life Ins. Co.	NW	16	130	59	--	1313	--
5.4-9.6	Nat. Life Ins. Co.	NW	16	130	59	1930	1313	14
5.2-9	Riverdale School	SW	16	130	59	--	1313	--
5.2-9	Riverdale School	SW	16	130	59	--	1313	--
4.6-10	Lamer	NE	17	130	59	--	1311	14
4.7-9.5	Corrigan	SE	17	130	59	1909	1311	17.8
4.2-8	J. Hoffsomer	SW	20	130	59	--	1302	14.5
4.2-8	J. Hoffsomer	SW	20	130	59	--	1302	--
5.9-9	M. Collins	NE	21	130	59	--	1311	--
5.2-8.9	G. Hankel	NW	21	130	59	--	1311	--
5.2-8.9	G. Hankel	NW	21	130	59	--	1311	--
5.1-8	H. Holling	SW	21	130	59	1940	1307	14.3
5.1-8	H. Holling	SW	21	130	59	--	1307	--
5.1-8	H. Holling	SW	21	130	59	--	1308	--
5.1-8	H. Holling	SW	21	130	59	--	1307	--
6.6-9	E. P. Wilson	NE	22	130	59	1939	1312	22
6.6-9	E. P. Wilson	NE	22	130	59	--	1312	--
6.6-9	E. P. Wilson	NE	22	130	59	1900	1312	16
7-8.4	E. Nielson	SE	22	130	59	--	1311	--
8.6-9	State Land Bank	NE	24	130	59	--	1312	--
8.6-9	State Land Bank	NE	24	130	59	--	1312	18

SAND PLAIN SOUTH OF OAKES, NORTH DAKOTA

Type of pump	Water level: Depth, below land surface	Water level: Date	Water level: Elevation above sea level	Use	Temperature, °F.	Measuring point and remarks
P	--	--	--	S	--	
P	--	--	--	D	--	
P	10.0	7-21-41	1301.93	G	52	Joint in pump, 1314.85, 2.9 feet above ground. Water sample analysed: See table 7, p. 80.
CL	12	1939	--	S	--	
P	--	--	--	D	--	
CL	--	--	--	S	--	
CL	--	--	--	D,S	--	
CL	--	--	--	D,S	--	
--	15	1939	--	--	--	
P	--	--	--	D	--	
CL	--	--	--	S	--	
CL	--	--	--	D,S	--	
P	--	--	--	D	--	
CL	--	--	--	S	--	
CL	10	1939	--	S	--	
P	--	--	--	D	--	
CL	12	1939	--	S	--	
P	--	--	--	PS	--	
R	--	--	--	PS	--	
CL	12	1939	--	D,S	--	
P	11.2	7-17-40	--	D	--	Dickey well 131.
P	9.2	7-25-41	1292.9	D	53	Top pump, 1304.48, 2.4 feet above ground.
CL	--	--	--	S	--	
CL	--	--	--	D,S	--	
P	--	--	--	D	--	
CL	--	--	--	S	--	
P	7.3	7-25-41	1299.37	S	54	Top pump, 1309.16, 2.5 feet above ground. Water sample analysed: See table 7, p. 80.
P	--	--	--	D	--	
P	--	--	--	S	--	
CL	--	--	--	S	--	
P	8.2	7-25-41	1303.43	G	50	Joint in pump, 1314.02, 2.4 feet above ground.
P	--	--	--	D	--	
CL	14	1939	--	S	--	
CL	--	--	--	D,S	--	
CL	--	--	--	S	--	
P	--	--	--	D	--	

RECORDS OF THE SHALLOW WELLS IN THE

No.	Name or owner	Location: Quarter	Section	T. N.	R. W.	Date com-pleted	Altitude above sea level, ft.	Tempera-ture, °F.
8-8.6	L. Palensky	NW	24	130	59	1920	1315	20
8-8.6	L. Palensky	NW	24	130	59	--	1315	--
8.6-8	L. Palensky	SE	24	130	59	--	1314	--
8.6-8	L. Palensky	SE	24	130	59	1920	1313	17
8-8.4	E. Robbins	SW	25	130	59	1920	1312	23
8-8.4	E. Robbins	SW	25	130	59	--	1312	--
7-8	H. J. Johnson	NW	26	130	59	1939	1312	18
7.3-8	H. J. Johnson	NW	26	130	59	--	1312	16
6.6-8	H. Sieg	NE	27	130	59	--	1311	--
6.2-8	E. Nielson	NW	27	130	59	--	1310	--
6.2-8	E. Nielson	NW	27	130	59	1914	1310	25
6-7.2	A. Nielson	SW	27	130	59	--	1309	--
6-7.2	A. Nielson	SW	27	130	59	1927	1309	14
5.1-7	G. Grotluschen	SW	28	130	59	--	1305	--
5.1-7	G. Grotluschen	SW	28	130	59	--	1305	--
5.1-7	G. Grotluschen	SW	28	130	59	1920	1305	13
5-8	E. A. Petersen	NE	29	130	59	--	1308	--
5-8	E. A. Petersen	NE	29	130	59	1905	1308	22
3-8	Union Central Life	NW	30	130	59	1900	1299	15
3-8	Union Central Life	NW	30	130	59	1910	1300	16.2
3.5-7	E. Robbins	SW	30	130	59	--	1298	--
3.4-7	H. C. Raish	NW	31	130	59	1900	1298	20
3.3-6	H. Robbins	SW	31	130	59	--	1300	--
5-7	J. C. Petersen	NE	32	130	59	1924	1305	14.9
5-7	J. C. Petersen	NE	32	130	59	--	1305	--
5-7	J. C. Petersen	NE	32	130	59	1913	1305	13
5-7	J. C. Petersen	NE	32	130	59	--	1305	--
4-6	E. Robbins	SW	32	130	59	1930	1302	16
4-6	E. Robbins	SW	32	130	59	--	1302	--
5-6	E. Hankel	SW	33	130	59	1912	1305	14
5-6	E. Hankel	SW	33	130	59	--	1305	--
6.7-7	R. Sorenson	NE	34	130	59	1907	1308	13
2.7-7.6	W. Hankel	NE	25	130	60	--	1294	--
2.7-7.6	W. Hankel	NE	25	130	60	--	1294	--
5.7-17.2	E. Mallor	SE	4	131	59	1911	1319	31
4-16	Johnson & Ramharter	SE	7	131	59	1900	1292	35
5-16	J. Sheridan	SE	8	131	59	1900	1331	45
5-16	J. Sheridan	SE	8	131	59	--	1330	--
5-16.1	Mrs. Patten	SW	9	131	59	--	1333	30
5-16.1	Mrs. Patten	SW	9	131	59	--	1333	--

SAND PLAIN SOUTH OF OAKES, NORTH DAKOTA

Type of pump	Water level: Depth, below land surface	Water level: Date	Water level: Elevation above sea level	Use	Temperature, °F.	Measuring point and remarks
CL	18	1939	--	S	--	
P	--	--	--	D	--	
P	--	--	--	D	--	
CL	15	1939	--	S	--	
CL	20	1939	--	S	--	
P	--	--	--	D	--	
P	6.1	7-18-40	--	D	--	
CL	14	1939	--	S	--	
CL	--	--	--	D,S	--	
P	--	--	--	D	--	
CL	22	1939	--	S	--	
P	--	--	--	D	--	
CL	14	1939	--	S	--	
P	--	--	--	D	--	
P	--	--	--	S	--	
CL	11	1939	--	S	--	
P	--	--	--	D	--	
CL	20	1939	--	S	--	
P	13	1939	--	D	--	
CL	11.7	5-18-41	1288.62	S	47	Brass nail, E. side well curb, 1301.37, 1.1 ft. above ground.
CL	--	--	--	D,S	--	
CL	18	1939	--	D,S	--	
P	--	--	--	D	--	
P	8.2	7-18-40	1296.47	D	--	Joint in pump, 1307.27, 2.6 feet above ground. Dickey well 133.
CL	--	--	--	S	--	
F	11	1939	--	S	--	
CL	--	--	--	S	--	
CL	13	1939	--	S	--	
P	--	--	--	D	--	
CL	12	1939	--	S	--	
P	--	--	--	D	--	
CL	10	1939	--	D,S	--	
P	--	--	--	D	--	
CL	--	--	--	S	--	
CL	--	--	--	--	--	
F	--	--	--	D,S	45	0.7 gpm Sept. 23, 1940.
CL	--	--	--	--	--	
--	--	--	--	--	--	
CL	--	--	--	--	--	
CL	--	--	--	--	--	

RECORDS OF THE SHALLOW WELLS IN THE

No.	Name or owner	Location: Quarter	Section	T. N.	R. W.	Date completed	Altitude above sea level, ft.	Temperature, °F.
5-16.1	Mrs. Patten	SW	9	131	59	--	1333	--
6.7-15	L. W. Longbella	SE	15	131	59	1935	1342	50
6-15	Lohmeyer & Pierce	SE	16	131	59	1920	1334	37
5-14.9	A. Schmidt	NE	20	131	59	1910	1328	38
5-14.9	A. Schmidt	NE	20	131	59	--	1327	42
4.5-14.5	A. M. Dahlbeck	NW	20	131	59	--	1299	96
4.4-14	McClosky	SW	20	131	59	--	1300	68
4.6-14	N.P.& C. & N.W. Ry's	SE	20	131	59	1883	1315	22
6-14.7	P. Roney	NE	21	131	59	--	1323	25
5-14.5	A. M. Dahlbeck	NW	21	131	59	1924	1330	23
5-14.5	A. M. Dahlbeck	NW	21	131	59	--	1330	--
5-14.5	A. M. Dahlbeck	NW	21	131	59	--	1330	--
5-14.5	A. M. Dahlbeck	NW	21	131	59	--	1330	--
6-14	P. Roney	SW	22	131	59	1914	1315	14
6.5-14	J. Kilzer	NE	27	131	59	--	1323	--
6.5-14	J. Kilzer	NE	27	131	59	--	1323	--
6-14.1	E. Eaton	NW	27	131	59	--	1314	--
6-14.1	E. Eaton	NW	27	131	59	1935	1314	14.0
6-14.1	E. Eaton	NW	27	131	59	--	1314	--
6-13.2	W. E. Zimmerman	SW	27	131	59	--	1311	16.2
6-13.2	W. E. Zimmerman	SW	27	131	59	--	1311	--
6.5-13.2	J. Leslie Estate	SE	27	131	59	--	--	--
6.5-13.2	J. Leslie Estate	SE	27	131	59	--	--	--
5.5-14	City of Oakes	NW	28	131	59	1917	1309	26.5
5.4-14	City of Oakes	NW	28	131	59	1915	1312	25
5.2-14	F. Elliott	NW	28	131	59	1910	1312	19.5
5.2-13.9	Church of Nazarene	NW	28	131	59	--	1311	22.7
5.1-13.6	Minn. St. Paul, & Sault Ste. Marie Ry.	NW	28	131	59	--	1317	--
4.6-14	T. A. Ball	NE	29	131	59	--	--	24
4.8-13.8	City of Oakes	NE	29	131	59	--	--	50
5-14	Std. Oil Co.	NE	29	131	59	1939	1316	22

SAND PLAIN SOUTH OF OAKES, NORTH DAKOTA

Type of pump	Water level: Depth, below land surface	Water level: Date	Water level: Elevation above sea level	Use	Temperature, °F.	Measuring point and remarks
P	--	--	--	D	--	
--	5	1935	--	--	--	
CL	24.1	8-30-41	1309.62	D,S	52	Flange, N. pt., 1333.68, at surface.
--	27	10-15-41	1300.5	U	--	Top casing, 1321.8, 6 feet below ground.
CL	20.5	1940	--	D	--	
--	1.0	7-30-41	1298.40	U	--	Curb, W. pt., 1299.42, at surface.
--	4	1940	--	D	--	
R	18	8-21-40	--	RR	--	
--	19.0	7-25-41	1303.81	U	--	Top casing, 1326.05, 3.2 feet above ground.
--	21	7-17-40	--	U	--	Dickey well 129.
--	--	--	--	D	--	
--	--	--	--	S	--	
--	--	--	--	S	--	
--	--	--	--	--	--	
P	--	--	--	D	--	
CL	--	--	--	S	--	
P	--	--	--	D	--	
CL	11.6	8-30-40	--	G	51	
CL	--	--	--	S	--	
P	8.2	7-25-41	1302.58	D	49	Joint in pump, 1314.18, 3.4 feet above ground.
CL	--	--	--	S	--	
P	--	--	--	D	--	
CL	--	--	--	S	--	
P	7.0	7-25-41	1302.12	CP	--	Top casing, 1310.60, 1.5 feet above ground. Dickey well 127.
P	8.7	7-25-41	1302.81	CP	47	Top casing, 1313.05, 1.5' above ground. Water sample analysed: See table 7, p.80.Dickey well 128
P	10.8	7-25-41	1301.60	S	--	Top pump, 1315.52, 3.1 feet above ground.
P	13	9-19-40	--	D,S	--	
CL	16.9	8-22-40	1300.21	RR	--	Rim manhole, 1317.09, at surface.
--	--	--	--	--	--	
C	11.9	6-17-40	--	PS	--	Fourteen driven sandpoint wells.
P	15.3	7-25-41	1300.79	AW	49	Well now destroyed.

RECORDS OF THE SHALLOW WELLS IN THE

No.	Name or owner	Location: Quarter	Location: Section	Location: T. N.	Location: R. W.	Date completed	Altitude above sea level, ft.	Temperature, °F.
4.4-14	H. J. Johnson	NW	29	131	59	--	--	128
4.6-13.3	M. Antone	SE	29	131	59	--	1312	19
5-13	M. Bishop	NE	32	131	59	1939	1313	21
5-13	M. Bishop	NE	32	131	59	--	1314	--
5-13	M. Bishop	NE	32	131	59	--	1314	--
4-12.5	L. Colman	SW	32	131	59	--	1293	20
5-12	J. Lyngen	SE	32	131	59	--	--	20
5-12.2	F. B. Sturken	SE	32	131	59	--	1306	20
5.6-13	A. T. Johnson	NE	33	131	59	--	1307	25
5.6-13	A. T. Johnson	NE	33	131	59	--	1307	--
5.0-12.5	Johnson Estate	NW	33	131	59	1938	1312	41.7
5.3-12.6	Johnson Estate	NW	33	131	59	1939	1309	38.9
5.3-12.4	Anderson Estate	SW	33	131	59	1939	1309	43
5-12.2	L. Sitts,Jr.,Tenant	SW	33	131	59	--	1310	14.9
6-12.4	C. F. Axelson	SE	33	131	59	1907	1307	15
6-12.4	C. F. Axelson	SE	33	131	59	--	1307	--
6.6-13	A. Sherborn	NE	34	131	59	--	1313	18
6.6-13	A. Sherborn	NE	34	131	59	--	1313	--
6-13	F. O. McCartney	NW	34	131	59	--	1314	10
6-13	F. O. McCartney	NW	34	131	59	--	1314	--

SAND PLAIN SOUTH OF OAKES, NORTH DAKOTA

Type of pump	Water Level: Depth, below land surface	Water Level: Date	Water Level: Elevation above sea level	Use	Temperature, °F.	Measuring point and remarks
--	--	--	--	--	--	
P	12.2	7-25-41	1300.08	D	--	Top pump, 1315.29, 3 feet above ground.
P	12.6	7-25-41	1300.64	S	49	Joint in pump, 1314.31, 1.1 feet above ground.
P	--	--	--	D	--	
CL	--	--	--	S	--	
--	--	--	--	--	--	
--	--	--	--	--	--	
--	--	--	--	--	--	
CL	--	--	--	S	--	
P	--	--	--	D	--	
C	10.2	6-30-41	1301.28	I	--	Top casing, 1301.04, 10.3 ft. below ground. Dickey well 107.
C	9.6	6-30-41	--	I	--	Dickey well 108.
C	13	6-30-41	--	I	--	Dickey well 109.
P	8.9	7-25-41	1300.99	S	50	Joint in pump, 1312.01, 2.3 feet above ground.
CL	--	--	--	S	--	
P	--	--	--	D	--	
CL	--	--	--	S	--	
P	--	--	--	D	--	
CL	--	--	--	S	--	
P	--	--	--	D	--	

TABLE IV

RECORDS OF DAKOTA SANDSTONE ARTESIAN WELLS IN

No.	Name or owner	Location: Quarter	Section	T. N.	R. W.	Depth (ft.)	Diameter (in.)	Date completed	Altitude above sea level (ft.)
7-6	D. Sjolin	NW	2	129	59	900	1½	1916	1307
6.5-5	Esterby Estate	SE	3	129	59	840	2-1	1915	1306
6.6-5	Esterby Estate	SE	3	129	59	...	...	1916	1307
4.1-6	E. Stearns	NW	5	129	59	...	1½	....	1302
3.4-5	Town of Ludden	SW	6	129	59	980	3-1½	....	1300
6.6-4	F. Wegner	NE	15	129	59	897	1¼	1935	1303
5.9-4	Scott Livestock Co.	NE	16	129	59	...	2-1	1917	1303
3.4-3.5	W. H. Grotluschen	SW	18	129	59	1,100	1½	1912	1302
3-2.8	Federal Land Bank	NE	19	129	59	820	1½	....	1302
5-2.8	M. Staley	NW	21	129	59	880	1½	....	1305
6-2.3	E. Beck	SW	22	129	59	837	2-1	....	....
7-2.4	H. Ulman	SW	23	129	59	830	1½	....	1300
7-1.6	J. West	NE	27	129	59	...	1½	....	1298
5-1.1	J. Kissinger	SW	28	129	59	850	1½-3/4	1915	1300
3.1-2	Federal Land Bank	NW	30	129	59	881	4-1	1906	1295
5-0.4	C. Wuolu	SE	32	129	59	900	1	1910	1297
5-0	J. Kissinger	SW	33	129	59	1,065	1½-3/4	1930	1295
6-0.3	C. Harholt	SW	34	129	59	810	2½-1¼	1920	1300
2-4.4	Sorenson Realty	SE	11	129	60	...	2½-1½	....	1295
2-2.5	G. E. Baldwin	NE	23	129	60	930	2-½	1907	1297
3-1.3	A. Buro	NW	23	129	60	1,100	5-2	....	1295
2-2.3	V. S. Doyen	SW	24	129	60	828	1½-1	1915	1302
2.7-2.4	E. A. Starkka	SE	24	129	60	812	1½	1911	1298
2-1.6	O. Backley	NE	26	129	60	900	2-1½	1906	1302
1.4-1.3	J. W. Staudinger	SW	26	129	60	1,000	2½-1¼	....	1291

THE SAND PLAIN SOUTH OF OAKES, NORTH DAKOTA

Flow (gallons a minute)								
Reported original flow	Measured flow	Date	Measured flow	Date	Measured flow a/	Date	Temperature, °F.	1940-41 measuring point
...	2.4	8-17-23	1.5	8-22-31	4.3	6-27-41	64	At cattletrough 200 feet from well.
7	1.7	8-7-23	...	...	.2	6-27-41	51	¼" brass tube in center of cattletrough.
...	...	...	...	...	P	6-27-41	..	
...	...	...	...	...	1.9	6-27-41	58	At cattletrough, other outlets closed.
...	5.7	8-8-23	...	...	3.4	Aug.'40	..	At 2 outlets, other faucets may be open.
...	...	...	...	...	10.6	6-27-41	55	At well, through faucet, other outlets closed.
...	3.8	8-7-23	...	...	A	...	..	
...	10.0	8-8-23	3.5	8-22-31	3.1	6-28-41	60	At well, other outlets off, but leaky.
...	5.5	8-8-23	2.5	8-22-31	2.4	6-28-41	56	At well spigot, other outlets off.
10	...	...	1.0	8-22-31	2.2	6-30-41	58	At well faucet, other outlets off.
...	4.0	1923	2.0	8-22-31	A	...	..	
10	4.0	1925	2.0	8-22-31	2.3	6-30-41	57	At cattletank, other outlets off.
...	...	...	...	...	A	...	..	
...	3.0	8-7-23	...	...	1.0	6-30-41	62	At cattletank, house shut off.
...	5.4	8-8-23	3.1	8-22-31	.7	6-28-41	59	At well, no outlets.
...	3.2	8-7-23	1.7	8-22-31	1.0	6-30-41	64	At cattletank.
32	...	...	...	...	2.3	6-30-41	60	At cattletank nearest to well, and at duckpond.
...	3.6	8-7-23	1.9	8-22-31	1.6	6-30-41	61	At cattletank.
...	10.0	1923	...	...	6.8	6-27-41	60	At well and at shed, house shut off.
...	1.0	8-4-23	...	...	1.2	6-28-41	54	At well faucet.
200	2.0	1923	...	...	43	6-28-41	60	At well faucet, wide open. Reduced in 1923.
...	2.3	8-4-23	...	...	1.9	8-24-40	58	At well faucet.
...	.9	8-4-23	...	...	1.2	6-28-41	65	At cattletank, other outlets closed.
...	.5	8-4-23	...	...	4.9	6-28-41	61	At well nozzle.
...	20.0	8-4-23	4.0	8-21-31	6.5	6-28-41	63	At well faucet, leaks estimated.

a/ A - abandoned. C - capped. P - plugged.

RECORDS OF DAKOTA SANDSTONE ARTESIAN WELLS IN

No.	Owner	Location: Quarter	Section	T.N.	R.W.	Depth, (ft.)	Diameter (in.)	Date com-pleted	Altitude above sea level, Ft.
2-1	Mrs. H. Wattula	SE	26	129	60	909	2½-1¼	1909	1301
2-0.7	C. Korpua	NE	35	129	60	1,035	1½	1911	1300
1.2-0.9	J. Korhela	NW	35	129	60	777	1½	1907	1293
9.3-11.2	C. Wies	SW	6	130	58	...	4	1910	...
11.9	P. Savey	SE	17	130	58	1,000	1½	....	1325
10.3-7	Sargent County	NW	32	130	58	900	1¼	....	1318
9-11.4	J. M. Schmit	SE	1	130	59	906	2½-1	1910	1330
7-11.6	A. Volland	NW	2	130	59	932	2-1	1908	1313
7-11	A. Kliment	SW	2	130	59	877	2-1	1908	1313
6-11.7	M. J. Reinhart	NW	3	130	59	860	3-2	1919	1310
5-11.9	J. A. Donnelly	NE	5	130	59	935	2½-1¼	1921	1308
4.7-9.4	Corrigan	SE	17	130	59	918	2-1	1914	1312
3.8-10	E. Kliment	NE	18	130	59	900	1½	1911	1308
3.5-9	Dr. Ryan	SW	18	130	59	885	2½-1¼	1912	1307
3-8.4	G. Teal	SW	19	130	59	885	2½-1¼	1919	1307
3.3-6	H. Robbins	SW	31	130	59	847	2½-1¼	1918	1305
8.1-7	State School Lands	NW	36	130	59	...	2½-1¼	1910	1312
2.6-9.2	H. P. Low	SE	12	130	60	900	1¼	1910	1308
5.3-17	J. Deiffenbacher	NW	9	131	59	...	2½-1¼	1920	....
	City of Oakes	SW	20	131	59	...	...	....	....
	City of Oakes	SE	20	131	59	...	...	....	....
	City of Oakes	SE	20	131	59	...	4	....	....
	City of Oakes	SW	21	131	59	...	...	....	....
	Catholic Parsonage	SW	21	131	59	...	...	....	....
5-13.2	Mrs. Schaub	SW	28	131	59	...	2-½	1908	1317
	City of Oakes	NE	29	131	59	977	...	1890	....
4.3-14	H. J. Johnson	NW	29	131	59	...	2-1	1912	1300

THE SAND PLAIN SOUTH OF OAKES, NORTH DAKOTA

Flow (gallons a minute)								
Reported original flow	Measured flow	Date	Measured flow	Date	Measured flow a/	Date	Temperature °F.	1940-41 measuring point
...	7.0	8-4-23	2.2	8-21-31	4.3	6-28-41	61	At well faucet.
...	10.6	8-4-23	2.0	8-2-31	10.0	6-28-41	61	At well faucet.
...	4.6	8-4-23	3.3	8-21-31	4.7	6-28-41	59	At well faucet and at trough.
...	...	...	...	...	4.4	10-25-40	59	At well.
...	...	...	...	...	3.2	6-27-41	59	At well and barn, house shut off.
...	...	...	...	...	.6	6-27-41	55	At cattletank.
20	2.5	9-2-27	2.5	8-26-35	1.2	10-24-40	55	At well.
15	2.5	9-2-27	2.0	8-26-35	2.0	10-19-40	56	At well.
5	1.1	9-2-27	.9	8-5-38	.5	10-24-40	57	At cattletank.
30	3.2	9-2-27	3.5	8-26-35	4.1	10-24-40	58	Cattletank, E. side of road; watertub, W. side of road.
10	1.8	9-2-27	2.1	8-26-35	2.0	10-16-40	56	Outlet at cattletank, reduced.
10	1.5	9-2-27	...	...	1.2	10-16-40	57	Outlet at cattletank.
15	10.0	9-2-27	7.0	8-26-35	7.8	10-26-40	61	At well.
10	3.1	1921	4.3	8-26-35	1.9	6-28-41	59	At well.
10	1.8	9-2-27	...	...	1.0	6-27-41	65	At well.
15	3.0	9-2-27	1.5	8-26-35	1.6	6-28-41	70	At sheep trough and at horse trough.
...	2.0	9-2-27	3.3	8-26-35	2.0	6-27-41	64	At cattletank.
15	1.5	8-31-27	...	...	2.4	6-28-41	54	At well.
...	2.1	9-6-27	2.0	7-27-32	...	...	..	
...	...	...	...	...	A	...	..	
...	4	9-7-27	...	...	A	...	..	
...	...	...	...	...	A	...	..	
...	...	...	...	...	A	...	..	
...	...	...	...	...	C	...	..	
...	1.6	9-7-27	...	...	0.9	10-16-40	54	At well.
317	...	...	...	...	A	...	..	
...	3.0	9-7-27	...	...	2.0	10-15-40	52	At well.

a/ A - abandoned. C - capped. P - plugged.

TABLE V

LOCATION, LOGS AND WATER LEVELS OF

No.	Location	Depth in feet	1st Material	Depth in feet	2nd Material
0.5-0	SW¼SW¼SE¼ Sec. 34, T. 129N., R. 60W.	0-9	Yellow pebbly clay	9-12	Blue pebbly clay
1-0	SE¼SE¼SE¼ Sec. 34, T. 129N., R. 60W.	0-2	Marsh clay	2-4	Brown sand
2-0	SW¼SW¼SW¼ Sec. 36, T. 129N., R. 60W.	0-3	Gray sandy silt	3-5	Brown fine sand
3-0	SW¼SW¼SW¼ Sec. 31, T. 129N., R. 59W.	0-½	Black topsoil	½-4½	Fine sandy silt
4-0	SW¼SW¼SW¼ Sec. 32, T. 129N., R. 59W.	0-4	Buff silty fine sand		
5-0	SW¼SW¼SW¼ Sec. 33, T. 129N., R. 59W.	0-2	Black topsoil	2-3	Black clay
6-0	SW¼SW¼SW¼ Sec. 34, T. 129N., R. 59W.	0-2	Black topsoil	2-3	Brown fine sand
6.8-0	SE¼SE¼SE¼ Sec. 34, T. 129N., R. 59W.	0-½	Black topsoil	½-3½	White & gray marly clay
7-0	SW¼SW¼SW¼ Sec. 35, T. 130N., R. 59W.	0-2	Black slough clay	2-2½	White marl
8-0	SE¼SE¼SE¼ Sec. 35, T. 130N., R. 59W.	0-1½	Black topsoil	1½-6	Brown medium sand
9-0	SE¼SE¼SE¼ Sec. 36, T. 129N., R. 59W.	0-1	Black topsoil	1-2	Silty marl
10-0	SW¼SW¼SW¼ Sec. 32, T. 129N., R. 58W.	0-1½	Black topsoil	1½-4	Dirty fine sand
1.3-1	SW¼SE¼SW¼ Sec. 26, T. 129N., R. 60W.	0-½	Black limey topsoil	½-3	Marl
2-1	NE¼NE¼NE¼ Sec. 35, T. 129N., R. 60W.	0-2	Buff fine sand	2-9	Yellow clay
3-1	NW¼NW¼NW¼ Sec. 31, T. 129N., R. 59W.	0-1	Black topsoil	1-7	Brown medium sand
4-1	SE¼SE¼SE¼ Sec. 30, T. 129N., R. 59W.	0-½	Black topsoil	½-3	Marl
5-1	SE¼SE¼SE¼ Sec. 29, T. 129N., R. 59W.	0-1½	Black sandy top-soil	1½-7	Buff fine sand
6-1	SE¼SE¼SE¼ Sec. 28, T. 129N., R. 59W.	0-½	Black topsoil	½-1½	Calcareous clay
7-1	SW¼SW¼SW¼ Sec. 26, T. 129N., R. 59W.	0-½	Black topsoil	½-12	Yellow clay
8-1	NW¼NW¼NW¼ Sec. 36, T. 129N., R. 59W.	0-½	Black topsoil	½-4	Brown medium sand
9-1	SW¼SW¼SW¼ Sec. 30, T. 129N., R. 58W.	0-½	Black topsoil	½-2	Gray clay
10-1	SE¼SE¼SE¼ Sec. 30, T. 129N., R. 58W.	0-1	Black limey topsoil	1-3	Gray fine sand

HOLES BORED IN THE OAKES AREA.

Depth in feet	3rd Material	Depth in feet	4th Material	Water level, summer-1941
				1,282.5
				1,286.0
5-8	Yellow clay	8-11	Blue clay	1,284.1
				1,291.1
				1,282.0
3-4	Yellow silty clay			1,288.3
3-4	Black clay	4-5	Yellow silty clay	1,291.1
3½-6	Brown fine sand			1,287.0
2½-3	Brown medium sand			1,287.2
				1,297.3
2-4	Buff fine sand	4-7	Yellow medium sand	1,304.2
4-6½	Marl	6½-10	Buff medium sand	1,315.5
3-6½	Yellowish black clay	6½-7	Buff medium sand	1,286.6
9-13	Blue-gray clay	13-17½	Buff fine sand	1,285.1
7-9	Gray calcareous sand			1,286.9
3-4	Black clay	4-10	Gray fine sand	1,289.7
				1,295.3
1½-8	Yellow clay			1,287.9
12-21	Blue clay			1,283.9
4-4½	Clay	4½-7	Brown medium sand	1,297.4
2-9	Medium sand			1,304.0
3-4	Marl	4-8	Fine sand	1,308.2

No.	Location	Depth in feet	1st Material	Depth in feet	2nd Material
2-2	SW¼SW¼SW¼ Sec. 24, T. 129N., R. 60W.	0-7	Yellow clay	7-14	Gray-blue clay
3-2	NW¼NW¼NW¼ Sec. 30, T. 129N., R. 59W.	0-½	Black topsoil	½-4	Buff fine limey sand
4-2	NE¼NE¼NE¼ Sec. 30, T. 129N., R. 59W.	0-½	Black topsoil	½-8	Buff fine sand
5-2	NE¼NE¼NE¼ Sec. 29, T. 129N., R. 59W.	0-1	Black topsoil	1-2	Gray silt
6-2	NW¼NW¼NW¼ Sec. 27, T. 129N., R. 59W.	1-8	Yellow & gray clay	at 8	Water zone
7-2	SE¼SE¼SE¼ Sec. 22, T. 129N., R. 59W.	0-½	Blue clay	½-4½	Yellow silty clay
8-2	SE¼SE¼SE¼ Sec. 23, T. 129N., R. 59W.	0-1	Black topsoil	1-7	Buff fine sand
9-2	NW¼NW¼NW¼ Sec. 30, T. 129N., R. 58W.	0-2	Black topsoil	2-7	Buff medium sand
10-2	SW¼SW¼SW¼ Sec. 20, T.129N., R. 58W.	0-1	Black sandy topsoil	1-7	Buff medium sand
2-3	SW¼SW¼SW¼ Sec. 13, T. 129N., R. 59W.	0-2	Limey clay	2-5	Buff fine sand
3-3	SW¼SW¼SW¼ Sec. 18, T. 129N., R. 59W.	0-1	Black topsoil	1-2	Buff fine sand
5-3	NW¼NW¼NW¼ Sec. 21, T. 129N., R. 59W.	0-9	Yellow fine sand		
6-3	SE¼SE¼SE¼ Sec. 16, T. 129N., R. 59W.	0-½	Black sandy topsoil	½-2	Calcareous silt
8-3	SE¼SE¼SE¼ Sec. 14, T. 129N., R. 59W.	0-½	Black topsoil	½-6	Buff medium sand
9-3	NW¼NW¼NW¼ Sec. 19, T. 129N., R. 58W.	0-2	Limey cemented sand	2-4	Medium sand
10-3	SW¼SW¼SW¼ Sec. 17, T. 129N., R. 58W.	0-1½	Black topsoil	1½-3	Marl
2-4	SE¼SE¼SE¼ Sec. 11, T. 129N., R. 60W.	0-7	Medium sand		
3-4	NW¼NW¼NW¼ Sec. 18, T. 129N., R. 59W.	0-1	Black topsoil	1-3	Buff fine sand
4-4	SW¼SW¼SW¼ Sec. 8, T. 129N., R. 59W.	0-½	Black topsoil	½-7½	Fine sand
5-4	SW¼SW¼SW¼ Sec. 9, T. 129N., R. 59W.	0-½	Black topsoil	½-5½	Buff fine sand
6-4	SE¼SE¼SE¼ Sec 9, T. 129N., R. 59W.	0-1½	Black sandy topsoil	1½-4	Gray fine sand
8-4	SE¼SE¼SE¼ Sec 11, T. 129N., R. 59W.	0-½	Black topsoil	½-3	Buff medium sand
9-4	NW¼NW¼NW¼ Sec. 18, T. 129N., R. 58W.	0-1½	Black topsoil	1½-7	Fine limey sand
10-4	SW¼SW¼SW¼ Sec 8, T. 129N., R. 58W.	0-1	Black topsoil	1-3	Gray sand & clay

Depth in feet	3rd Material	Depth in feet	4th Material	Water level, summer-1941
				1,288.6
				1,287.1
				1,296.4
2-8	Buff fine sand			1,298.0
8-19	Gray clay			1,286.4
				1,290.9
				1,302.6
				1,303.2
				1,307.9
5-8½	Gray clay			1,289.4
2-4	Orange medium sand			1,290.0
				1,292.4
2-6	Brown medium sand			1,295.0
				1,302.5
				1,304.2
3-8	Buff fine sand			1,307.1
				1,294.5
3-4½	Buff medium sand			1,291.2
				1,294.3
				1,297.4
4-6	Calcareous clay	6-8	Brown medium sand	1,296.7
3-3½	Cemented sand	3½-4½	Brown medium sand	1,302.1
7-8	Cemented sand	8-10	Gray clay	1,304.9
3-5	Buff fine sand	5-7	Brown coarse sand	1,306.4

No.	Location	Depth in feet	1st Material	Depth in feet	2nd Material
3-5	NE¼NE¼NE¼ Sec. 12, T. 129N., R. 60W.	0-½	Black topsoil	½-8	Buff fine sand
4-5	NW¼NW¼NW¼ Sec. 8, T. 129N., R. 59W.	0-1½	Black topsoil	1½-2½	Buff fine sand
5-5	SW¼SW¼SW¼ Sec. 4, T. 129N., R. 59W.	0-4	Fine sand		
6-5	SW¼SW¼SW¼ Sec. 3, T. 129N., R. 59W.	0-1½	Gray clay		
7-5	NE¼NE¼NE¼ Sec. 10, T. 129N., R. 59W.	0-1	Black topsoil	1-5	Tan fine sand
8-5	NW¼NW¼NW¼ Sec. 12, T. 129N., R. 59 W.	0-1½	Gray limey sand		
9-5	NW¼NW¼NW¼ Sec. 7, T. 129N., R. 58W.	0-3½	Gray fine sand		
10-5	SE¼SE¼SE¼ Sec. 6, T. 129N., R. 58W.	0-½	Black topsoil	½-6	Coarse limey sand
3-6	SW¼SW¼SW¼ Sec. 31, T. 130N., R. 59W.	0-½	Black topsoil	½-2	Gray clay
4-6	NW¼NW¼NW¼ Sec. 5, T. 129N., R. 59W.	0-1	Black topsoil	1-4	Buff fine sand
5-6	SE¼SE¼SE¼ Sec. 32, T. 130N., R. 59W.	0-2	Black topsoil	2-5	Brown medium sand
6-6	SE¼SE¼SE¼ Sec. 33, T. 130N., R. 59W.	0-1½	Black topsoil	1½-7	Tan medium sand
8-6	SW¼SW¼SW¼ Sec. 36, T. 130N., R. 59W.	0-1½	Black topsoil	1½-4	Tan medium sand
10-6	NW¼NW¼NW¼ Sec. 5, T. 129N., R. 58W.	0-1	Black topsoil	1-3	Tan medium sand
3-7	SW¼SW¼SW¼ Sec. 30, T. 130N., R. 59W.	0-½	Black topsoil	½-1	Limey clay
4-7	SW¼SW¼SW¼ Sec. 29, T. 130N., R. 59W.	0-1	Black topsoil	1-2	Gray silt
5-7	SW¼SW¼SW¼ Sec. 28, T. 130N., R. 59W.	0-1½	Fine limey sand	1½-3	Limey clay
6-7	NE¼NE¼NE¼ Sec. 33, T. 130N., R. 59W.	0-½	Black sandy topsoil	½-1	Tan fine sand
7-7	NE¼NE¼NE¼ Sec. 34, T. 130N., R. 59W.	0-1	Black topsoil	1-5	Find sand
8-7	SW¼SW¼SW¼ Sec. 25, T. 130N., R. 59W.	0-1	Black limey topsoil	1-5	Brown fine limey sand
9-7	SW¼SW¼SW¼ Sec. 30, T. 130N., R. 58W.	0-1	Black topsoil	1-5	Brown medium sand
10-7	SW¼SW¼SW¼ Sec. 29, T. 130N., R. 58W.	0-1	Black limey topsoil	1-4	Brown medium limey sand

Depth in feet	3rd Material	Depth in feet	4th Material	Water level, summer, 1941
				1,288.9
2½-3½	Gray clay	3½-9	Buff medium sand	1,296.8
				1,297.6
				1,298.9
				1,301.2
				1,304.7
				1,307.5
				1,307.8
2-7	Buff fine sand			1,284.5
4-7	Brown medium sand			1,294.5
				1,297.8
				1,300.3
				1,304.9
				1,308.8
1-3	Brown limey sand			1,286.6
2-3½	White limey silt	3½-11	Brown fine sand	1,295.5
3-5	Brown medium sand			1,297.8
1-5	Brown medium sand	5-8	Blue-gray fine sand	1,301.0
5-9	Black-brown sand			1,303.5
5-8	Yellow clay	8-9	Black sand	1,305.6
				1,309.6

No.	Location	Depth in feet	1st Material	Depth in feet	2nd Material
4-8	SW¼SW¼SW¼ Sec. 20, T. 130N., R. 59W.	0-1	Marl	1-2½	Buff clay
5-8	NW¼NW¼NW¼ Sec. 28, T. 130N., R. 59W.	0-1	Black topsoil	1-7	White clay
6-8	NE¼NE¼NE¼ Sec. 28, T. 130N., R. 59W.	0-½	Black sandy topsoil	½-3	White medium sand
7-8	SW¼SW¼SW¼ Sec. 23, T. 130N., R. 59W.	0-½	Black topsoil	½-3	Tan medium sand
8-8	SW¼SW¼SW¼ Sec. 24, T. 130N., R. 59W.	0-½	Black topsoil	½-5	Tan fine sand
9-8	NE¼NE¼NE¼ Sec. 25, T. 130N., R. 59W.	0-½	Black sandy topsoil	½-1½	Tan fine sand
10-8	NW¼NW¼NW¼ Sec. 29, T. 130N., R. 58W.	0-½	Sandy topsoil	½-6	Brown medium sand
3-8.5	SW¼SW¼NW¼ Sec. 19, T. 130N., R. 59W.	0-½	Black topsoil	½-5	Yellow clay
2.6-9	SE¼SW¼SE¼ Sec. 13, T. 130N., R. 60W.	0-5	Yellow clay		
3-9	NW¼NW¼NW¼ Sec. 19, T. 130N., R. 59W.	0-5½	Brown clay	5½-7	Clayey sand
4-9	SW¼SW¼SW¼ Sec. 17, T. 130N., R. 59W.	0-½	Black topsoil	½-6	Tan fine sand
5-9	SW¼SW¼SW¼ Sec. 16, T. 130N., R. 59W.	0-1	Black topsoil	1-3½	Brown clay
6-9	NW¼NW¼NW¼ Sec. 22, T. 130N., R. 59W.	0-½	Black topsoil	½-2	Limey sand
7-9	SE¼SE¼SE¼ Sec. 15, T. 130N., R. 59W.	0-½	Black topsoil	½-1½	Tan sand
8-9	SE¼SE¼SE¼ Sec. 14, T. 130N., R. 59W.	0-2	Black topsoil	2-6	Tan medium sand
9-9	SE¼SE¼SE¼ Sec. 13, T. 130N., R. 59W.	0-½	Black limey topsoil	½-1	Brown medium limey sand
10-9	SW¼SW¼SW¼ Sec. 17, T. 130N., R. 58W.	0-½	Brown sandy topsoil	½-3	Tan ferruginous clay
11-9	NW¼NW¼NW¼ Sec. 21, T. 129N., R. 58W.	0-1	Black topsoil	1-6	Fine sand
3-10	NE¼NE¼NE¼ Sec. 13, T. 130N., R. 60W.	0-1½	Black topsoil	1½-6	Coarse sand with cobbles
4-10	SE¼SE¼SE¼ Sec. 7, T. 130N., R. 59W.	0-2½	Black topsoil	2½-5	Sand
5-10	SE¼SE¼SE¼ Sec. 8, T. 130N., R. 59W.	0-½	Black topsoil	½-7½	Brown coarse sand
6-10	NW¼NW¼NW¼ Sec. 15, T. 130N., R. 59W.	0-1	Black topsoil	1-2	Marl
7-10	SW¼SW¼SW¼ Sec. 11, T. 130N., R. 59W.	0-1	Black topsoil	1-3	Marl

Depth in feet	3rd Material	Depth in feet	4th Material	Water level, summer-1941
2½-7½	Yellow and gray sand	7½-9	Blue clay	1,290.7
7-8	Gray clay	8-9	Black sand	1,298.7
3-6	Brown medium sand	6-7	Gray sand	1,301.9
3-6	Yellow medium sand	6-8	Gray sand	1,303.7
5-7	Gray fine sand			1,305.7
1½-6	Tan medium sand			1,307.7
6-7	Black medium sand			1,310.0
5-14	Coarse pebbly sand	14-15	Pebbly blue clay	1,292.0
				1,289.0
7-10	Sandy clay with cobbles			Below 1,295.5
6-7	Gray fine sand			1,289.8
3½-10	Brown sand			1,301.0
2-8	Brown sand	8-10	Brown & black sand	1,302.5
1½-2½	Limey sand	2½-7½	Brown sand	1,303.6
				1,304.6
1-5	Brown medium sand			1,305.7
3-8	Blue clay	8-	Gray shaly sand	1,308.1
6-15	Coarse pebbly sand			1,309.6
5-8½	Limonite streaked clay	8½-21½	Blue clay	
				1,301.9
2-6	Brown medium sand	6-7	Black peaty sand	1,302.7
3-5	White silt	5-8	Gray shaly sand	1,303.0

No.	Location	Depth in feet	1st Material	Depth in feet	2nd Material
8-10	SE¼SE¼SE¼ Sec. 11, T. 130N., R. 59W.	0-1½	Black topsoil	1½-3	Limey sand
9-10	NE¼NE¼NE¼ Sec. 13, T. 130N., R. 59W.	0-1	Black limey topsoil	1-3½	Tan medium sand
10-10	NE¼NE¼NE¼ Sec. 18, T. 130N., R. 58W.	0-2	Black topsoil and marl	2-7	Yellow limey clay
4-11	SW¼SW¼SW¼ Sec. 5, T. 130N., R. 59W.	0-2	Black topsoil	2-4	Fine limey sand
5-11	SW¼SW¼SW¼ Sec. 4, T. 130N., R 59W.	0-1	Black topsoil	1- 5	Brown sand
6-11	SE¼SE¼SE¼ Sec. 4, T. 130N., R. 59W.	0-1	Black topsoil	1-2½	Yellow clay
7-11	NW¼NW¼NW¼ Sec. 11, T. 130N., R. 59W.	0-½	Black topsoil	½-2	Sandy clay
8-11	NE¼NE¼NE¼ Sec. 11, T. 130N., R. 59W.	0-½	Black topsoil	½-2	Gray limey clay
9-11	SE¼SE¼SE¼ Sec. 1, T. 130N., R. 59W.	0-1	Black topsoil	1-5	Gray limey clay
10-11	NE¼NE¼NE¼ Sec. 7, T. 130N., R. 58W.	0-1½	Black topsoil	1½-17½	Marl & yellow clay
4-12	SW¼SW¼SW¼ Sec. 32, T. 131N., R. 59W.	0-8	Blue clay	8-9	Clayey sand
5-12	NE¼NE¼NE¼ Sec. 5, T. 130N., R. 59W.	0-½	Black topsoil	½-1	Marl
6-12	SW¼SW¼SW¼ Sec. 34, T. 131N., R. 59W.	0-½	Black topsoil	½-2½	Gray fine sand
7-12	NE¼NE¼NE¼ Sec. 3, T. 130N., R. 59W.	0-1½	Black topsoil	1½-8	Buff fine sand
8-12	NW¼NW¼NW¼ Sec. 1, T. 130N., R. 59W.	0-½	Black limey topsoil	½-6	Brown clay
9-12	SE¼SE¼SE¼ Sec. 36, T. 131N., R. 59W.	0-1	Black & white limey topsoil	1-5	Yellow clay
10-12	SE¼SE¼SE¼ Sec. 31, T. 131N., R. 58W.	0-9	Yellow clay	9-19	Pebbles & cobbles in blue clay
7.9-12.4	NE¼SE¼ Sec. 35, T. 131N., R. 59W.	0-7	Sandy clay	7-9	Sand
4-13	SW¼SW¼SW¼ Sec. 29, T. 131N., R. 59W.	0-11½	Blue & gray clay	11½-12	Sand
6-13	NE¼NE¼NE¼ Sec. 33, T. 131N., R. 59W.	0-1	Sandy black top-soil	1-6	Clay
7-13	NE¼NE¼NE¼ Sec. 34, T. 131N., R. 59W.	0-1	Black topsoil	1-6	Brown medium sand
4-14	NW¼NW¼NW¼ Sec. 29, T. 131N., R. 59W.	0-1	Black topsoil	1-2	Silty clay
6-14	NE¼NE¼NE¼ Sec. 28, T. 131N., R. 59W.	0-1	Black topsoil	1-3	Gray clay
7-14	NE¼NE¼NE¼ Sec. 27, T. 131N., R. 59W.	0-½	Black topsoil	½-33	Calcareous gravelly sand

Depth in feet	3rd Material	Depth in feet	4th Material	Water level, summer, 1941
3-5	Brown medium sand			1,303.9
3½-7	Greenish-gray fine sand			1,304.3
7-17	Limey clay	17-18	Gray medium sand	1,308.0
4-7	Gray limey sand			1,288.5
5-7	Brown medium sand	7-10	Black peaty sand	1,301.7
2½-5	Brown medium sand	5-7	Black peaty sand	1,302.3
2-5	Clay	5-9	Gray, red medium sand	1,302.8
2-3½	Tan limey sand	3½-4½	Red & gray sand	1,303.0
5-6	Limey sand	6-9	Brown, red medium sand	1,303.7
17½-26½	Blue clay	26½-28	Blue clay & cobbles	1,297.6
9-11	Brown sand	11-11.8	Blue clay	1,286.4
1-5	Yellow clay	5-11	Blue clay	1,300.4
2½-3	Marl	3-9	Yellow clay	1,300.8
8-13	Medium sand			1,303.5
6-7	Brown-gray medium sand			1,303.4
5-8	Yellow clayey sand	8-11	Yellow & blue clay	Below 1,296
				Below 1,284
9-12	Hard clay	12-15	Sand	
				1,284.0
6-7	Sandy clay	7-8	Brown sand	1,302.5
				1,302.9
2-3	Buff fine sand	3-5	Medium sand	1,286.9
3-10	Buff medium sand			1,303.4
				1,308.8

No.	Location	Depth in feet	1st Material	Depth in feet	2nd Material
4.5-14.8	SE¼NE¼NW¼ Sec. 20, T.131N., R.59W.	0-½	Black topsoil	½-4½	Limey white clay
4.5-14.9	NE¼NW¼ Sec. 20, T. 131N., R.59W.	0-1	Black topsoil	1-2½	White clay
4.7-15	NE¼NW¼NE¼ Sec. 20, T. 131N., R.59W.	0-½	Black topsoil	½-13	Yellow sand
5-15	SW¼SW¼SW¼ Sec. 16, T. 131N., R.59W.	0-28	Sand & gravel		
5-16	SW¼SW¼SW¼ Sec. 9, T. 131N., R.59W.	0-27	Coarse sand and gravel		
6-16	SE¼SE¼SE¼ Sec. 9, T. 131N., R.59W.	0-8	White gravelly sand	8-28	Brown sand and gravel
5.2-17	NE¼NW¼NW¼ Sec. 9, T. 131N., R.59W.	0-2	Black topsoil	2-3	Sandy loam

Depth in feet	3rd Material	Depth in feet	4th Material	Water level, summer, 1941
4½-16	Gray & yellow sand	16-19	Blue clay	
2½-14	Brown clay	14-22	Blue clay	
13-16	Sand & gravel			
				1,301.9
				1,308.0
				1,316.1
3-8	Pebbly medium sand	8-9	Blue clay	1,295.4

TABLE VI

LOGS OF TEST HOLES

Test hole 4.4-14.6 Surface elevation 1,301 feet	Thickness (feet)	Depth (feet)
Lake Dakota sediments		
Topsoil	3	3
Brown sand	27	30
Gray sand	10	40
Gray sand mixed with blue clay	10	50
Glacial till		
Clay	5	55
Coarse gravel, rocks	1	56
Boulder blue clay	10	66

Test hole 6-13
Surface elevation 1,312 feet

Lake Dakota sediments		
Topsoil	1	1
Yellow sand	10	11
Coarse yellow sand mixed with shale pebbles	14	25
Lignite	2	27
Sand	27	54
Gravel and cobbles	1	55
Gray sand	26	81
Sandy silt	4	85
Glacial till		
Hardpan or gravel	1	86
Blue clay	5	91
Gravel	5	96
Soft clay	10	106

Test hole 6-11
Surface elevation 1,310 feet

Lake Dakota sediments		
Black topsoil	½	½
Brown silt	3½	4
Brown sand	4	8
Gray sand, shale grains	2	10
Gray fine sand	3½	13½
Gray coarse sand	1½	15
Gray sand	12	27
Blue silt	35	62
Sand	26	88
Glacial till		
Clay	3	91

Test hole 6-9 Surface elevation 1,313 feet	Thickness (feet)	Depth (feet)
Lake Dakota sediments		
Topsoil	½	½
Yellow sand	45½	46
Sandy silt	14	60
Glacial till		
Clay	10	70

Test hole 6-7
Surface elevation 1,305 feet

Lake Dakota sediments		
Topsoil	1½	1½
Sand, yellow	28	29½
Lignite	½	30
Sand	10	40
Sandy silt	36	76
Glacial till		
Rocks and clay	1	77
Clay	5	82

Test hole 6-5

Lake Dakota sediments		
Sandy topsoil	1	1
Yellow sand	4	5
Gray sand	45	49
Sand and silt streaked	10	59
Glacial till		
Blue clay	22	81

Test hole 6-3
Surface elevation 1,301 feet

Lake Dakota sediments		
Topsoil	2	2
Yellow sand	12	14
Gray sand, trace of lignite	35	49
Sandy silt	18	67
Glacial till		
Clay	10	77

Test hole 6-1 Surface elevation 1,296 feet	Thickness (feet)	Depth (feet)
Lake Dakota sediments		
Topsoil	2½	2½
Yellow silt	12½	15
Silt, thin streaks of sand	37	52
Glacial till		
Blue clay	29	81

Test hole 4-9
Surface elevation 1,298 feet

Lake Dakota sediments		
Topsoil	6	6
Yellow silt and clay	3	9
Fine yellow sand	12	21
Very fine gray sand	15	36
Glacial till		
Gray clay	32	68
Gravel	2	70
Rocks	1	71

Test hole 8-9
Surface elevation 1,314 feet

Lake Dakota sediments		
Sand	72	72
Glacial till		
Clay	10	82

Test hole 10-9
Surface elevation 1,311 feet

Lake Dakota sediments		
Topsoil	2	2
White sand	5	7
Dark brown sand	3	10
Gray sand	17	27
Dark gray sand, with streaks of silt	25	52
Gray brown sand with streaks of sand	17	76
Glacial till		
Firm clay	2	78
Soft clay and rocks	10	88

Test hole 3-3 Surface elevation 1,296 feet	Thickness (feet)	Depth (feet)
Lake Dakota sediments		
Topsoil	1½	1½
Sandy silt	2½	4
Yellow sand	7	11
Gray sand	7	18
Sandy silt	17	35
Silt streaked with sand	11	46
Gravel (coarse sand)	1	47
Clacial till		
Clay	7	54
Rocks	1	55
Clay	10	65

TABLE VII

Analyses of water from wells in Dickey County N.Dak.
(Well numbers correspond to numbers in table 9)
Analyzed by G. J. Petretic, except No. 47, analyzed by H. B. Riffenburg,
Geological Survey, United States Department of the Interior

Parts per million

Well No.............	3.2-5	5-10.7	6-2.3	5.1-8	5.5-14	9.4-9	47
Date of collection..	10-2-40	10-2-40	10-2-40	10-2-40	10-3-40	10-3-40	6-19-21
Silica (SiO_2)	15	24	28	14	28	31	32
Iron (Fe)	8.3	4.7	1.2	.30	.58	3.1	.24
Calcium (Ca)	140	146	96	114	74	84	115
Magnesium (Mg)	48	61	30	45	22	25	38
Sodium (Na)	39	47	107	24	18	9.6	(74
Potassium (K)	8.4	5.4	9.5	3.8	4.4	3.4	(
Bicarbonate (HCO_3)	430	553	536	444	322	366	364
Sulfate (SO_4)	273	182	85	45	36	22	184
Chloride (Cl)	5	38	52	14	8	10	80
Fluoride (F)	.4	.0	.2	.4	.1	.0	--
Nitrate (NO_3)	.05	30	2.0	112	.6	.38	6.7
Dissolved solids	798	826	674	623	347	364	723
Total hardness as $CaCO_3$	547	615	363	470	275	312	443

Equivalents per million

Calcium (Ca)	6.99	7.29	4.79	5.69	3.69	4.19	5.74
Magnesium (Mg)	3.95	5.02	2.47	3.70	1.81	2.06	3.12
Sodium (Na)	1.70	2.04	4.65	1.04	.78	.42	(3.22
Potassium (K)	.21	.14	.24	.10	.11	.09	(
Bicarbonate (HCO_3)	7.05	9.06	8.79	7.28	5.28	6.00	5.97
Sulfate(SO_4)	5.68	3.79	1.77	.94	.75	.46	3.83
Chloride (Cl)	.14	1.07	1.47	.39	.23	.28	2.26
Fluoride (F)	.02	.00	.01	.02	.01	.00	--
Nitrate (NO_3)	.00	.48	.03	1.81	.01	.01	.11

TABLE VIII

Physical properties of deposits of the
Lake Dakota Basin, near Oakes, North Dakota

Collected by W. C. Rasmussen
(Analyzed by V. C. Fishel)

Test hole No.	Lab. No.	Depth (ft.)	Mechanical analysis (size in milli-meters--percent by weight) 1.0	1.0-0.50	0.50-0.25	0.25-0.125	0.125-0.062	0.062	Apparent specific gravity	Porosity (%)	Moisture equivalent by volume (%)	Coefficient of permeability gpd/ft2	Description
6-11	2470	8-10	3.4	17.4	37.4	27.1	7.5	6.5	1.38	44.4	16.8	15	
6-11	2471	10-12	15.3	12.0	29.8	29.6	6.8	5.3	1.07	49.0	34.8	20	
6-11	2472	12-17	1.4	9.8	37.9	46.8	3.2	0.4	1.45	43.2	7.5	300	
6-11	2473	17-22	1.0	9.3	39.1	46.9	2.6	0.6	1.48	42.7	6.5	330	
6-11	2474	22-27	0.6	9.4	35.9	50.0	2.7	0.4	1.48	43.2	6.3	320	
6-11	2475	27-62	3.1	5.4	13.0	13.2	14.6	49.9	1.36	45.1	31.0	1	
6-11	2476	62-65		0.8	9.9	47.0	26.3	15.2	1.45	21.3	9.6	25	
6-11	2477	65-70		0.5	19.7	56.4	14.8	8.0	1.47	44.2	6.8	55	
6-11	2478	70-75		1.0	21.9	50.0	15.0	11.4	1.39	46.3	12.5	30	
6-11	2479	75-80		0.9	35.3	40.6	14.0	8.3	1.46	44.2	8.4	55	
6-11	2480	85-91		1.6	19.8	54.4	14.4	9.0	1.42	41.9	15.3	35	
5-12	2481	11.5		0.6	5.8	6.4	29.3	56.7	1.36	47.5	22.7	3	Blue clay.
5-8	2482	9	5.8	29.3	35.5	22.0	3.2	2.7	1.17	50.1	25.5	40	Blk. peaty sand
6-12	2483	14.5-15	1.3	22.7	48.8	20.4	2.5	3.4	1.56	41.8	10.6	35	Coarse sand.
5-9	2484	9.5	0.2	14.8	55.1	19.7	7.4	2.3	1.44	43.7	11.4	100	Brown sand.
8-8	2485	6.5		0.2	5.1	60.7	28.1	5.3	1.44	45.5	4.8	160	Gray sand.
7-9	2486	7	0.5	16.2	63.1	16.5	1.4	0.6	1.52	42.9	4.2	590	Brown sand.

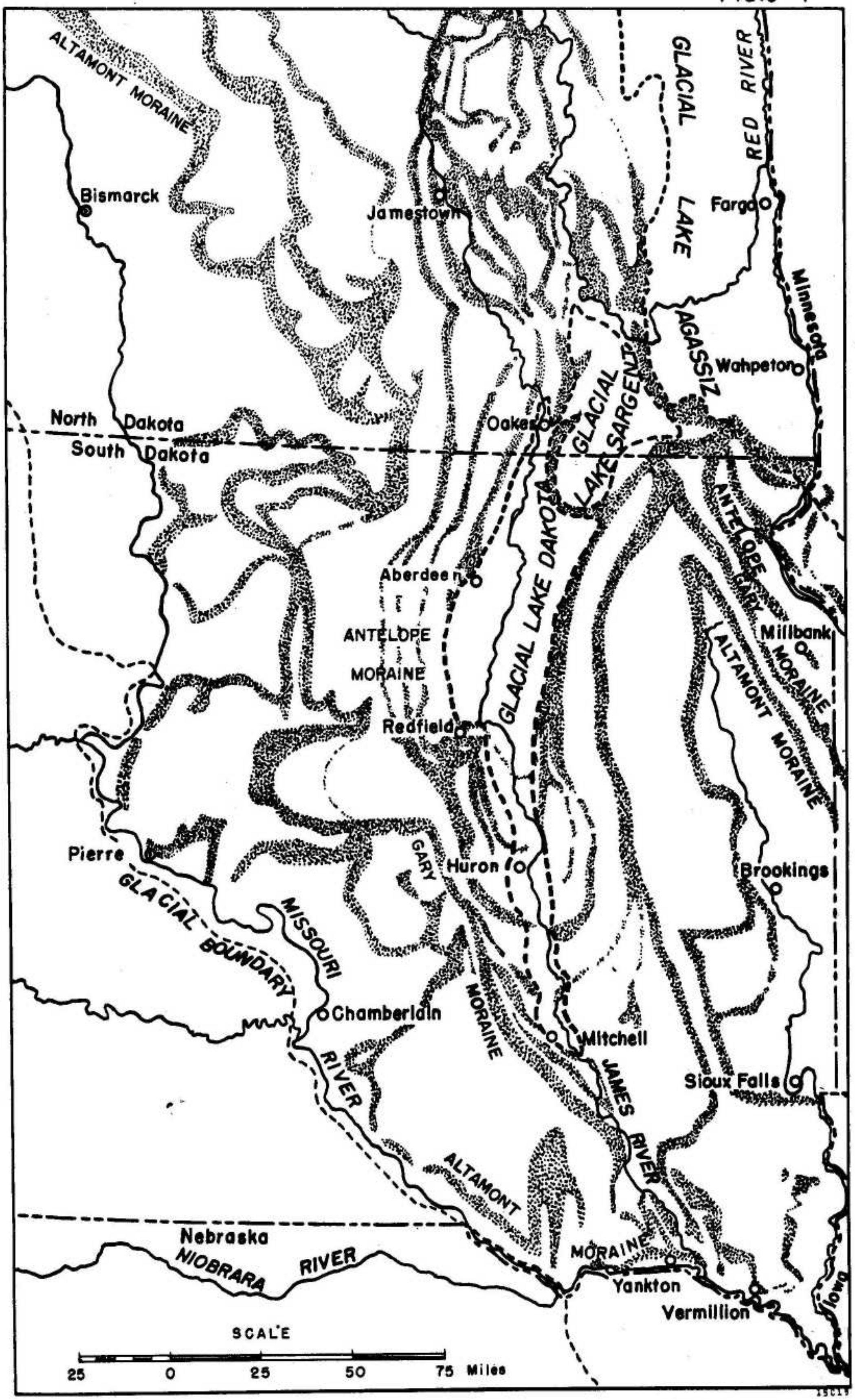
Location:

6-11 2470 to 2480 Oakes area: SE¼SE¼SE¼ Sec. 4, T. 130N., R.59W., in ditch at N. W. corner of intersection
5-12 2481 SW¼SW¼SW¼ Sec. 32, T. 131N., R.59W., at intersection by N. W. concrete culvert.
5-8 2482 SW¼SW¼SW¼ Sec. 21, T. 130N., R.60 W., in ditch at N.E. corner of intersection.
6-12 2483 SE¼SE¼SE¼ Sec. 33, T. 131N., R. 59W., in ditch at N.W. corner of intersection.
5-9 2484 SW¼SW¼SW¼ Sec. 16, T. 130N., R.59W., in ditch at N. side.
8-8 2485 NW¼NW¼NW¼ Sec. 25, T. 130N., R.59W., in ditch.
7-9 2486 SE¼SE¼SE¼ Sec. 15, T. 130N., R.59W., in ditch at N. W. corner.

15015

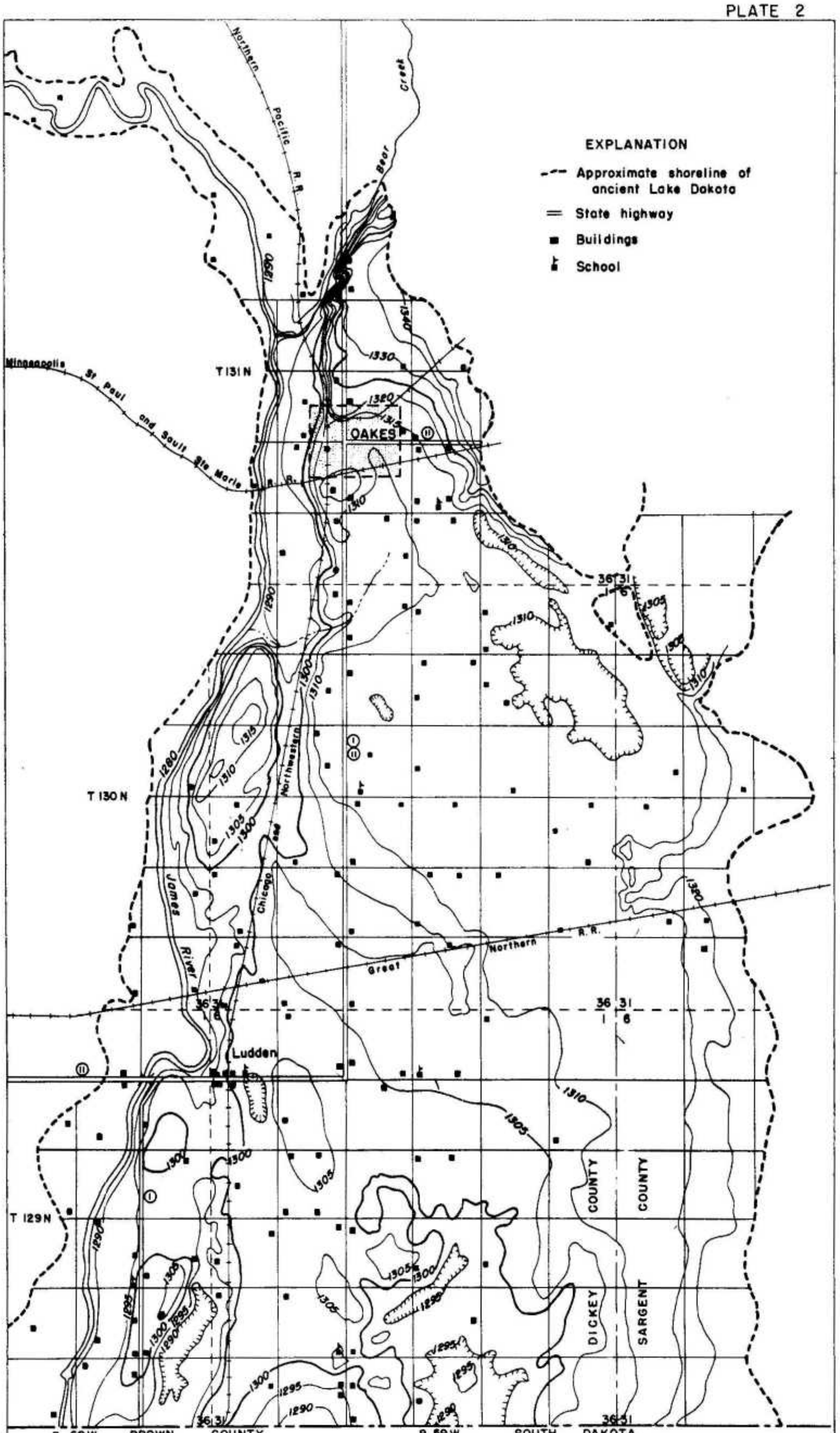
Figure 1 - Index map showing location of the Oakes area in North Dakota

Plate I



GLACIAL FEATURES OF THE REGION AND SHORELINES OF GLACIAL LAKE DAKOTA

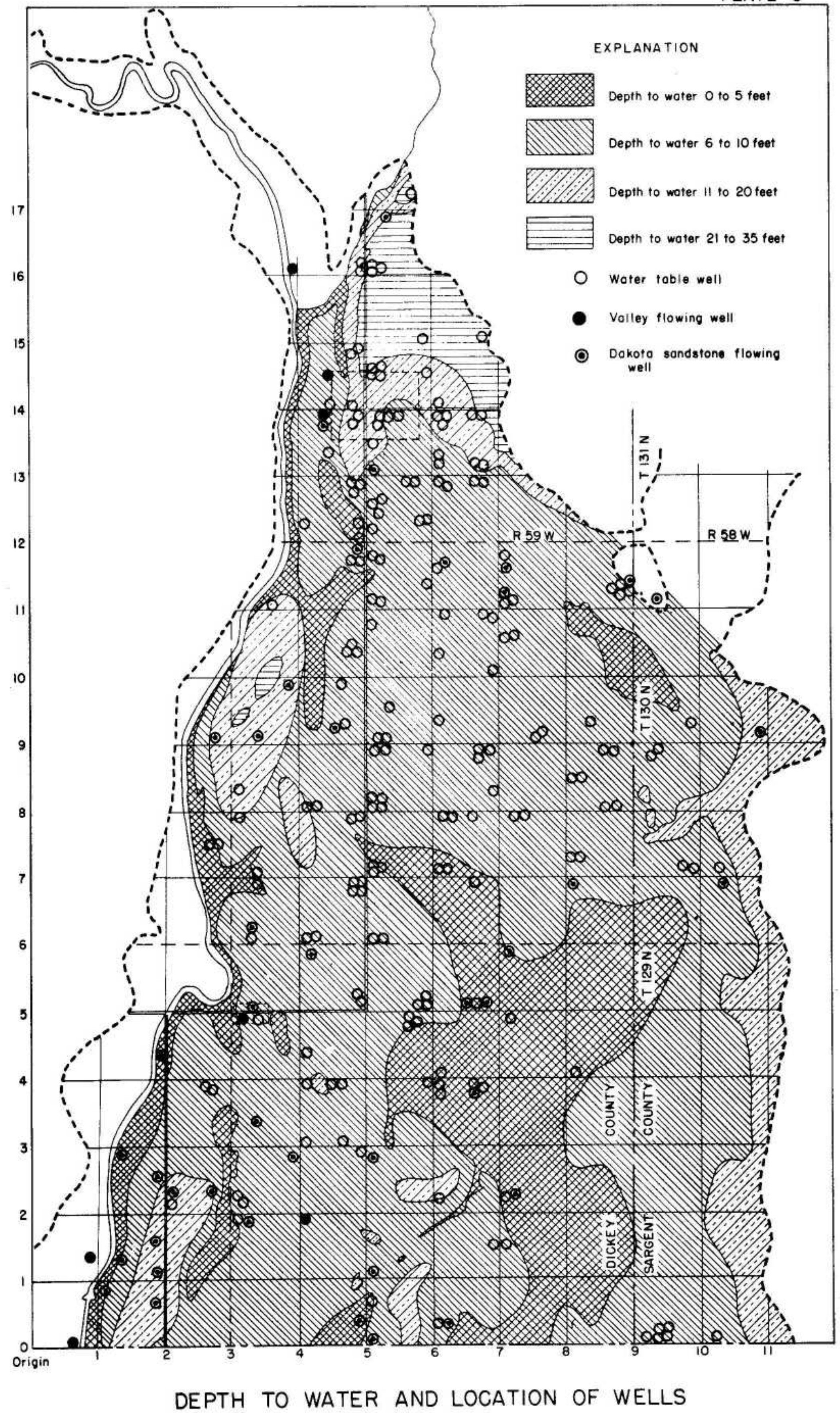
(Compiled from maps by J. E. Todd, Warren Upham, D. E. Willard and others).



TOPOGRAPHY OF OAKES AREA, NORTH DAKOTA

1 0 1 2 3 Miles

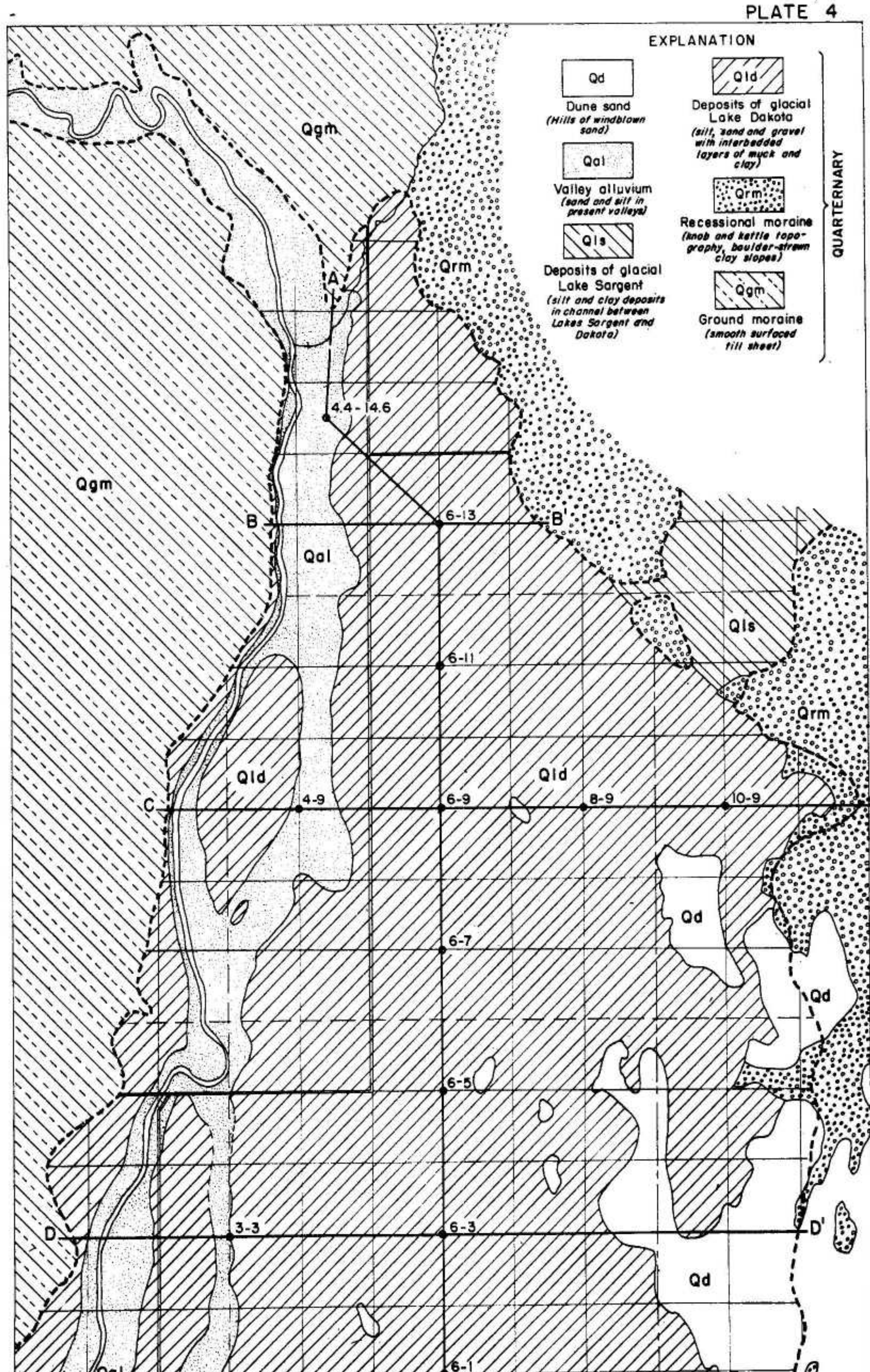
Contour interval 5 feet
Datum is mean sea level



DEPTH TO WATER AND LOCATION OF WELLS

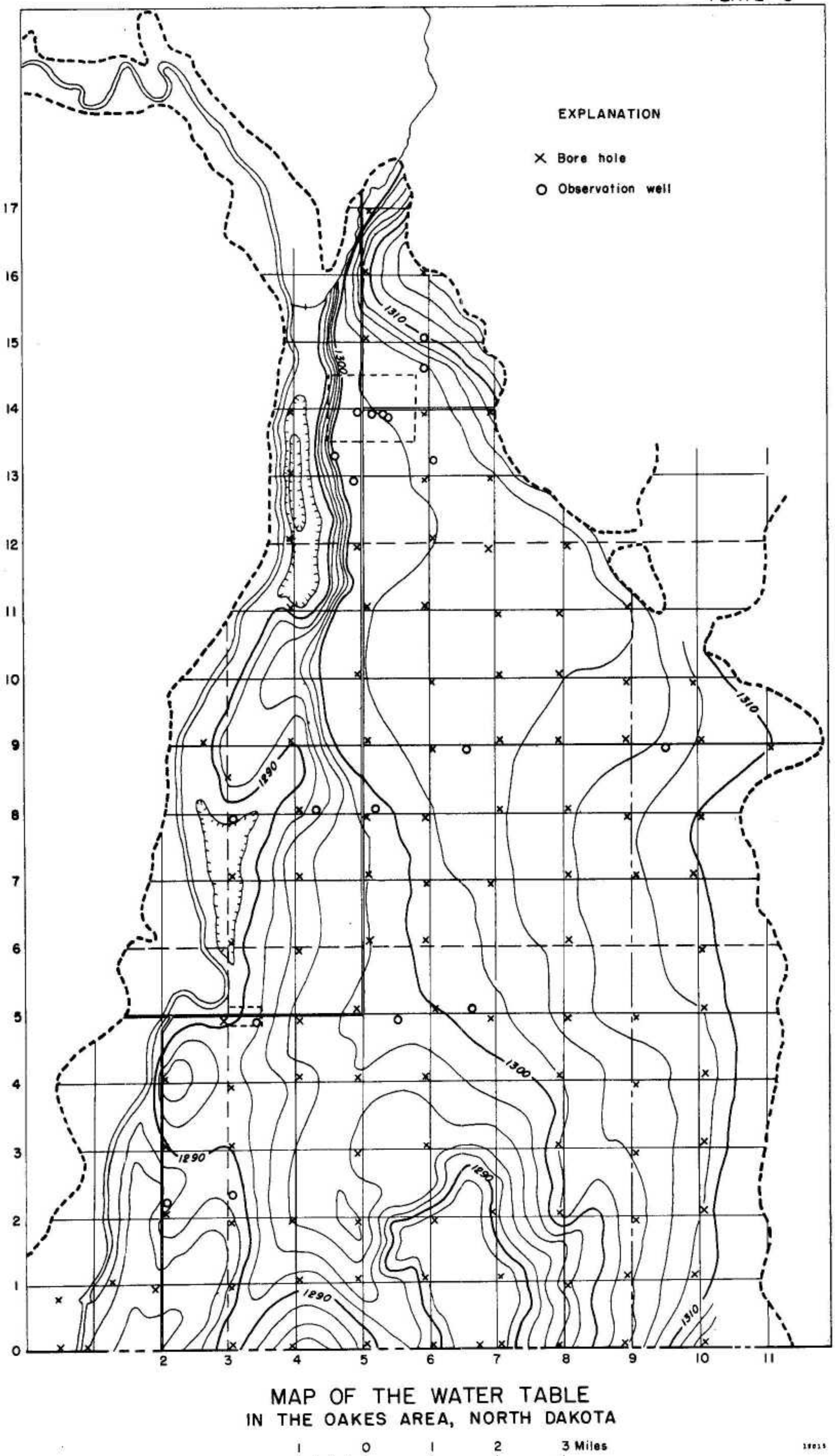
OAKES AREA, NORTH DAKOTA

1 0 1 2 3 Miles



GEOLOGIC MAP OF THE OAKES AREA, NORTH DAKOTA

PLATE 5



MAP OF THE WATER TABLE
IN THE OAKES AREA, NORTH DAKOTA

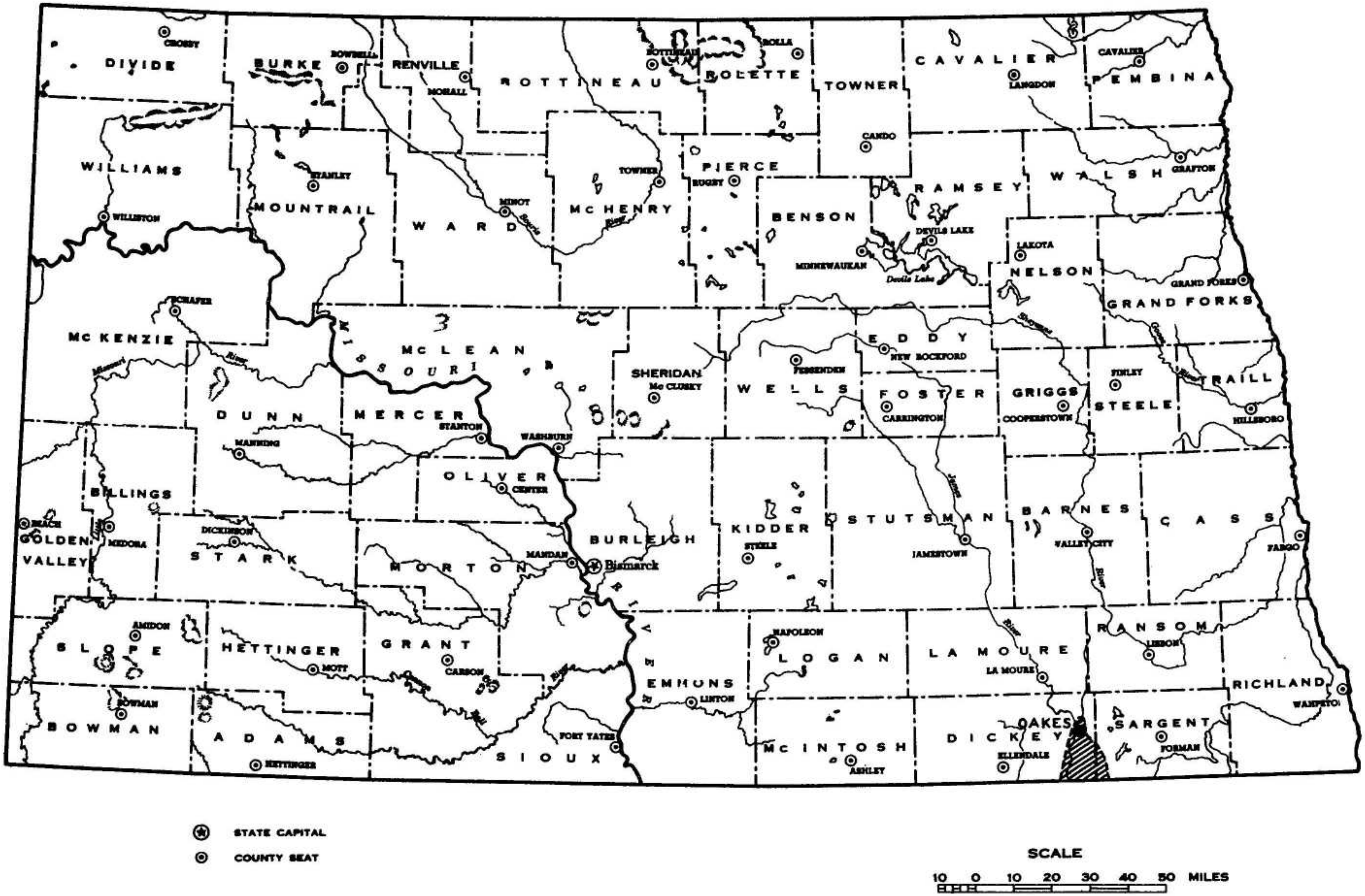


Figure 1 - Index map showing location of the Oakes area in North Dakota

15015

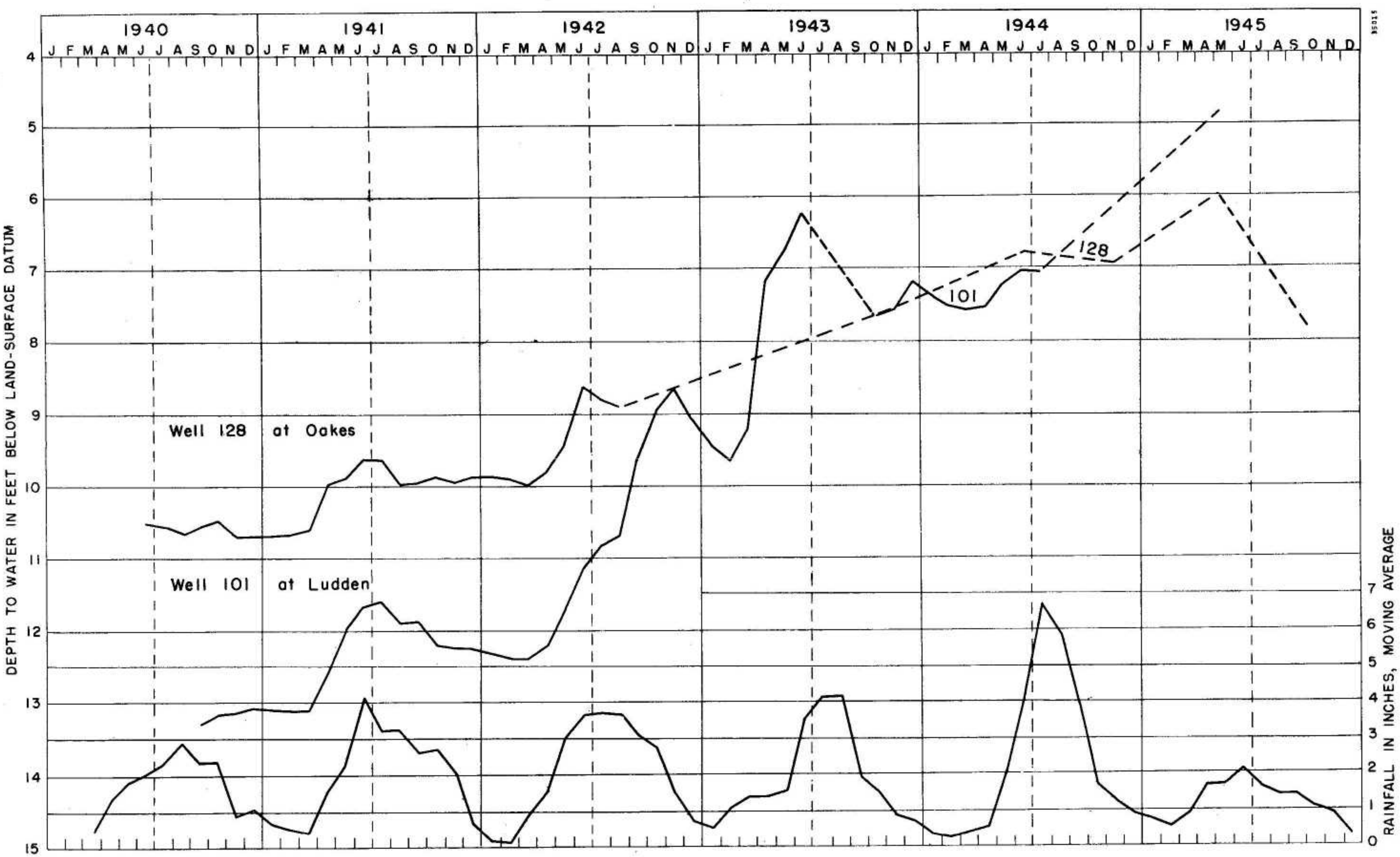


Figure 2 - Hydrographs of two wells in the basin and moving average monthly rainfall, 1940-45

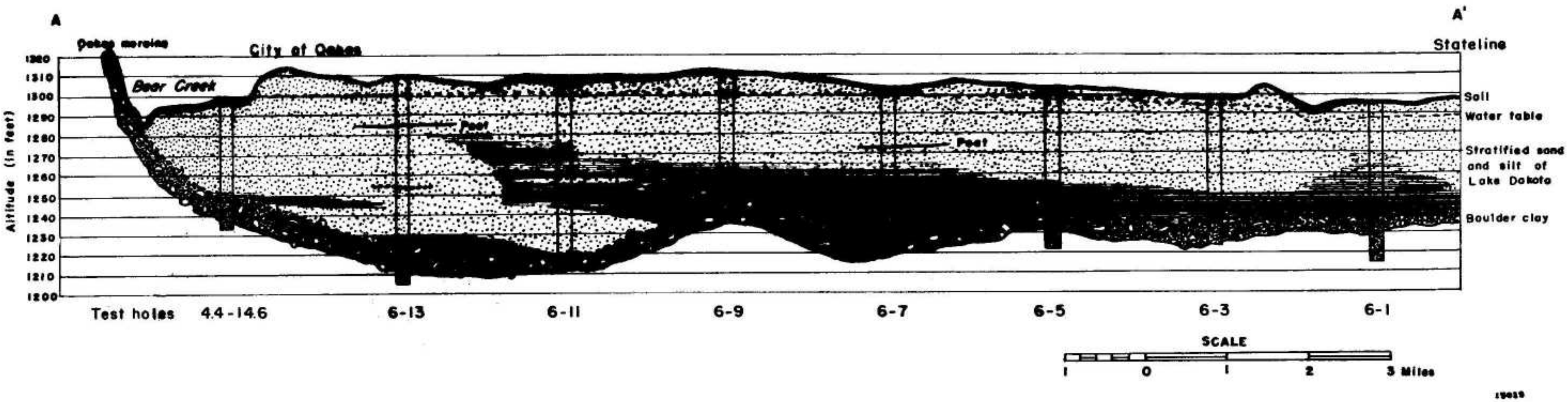


Figure 3 - North-south cross-section, A-A', along the Lake Dakota basin, North Dakota

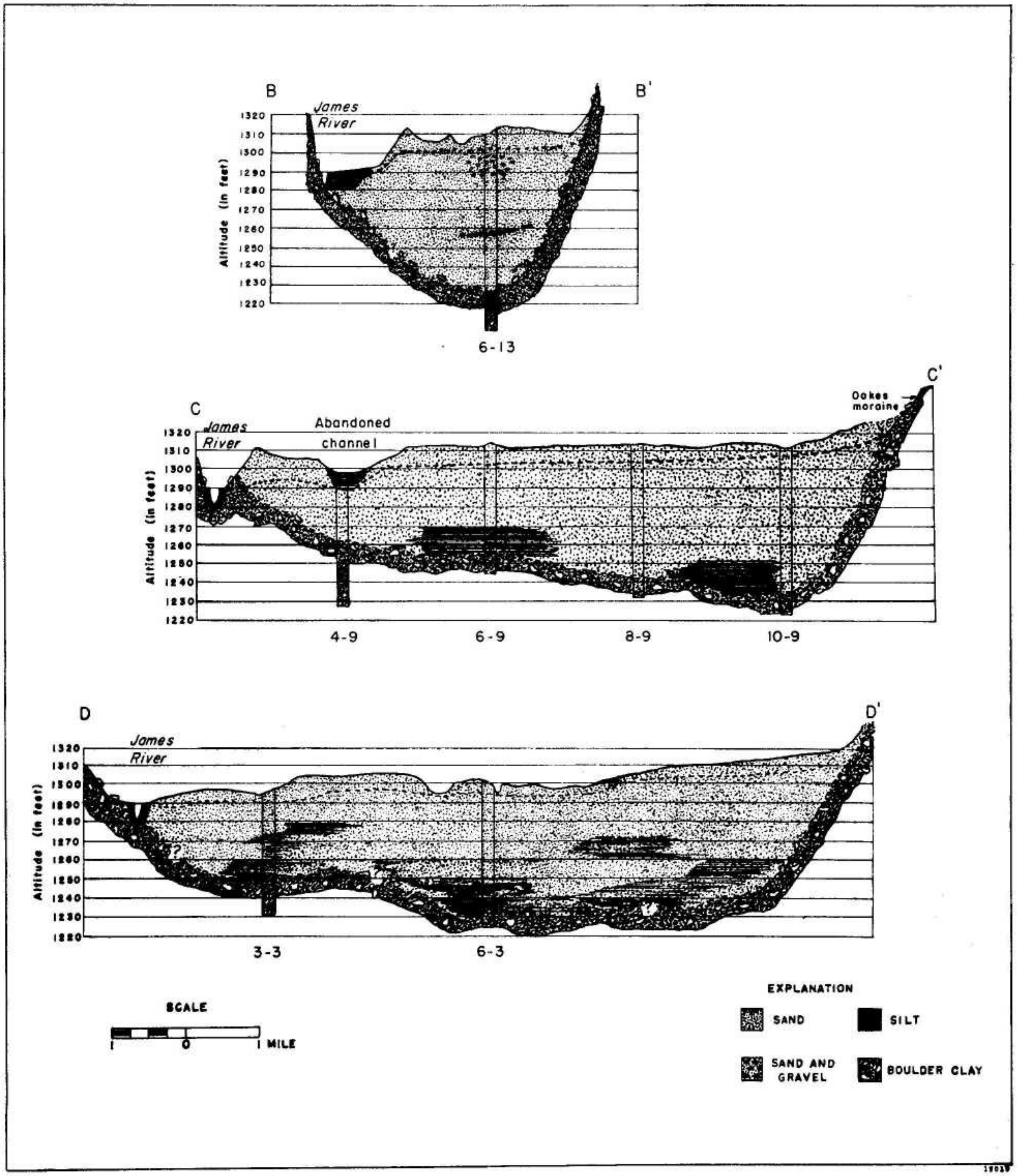


Figure 4 - East-west cross-sections B-B', C-C', and D-D' across the Lake Dakota basin, North Dakota

Figure 5

Semi-log time-drawdown graph for test of Dickey well 107, Aug. 30, 1940

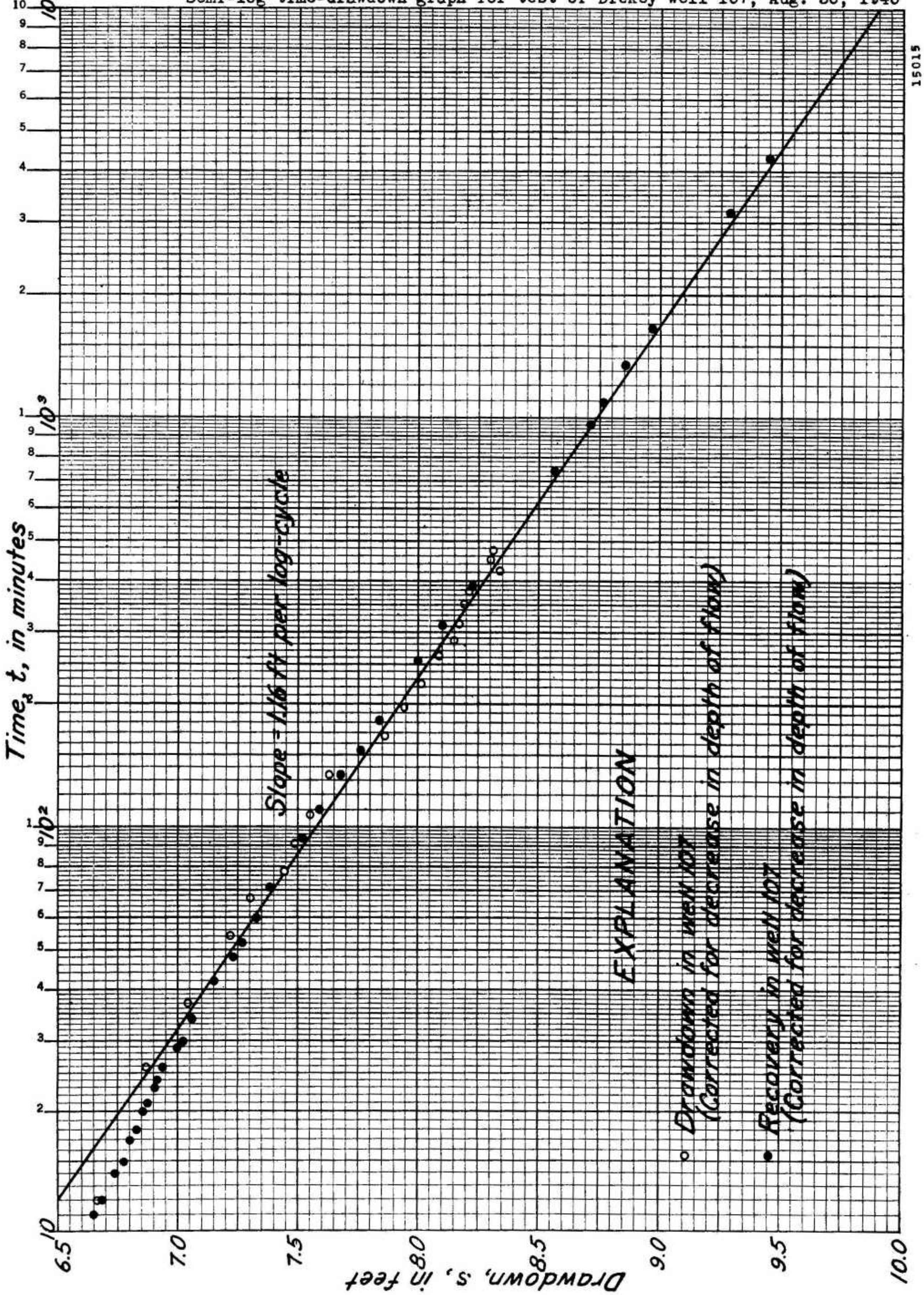


Figure 6

Semi-log time-drawdown graph for test of Dickey well 108, Oct. 7, 1940

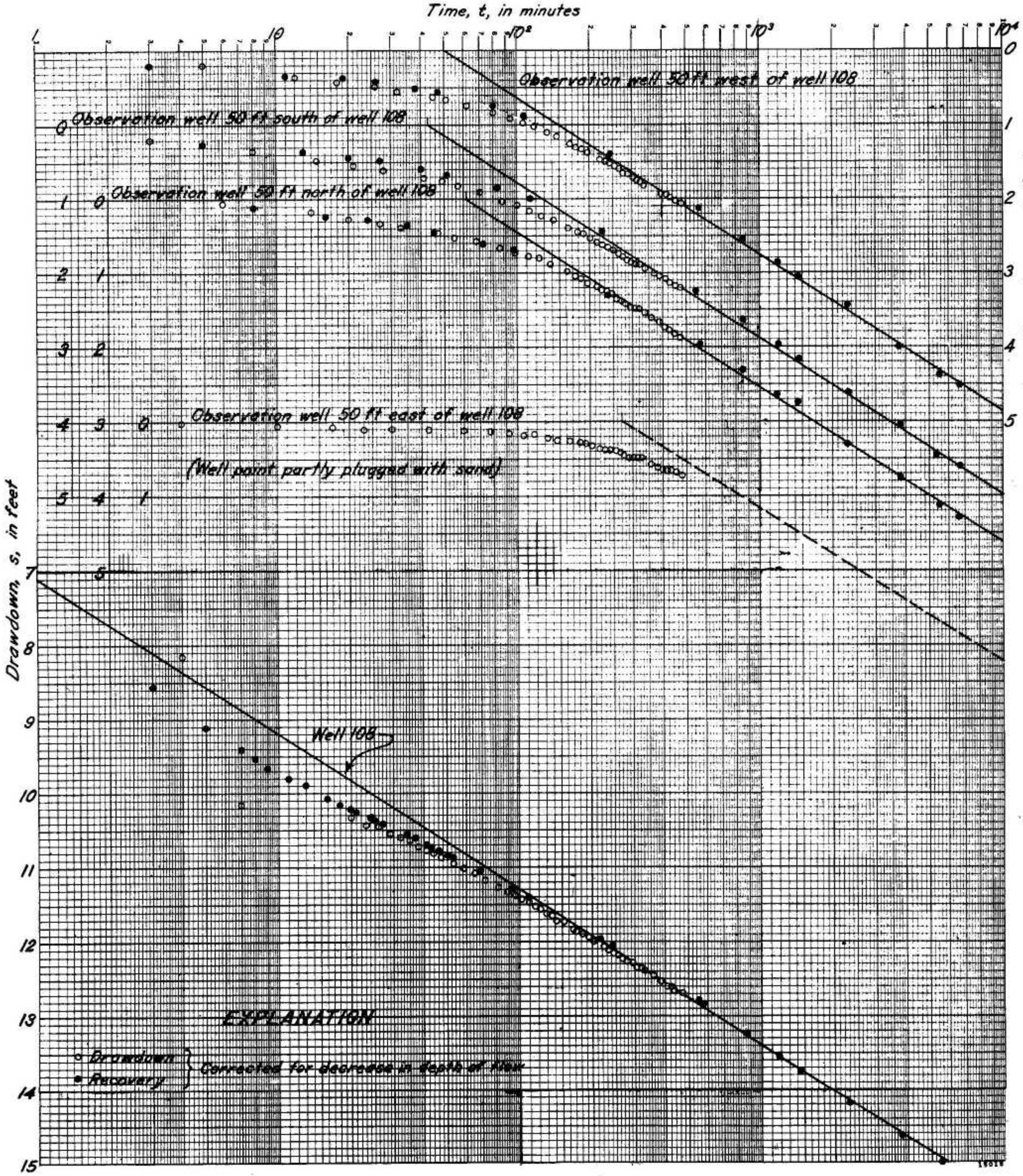


Figure 7

Semi-log time-drawdown graph for test of Dickey well 109, Nov. 3, 1940

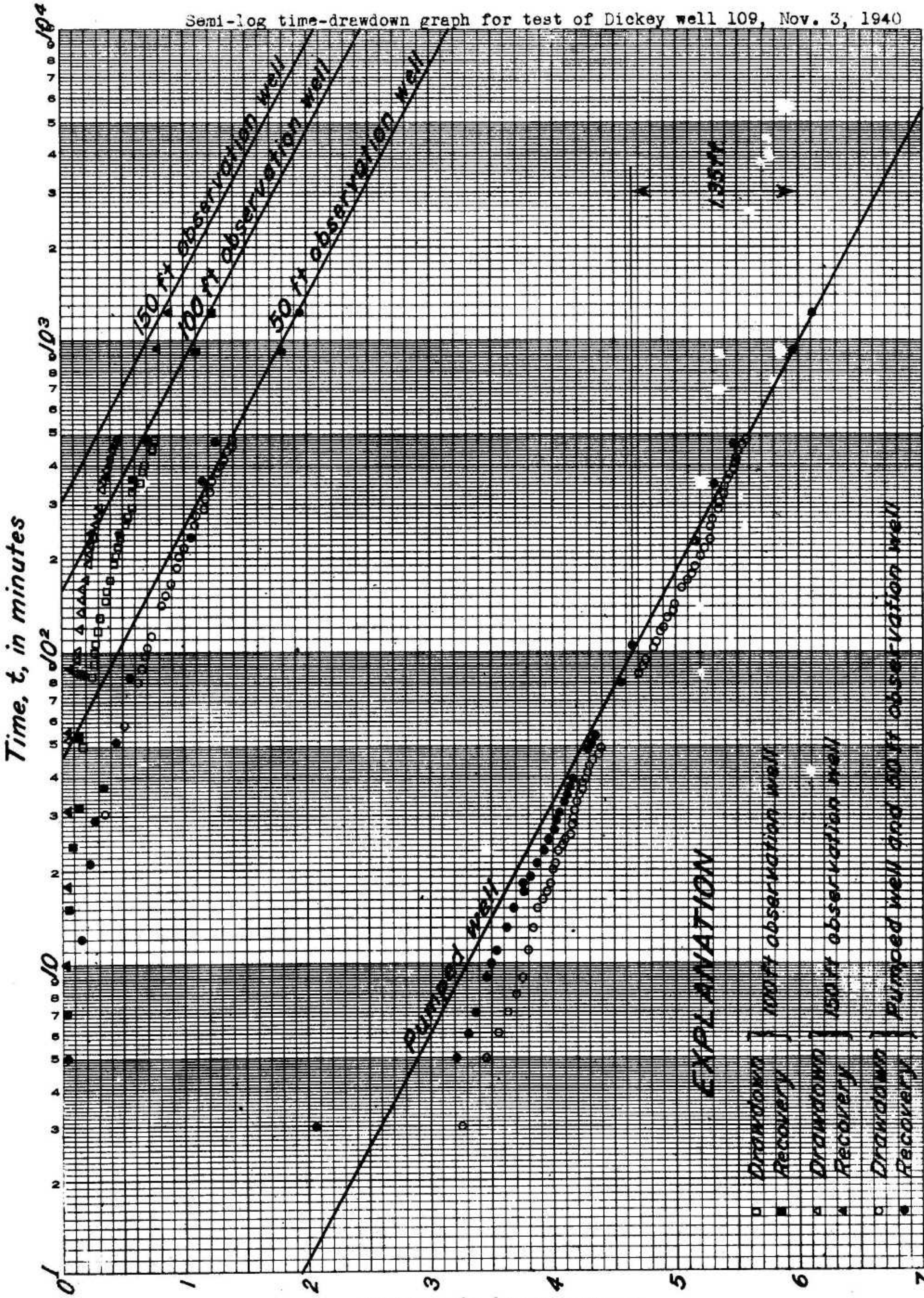
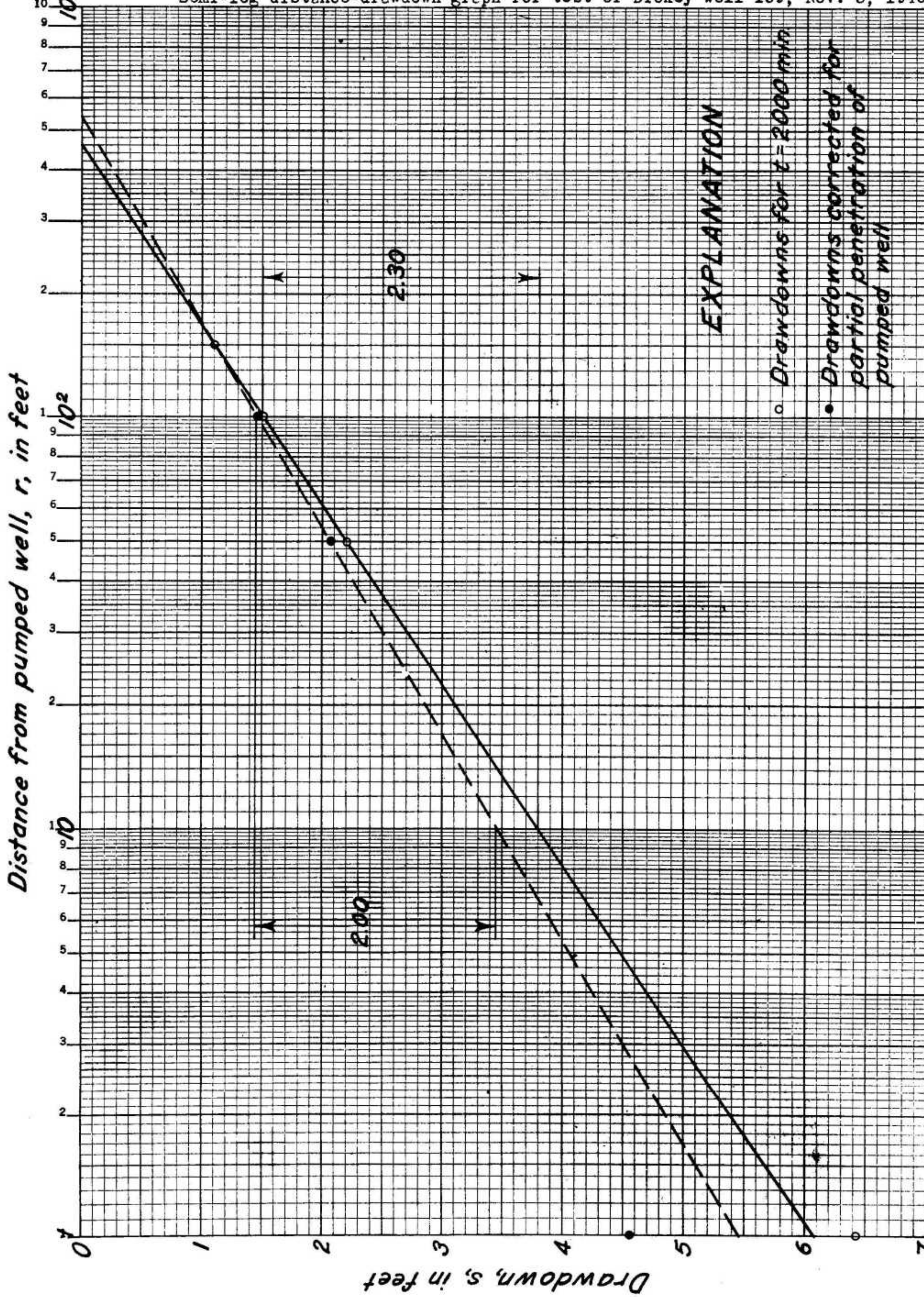


Figure 8

Semi-log distance-drawdown graph for test of Dickey well 109, Nov. 3, 1940

15015



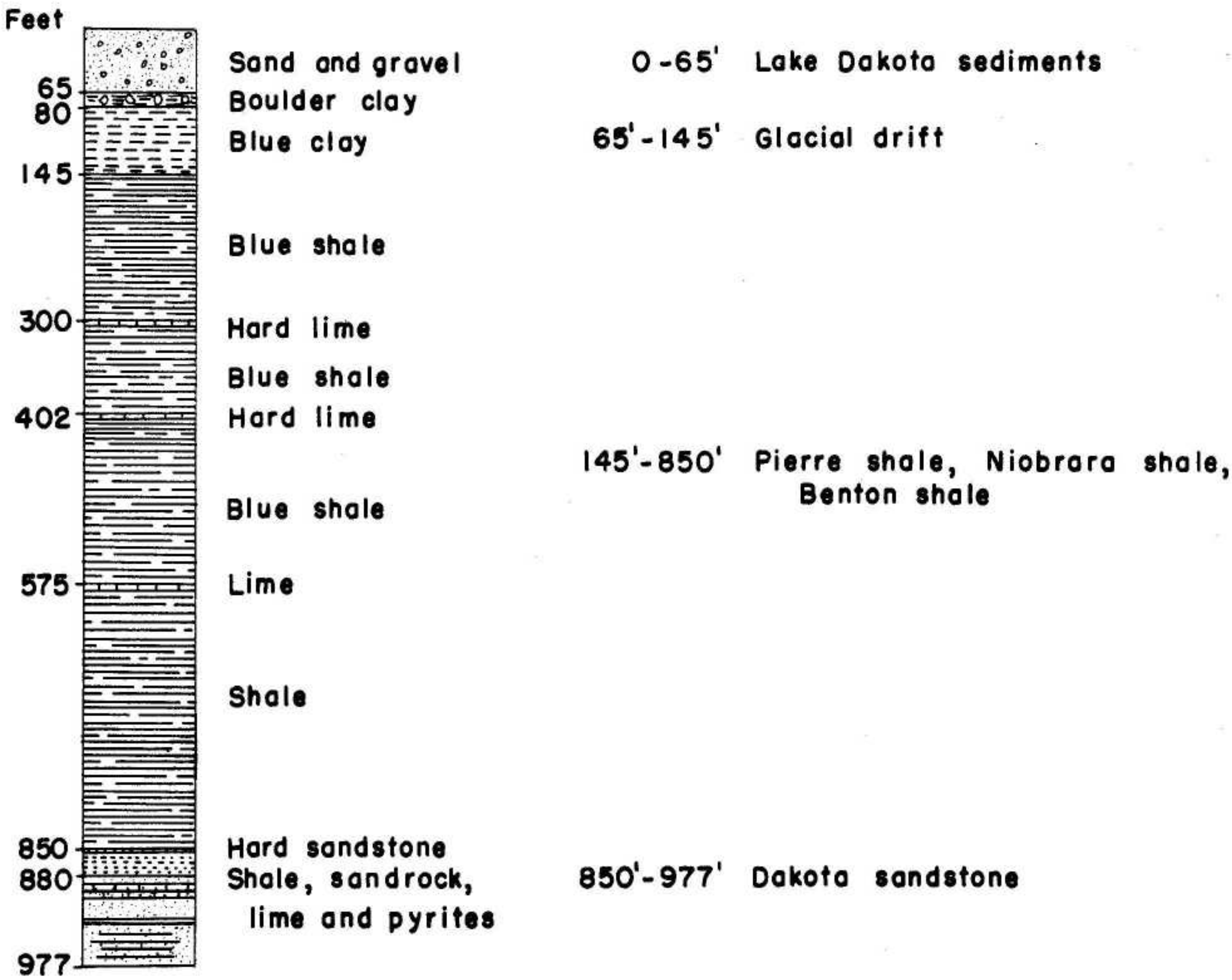


Figure 9 - Log of the Oakes city artesian well, elevation about 1,310 feet.

(Modified from Hard, H. A., Geology and water resources of the Edgeley and La Moure Quadrangles: U. S. Geol. Survey Bull. 801, fig. 3, p. 14, 1929.)

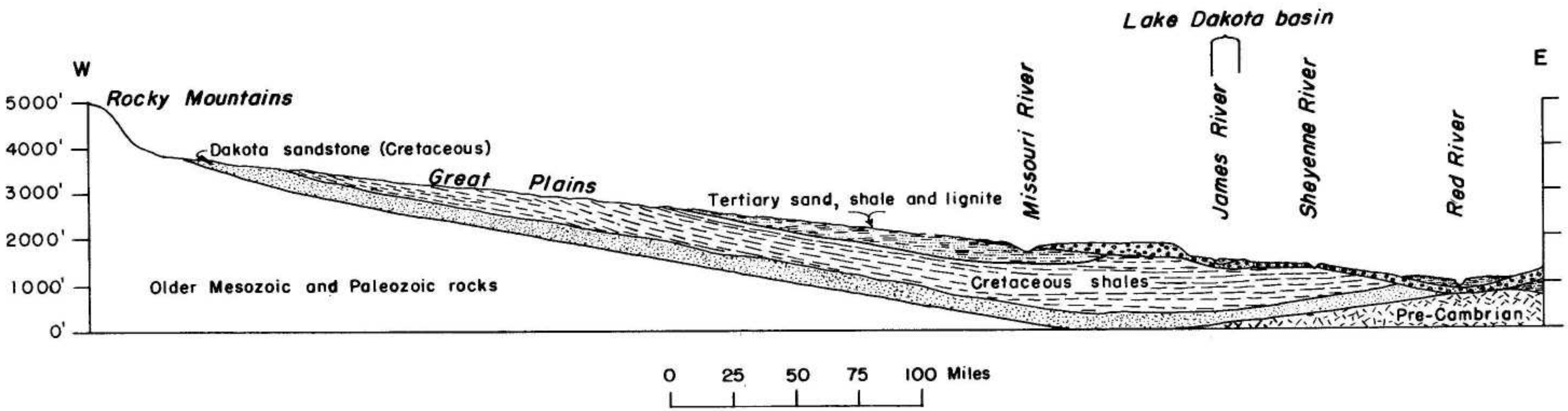


Figure 10 - Generalized geologic section from the Rocky Mountains to the Red River valley.

Vertical scale = 100 times the horizontal scale.

(After Warren Upham)