# GROUND WATER

# AT DICKINSON, NORTH DAKOTA

By

Thad G. Mclaughlin

with a section on geology by

A. L. Greenlee

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## ABSTRACT

The City of Dickinson, North Dakota, depends largely upon ground water for its municipal and industrial needs. The wells are at present located in a single well field within an area about one mile by one-half mile, and they all draw from the same aquifer. Normal growth and industrial development increased maximum daily pumpage from about 300,000 gallons in 1937 to about 550,000 gallons in 1944. This investigation had as its purpose the defining of the area of influence of the existing wells and the determination of the capacity of the aquifer to transmit additional quantities of water. It was the intention of the City to drill additional wells in the present well field if they were warranted,

The financial limits of the cooperation did not permit extensive test-drilling for locating additional well fields at some distance nor did they permit deep drilling to test additional aquifers at depth.

The existing well field is being depleted at the present rate of pumping. The transmissibility, or capacity of the aquifer to transmit water, is relatively low. Approximately 80 feet of aquifer have been permanently unwatered in the east end of the field. Conclusions of this investigation indicate that additional wells in the same bed in this vicinity are not justifiable and would only tend to deplete the present supply more rapidly. Other recommendations are based on an analysis of previous reports and records of earlier test drilling and a study of the geology of the area.

## INTRODUCTION

Ground water levels in the municipal well field at Dickinson have declined rapidly in recent years, resulting in increased pumping lifts and decreased yields. During the summer of 1943 the demand for water exceeded the capacity of the wells, making it necessary to restrict the use of water. In the spring of 1944 the city planned to drill test wells in the field in order to choose a site for an additional supply well. In March 1944 the city council requested the cooperation of the North Dakota State Department of Health in conducting a quantitative study of ground water resources of the area. The Health Department presented the problem to the State Geologist who suggested that a cooperative study with the Federal Survey be arranged. The work was done by the United States Geological Survey cooperating with the North Dakota State Department of Health through the office of the State Geologist, and with the City of Dickinson. The investigation was made under the direction of A. L. Greenlee, federal geologist in charge of ground water investigations in North Dakota and K. C. Lauster, acting director of the Division of Sanitary Engineering of the North Dakota State Department of Health.

The field work was done during the period from March 27 to May 6, 1944. Two test holes (3B and 7A on fig. 1*) were drilled for the city by the McCarthy Well Company in order to determine the thickness and character of the water-bearing materials and to measure the fluctuations of the water levels during pumping tests. Levels were run to all of the wells and test holes, and pumping tests were made of well 3 in the eastern part of the well field and well 7 at the western end of the well field.

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*Figure 1 - Map of a part of the City of Dickinson showing the location of the municipal wells.

W. L. Littlehales, city water superintendent, supplied data on the municipal wells and assisted in the conduction of the pumping tests. A. L. Greenlee visited the area of investigation several times and assisted in planning the field work and in making computations. The report was reviewed critically by O. E. Meinzer, S. W. Lohman, V. C. Fishel, and C. E. Jacob of the Federal Geological Survey, and by K. C. Lauster of the North Dakota State Department of Health. Most of the calculations were made by C. E. Jacob.

## GENERAL INFORMATION

The well field at Dickinson is located in the northern part of the city in the N½ sec. 4, and the NW¼ sec. 3, T. 139 N., R. 96 W. (fig. 1). The area of the well field is divided approximately in half by a long narrow hill that trends northward (fig. 2*). The eastern half of the field was the first to be developed and at the time of the investigation it had four wells. One well (no. 4) is equipped with a double acting cylinder pump powered by a 15 horse power oil engine. The other wells (nos. 1, 2 and 3) are gravel walled wells equipped with turbine pumps that are powered by electric motors. Water from these wells is discharged into concrete catch basins and then flows by gravity to a concrete cistern of about 200,000 gallons capacity which is located near the pump station. From the cistern, the water can be pumped directly into the mains or into a steel reservoir of 849,000 gallons capacity which is located at the crest of the hill that transects the well field. Wells 1, 2, 3 and 4 range in depth from about 170 feet to 196 feet below land surface. In April 1944 the altitude of the static water level in the wells ranged from 179.55 to 201.20 feet above the assumed datum. The depths to water level below the measuring points ranged from 97.72 feet in well 4 to 132.05 feet in well 3 (fig. 2).

There are three wells in the western half of the municipal well field (nos. 5, 6, and 7 on fig. 1). Each is a gravel-walled well and is equipped with a turbine pump powered by a 20 horsepower electric motor. Water from these wells is discharged into a 6 inch pipeline and is pumped eastward over the hill by the turbine pumps. At a point near well 3 the water enters a concrete catch basin and then flows by gravity to the concrete cistern near the pump station. Wells 5, 6, and 7 range in depth from 135 to 155 feet below land surface. The altitudes above assumed datum of the water levels in wells 5, 6, and 7 on May 5, 1944 were 218.23, 261.65, and 262.30 feet, respectively.

## HISTORY OF THE WATER SUPPLY

Before the construction of municipal water works the residents of Dickinson obtained water from many shallow dug wells. A few wells in the higher parts of the city, however, were more than 50 feet deep. The water table was not far below ground in the southern part of the town, adjacent to the Heart River, until sewers and drainage ditches were constructed. Thereafter the water table declined several feet.

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*Fig. 2 - Cross section of Dickinson well field

During the installation of the municipal water system a well was drilled at the site of the present city hall to a depth of about 1,200 feet in an attempt to obtain an adequate supply of potable ground water. A moderately large quantity of water was reported encountered at a depth of about 500 feet but the quality of the water was unsatisfactory. Previous attempts by the Northern Pacific Railway Company to obtain ground water of satisfactory quality at great depths had been unsuccessful.

The failure of the deep well at the site of the city hall to yield an adequate quantity of potable ground water led to the construction of a bored well in the eastern half of the present well field, about 150 feet northwest of the present well 3. The well was bored to a depth of about 130 feet. It encountered relatively hard but potable water.

Since the first bored well was put down in the present well field more than 40 test holes and wells have been bored or drilled by the City in order to maintain an adequate supply of water. The exact location of all these test holes is not available although it is reported that they were drilled within the present city limits. Approximately one-third of the testing was done within or near the present well field area. Many of the earlier test wells were less than 100 feet in depth.

A well reported about 200 feet in depth drilled at the site of the now abandoned flour mill located on the bank of the Heart River about 3/4 mile southwest of the present well field proved inadequate for the needs of the mill. It was reported as having a maximum capacity of about 50 gallons per minute.

Farm wells in the vicinity usually are dug or bored wells about 25 to 45 feet in depth. They prove adequate for farm and household needs. Shallow wells within or next to the city limits are reported to have gone dry during the drought years of 1933-37 and have been abandoned with very few exceptions.

Sufficiently coarse sands judged suitable for development were located only in the vicinity of the existing well field. The more recent wells were drilled to a depth of approximately 200 feet in order to penetrate all the water-bearing materials containing water of suitable quality.

The firm of Burns and McDonnel, consulting engineers, made a study of the Dickinson water system in 1927, after which they recommended the construction of three gravel-walled wells in the eastern part of the well field. These were constructed between 1928 and 1930 and are designated as wells 1, 2, and 3 (fig. 1). At the time of the construction of these wells the water table had declined from a probable original altitude of about 265 feet above the assumed datum or 42 feet below ground to an altitude of 223 feet, or 87 feet below ground at well 3 and to an altitude of 227 feet at well 1. The altitudes of the water levels in wells 1 and 3 in April 1944 were 195.4 and 179.6 feet, or 105 feet and 129 feet respectively below ground. The average total decline of water level in the eastern half of the well field has been about 80 feet.

The increased pumping lifts resulting from declining water levels had decreased the yields of the wells so that by 1934 the quantity of water available was just adequate for the City's needs. In order to prevent water shortages that might result from the failure of wells or break-down of pumps, test drilling was begun on the west side of the hill. The test drilling resulted in the construction of well 5 in 1937 (fig. 1). More test drilling was done in 1938, and in 1939 wells 6 and 7 were constructed. The water table in the vicinity of wells 6 and 7 declined about 19 feet between 1939 and May 1944.

## GEOLOGY OF THE DICKINSON AREA

A. L. Greenlee

A large part of the geology of the Missouri Slope Region of North Dakota, which includes the Dickinson area, remains to be worked out. There is still some divergence of view regarding the relationships of beds originally referred by A. G. Leonard 1/ to the Fort Union and Lance formations. More recent studies by Virginia Kline, 2/ O. A. Seager et. al., 3/ Wilson M. Laird, 4/ and W. T. Thom, Jr., 5/ supply additional data for further classification. The following table gives a probable correlation of the formations described by Leonard with those of more recent authors.

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1/ Leonard, A. G. The geology of southwestern North Dakota with special reference to coal: North Dakota Geol. Survey, 5th Bienn. Rept., pp. 51-64, 1908.

2/ Kline, Virginia, Stratigraphy of North Dakota: Am. Assoc. Petroleum Geologists Bull., vol. 26 (no. 3), pp. 336-79, 1942.

3/ Seager, O. A., et al., Stratigraphy of North Dakota: Am. Assoc. Petroleum Geologists Bull., vol. 26 (no. 8), pp. 1414-1423, 1942.

4/ Laird, Wilson M., Stratigraphy and structure of North Dakota: Nat'l. Oil Scouts and Landmen's Assoc. Year Book, vol. XIV, pp. 420-430, 1944.

5/ Thom, W. T., Jr. and Dobbin, C. E., Stratigraphy of the Cretaceous-Eocene transition beds in eastern Montana and Dakota: Geol. Soc. America Bull., Vol. 35, pp. 481-506, 1924.

**A. G. Leonard**

| | | | |
| --- | --- | --- | --- |
| Cenozoic | Tertiary | Oligocene | White River Fm. |
| Cenozoic | Tertiary | Eocene | Upper Fort Union 500' dark gray shale and sandstone and lignite |
| Cenozoic | Tertiary | Eocene | Middle Fort Union 500' buff and light gray shale and sandstone. Thin beds of lignite |
| Cenozoic | Tertiary | Eocene | Lower Fort Union 600' dinosaur-bearing somber beds Dark gray-brown sh. ss. and lignite |
| Mesozoic | Cretaceous | | Fox Hills |
| Mesozoic | Cretaceous | | Pierre |
| Mesozoic | Cretaceous | | Niobrara |
| Mesozoic | Cretaceous | | Benton |
| Mesozoic | Cretaceous | | Dakota |

**O. A. Seager, W. M. Laird and others**

| | | | | |
| --- | --- | --- | --- | --- |
| Cenozoic | Tertiary | Eocene | Wasatch Group | White River Fm. |
| Cenozoic | Tertiary | Eocene | Wasatch Group | Unnamed Fm. 100' light-colored clay, ash, sandstone |
| Cenozoic | Tertiary | Eocene | Wasatch Group | Sentinel Butte Fm. 550' dark-colored clay, bentonite, silicified stumps |
| Cenozoic | Tertiary | Paleocene | Fort Union Group | Tongue River Fm. 300' light-colored calcareous shale and sandstone and lignite. |
| Cenozoic | Tertiary | Paleocene | Fort Union Group | Cannonball-Ludlow Fm. 0-300' marine sands, clays, Ludlow 0-250' lignite, shale and sandstone |
| | | | | Hell Creek Fm. 100-575' gray bentonitic sandstone and shale, lignitic shale and concretions |
| Mesozoic | Upper Cretaceous | | Montana Group | Fox Hills 180-320' brown to gray sandstone with ironstone concretions |
| Mesozoic | Upper Cretaceous | | Montana Group | Pierre Fm. 930-2390' gray sh and ironstone concretions |
| Mesozoic | Upper Cretaceous | | Colorado Group | Niobrara 200-250' gray shale and cement rock |
| Mesozoic | Upper Cretaceous | | Colorado Group | Benton 500-1000' dark gray shale |
| Mesozoic | Upper Cretaceous | | Colorado Group | Dakota 15-90' micaceous white sandstone with pyrite, gypsum and lignite |

There are no sediments belonging to the White River formation, of Oligocene age, in the immediate vicinity of Dickinson. Soft dark-gray sandstones and shales described by Leonard as Upper Fort Union, and later named the Sentinel Butte formation of Eocene age, are exposed at the surface and along the banks of the Heart River. Samples taken from test holes drilled in the present well field may be correlated favorably with the exposures described by Leonard in the "bad-land" area about 35 miles west of Dickinson. Leonard's description is as follows: "The Fort Union is readily separated into three divisions by a marked difference in character and appearance. The upper beds are composed of rather dark gray sandstones and shales, with many brown, ferruginous sandy nodules and concretions. The middle division is formed of light ash-gray and buff shales and sandstones which are remarkably uniform in color and appearance over extensive areas. The lower member has a dark and somber aspect in striking contrast to the light colored beds above. It is composed of alternating layers of dark gray and brown shales and sandstones, containing many sandy nodules. The lower portion contains no workable beds of coal." A little later he adds, "The top of the Fort Union is formed of a rather hard sandstone 80 to 100 feet thick." 6/ A typical section of the upper Fort Union as found in Sentinel Butte and described by Leonard follows:

| | Feet | Inches |
|---|---|---|
| Sandstone, gray, hard | 80 | |
| Shale, sandy, gray and yellow | 30 | |
| Shale, brown, with thin seam of coal | 1 | 6 |
| Shale, sandy, gray and yellow | 53 | |
| Coal | | 6 |
| Sandstone, fine-grained, clayey | 12 | |
| Shale, brown and gray, containing many selenite crystals | 4 | |
| Sandstone, soft, fine-grained | 1 | |
| Coal | | 12-18 |
| Shale, brown and carbonaceous | 1 | |
| Shale, bluish gray | 10 | |
| Sandstone, gray | 12 | |
| Shale, and sandstone, not well exposed | 55 | |
| Coal | | 2-6 |
| Shale, sandy, gray | 37 | |
| Shale, gray, with no sand | 2 | |
| Coal | 6 | |
| Shale, sandy, brown at the top | 5 | |
| Sandstone, fine, gray | 4 | |
| Shale, sandy, gray, containing nodules | 15 | |
| Sandstone, finely laminated | 4 | |
| Shale, sandy, gray, with ferruginous bands | 8 | |
| Shale, sandy, brown | 1 | |
| Shale, gray | 5 | |
| Shale, gray, sandy, containing abundant siliceous and ferruginous nodules, arranged mostly in bands at certain horizons; those hard nodules project from the surface of softer shale and cap small clay columns | 25 | |
| Sandstone and shale, not well exposed | 25 | |
| Coal | 21 | 2 |
| Unexposed to level of railroad at station of Sentinel Butte | 190 | |
| | 610 | 2 |

6/ Op. Cit., p. 235

The 80 to 100 foot hard sandstone cap rock is not found in the Dickinson area. Samples from test holes show that soft gray sandstones and shales exist to a depth of 200 feet. It is assumed therefore that only the lower part of the Sentinel Butte is present and it is from this formation that the city is now obtaining its water supply. Near Dickinson, where these beds are exposed along roadcuts and in stream valleys, and in the typical butte country east of Dickinson the sand and shale layers are very lenticular and often thicken from a few inches to as much as 10 feet within one hundred yards. Other beds are more extensive and can be traced for several miles, repeating the characteristic thinning and thickening. Lignite beds are numerous in the Sentinel Butte. Coal seams were encountered by test hole 7A between 135 and 142 feet.

Approximately 500 feet of beds of the Tongue River and Ludlow formations (Leonard's Middle Fort Union) underly the Dickinson area. The marine sandstones and shales of the Cannonball are believed not to underlie this area, the continental Ludlow beds being their probable time equivalents. Leonard 7/ gives the following section as typical of his Middle Fort Union (the Tongue River and Ludlow formations of Laird). The outcrop described is about 40 miles northwest of Dickinson.

| | feet | inches |
|---|---|---|
| Sandstone, clayey, gray and yellow, finer grained rock below | 10 | |
| Sandstone, gray, soft, coarse-grained, massive, forms vertical escarpment near top of bluff | 35 | |
| Coal and carbonaceous shale | | 1-4 |
| Shale, gray and yellow | 7 | |
| Coal | | 3-4 |
| Shale | | 6 |
| Sandstone, clayey, fine-grained, gray | 5 | |
| Shale, yellow | 1 | 6 |
| Coal | | 6 |
| Shale, gray | 1 | |
| Shale, sandy, gray | 5 | |
| Shale, gray | 1 | 6 |
| Shale, brown, carbonaceous, with thin coal seam | 1 | |
| Shale, gray | 4 | |
| Sandstone, clayey, gray and buff, fine-grained, laminated in places, forms hard ledge projecting beyond softer clays above and below | 10 | |
| Shale, with some sandy streaks, gray and yellow | 5 | |
| Shale, brown, with plant impressions | | 4 |
| Coal | 1 | 6 |
| Shale, gray and yellow, with sandy layers and a thin streak of coal | 25 | |
| Shale, sandy and passing toward the top into a hard, compact, fine-grained, gray sandstone, which forms a projecting ledge | 3-4 | |
| Shale, gray and yellow | 5 | 6 |
| Sandstone, fine-grained | 2 | |
| Shale, gray and yellow | 4 | 6 |
| Shale, sandy, gray, fine-grained | 5 | |
| Coal streak, and brown, carbonaceous clay | | 1-2 |

7/ Leonard, A. G., op cit., p. 54

| | Feet | Inches |
|---|---|---|
| Sandstone and sandy clay, gray, in places the sand is cemented into hard rock, forming a projecting ledge ---------- | 7 | |
| Shale, gray ---------- | 1 | |
| Shale, brown ---------- | | 8 |
| Coal ---------- | 1 | |
| Shale, gray and yellow ---------- | 20 | |
| Shale, brown, carbonaceous ---------- | 2 | |
| Coal ---------- | 4 | |
| Shale, brown, with abundant plant remains, mostly stem impressions ---------- | 1 | |
| Shale, gray ---------- | 3 | |
| Sandstone, fine-grained and sandy shale---------- | 16 | |
| Shale ---------- | 4 | |
| Shale, sandy ---------- | 6 | |
| Shale, gray ---------- | 1 | |
| Coal ---------- | | 2 |
| Shale ---------- | | 2 |
| Coal ---------- | 8 | |
| Shale ---------- | | 3-5 |
| Coal ---------- | | 11 |
| Shale and sandstone, not well exposed, to river ---------- | 40 | |
| | 251 | 6 |

The Hell Creek formation (or lower Fort Union of Leonard) should be present in the Dickinson area at considerable depth. This formation is below the stream level of the Little Missouri River in the area of badlands around Medora but crops out along the east slope of the Baker anticline south of Marmarth which is about 75 miles southwest of Dickinson. The beds are described by Leonard 8/ as follows:

| | Feet | Inches |
|---|---|---|
| Burnt clay bed, capping the buttes ---------- | 26 | |
| Clay, gray ---------- | 2 | |
| Sandstone, fine-grained, buff ---------- | 8 | 9 |
| Shale, gray ---------- | 2 | 9 |
| Shale, light buff ---------- | 9 | |
| Shale, chocolate brown, carbonaceous ---------- | 2 | |
| Coal, impure and dirty ---------- | | 11 |
| Shale, brown ---------- | | 9 |
| Coal, impure ---------- | | 8 |
| Sandstone and shale, chocolate brown, carbonaceous ---------- | 2 | |
| Sandstone, gray ---------- | 12 | |
| Shale, gray ---------- | 2 | |
| Shale, brown, carbonaceous ---------- | 4 | 3 |
| Coal, impure ---------- | | 8 |
| Sandstone, fine-grained, gray ---------- | 15 | 6 |
| Shale, chocolate brown ---------- | 1 | 7 |

8/ Leonard, A. G., op. cit., p. 47

| | Feet | Inches |
|---|---|---|
| Sandstone and shale, not well exposed----------- | 21 | 5 |
| Shale, brown ------------------------------------ | 1 | |
| Sandstone, gray --------------------------------- | 11 | 3 |
| Earth, black, carbonaceous ---------------------- | | 3 |
| Sandstone, argillaceous, gray ------------------- | 3 | 7 |
| Shale, gray ------------------------------------- | 5 | 9 |
| Sandstone, gray --------------------------------- | 3 | 9 |
| Shale, gray ------------------------------------- | 10 | 6 |
| Coal, impure and dirty -------------------- | | 11 |
| Shale, chocolate brown -------------------------- | 1 | 2 |
| Sandstone --------------------------------------- | | 10 |
| Shale, chocolate brown -------------------------- | 1 | 3 |
| Sandstone, argillaceous ------------------------- | 3 | 7 |
| Shale, brown, carbonaceous, with some coal ------ | 1 | |
| Shale, gray ------------------------------------- | 2 | |
| Coal, impure ------------------------------ | | 6 |
| Sandstone, light gray --------------------------- | 23 | |
| Coal, impure, with 7-inch clay parting ---- | 2 | |
| Shale, chocolate brown, carbonaceous ------------ | 2 | |
| Shale, sandy, changing in places to sandstone---- | 58 | |
| Coal and brown shale ---------------------- | 1 | 4 |
| Sandstone with some clay, gray ------------------ | 8 | 9 |
| Shale, brown, carbonaceous ---------------------- | 1 | 4 |
| Coal, impure ------------------------------ | 2 | |
| Shale, brown, carbonaceous ---------------------- | | 8 |
| Sandstone, gray, with some shale ---------------- | 63 | 4 |
| Shale, brown, carbonaceous ---------------------- | 1 | |
| Shale, gray ------------------------------------- | 1 | 6 |
| Sandstone, gray --------------------------------- | 6 | |
| Shale, brown, carbonaceous ---------------------- | 2 | 3 |
| Sandstone --------------------------------------- | 3 | |
| Shale, gray ------------------------------------- | 7 | 5 |
| Sandstone, gray, with limonitic concretions ----- | 16 | 6 |
| Shale, gray ------------------------------------- | 4 | 9 |
| Shale, sandy, passing into sandstone above, gray, contains numerous brown, limonitic nodules ------------------------------------ | 22 | |
| Shale, dark brown, carbonaceous, with thin streaks of coal ---------------------------- | 1 | 1 |
| Shale, light gray ------------------------------- | 6 | 10 |
| Shale, dark gray to brown ----------------------- | 2 | 9 |
| Shale, gray, sandy above ------------------------ | 5 | 2 |
| Shale, brown, carbonaceous ---------------------- | 3 | 4 |
| Clay, greenish gray ----------------------------- | 2 | 6 |
| Sandstone, gray, with great numbers of sandstone concretions and lenses ----------- | 13 | 4 |
| Shale, brown, carbonaceous ---------------------- | 2 | 9 |
| Clay, greenish gray ----------------------------- | 3 | |
| Sand, gray -------------------------------------- | 3 | 9 |
| Shale, brown, carbonaceous, with streaks of coal- | 4 | 7 |
| Shale, sandy ------------------------------------ | 5 | |
| Unexposed to river ------------------------------ | 20 | |
| | 460 | |

The Fox Hills sandstone, the Pierre, Niobrara, and Benton shales, and the Dakota sandstone are believed to be present in the Dickinson area. Of these the Fox Hills is most likely to contain an adequate quantity of potable water. Leonard 9/ describes an outcrop of the Fox Hills strata along Little Beaver Creek in Sec. 7, T. 132 N., R. 106 W. as follows:

| | Feet |
|---|---|
| Sandstone, light greenish-gray, massive ----------- | 50 |
| Sandstone, ledge, yellow ------------------------- | 10 |
| Clay, sandy, finely laminated ------------------- | 25 |

This outcrop is about 80 miles southwest of Dickinson. The Carter Oil Co. No. 1 Semling, drilled about 90 miles east and north of Dickinson, encountered about 175 feet of sandstone described as Fox Hills at a depth of 915 feet below land surface. The top 70 to 80 feet was described as coarse sandstone. This formation should be encountered in the Dickinson area at depths between 1000 and 1300 feet below land surface. The next aquifer productive of moderate amounts of water is the Dakota sandstone. The top of the Dakota should be reached at about 5100 feet below land surface or at about 2700 feet below sea level. 10/

## POTENTIAL WATER-PRODUCING AQUIFERS IN THE DICKINSON AREA

A. L. Greenlee

The present well field at Dickinson is the largest producing field known to exist in North Dakota that obtains water from the Sentinel Butte (or Upper Fort Union) formation. An analysis of the type sections listed above gives the following total thickness of clay, shale, and coal, and of sandstone and clayey sandstone in the exposed sections; also the thickness of the three principal sandstone beds in each unit.

| | Total thickness, in feet | | Thickness of principal |
|---|---|---|---|
| | Shale, clay, and coal | Sandstone | sandstone beds, in ft. |
| Sentinel Butte (*Upper Fort Union) | 307 | 113 | 80 - 12 - 12 |
| Tongue River-Ludlow (*Middle Fort Union) | 129 | 85 | 35 - 16 - 10 |
| Hell Creek (*Lower Fort Union) | 243 | 199 | 63 - 23 - 16 |

Most of the sandstones are very fine-grained and have varying amounts of clay and in many places thin seams of shale. They have high porosity but low specific yield and transmissibility. To produce any large amount of water, the beds would have to be of considerable thickness. It is doubtful whether the yield from beds less than 30 to 35 feet thick would justify the cost of development. Of the total section described, only the Sentinel Butte and Hell Creek formations are known to contain a bed of sandstone over 35 feet thick. Water may be found in the seams of lignite but it has a high organic content and a dark brown color and is, therefore, unsuitable for a municipal supply.

9/ Leonard, A. G., op. cit., pp. 43-44
10/ Ballard, Norval, Regional geology of Dakota basin: Amer. Assoc. Petrol. Geol. Bull., Vol. 26 p. 1568, 1942.
*Nomenclature by A. G. Leonard

The Fox Hills sandstone is a potential aquifer though it lies at considerable depth. Test-drilling and test-pumping will be required to supply quantitative and qualitative data needed to evaluate its potentialities. However, three wells which have been drilled to this formation in the vicinity of Dickinson failed to obtain an adequate quantity of potable water as discussed later (p. 17-18).

The Dakota sandstone is known to contain highly mineralized water in other parts of the State. The poor quality of the water and its great depth in the Dickinson area preclude its development for a municipal supply.

Despite the lowering of the water table in the eastern half of the well field, a few wells obtain small quantities of water at relatively shallow depths. These wells probably penetrate bodies of perched water that are held above the normal water table by the relatively impermeable lenses of clay shale. Test hole 3B encountered water between depths of 51 and 53 feet. The water there was held above the normal water table by the underlying 44-foot bed of clay.

The water encountered in the well field at depths less than 200 feet generally is relatively hard but is satisfactory for most domestic uses. At depths greater than 200 feet most wells encounter brown lignite-stained water that is relatively soft but is not suitable for public supply because of its color. In the vicinity of wells 3 and 6 this water has been encountered at a depth of about 235 feet.

## PHYSICAL PROPERTIES OF WATER BEARING MATERIALS

### Definitions and general considerations

The following discussion of the principles governing the occurrence and movement of ground water has been based chiefly on the authoritative and detailed treatment of the occurrence of ground water by Meinzer (1923), to which the reader is referred for more extended consideration.

The rocks that make up the outer crust of the earth generally are not entirely solid, but have numerous openings, called voids or interstices, which may contain air, natural gas, oil, or water. The number, size, shape, and arrangement of the interstices in rocks depend upon the character of the rocks. The occurrence of ground water in any region is therefore modified by the geology.

The open spaces in rocks vary greatly in size. Generally they are connected so that water can percolate from one to another, but in some rocks these open spaces are isolated and the water has little or no chance to percolate.

The porosity of a rock is the percentage of the total volume of the rock that is occupied by interstices. A rock is said to be saturated when all its interstices are filled with water or other liquid, and the porosity is then practically the percentage of the total volume of rock that is occupied by water. The porosity of a rock determines only the amount of water a given rock can hold, not the amount it may yield to wells. Some rocks, such as certain clays, may be highly porous but will yield only very small quantities of water to wells;

The rate of movement of ground water is determined by the size, shape, number and degree of interconnection of the open spaces in rocks and by the hydraulic gradient from one point to another. The permeability of a water bearing material is its capacity for transmitting water. The coefficient of peremeability may be expressed as the number of gallons of water a day, at 60° F., that is conducted laterally through each mile of the water-bearing bed (measured at right angles to the direction of flow), for each foot of thickness of the bed, and for each foot per mile of hydraulic gradient (Stearns, 1927, p. 148). The field coefficient of permeability is expressed as the number of gallons of water a day that percolates under prevailing conditions through each mile of water bearing bed under investigation (measured at right angles to the direction of flow), for each foot of thickness of the bed, and for each foot per mile of hydraulic gradient. The coefficient of transmissibility may be expressed as the number of gallons of water a day transmitted through each section one mile wide extending the height of the aquifer, under a hydraulic gradient of one foot to the mile (Theis, 1935, p. 520). It is equivalent to the field coefficient of permeability multiplied by the thickness of the saturated part of the aquifer.

The specific yield of a water bearing formation is defined as the ratio of (1) the volume of water which a saturated aquifer will yield by gravity to (2) its own volume (Meinzer, 1923, p. 28). It is a measure of the yield of a water bearing bed when it is drained by a lowering of the water table. The quantity of water that may be removed from storage in a saturated body of material thus depends upon the specific yield of the material.

## Behavior of the water level near a pumped well

The following discussion has been adapted for use in this report from similar discussions by Wenzel (1942, pp. 98-101) and other members of the United States Geological Survey.

When a pump begins discharging water from a well under water table conditions, the water table near the well is lowered and a hydraulic gradient toward the well is established. The water table soon assumes a form similar to that of an inverted cone with its apex at the well. For a short time after pumping begins most of the water that is discharged from the well is derived by unwatering sediments near the well, but as pumping continues water will be transmitted laterally to the well through the water-bearing material at approximately the rate that it is being pumped; that is, a steady state of flow will be established. Continued pumping at a constant rate causes continued expansion of the cone of depression and further decline of the water table. The decline of the water table is completely arrested only after the influence of pumping has reached one or more boundaries of the aquifer and reduced the outflow or increased the inflow thereby an amount equal to the discharge of the well (Theis, 1940).

After the discharge of a well is stopped, water continues to move toward the well for a time under the hydraulic gradient created by pumping, but instead of being discharged from the well it refills the well and the adjacent unwatered sediments. At a considerable distance from the well the water level may continue to decline for a time after pumping has been stopped because water continues to move toward the well until the hydraulic gradient returns to normal. As the sediments around the well are refilled, the hydraulic gradient decreases gradually and the recovery of the water level in the well becomes progressively slower. Eventually there is a general equalization of water levels over the entire area affected, and the water table tends to assume its original form, although in some cases a part of the sediments may remain temporarily or permanently unwatered.

## PUMPING TESTS

### Schedule of Operation

Wells 3 and 7 in the Dickinson well field were test pumped during the investigation. Well 3 was pumped continuously for 49 hours at an average rate of 105 gallons a minute. Periodic water level measurements were made in wells 1, 2, 3, 4, and 5, in well 3A, which is an abandoned well, and in well 3B, which is a test hole drilled during the investigation. Excessive withdrawals of ground water from the eastern part of the well field had created a large, irregular cone of depression that extends the entire width of the well field. Because of the low yield of the wells and the inadequate storage facilities it was not possible to stop all of the pumps and allow the water levels to recover fully. Wells 6 and 7, therefore, were pumped continuously during the test on well 3. When the pumps in the eastern part of the field were stopped prior to the test, the water table rose rapidly for a few hours but the rate of recovery gradually decreased so that after two or three days the rate of rise was only a few hundredths of a foot a day, indicating that the water table was approaching static conditions on a large cone of depression.

When the pumping of well 3 began, the water levels in wells 1, 2, and 5 were rising and they continued to rise during a large part of the pumping test. A near-equilibrium cone of depression was not established at wells 1, 2 and 5 so the water level measurements at these wells were not used in the calculations of permeability.

The water level in well 4 rose and declined several times during the pumping test on well 3. By plotting the water level in well 4 and the water level in the near-by concrete cistern it was found that they fluctuated together. When the cistern is full it holds approximately 830 tons of water. The weight of the water apparently compresses the water bearing materials sufficiently to cause a rise in water level in the vicinity of the cistern. As the cistern is emptied the pressure is removed and the water table declines. Because of the fluctuations of the water table caused by the addition and withdrawal of water from the cistern, the water level measurements in well 4 were not used in the calculations of permeability.

The pumping test of well 7 was made about two weeks after the test on well 3. Because of the greater demand for water occasioned by the warmer weather and because of a break down of the pumping equipment in well 1 it was necessary to pump wells 2, 3, and 5 during the test of well 7. Well 7 was pumped continuously for 44.5 hours at an average rate of 130 gallons a minute. Periodic water level measurements were made in wells 6 and 7, and in well 7A, which is a test hole that was drilled during the investigation.

### Determination of Transmissibility

The data obtained from the pumping tests of wells 3 and 7 were used to determine the coefficient of transmissibility of the water bearing materials in the Dickinson well field. The transmissibility is the product of the permeability by the original depth of flow (assumed to be uniform when the water table is in its undisturbed position).

According to Darcy's law of the flow of ground water (Darcy, 1856), the discharge (Q) through any section of water bearing material is equal to the product of the permeability of the material (P) by the hydraulic gradient (I) by the cross sectional area (A). Hence $Q = PIA$ and $P = Q/IA$. In the vicinity of a pumped well, A is equal to the area of a cylindrical surface co-axial with the well, having a height equal to the thickness of saturated water-bearing material. Therefore, $A = 2\pi r(m-s) = 2\pi rh$ in which

- r = distance from the pumped well.
- m = initial thickness of saturated material.
- s = drawdown at distance r from pumped well.
- h = elevation of water table above base of aquifer at distance r.

The permeability of a water bearing material can be computed by substituting these values in the equation $P = Q/IA$. This method was first used by G. Thiem (1906), who developed the following formula for computing permeability by using measurements of the water levels in two observation wells to define the gradient and using the measured discharge of the pumped well.

$$P = Q \log (r2/r1)/\pi(h_2^2 - h_1^2)$$

The transmissibility, which is equal to the product Pm, is expressed as follows in terms of the drawdowns at two different distances.

$$T = \frac{2.30\ Q \log 10\ (r2/r1)}{2\pi\left[(s_1 - s_1^2/2m) - (s_2 - s_2^2/2m)\right]} =$$

$$= 2.30\ Q \log 10(r2/r1)/2\pi(s_1' - s_2')$$

T = coefficient of transmissibility. $r_1$ and $r_2$ = distances from the pumped well. $s_1$ and $s_2$ = drawdowns at distances $r_1$ and $r_2$. m = initial thickness of saturated material. $s' = s - s^2/2m$ = adjusted drawdown, which is the same as the drawdown that would occur in an equivalent confined aquifer.

The analogy that exists between the nonsteady flow of water in unconfined beds and the nonsteady conduction of heat was pointed out by Boussinesq (1904). Head, or elevation of the water surface in a well, is analogous to temperature; hydraulic gradient is analogous to temperature gradient: permeability to thermal conductivity; and specific yield per unit thickness to specific heat times density. On the basis of this analogy Theis (1935) derived the relation for the lowering of head in the vicinity of a well discharging at a steady rate from an extensive aquifer. The drawdown at a distance r and at a time t after the beginning of discharge is given approximately by

$$s = (Q/4\pi T)\ 2.30 \log_{10}(2.25\ Tt/r_1^2 S')$$

where S is the specific yield or "coefficient of storage".

With the value of t fixed this relation expresses the variation of drawdown with the logarithm of the distance from the discharging well and reverts back to the preceding equation. By plotting values of s' against $\log_{10} r$ one can obtain T from the slope of the straight-line plot. The computations are simplified by taking $\Delta s' = s_1' - s_2'$ as the change in drawdown over one log cycle, putting $\log_{10} r_2/r_1 = 1$.

Then: $T = \frac{2.30Q}{2\pi \Delta s'}$

The above method was used in determining the transmissibility at Dickinson. The data for the pumping test of well 3 are shown in figures 3* and 4*. Because of the decline in discharge shown at the bottom of figure 3, it was not satisfactory to use the drawdown data without making some adjustment for that decline. A simpler procedure was to work with the recovery observed in three wells and treat it as though it were a negative drawdown. The value of T was found to be about 8,500 gallons per day per foot.

### Determination of Specific Yield

The storage coefficient is determined from the intercept of the straight line and the zero drawdown line. Putting $s = 0$, it is found that

$$S = 2.25tb/r_0^2$$

where $r_0$ is the distance at which $s = 0$ on the straight line. The value of S determined from this test is about 0.001 which suggests that the water bearing formation is confined or semi-confined, at least in the vicinity of well 3.

The data for the pumping test of well 7 are shown in figures 5* and 6*. Here again, there was a decline in discharge during the pumping test. For this reason the recovery method was used in the determination of transmissibility. The slope of the line (Fig. 6) was 7.3 feet over one logarithmic cycle. The transmissibility in this case was found to be about 4,500 gallons per day per foot and the coefficient of storage was found to be 0.016. This high apparent coefficient of storage may be due to the fact that well 7 draws water from a confined sand and from an overlying unconfined sand.

## QUANTITY OF GROUND WATER

### Yield of municipal wells

The yields of the municipal wells at Dickinson range from about 60 gallons per minute for well 5 to about 130 gallons per minute for well 7. Wells 5, 6, and 7 are located on the west side of the hill and their pumps must boost the water over the hill in addition to lifting it to the surface. As a result, the rate at which these wells discharge water into the cistern is much less than the rate at which they discharge water at the well houses. The three wells have a total yield of about 320 gallons per minute when allowed to discharge at the well sites but they discharge only 160 gallons per minute into the cistern. The combined discharge of all the wells except well 4, which generally is not used, is 417 gallons per minute at the cistern.

### Determination of steady-state drawdown

Assuming that the effective radius of each well is 0.5 foot and that four wells yielding 100 gpm each are needed to meet the peak demand, the effective radius

*Fig. 3 - Graph of data from pumping test of well 3.
*Fig. 4 - Time drawdown graph for test of well 3.
*Fig. 5 - Graph of data from pumping test of well 7.
*Fig. 6 - Time drawdown graph for test of well 7.

of a battery of four wells (such as wells 1, 3, 5, and 7) is computed to be about 240 feet.

Knowing the effective radius of a battery of four wells such as wells 1, 3, 5 and 7, one can calculate the approximate steady-state drawdown of the Dickinson wells. The four wells (1, 3, 5, and 7) are situated about 6,000 feet north of the Heart River, along which there assumedly is salvageable natural discharge. The river is considered to be a constant head line source of water.

Assume that T = 6,500 gpd per ft.,

$r_b$ (effective radius of battery of four wells) = 240 ft.,

Q (approximate peak daily discharge) = 576,000 gpd,

$s_b$ = steady-state drawdown

a (distance to straight line source) = 6,000 ft.

Then:

$$s_b = \frac{2.303Q}{2\pi T} \log 10 \frac{2a}{r_b} =$$

$$s_b = \frac{2.303 \times 576{,}000 \times \log 10\ 12{,}000/240}{2\pi \times 6{,}500} = 55 \text{ feet.}$$

The well loss of well 3 when pumping at the rate of 102 gpm was inferred to be about 10 feet (Fig. 4). Adding this to the computed drawdown of 55 feet gives 65 feet for the probable total ultimate drawdown when four wells operate continuously. This leaves very little margin for future operation at rates exceeding 400 gallons per minute because the thickness of saturated material in the Dickinson well field ranges from a little less than 30 feet to a little more than 90 feet and averages only about 75 feet.

## CONCLUSION

It would not be practicable to drill additional wells in the existing well field to augment the water supply for Dickinson because the present wells are equipped to pump more than 400 gallons a minute (an amount sufficient to cause a drawdown of 65 feet). This is based on the assumption that the permeability and thickness of the water bearing materials are the same for the entire area as they are at the well field. Approximately 40 wells and test holes have been drilled in the vicinity of Dickinson by the City and by the Northern Pacific Railroad Company but most of them were abandoned because of a lack of adequate potable water. The thickest and coarsest water bearing materials were encountered in the well field, and therefore it is not logical to assume that the thickness and permeability of the water bearing bed are as great adjacent to the well field as they are at the well field. The early Tertiary sediments that underlie the Dickinson area consist predominantly of clay and fine sand. The sand beds vary greatly in thickness and may pinch out in relatively short distances. In addition, the ratio of clay to sand and hence the permeability may vary greatly within short distances. Many test holes in the Dickinson well field have been abandoned because the water bearing sand contained so much clay that it was not feasible to develop a well at that site.

Drilling to greater depths in order to obtain an adequate supply of water also would be inadvisable because of the character of the underlying sediments. 11/ Three wells have been drilled in the vicinity of Dickinson to depths in excess of 1,000 feet (1,200, 1,800 and 1,823 feet) but none obtained an adequate quantity of potable water.

It has been suggested that a solution to the water supply problem at Dickinson may be the impounding of water in the Heart River which flows past the southern edge of the city. Studies have been made of the Heart River in the vicinity of Dickinson by the Bureau of Reclamation to determine the feasibility of impounding water for municipal, industrial, and irrigation use. It has been estimated by them that the average annual discharge of the Heart River at Dickinson is about 12,000 acre feet (approximately 3,900,000,000 gallons).* The quantity of water available from the Heart River would be adequate for the needs of the city, allowing for moderate growth. The storage reservoir should be sufficiently large to impound adequate water for the needs of the city during periods of small stream flow. In the event of prolonged droughts the wells could again be pumped until adequate water had been impounded in the reservoir. If cooler water is desired, the wells could be pumped in the summer and surface water could be used during the rest of the year. Because of the better quality of the river water, however, it probably would be desirable to use it as much as possible.

Automatic water level recorders have been installed on wells 3A and 7A so that a continuous record of water levels in both sides of the well field can be kept. This will allow for properly balanced pumping on both sides of the field. In this way the city should be able to obtain a more economic distribution of pumpage and to delay somewhat the decline of pumping levels.

This investigation has not exhausted the possibilities of additional ground water supplies at some distance beyond the influence of the present well field. However, the results of test drilling have not been encouraging on this score.

## WELL LOGS

The materials encountered in test holes 3B and 7A are described below. The holes were drilled by a cable tool drilling machine owned and operated by the McCarthy Well Company. Samples were collected by the driller and the descriptions were made by the writer.

Log of test hole 7A, 99 feet southeast of well 7. Altitude of top of casing, 310.81 feet above datum. Static water level 48.82 feet below top of casing, May 28, 1944.

| | Thickness Feet | Depth Feet |
|---|---|---|
| Soil, brown, sandy | 5 | 5 |
| Clay, sandy, gray and tan, containing thin seams of lignite | 20 | 25 |

11/ Simpson, H. E. Geology and ground water resources of North Dakota: U. S. Geological Survey Water Supply Paper 598, p. 226.

*Personal communication, Charles T. Hinze, Engineer for Bureau of Reclamation

| | Thickness Feet | Depth Feet |
|---|---|---|
| Sand, very fine, gray, containing clay, lignite encountered at depth of 80 feet | 60 | 85 |
| Sand, fine to very fine, blue, containing clay, gray | 41 | 126 |
| Clay, blue-gray | 6 | 132 |
| Clay, brown, containing thin beds of lignite | 10 | 142 |

Logs of test hole 3B, 75.5 feet northwest of well 3. Altitude of top of casing 312.16 feet above datum. Static water level 129.12 feet below top of casing, May 14, 1944.

| | Thickness Feet | Depth Feet |
|---|---|---|
| Sand, fine and clay, gray | 8 | 8 |
| Sand, fine, hard, bluish gray, containing clay, gray. Water encountered between depths of 29 and 30 feet. | 38 | 46 |
| Sand, fine to medium, poorly sorted, bluish-gray, containing silt and clay, gray. Encountered thin bed of lignite at a depth of 46 ft. | 5 | 51 |
| Sand, fine to medium, bluish gray, containing water | 2 | 53 |
| Clay, dark blue-gray | 44 | 97 |
| Sand, very fine, bluish gray, containing clay, gray | 31 | 128 |
| Sand, fine, bluish gray, containing clay, gray | 29 | 157 |
| Sand, fine, bluish gray | 34 | 191 |

## WELL SCHEDULES

Well 1

Diameter: 20 inches to 12 inches
Depth: 191 feet on April 1, 1944
Driller: C. L. Tillquist
Depth to water: 107.20 feet below measuring point on April 1, 1944
Measuring point: Top of 4 inch hole on east side of concrete pump base which is 0.88 foot above concrete floor
Elevation of measuring point: 302.61 feet above datum
Pump: Turbine
Power: Electric motor (15 horsepower)
Yield: 100 gallons a minute (reported)
Draw-down: 19 feet after 24 hours of pumping

Well 2

| | |
|---|---|
| Diameter: | 20 inches to 10 inches |
| Depth: | 196 feet (reported) |
| Driller: | C. L. Tillquist |
| Depth to water: | 124.59 feet below measuring point on April 1, 1944 |
| Measuring point: | Top of 1.5 inch hole in northwest side of pump which is 1.0 foot above concrete floor of pump house. |

Elevation of measuring point: 306.45 feet above datum

| | |
|---|---|
| Pump: | Turbine |
| Power: | Electric motor (15 horsepower) |
| Yield: | 100 gallons a minute (reported) |

Well 3

| | |
|---|---|
| Diameter: | 20 inches to 8 inches |
| Depth: | 182 feet (reported) |
| Driller: | C. L. Tillquist |
| Depth to water: | 128.92 feet below measuring point on April 14, 1944. |
| Measuring point: | Top of 5 inch hole in side of concrete pump base which is 0.53 foot above concrete floor of pump house. |

Elevation of measuring point: 311.60 feet above datum

| | |
|---|---|
| Pump: | Turbine |
| Power: | Electric motor |
| Yield: | 105 gallons a minute |
| Drawdown: | 33.14 feet after 49 hours of pumping |

Well 3A

| | |
|---|---|
| Diameter: | 8 inches |
| Depth: | 191 feet on April 11, 1944 |
| Driller: | C. L. Tillquist |
| Depth to water: | 129.50 feet below measuring point on April 14, 1944. |
| Measuring point: | Top of casing which is 1.9 feet above land surface |

Elevation of measuring point: 311.88 feet above datum.

Well 4

| | |
|---|---|
| Diameter: | 8 inches |
| Depth: | 170 feet (reported) |
| Driller: | C. L. Tillquist |
| Depth to water: | 97.72 feet below measuring point on March 31, 1944. |
| Measuring point: | Top of 0.5 inch hole in west side of pump base which is 1.0 foot above concrete floor of pump station. |

Elevation of measuring point: 298.92 feet above datum

| | |
|---|---|
| Pump: | Cylinder |
| Power: | Kerosene engine (15 horsepower) |
| Yield: | 50 gallons a minute (reported) |

Well 5

| | |
|---|---|
| Diameter: | 20 inches to 12 inches |
| Depth: | 154 feet on April 1, 1944 |
| Driller: | McCarthy Well Company |
| Depth to water: | 92.14 feet below measuring point on April 1, 1944 |
| Measuring point: | Top of 5 inch hole in north side of concrete pump base which is 0.65 foot above concrete floor of pump house |
| Elevation of measuring point: | 310.37 feet above datum |
| Pump: | Turbine |
| Power: | Electric motor (20 horsepower) |
| Yield: | 65 gallons a minute |
| Draw-down: | 33 feet after 60 hours of pumping |

Well 6

| | |
|---|---|
| Diameter: | 20 inches to 12 inches |
| Depth: | 135 feet (reported) |
| Driller: | McCarthy Well Company |
| Depth to water: | 48.64 feet below measuring point on May 5, 1944 |
| Measuring point: | Top of 4 inch hole in south side of concrete pump base which is 0.47 foot above concrete floor of pump house |
| Elevation of measuring point: | 310.29 feet above datum |
| Pump: | Turbine |
| Power: | Electric motor (20 horsepower) |
| Yield: | 124 gallons a minute |
| Draw-down: | 13 feet after 24 hours of pumping |

Well 7

| | |
|---|---|
| Diameter: | 20 inches to 12 inches |
| Depth: | 140 feet (reported) |
| Driller: | McCarthy Well Company |
| Depth to water: | 51.72 feet below measuring point on May 5, 1944 |
| Measuring point: | Top of 4 inch hole in south side of concrete pump base which is 0.52 foot above concrete floor of pump house |
| Elevation of measuring point: | 314.02 feet above datum |
| Pump: | Turbine |
| Power: | Electric motor (20 horsepower) |
| Yield: | 130 gallons a minute |
| Draw-down: | 43.0 feet after 44.5 hours of pumping |

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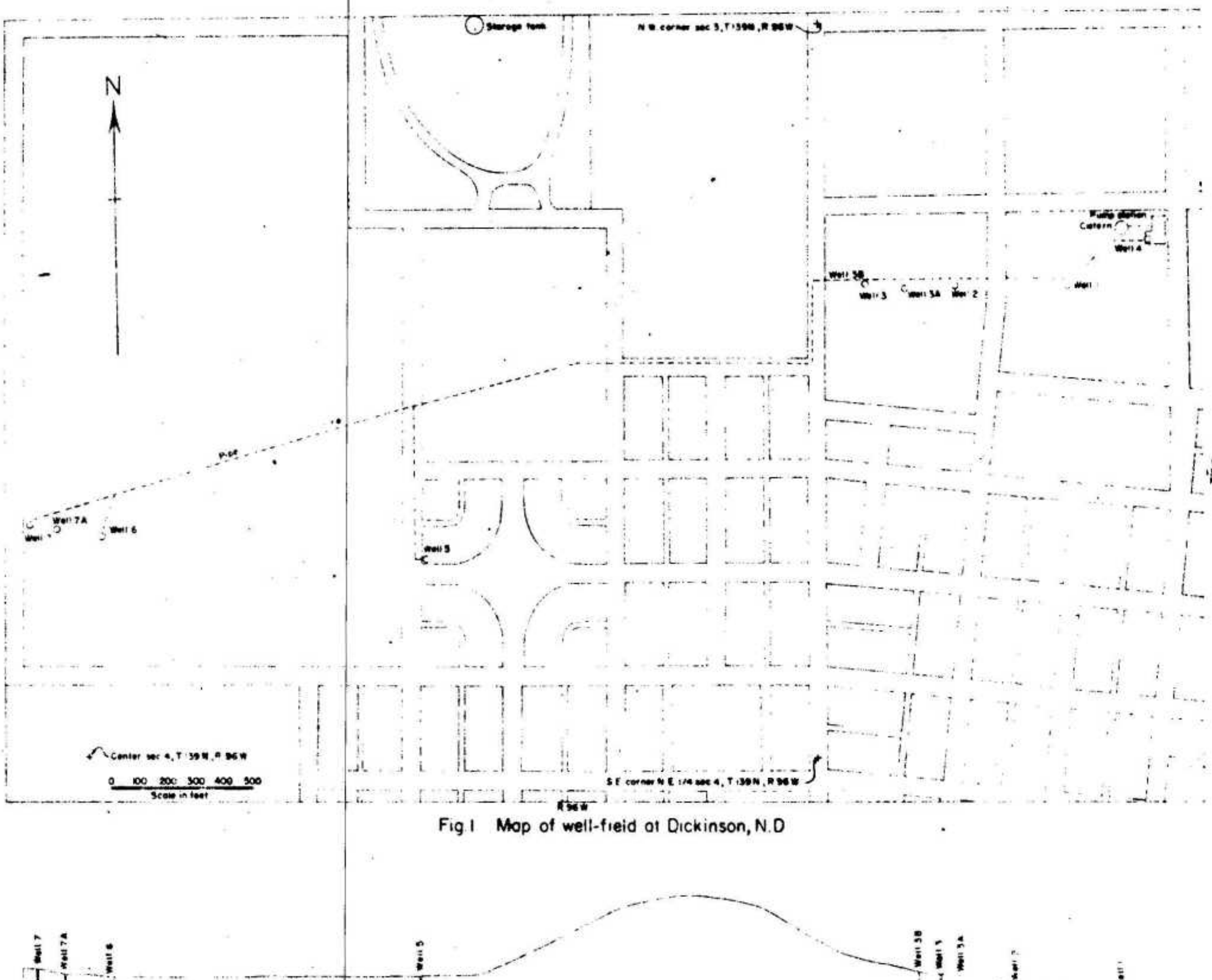



Fig. 1 Map of well-field at Dickinson, N.D.

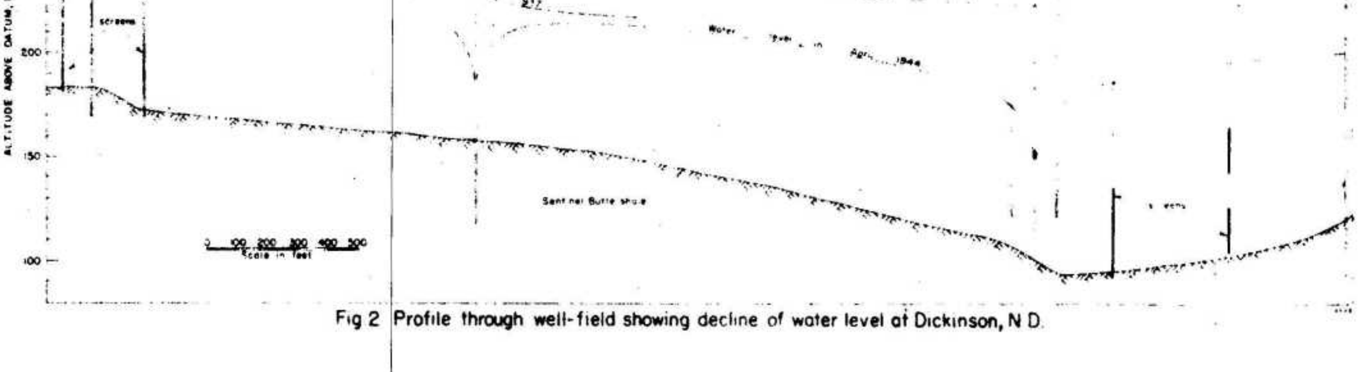
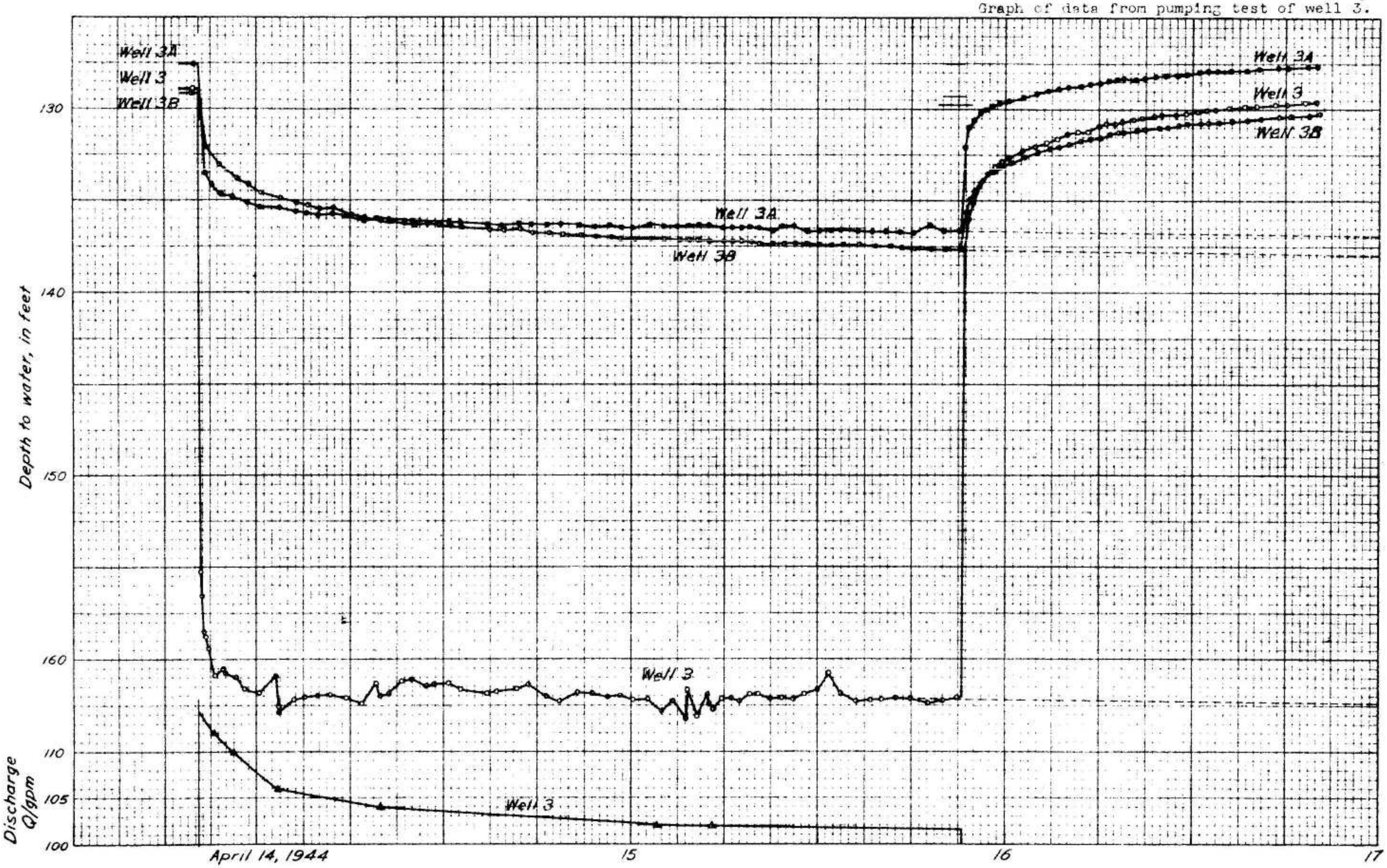



Fig 2 Profile through well-field showing decline of water level at Dickinson, N.D.

8590 Figure 3

Graph of data from pumping test of well 3.



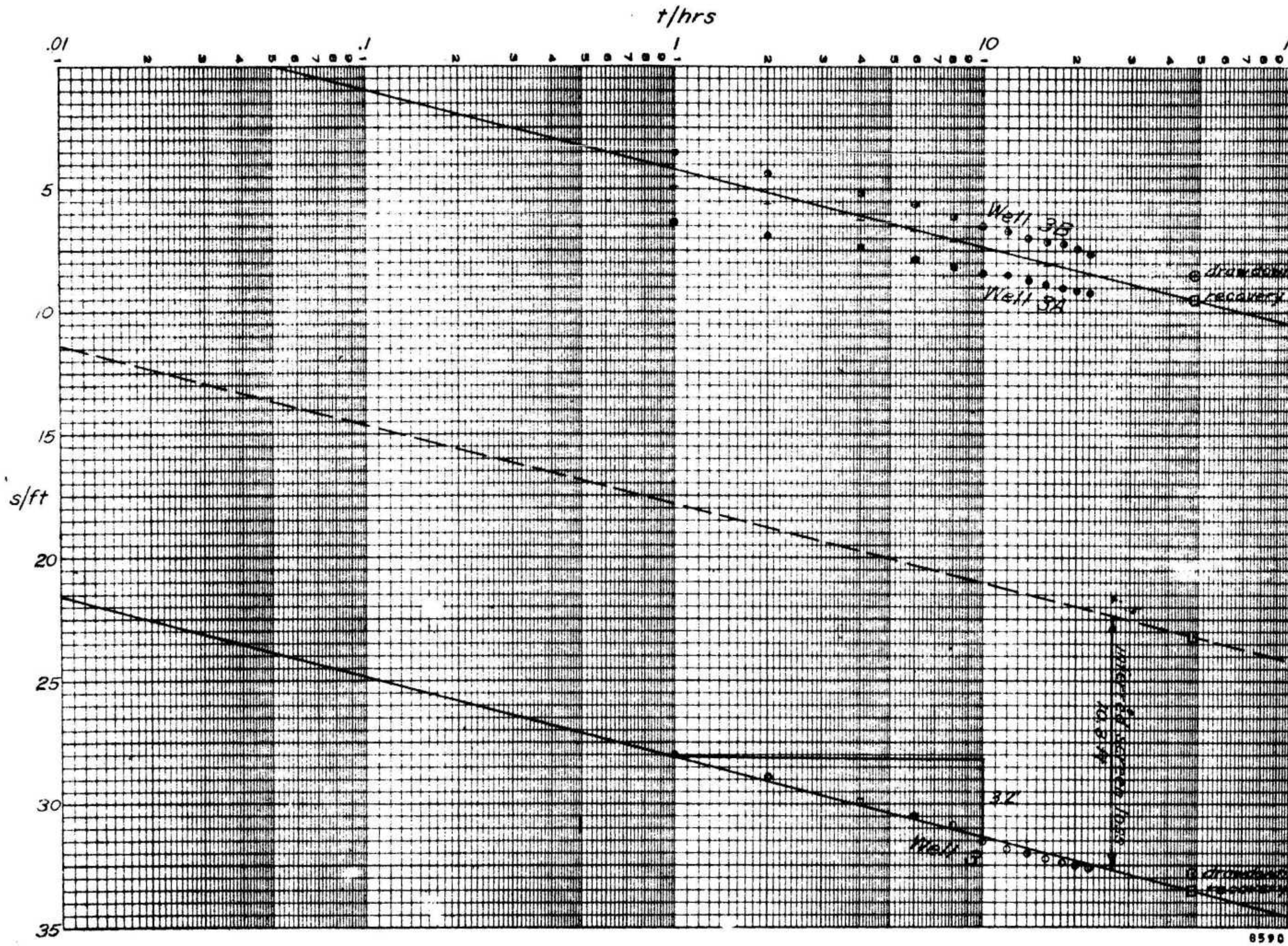



Figure 4

Time-drawdown graph for test of Well 3.

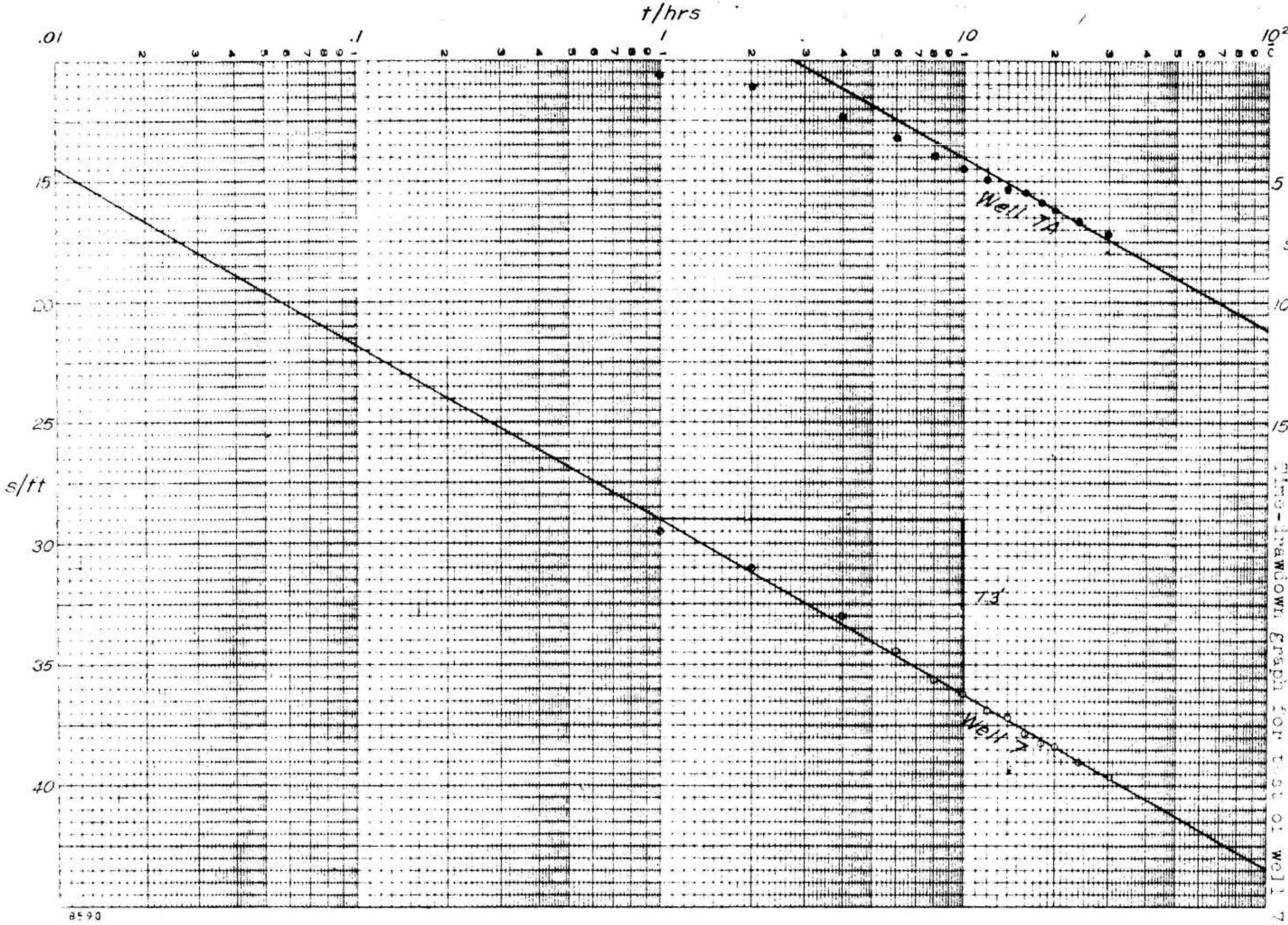



Figure 6
Time-drawdown graph for test of well 7.

Figure 5

Graph of data from pumping test of well 7.