GROUND WATER IN THE ZEELAND AREA MC INTOSH COUNTY, NORTH DAKOTA

By
Wilson M. Laird
State Geologist
North Dakota Geological Survey

With Chapters on Pumping Tests and Quality of the Water

By
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NORTH DAKOTA GROUND WATER STUDIES

NO. 12

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

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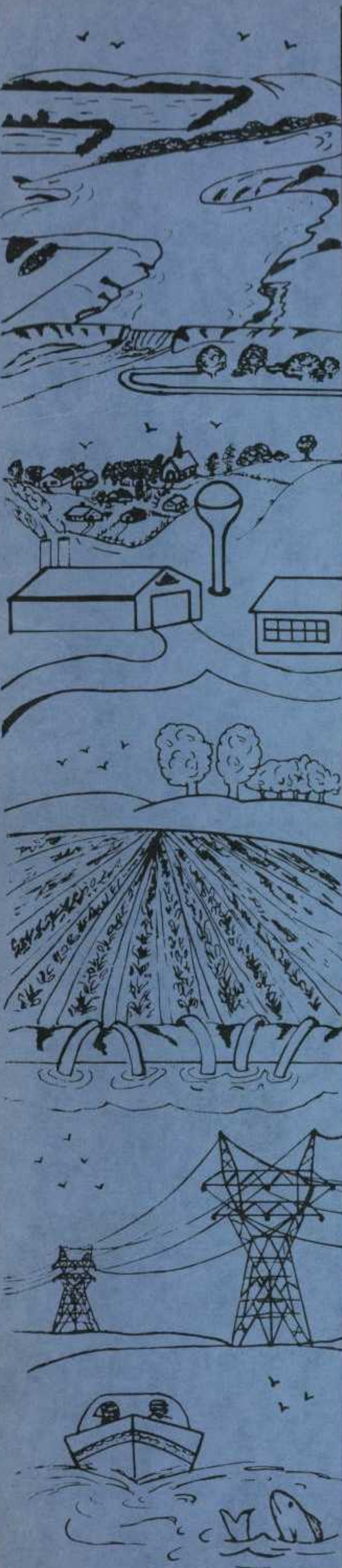

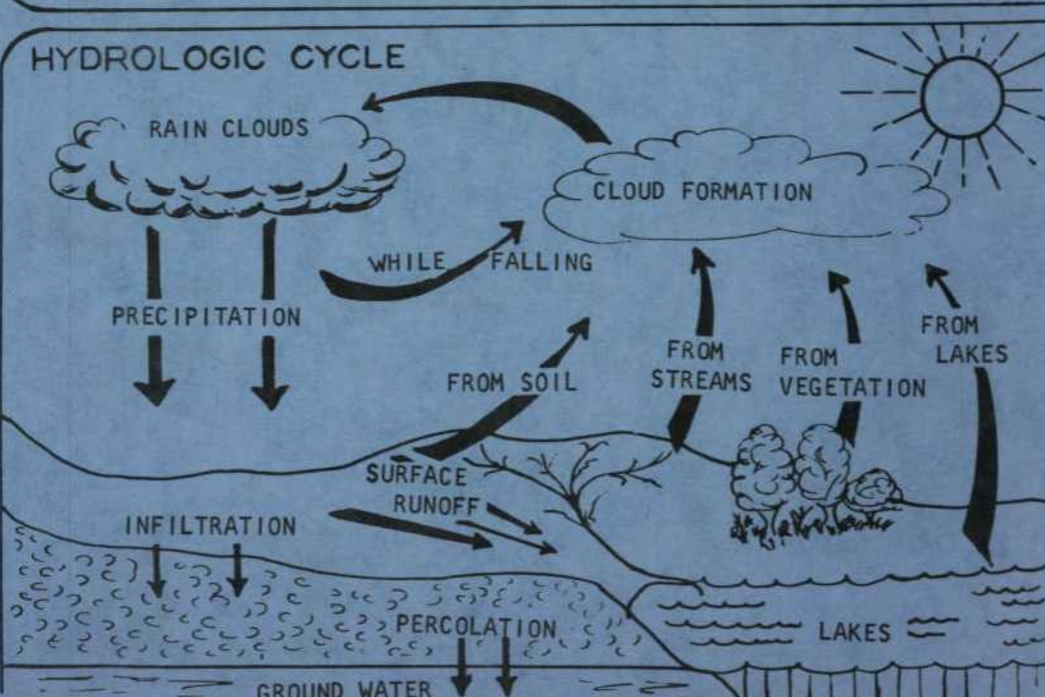

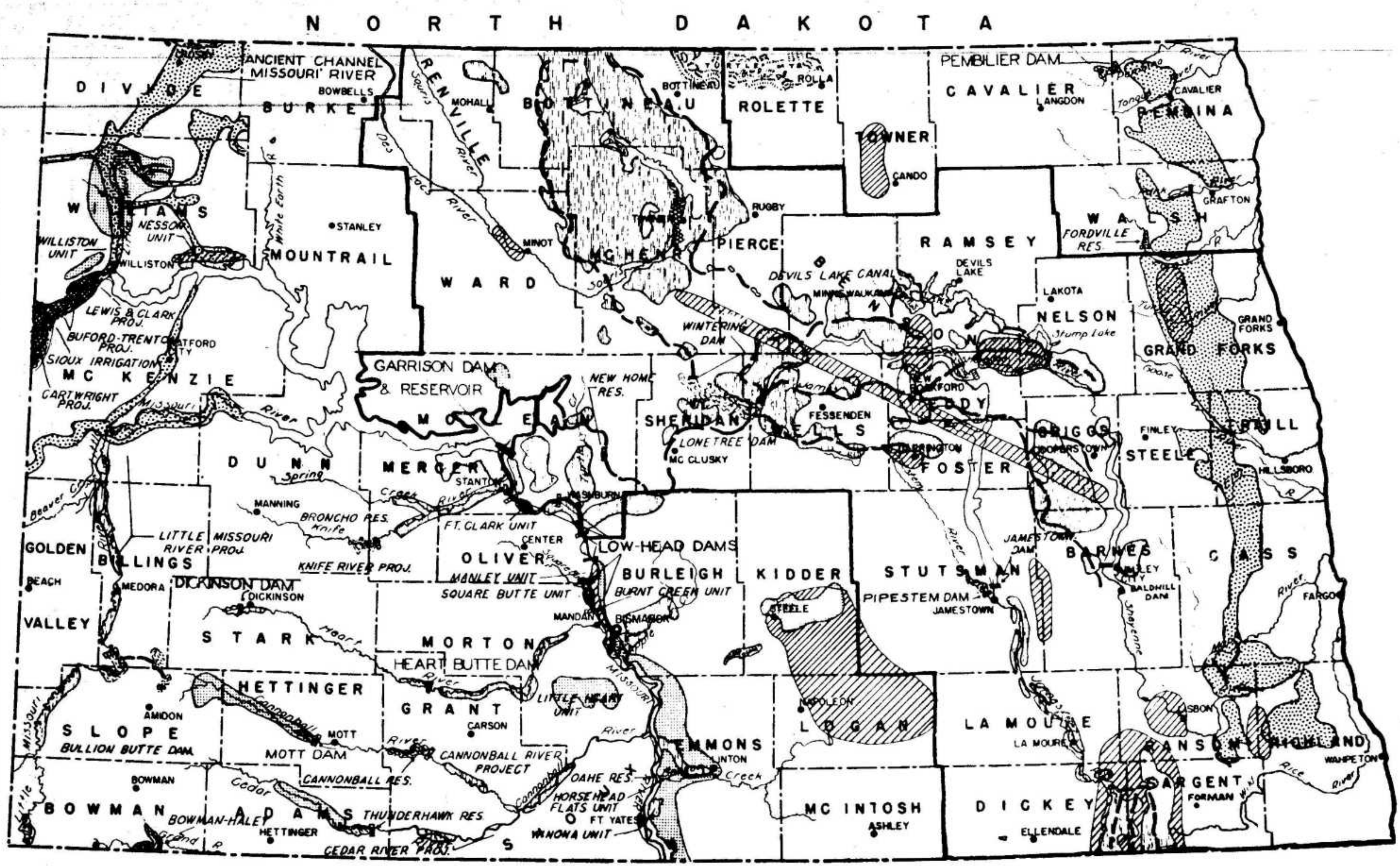

NORTH DAKOTA STATE WATER CONSERVATION COMMISSION

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

GARRISON DIVERSION CONSERVANCY DISTRICT BOUNDARY

GROUNDWATER AQUIFERS

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List of Illustrations

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GROUND WATER IN THE ZEELAND AREA, NORTH DAKOTA

By

Wilson M. Laird

State Geologist

ABSTRACT

The geology and ground-water resources of the Zeeland area were studied during the summers of 1946 and 1947. Water levels were measured in most of the wells in T. 129 N., R. 73 W. A water-table contour map and a map showing depth to water were prepared. A shallow aquifer yielding water of excellent quality is present about 2 miles west of Zeeland. The results of pumping tests on a single well in the aquifer indicate a transmissibility of about 9,000 gallons per day per foot and a storage coefficient of about 0.19. The failure of the well to recover completely its static water level after pumping and certain characteristics of the recovery curve suggest that the aquifer may be of limited extent, and more information is necessary to determine the perennial supply available from it. The data at hand suggest that a perennial yield sufficient for suitable municipal water supply for Zeeland is not available from it.

INTRODUCTION

In March 1945 the State Geologist received a letter from Mr. Wade Zick, secretary of the Zeeland Commercial Club, requesting that a study be made of the ground water in the vicinity of Zeeland, but owing to the pressure of other work it was not possible to undertake the investigation until the field season of 1946.

The field work on which this report is based was done by the State Geologist from June 21 to July 11, 1946, and by P. D. Akin of the United States Geological Survey from August 18 to August 28, 1947.

Location of the area

The city of Zeeland is in the SW$\frac{1}{4}$ sec. 21 and the NW$\frac{1}{4}$ sec. 28, T. 120 N., R. 73 W., in the southwestern corner of McIntosh County. In the course of the study, the whole area of T. 129 N., R. 73 W., was studied, as well as parts of adjacent townships in McIntosh and Emmons Counties.

Previous geologic investigations in this area

Very little geologic work had been done previously in this area and none of it is of detailed nature. Therefore, practically all the geologic and hydrologic information was gathered in the course of this study. An extensive search of the literature has not been made, but it is believed that the following references include practically all the significant geologic information published on the area.

One of the earliest reports is that of Todd. 1/ He notes that the southwestern township of McIntosh County is covered with a poorly developed and straggling portion of the Altamont moraine of Wisconsin age. He terms this portion of the moraine the Blue Blanket loop and notes that it is divided into two or three subsidiary loops which lie northward from the main trend of the Altamont moraine in South Dakota. Todd also suggests that the whole area is covered with a loam which, he says, is material resembling loess. According to him the elevation of the Blue Blanket loop declines from about 1,900 feet on the south to about 1,700 feet on the north.

1/ Todd, J. R., The Moraines of the Missouri coteau: U. S. Geol. Survey Bull. 144, pp. 21-31, 1896.

A. G. Leonard 2/ discusses this area in a generalized report on the south-central part of the State. However, most of his report deals with the area west of the Missouri River. In it he gives a general description of the geologic formations of the area. He states that the Lance formation directly underlies the glacial drift in western McIntosh County. He speaks of the glacial drift as "extra-morainic" inasmuch as it is outside the main area of the so-called Altamont moraine. He refers the drift provisionally to the Kansan stage. He mentions that most of the water wells in the area are in shallow gravel lenses in this drift.

In a later article Leonard 3/ revises his opinion of the age of the drift east and north of the Missouri River, assigning it to the early Wisconsin.

Daniel E. Willard 4/ in his popular books says very little specifically about this area, although he does mention that the drift west of the Altamont moraine is older and represents deposits from an earlier glacial stage (probably pre-Wisconsin).

Howard E. Simpson 5/ in his report on the ground-water resources of North Dakota notes that the whole area of McIntosh County is underlain by the Pierre shale of Cretaceous age, but that this is overlain in the western half of the county by the Lance formation of Tertiary (?) age. He notes that water is obtained from gravel and sand in the drift and from bedrock; the water from the drift being hard with varying mineral content and that from the bedrock being soft but often highly

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2/ Leonard, A. G., The geology of south-central North Dakota: North Dakota 6th Bienn. Rept., pp. 27-99, 1912.

3/ Leonard, A. G., The pre-Wisconsin drift of North Dakota: Jour. Geology, vol. 24, p. 532, 1916.

4/ Willard, D. E., The story of the prairies, 10th ed., 375 pp., 1923.

5/ Simpson, H. E., Geology and ground-water resources of North Dakota: U. S. Geol. Survey Water-Supply Paper 598, pp. 161-163, 1929.

mineralized his table, on page 163, shows the wells in Zeeland to be generally bored wells from 40 to 160 feet deep, 60 feet being the most common depth.

Acknowledgments

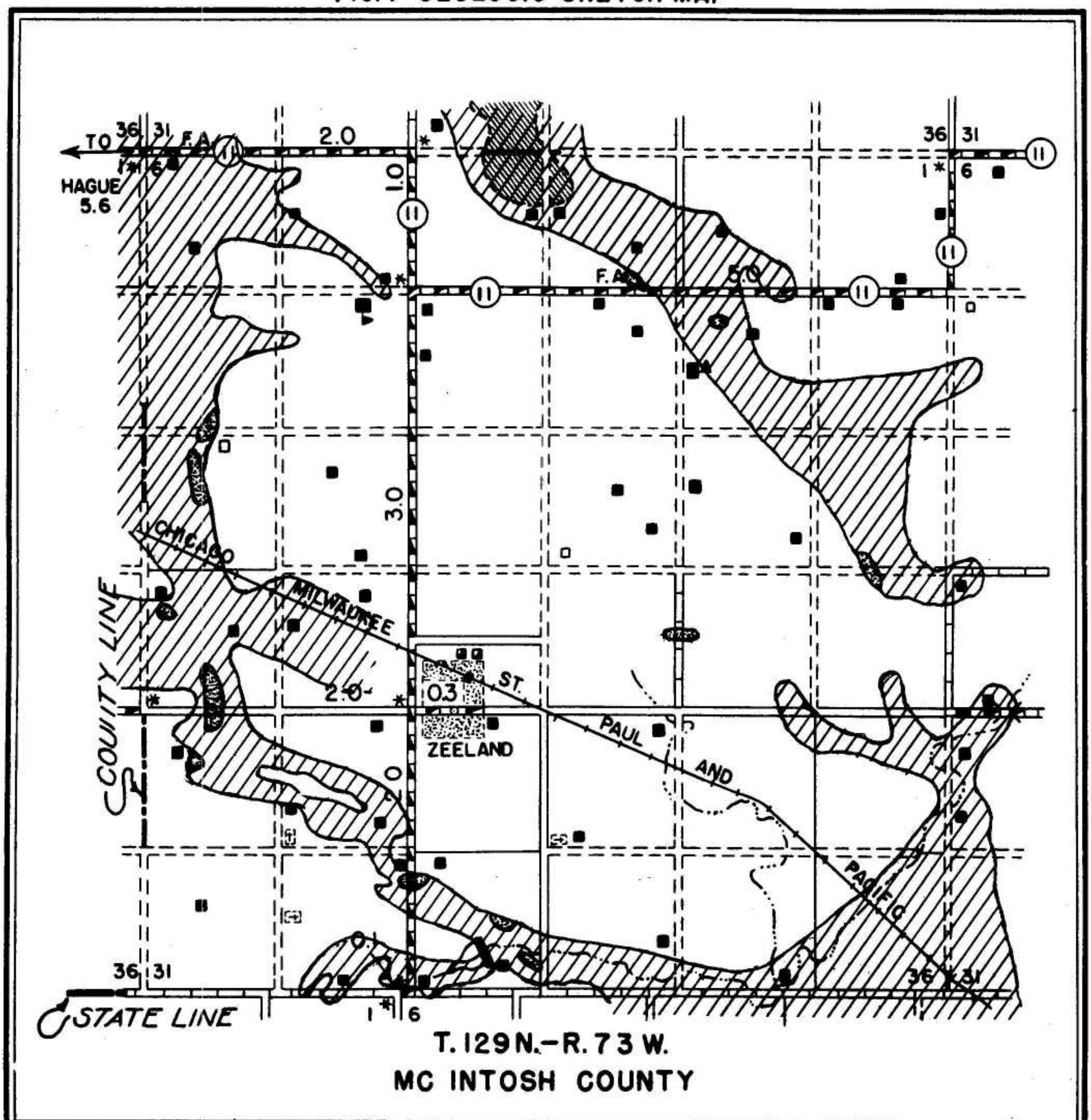
This study was materially aided by a number of people in the Zeeland community. Special thanks are due the late Mr. M. M. Braun, Mayor of Zeeland, who devoted much time to obtaining the driller and needed equipment, as well as assisting in making well measurements. Much assistance was also given by Mr. John Jangula, driller, and Mr. Tony Klein, driller's helper, in the drilling operations. Thanks are also due to members of the city council, notably Mr. Ben Wolf, the present mayor, who gave much help and encouragement in the course of the work, and to Mr. Edwin Boschee, on whose land the best test hole is located.

PHYSIOGRAPHY

A large recessional moraine crosses the township in which Zeeland is located, trending in a northwesterly direction. (See geologic map, fig. 1.) A smaller and probably closely related recessional moraine crosses the southwesternmost corner of the township. The topography of these morainal areas is only slightly rolling and no distinct knobs and kettles are present.

Between the two morainal areas is a low, elongate depression which extends through secs. 13, 19, 29,30,32,33,and 35, of T. 129 N., R. 73 W. This has the appearance of a stream valley, but no through stream now occupies it, although water does stand in the lower depressions of the slough during much of the year, particularly during wet years. Low and indistinct divides are present, transverse to the trend of the slough, and inhibit through drainage. The general shape of the

FIG. 1-GEOLOGIC SKETCH MAP



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EXPLANATION

TILL (EXPOSED) (MAINLY MORAINAL AREA)

TILL (UNEXPOSED) (COVERED BY THIN VENEER OF ALLUVIUM IN SLOUGH)

KAME OR ESKER DEPOSIT

slough suggests a preglacial stream channel which was filled unequally during the glacial period with glacial drift and glaciofluvial deposits of gravel and sand. Gravel deposits of some size are present in and along the sides of this valley, particularly in secs. 18, 29, 30, and 33. The largest and cleanest deposits are found in secs. 29 and 30.

Another elongate depression trending in a northwesterly direction crosses the northeastern corner of the township. This slough-like area crosses parts of secs. 3, 10, 11, 12, 13, 14, and 24. It is separated by a low, rolling divide trending at an angle across the slough from another similar slough located in secs. 25, 26, and 36 which appears to be a continuation of the above-mentioned depression and trends in the same general direction. The divide mentioned between these sloughs is probably a part of the main morainal area. The depression separates the main morainal area running through the center of the township from a similarly trending moraine to the northeast. The slough in the northeastern corner of the township does not appear to have been as active a channel for glaciofluvial action as the one in the southwestern corner of the township, as far fewer deposits of gravel are associated with it.

GEOLOGY

Glacial Till

The glacial till of this area is primarily a blue clay with pebbles of Pierre shale and of limestone, dolomite, and some crystalline rocks. The Pierre shale, the bedrock, probably contributed much of the clay matrix as well as shale pebbles. The till has such a variable thickness that measurements of specific sections have only general significance. It ranges from about 10 feet to nearly 100 feet, although the average probably is less than 50 feet. 6/

Glaciofluvial material

The glaciofluvial material of this area consists of gravel deposit which form kames and eskers, located mainly in secs. 18, 19, 29, 30, 33, T. 129 N., R. 73 W. In textural composition these deposits range from sand to pebbles as much as a foot or more in diameter. The grains and pebbles consist primarily of limestone, dolomite, crystalline igneous and metamorphic rocks, and shale. The thickness of these deposits ranges from about 3 to 40 feet, the thickest deposits being located on the Boschee farm in sec. 30, T. 129 N., R. 73 W.

The erratic location of these deposits along the sides of the valleys and the rather poor sorting which most appear to have undergone suggest that they are of the kame terrace type of deposits,laid down at the time the ice was stagnated in this valley after the main forward motion of the ice in a southward direction had ceased. At this time the ice was melting and streams in all probability were running along the edges of the ice carrying away the meltwater and depositing the material being set free by the melting. Explaining the origin of the gravel deposits in this way accounts for their position on the sides of the valley. However, some of the gravel deposits are located in the center of the valley, and these can be explained by attributing them to deposition of material of subglacial streams running beneath the waning ice sheet. This type of deposit is called an esker.

6/ Recent atudies made by R. F. Flint in South Dakota indicate that the age of this till is late Wisconsin.

A thin layer of sand and gravel is present over the surface of the slough. It may have been washed there from the kame terraces and esker deposits since the ice melted. Small amounts of water are present in these deposits also, but the gravels and sands are so thin that they do not make adequate aquifers. The relationships of these kame and other glaciofluvial materials can be seen in figures 1 and 5.

Pierre shale

Several test holes drilled during this investigation encountered the Pierre shale immediately beneath the glacial drift; this occurrence is confirmed by reports on other holes drilled by the local drillers. Previous reports have suggested the presence of the Lance formation beneath the drift in the western part of McIntosh County in the vicinity of Zeeland, but no evidence was obtained in the current study that indicated the presence of the Lance formation.

The Pierre shale is a micaceous dark-gray shale often containing abundant pyrite and selenite. In some parts of the State thin sand lenses are present, but no direct or indirect evidence was obtained to indicate that such lenses occur in this area. The formation was not observed in outcrop anywhere in the area investigated but was found in test holes to underlie the glacial drift at shallow depths. "Quicksand" is reported in a number of wells which penetrate only the upper part of the shale, and it is suggested that the quicksand may be a weathered soil profile on the Pierre developed in preglacial times. This origin is suggested by the absence of pebbles and grains of any rock material other than Pierre shale.

The exact thickness of the Pierre shale in this area is not known because wells have penetrated only its upper portion. However, in the Northern Ordnance

Franklin Investments No. 1 well, located in the NW¼SW¼ sec. 35, T. 133 N., R. 75 W., the shale is reported to be 1,010 feet thick. 7/

The Pierre shale disconformably underlies the glacial drift and evidence from other areas indicates that a mature topography was developed on the shale prior to the deposition of the glacial drift. The relation of the shale to the underlying formations in this area is not known.

Fossils were found in a few samples drilled in the shale. They appear to be pelecypods, gastropods, and cephalopods.

The Pierre shale is not a good aquifer. The sand lenses which it contains in other areas transmit water very slowly as a rule, so that they yield only limited quantities to wells. No water-bearing sand lenses were encountered in the test holes drilled during the course of this study and none are reported from other wells in the immediate area. In some places a limited quantity of water is obtained from the "quicksand" at the top of the shale, but the supply is much too small to meet the needs of a municipality.

WATER-TABLE CONDITIONS

During the course of this investigation the depth to water in nearly every well in the township was measured. Where possible, the depth of the well also was measured. The altitude of the measuring point at each well was established by means of a Paulin altimeter reading to 2 feet. Each elevation was tied in to a bench mark at Zeeland which is 2,013 feet above sea level and was carefully corrected for diurnal pressure variations. The base map used was that of the State

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7/ Laird, W. M., Stratigraphy and structure of North Dakota: North Dakota Geol. Survey Bull. 18, p. 10, 1944.

FIG. 2- WATER-TABLE CONTOUR MAP
(BASED ON SEA-LEVEL DATUM)

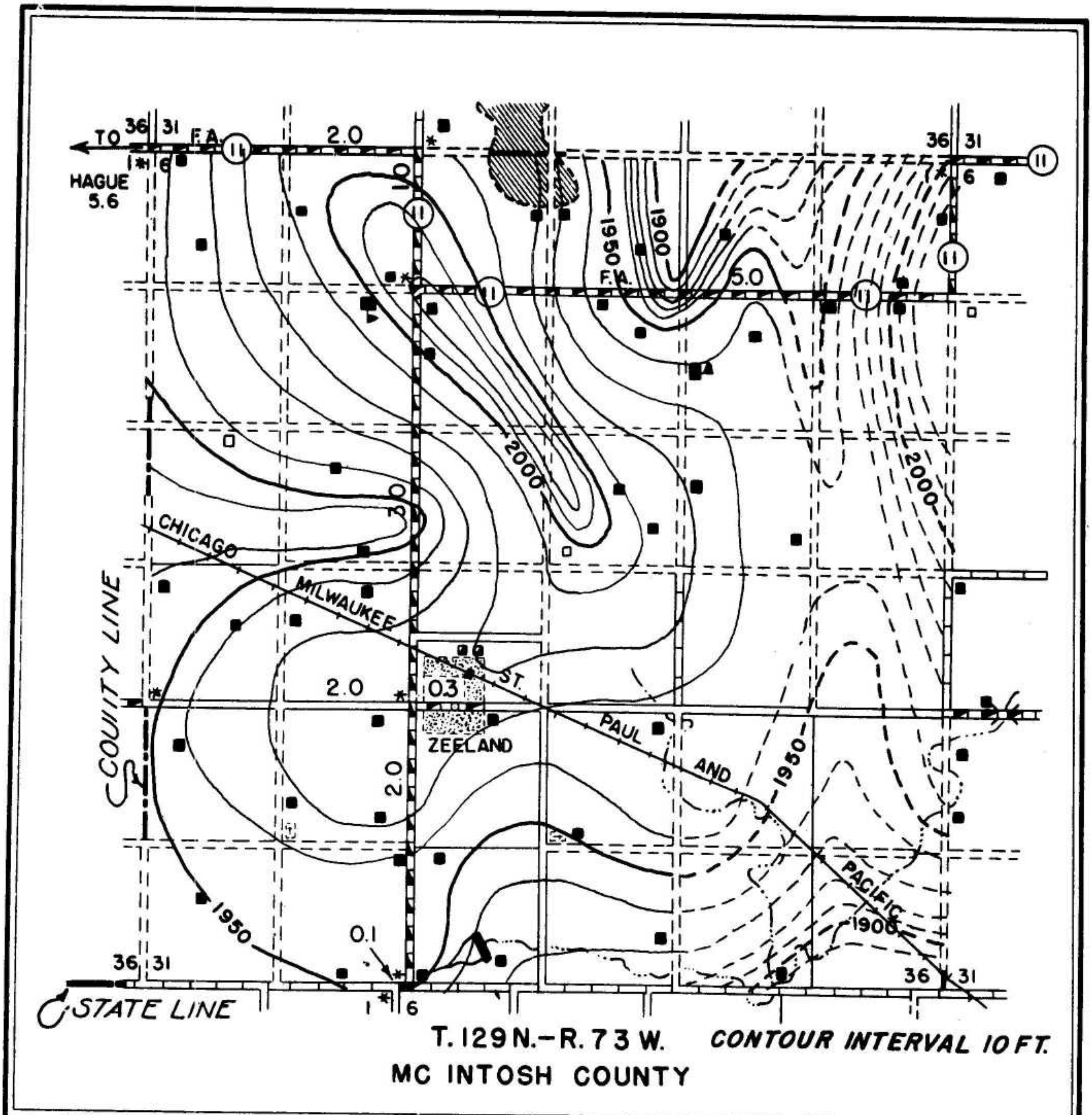

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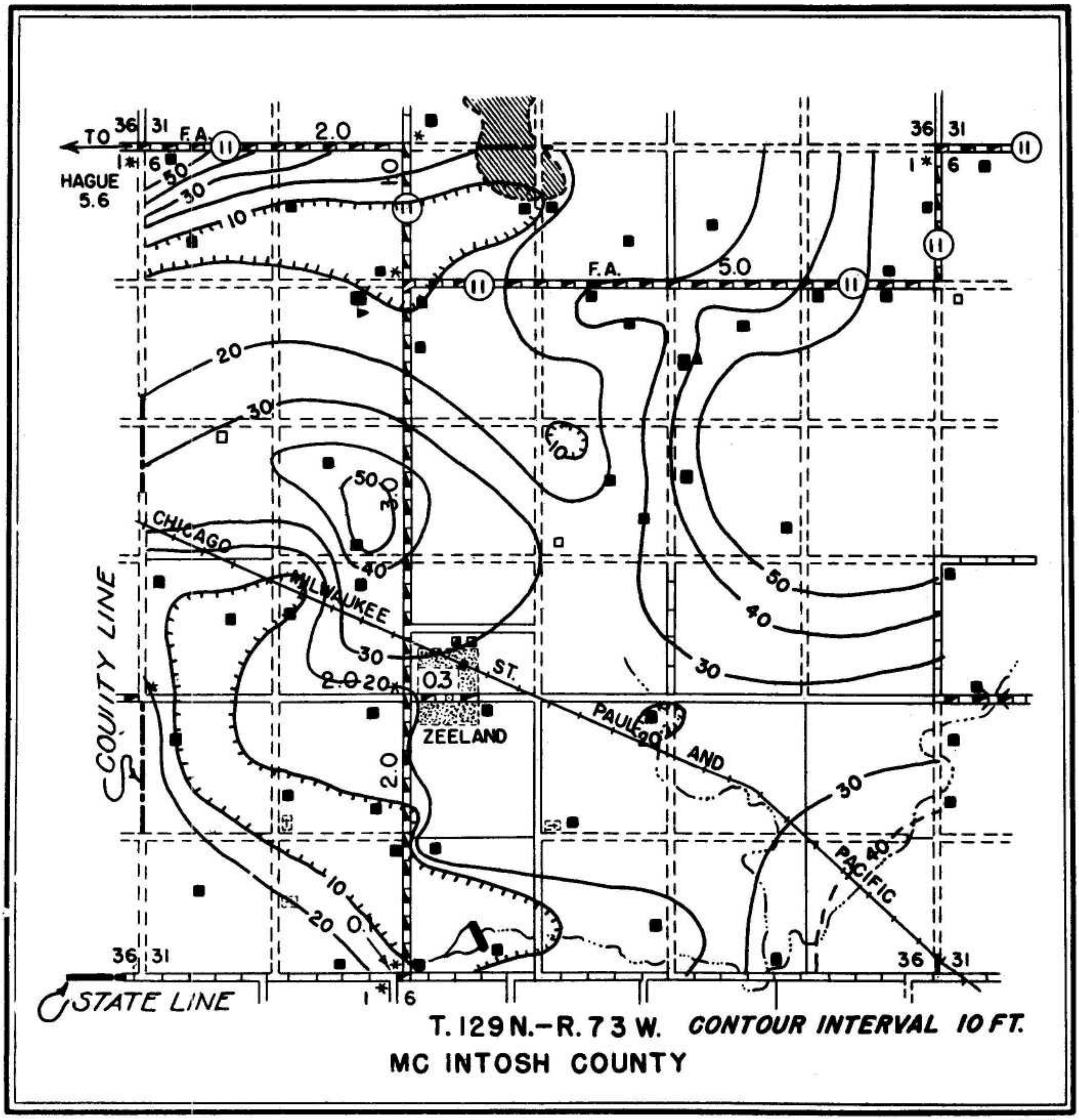
FIG. 3-DEPTH TO WATER BELOW LAND SURFACE



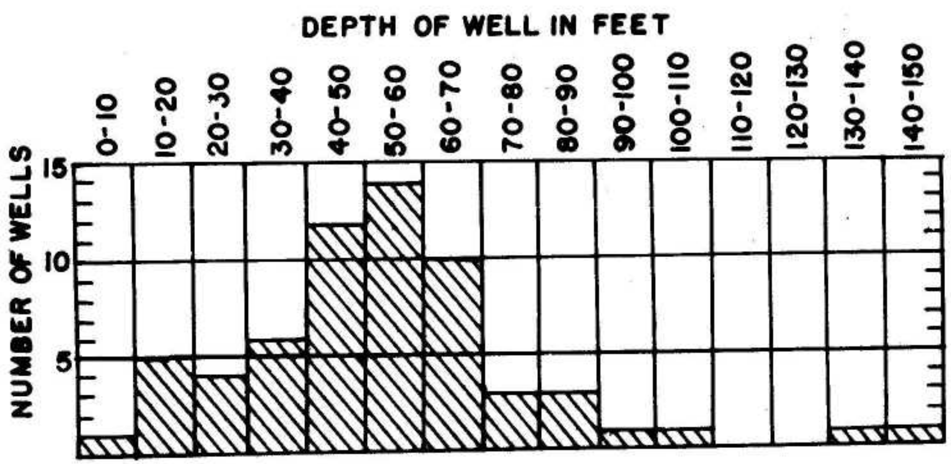


FIG. 4—NUMBER OF WELLS OF VARIOUS DEPTHS. T. 129 N. R. 72 W.

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Highway Department, which has a scale of 1 inch to the mile. All geologic and ground-water data were originally plotted on this base (fig. 2).

From the ground-water information gathered, two maps were made (figs. 2 and 3). One of these maps shows the altitude of the water table in the township. In general, as might be expected, it follows the relief of the land surface in a subdued fashion. The other map shows the depth to the water table below the surface. When both of these maps are studied together, it will be observed that the water table lies at a greater depth below the hills than in the valleys.

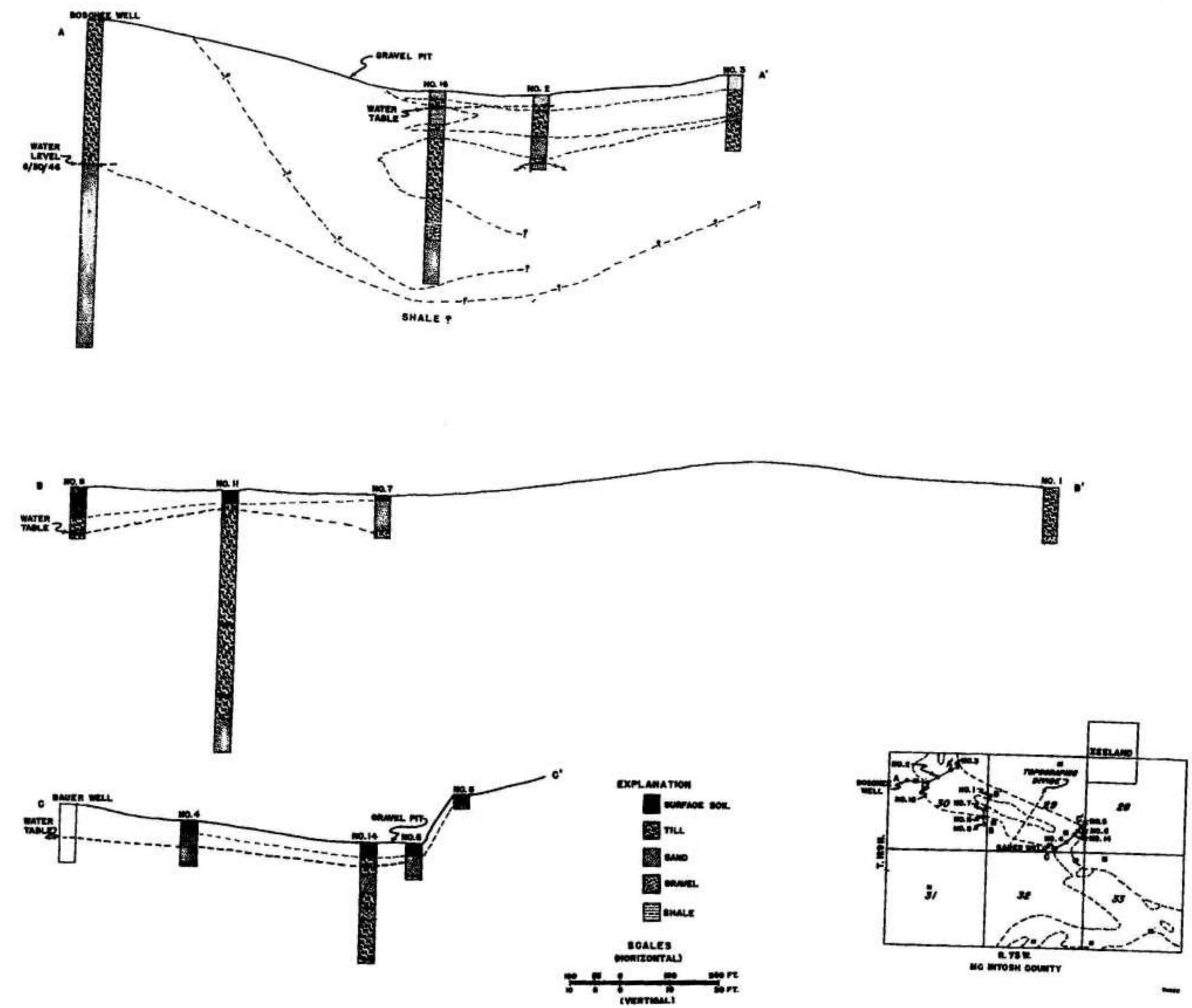
Figure 4 shows that the greatest number of wells in this township are between 40 and 70 feet deep. This would suggest that more water is found at these depths than elsewhere. However, when the distribution of these wells is known it is found that more wells are located on the higher ground (where it is necessary to go deeper to get water) than in the lower areas, such as the slough areas where the water table is nearer the surface. Furthermore, many of the wells in the higher area cannot be regarded as adequate. A glance at the water-table map will show that those wells located in the central portion of the township are situated in areas from which the ground water is moving toward the lower areas, where the water table is nearer the surface. Thus it would appear that the best location for a permanent city supply would be in one of these lower areas toward which the ground water is moving.

All water found in the ground is derived directly or indirectly from rainfall and snowfall. Therefore the precipitation of any area is important in making calculations as to the amount of water that will become available to a well. This precipitation not only falls on the area in the immediate vicinity of the well and thus recharges the well, but also may travel some distance underground to the well. All the water which thus sinks into the ground anywhere that affects the aquifer in question is collectively known as recharge.

In addition to the necessity of having the underground water body recharged, it is also necessary to find a suitable aquifer in which the ground water can be stored and through which it will flow readily to the well when completed. The wells situated in the higher parts of the Zeeland area for the most part do not have adequate aquifers for the storage of the water, as most of the area is covered with an impermeable glacial till in which only a few gravel pockets are locally present. Some of the wells of the topographically higher areas obtain their water from the "quicksand" at the top of the Pierre shale. At no place in the area were large quantities of water reported available at this horizon. On the other hand, however, the gravels and sands mentioned in the kame terraces found in sec. 30, T. 129 N., R. 73 W., are permeable and allow for considerable storage.

Although most of the ground water in this area appears to be free or unconfined (occurring under water-table conditions), it appears that in the kame terrace in sec. 30 there is a slight artesian head. This head is not enough to make the wells flow but it is enough to raise the static water level very near the surface. By reference to figure 5 it will be noted that west of well 10 there is a considerable body of gravel which is exposed at the surface in a gravel pit only a few feet from the well. It is suggested that the lower portion of this gravel, where it lenses out beneath the slough, is saturated with

FIG. 5 - GEOLOGIC SECTIONS NEAR ZEELAND, N. DAK.



water and that the clays overlying the slough edge of this gravel are impermeable enough to seal the water in the gravel body, thus giving rise to a slight artesian head in the aquifer.

It is reasonable to inquire why some location in the city was not chosen as a site for further investigation. The answer is twofold. In the first place, there are at present no wells of both good quality and good quantity within the city boundaries. Secondly, a number of residents are using old wells for sewage disposal. As most of the wells appear to be drawing water from approximately the same horizon and as this horizon is apparently the only one of any capacity within the city limits, this would constitute a sanitary problem of some magnitude.

TEST DRILLING

The test drilling in this area was done by means of a hand-operated 4-inch post-hole auger with extensions and a horse-powered boring machine. The horse-powered boring machine was operated by Mr. John Jangula, Jr. It was equipped with a 3-foot kettle, a $2\frac{1}{2}$-foot and an 8-inch kettle. In most cases, the holes were drilled with the $2\frac{1}{2}$-foot kettle to a depth of about 10 or 12 feet, below which the 8-inch kettle was used.

This machine operated satisfactorily so long as there was little or no water in the hole. If considerable water was present in the hole the material washed out of the kettle as it was being pulled to the surface. Therefore, it is impossible to enter far into a productive water-bearing formation such as that encountered on the Edwin Boschee farm in sec. 30 (test wells 10 and 16). Samples obtained with this machine were very representative of the materials above the principal water-bearing beds, but very poor samples of only the uppermost part of the water-bearing gravel itself were obtained for study.

Because the till hills offered little promise of containing important aquifers, the test drilling was confined to the slough areas, and test drilling was begun in sec. 30. Auger holes (Nos. 2 and 3) bored with a hand-operated 4-inch post-hole auger were put down along line A-A' of figure 5. This preliminary augering disclosed the presence of shallow water-bearing sands and gravels, so it was determined that a machine-drilled hole would be placed just below the gravelpit at the foot of the slope and only slightly above the general level of the slough bottom. The log of this test hole (No. 10) drilled to a depth of 36 feet is given on page 31 of this report.

After drilling a number of other test holes described below it was decided that the first location drilled was the most promising and the rig was returned to that location, where an attempt was made to go deeper. During the last attempt one hole was drilled to a depth of 15 feet but was stopped at that point by a large rock. Another hole was started a few feet away and drilled to a depth of 31 feet. The log of this hole (No. 16) can be found on page 34. This hole was cased with wood and subjected to a short pumping test.

Another series of auger holes (Nos. 1, 7, 8) were placed across the depression extending southeast in sec. 30 along line B-B', along the road on the section line between secs. 29 and 30. The logs of these holes are shown in figure 5. As a result of this preliminary augering, a hole was machine-drilled in the NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 30, T. 129 N., R. 73 W., to a depth of 54 feet. The log of this well (No. 11) can be found on page 31 of this report.

A series of auger holes were drilled by hand in a north-south line along line C-C' (Nos. 4, 5, 6) of figure 5, in the SE$\frac{1}{4}$ sec. 29. A machine-drilled test hole (No. 14) was bored here to a depth of 25.5 feet, the Pierre shale being found in the bottom of the hole. A log of this hole can be found on page 33 of this report.

A preliminary auger hole (No. 9) was drilled in the SE$\frac{1}{4}$ sec. 33, T. 129 N., R. 73 W., and two machine-drilled test holes were put down in this quarter section. One hole (No. 12) was drilled near the east line of the quarter section to a depth of 30 feet, where the Pierre shale was encountered. The other (No. 13) was drilled near the northwestern part of the quarter section, behind the barn of Mr. Andrew Knowles, to a depth of 40 feet and apparently reached the "quicksand" on the top of the Pierre shale. There the hole was abandoned, owing to the fact that the kettle of the rig could not take out the sand because of the water in the hole. In both of these holes water was encountered only at shallow depths and apparently in limited quantities.

PUMPING TESTS

By P. D. Akin

Descriptions of the tests

The pumping tests described in this section were made on a well constructed by the City of Zeeland as a potential supply well during the early part of January 1947. It was drilled by the Independent Drilling Company, Aberdeen, South Dakota. It is located 14.4 feet approximately southwest of test hole No. 16 described in this report, in the NW$\frac{1}{4}$ sec. 30, T. 129 N., R. 73 W. It is 41 feet deep. The lower 15 feet of the well is screened and upper section is cased with 8-inch standard galvanized iron pipe. The following is a driller's log of the material penetrated:

Material	Thickness (feet)	Depth (feet)
Clay and sand	25	25
Gravel, coarse	5	30
Sand, coarse	11	41

Detailed descriptions of the samples of material taken from the well are included in the section on well logs.

The pumping tests were made by the writer from August 18 to 28, 1947. The well was pumped at a rate averaging 107 gallons a minute for a period of about 43 hours. There was some difficulty in starting the pump and setting the discharge to the desired rate, and for this reason there was a small amount of pumping a few hours prior to the actual beginning of the test. Water-level measurements were made at intervals in the pumped well with a steel tape. A Friez FW-1 water-level recorder was installed on test hole 16, which is 14.4 feet from the pumped well. The well-level recorder was operated with daily time gears (1 hour= 0.45 inch)during the pumping period and for 23 hours after pumping was stopped. The recorder was then set to operate with weekly time gears (24 hours = 1.8 inches) and the recovery of the water level in the observation well was observed for a full week following the pumping period.

During the first 5 minutes of pumping the rate of drawdown in the observation well was checked by using a stop watch in connection with the water-level recorder. Frequent watch readings were taken for about 30 minutes after pumping started. The same procedure was followed to obtain the early part of the recovery curve after the well was turned off.

Figure 6 shows the position of the water level in the observation well during the pumping period and during the following week. Also shown is the water level in the pumped well and the rate of pumping as measured during the test.

Computation of coefficients of storage and transmissibility

Two important hydraulic characteristics of an aquifer generally can be computed from the results of pumping tests. They are (1) the coefficient of transmissibility and (2) the coefficient of storage. The coefficient of transmissibility, as here used, is defined as the number of gallons of water which will move in 1 day through a vertical strip of the aquifer 1 mile wide under a hydraulic gradient of 1 foot per mile. It is a measure of the relative ease with which water can be transmitted through the aquifer.

The coefficient of storage is defined as the volume of water in cubic feet that will be released from storage in each column of the aquifer having a base of 1 square foot when the water level drops 1 foot.

An expression relating the drawdown of the water level in the aquifer due to pumping a well to the hydraulic coefficients, the duration and rate of pumping, and

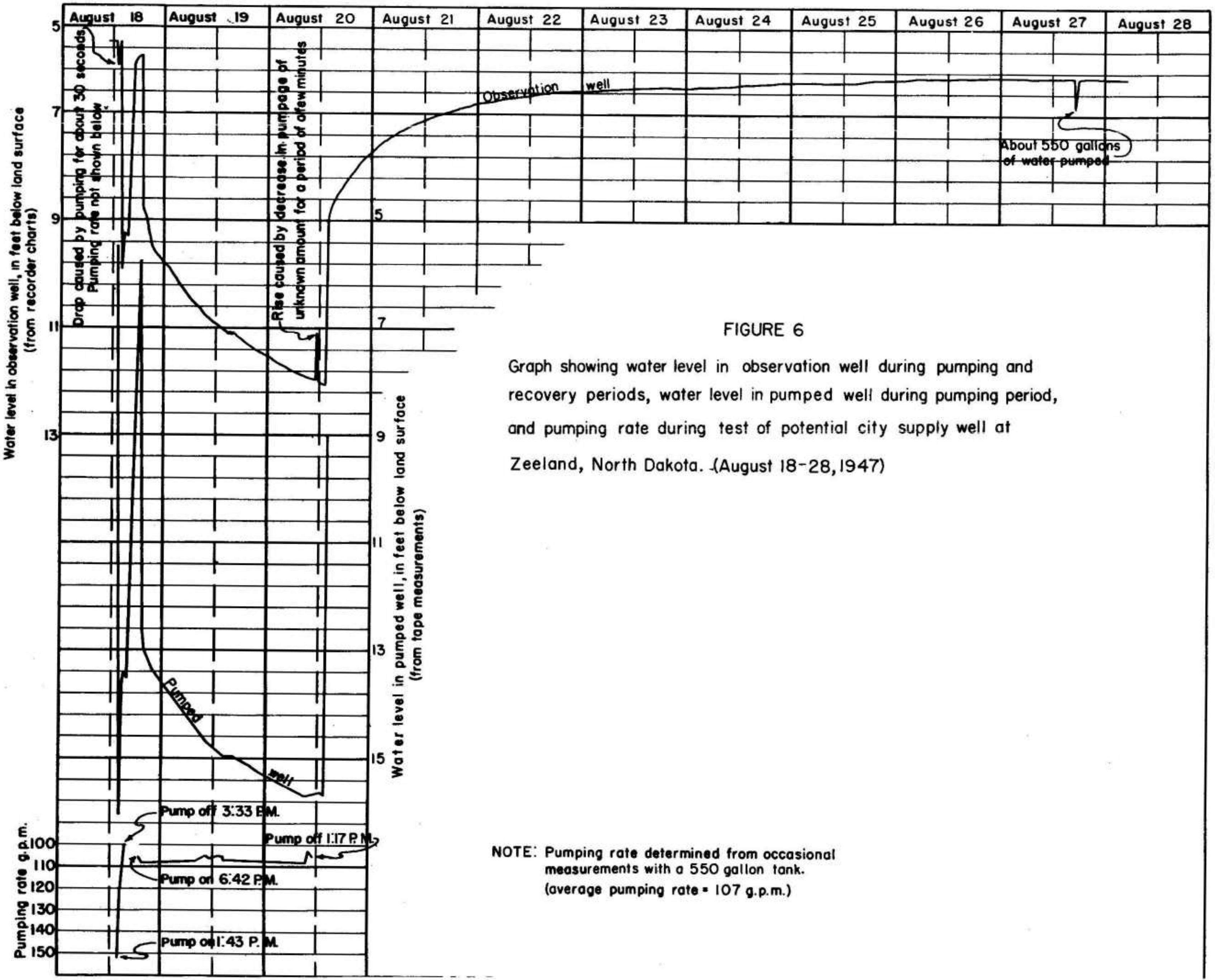


FIGURE 6

Graph showing water level in observation well during pumping and recovery periods, water level in pumped well during pumping period, and pumping rate during test of potential city supply well at Zeeland, North Dakota. (August 18-28, 1947)

NOTE: Pumping rate determined from occasional measurements with a 550 gallon tank. (average pumping rate = 107 g.p.m.)

the distance from the pumped well to the point where the drawdown is measured is:

$$s = \frac{114.6\ Q}{T} \int_{u}^{\infty} \frac{e^{-u}}{u}\, du \qquad \underline{8/}$$

Where $u = \frac{1.87\ r^2\ S}{Tt}$

Where s = drawdown, in feet
Q = pumping rate of well, in gallons per minute
T = coefficient of transmissibility, gallons per day per foot
S = coefficient of storage
r = distance from pumped well to point where the drawdown is observed, in feet
t = time since pumping of well began, in days.

There are several methods of computing the coefficients of storage and transmissibility from this equation and from approximate expressions derived from it. The coefficients of transmissibility and storage were computed by several methods in order to ascertain whether any boundaries or marked changes in the character of the aquifer are present near the well which might be recognized by the nature of the results obtained.

It has been shown 9/ that when the water level is dropping at its greatest rate, the values of "u" in the foregoing equation will be 1. That is:

$$u = \frac{1.87 r^2 S}{Tt} = 1 \text{ when } \qquad \frac{\partial s}{\partial t} = \text{maximum}$$

Also, when u = 1

$$\int_{u}^{\infty} \frac{e^{-u}}{u}\, du = 0.2194$$

8/ Theis, C. V., The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage: Am. Geophys. Union Trans., p. 520, 1935.

9/ Jacob, C. E., On the flow of water in an elastic artesian aquifer: Am. Geophys. Union Trans., p. 581, 1940.

$$\text{and } s = \frac{114.6\ Q}{T} \times 6.2194 = \frac{25.14\ Q}{T}$$

$$\text{or } T = \frac{25.14\ Q}{s}$$

From the early part of the drawdown curve, when values of s and t at the observation wells were obtained with a stop watch, it was estimated that:

$$\left.\begin{array}{l} s = 0.42 \text{ foot} \\ t = 42 \text{ seconds} \end{array}\right) \text{--when } \frac{\partial s}{\partial t} = \text{maximum;}$$

also $r = 14.4$ feet
$Q = 107$ gallons per minute;

then $T = \dfrac{25.14 \times 107}{0.42} = 6{,}410$ gpd/ft.

$$S = \frac{6{,}410 \times 42}{86{,}400 \times 1.87 \times 207.4} = 8.03 \times 10^{-3}$$

From the early part of the recovery curve it was estimated that:

$$\left.\begin{array}{l} s = 0.46 \text{ foot} \\ t = 40 \text{ seconds} \end{array}\right) \text{--when } \frac{\partial s}{\partial t} = \text{maximum}$$

and $T = \dfrac{25.14 \times 107}{0.46} = 5{,}840$ gpd/ft.

$$S = \frac{5{,}840 \times 40}{86{,}400 \times 1.87} \times 207.4 = 6.97 \times 10^{-3}$$

The values of s and t used in making the above computation are considered to be not highly accurate because of the nearness of the observation well to the pumped well and the consequent rapid drawdown at the beginning of the pumping period. However, the values derived from the computations are considered to be of the correct order of magnitude of these coefficients in the vicinity of the pumped well. Low values of S are typical for ground water under confined conditions and the low value in this instance supports the evidence in the log of this well, which indicates that the water is confined beneath clay which overlies the water-bearing sand and gravel.

An approximate method for computing T and S from the drawdown is as follows:

Plot s against log t. For large values of t the points will follow a straight line if the actual conditions in the aquifer are similar to the assumed conditions upon which the nonequilibrium formula is based. The coefficients of storage and transmissibility are then computed from the graph as follows:

$$T = \frac{264\ Q}{\Delta s}$$

and $$S = \frac{2.08 \times 10^{-4} T t_o}{r^2}$$

where T= coefficient of transmissibility, gpd/ft.

Q= discharge of well, gallons per minute

Δs= drawdown along the straight line on the graph over 1 log cycle of time, feet

S= coefficient of storage

t_o= time, in minutes, where the straight line intersects the line of zero drawdown

r= distance from pumping well to point where drawdown, s, is measured, feet.

Such a plot of s against log t for the period of pumping is shown in figure 7. Computations of S and T from this graph are:

$$T = \frac{264 \times 107}{3.03} = 9{,}320 \text{ gpd/ft.}$$

$$S = \frac{2.08 \times 10^{-4} \times 9{,}320 \times 20}{207.4} = 0.187$$

Figure 8 is a plot of log $\frac{t}{t'}$ against s obtained from the recovery of water level after pumping was stopped, where

t= time since pumping started

$\frac{t}{t'}$= time since pumping stopped

s= residual drawdown at corresponding values of $\frac{t}{t'}$ in feet.

For ideal conditions, the plot would form a straight line passing through the origin. It will be noted that the plotted points pass above the origin. The probable reason for this behavior will be discussed in a later section.

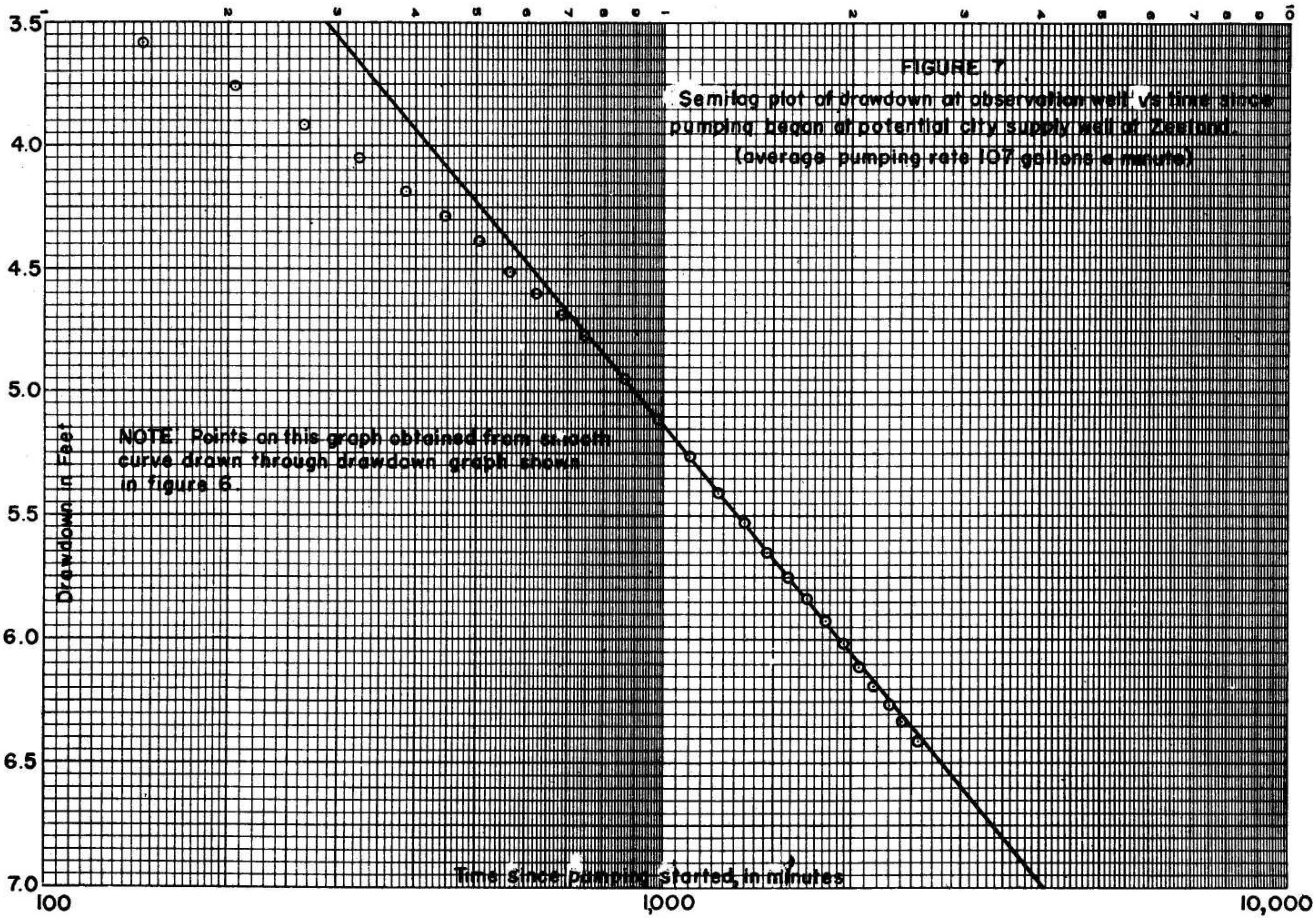


FIGURE 7
Semilog plot of drawdown at observation well vs time since pumping began at potential city supply well at Zeeland.
(average pumping rate 107 gallons a minute)
NOTE: Points on this graph obtained from smooth curve drawn through drawdown graph shown in figure 6.
Drawdown in Feet
Time since pumping started, in minutes
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
100
1,000
10,000

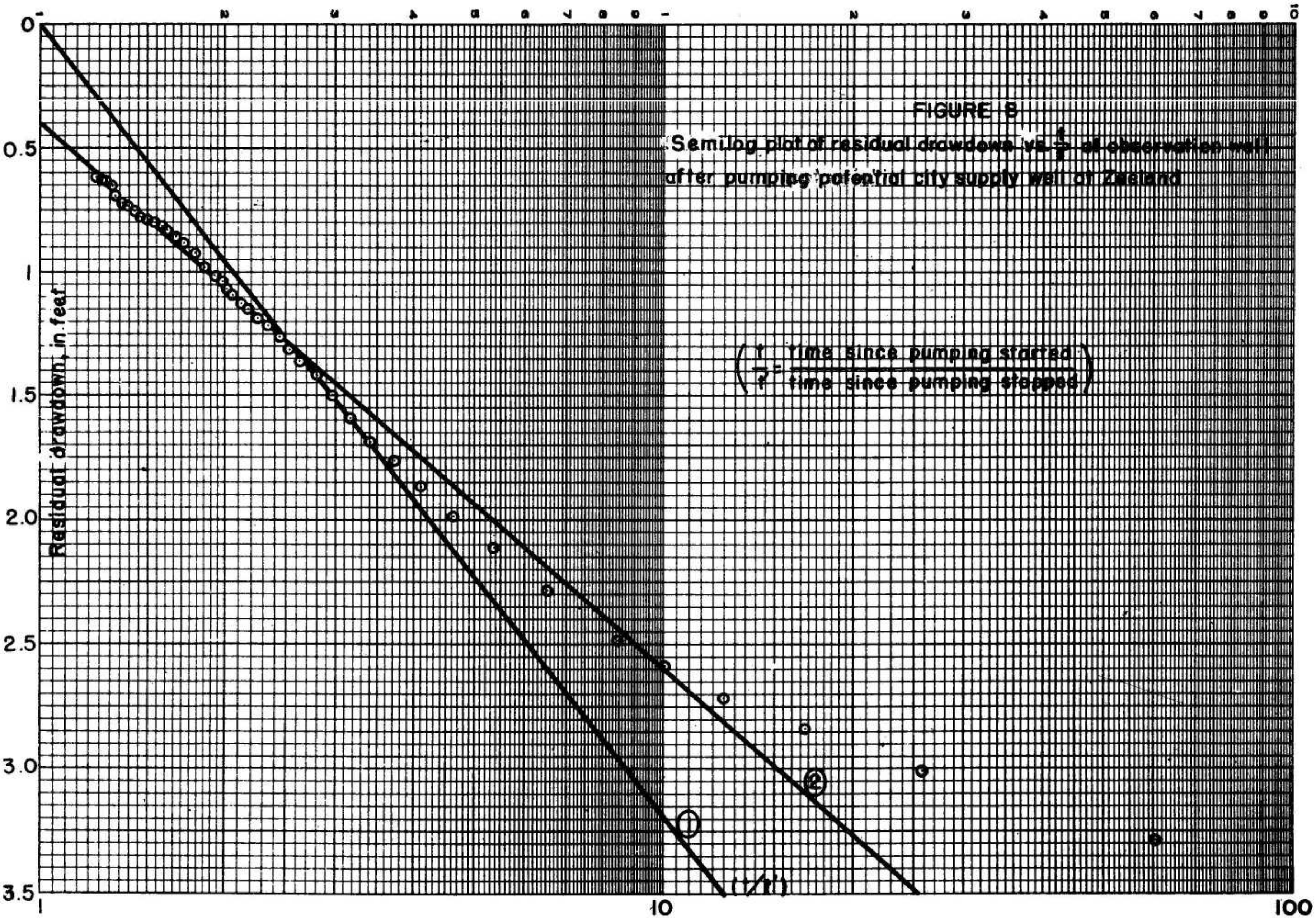


FIGURE 8

Semilog plot of residual drawdown vs $\frac{t}{t'}$ of observation well after pumping potential city supply well at Zeeland

The coefficient of transmissibility is calculated from the equation where

$$T = \frac{264\ Q}{s} \log \frac{t}{t'} = \frac{264\ Q}{\Delta s}$$

Δs is the change in residual drawdown over 1 log cycle of $\frac{t}{t'}$.

Two straight lines, labeled 1 and 2, have been drawn through the plotted points in figure 8. Line 1 is drawn through the origin and through a number of points in the plotted curve. The coefficient of transmissibility computed from this line is

$$T = \frac{264 \times 107}{3.19} = 8{,}850 \text{ gpd/ft.}$$

which is somewhat lower than the value of this coefficient computed from the semi-log plot of the drawdown but is of the same order of magnitude.

Line 2 of this graph is a line passing through the greatest number of points near the end of the recovery period. This line passes considerably below the origin. The coefficient of transmissibility computed from this line is:

$$T = \frac{264 \times 107}{2.20} = 12{,}850 \text{ gpd/ft.}$$

which is considerably higher than the value of this coefficient calculated by other methods.

The following table is a summary of the calculations of the coefficients of transmissibility and storage as computed according to the various methods and data:

Method of calculation	Coefficient of transmissibility (gpd/ft.)	Coefficient of storage, early part of pumping and recovery period	Coefficient of storage, later part of pumping period
Max. $\frac{\partial s}{\partial t}$	6,410	0.00803	
" "	5,840	.00697	
Semilog plot of drawdown	9,320		0.187
Semilog plot of recovery (line 1)	8,850		
(line 2)	12,850		

Significance of the results of the pumping tests

The results of the pumping tests indicate that the effective coefficient of transmissibility within the area significantly influenced during the period of pumping and recovery is of the order of 9,000 gpd/ft. The low coefficient of storage calculated from data obtained during the very early part of the pumping period and during the very early part of the recovery period suggest that the ground water in the immediate vicinity of the well occurs under confined conditions, as would be indicated by the log of the pumped well. The higher coefficient of storage obtained during the latter part of the test suggests that the aquifer may not be confined over its entire extent and that the pumping effects soon extend beyond the limits of the confining beds in one or more directions. Water is then withdrawn from areas where the ground water occurs under water-table conditions. The results indicate that the effective coefficient of storage within the area significantly influenced during the period of pumping is about 0.19.

Glaciofluvial aquifers such as the one under consideration are frequently very limited in areal extent, and it was considered important to learn as much as possible about the probable size of the aquifer from the nature of the drawdown and recovery of the water level in the well.

The formulas used to compute the coefficients of transmissibility and storage in this section are all based upon the effects of pumping from an aquifer of infinite areal extent. The use of the formulas is valid for aquifers of finite extent only so long as the pumping effects do not reach the boundaries of the aquifer in a measurable degree. When the pumping effects do reach the boundaries of the aquifer in a measurable degree, the shape of the drawdown and recovery curves will be altered.

For instance, if the present well were situated in an aquifer of relatively small areal extent, it would be expected that the drawdown points plotted in figure 7 would begin to fall away from the straight-line order as soon as interference effects had sensibly reached the boundaries of the aquifer. There is some suggestion that the points in figure 7, which are plotted for a pumping time greater than about 2,000 minutes, are beginning to fall below the straight line, which would indicate that the interference effects had sensibly reached boundaries of less permeable material or that water was being withdrawn from areas having a lower coefficient of storage than the part of the aquifer which had previously contributed the principal part of the water pumped. However, the departure of the plotted points from the straight line in figure 7 is of such small magnitude that no definite interpretation of the cause can be made, because factors such as slight pumpage changes and natural water-level fluctuations would be sufficient to cause variations of this magnitude.

The nature of the recovery of the water level is of considerable interest. Eight days after pumping stopped, the water level was still 0.63 foot below the static level measured before pumping began. From the semi-log plot of the recovery of the water level (line 2, fig. 8) it is estimated that, if the water-level recovery continued indefinitely with approximately the same trend, it would come to rest at least 0.40 foot lower than the original static water level. Furthermore, the arrangement of the plotted points to the left of line 1 follows a pattern which would be expected in the recovery of water levels from pumping within a closed or partly closed basin.

It is estimated that approximately 288,000 gallons of water was pumped during the test. If 0.40 foot is taken to represent the depth of permanent unwatering of the entire aquifer due to withdrawing 288,000 gallons of water, the area of the aquifer can be computed as follows:

$$A = \frac{288,000}{0.40 \times 0.19 \times 7.5} = 505,000 \text{ sq. ft.}$$

$$= 11.6 \text{ acres}$$

Source of recharge to the aquifer

The principal source of recharge to the aquifer appears to be that part of the rainfall which seeps into the aquifer in the slough area adjacent to the well and in the adjoining gravel-pit area. Some water is contributed to the slough from surface runoff from the higher lands, and there is movement of ground-water through the adjacent till toward the sloughs. Although the magnitude of these contributing sources cannot be estimated from present data, experience in other sections of the State has indicated that the till generally is characterized by such low permeability that ground-water underflow from the till into deposits of sand and gravel can generally be neglected unless the sand and gravel deposits are quite extensive in at least one direction. The till in this area may have a permeability much higher than the average, but in the absence of specific data to this effect it would be unwise to assume any considerable contribution from this source. Statements from residents in the area as well as the absence of through drainage in the sloughs indicate that the contribution to the ground water in the aquifer from surface runoff is also negligible. The excellent quality of the water pumped during the test indicates that its source is near at hand, as most shallow wells in the surrounding drift yield much more highly mineralized waters. Assuming, then, that the principal part of the water in the aquifer must be derived from that part of the rainfall which seeps into it in the slough area and in the adjoining gravel-pit areas, the dimensions of the aquifer necessary to support any given demand can be estimated very roughly.

It is estimated that the water demand at Zeeland might reach 50,000 gallons a day in the near future. If this would be an average daily demand over a year's time, then 18,250,000 gallons a year would be required. The average annual precipitation in the area is about 19 inches. In general, the amount of precipitation reaching the aquifer will be considerably less than the total precipitation. If the average percentage of precipitation reaching the aquifer is taken as 10 percent (a figure that may be conservative but cannot be checked with the present data), then an area of the aquifer equal to $\frac{18,250,000 \times 12}{19 \times 7.5 \times 0.10} = 15,350,000$ sq. ft. = 350 acres (roughly) would be required to furnish the required amount of water perennially.

Summary of the results of pumping tests

Results of the pumping tests indicate that the average effective coefficient of transmissibility of the aquifer is of the order of 9,000 gpd/ft. and that the average effective coefficient of storage is of the order of 0.19. These indicate that the ability of the aquifer to transmit and store water is sufficient to supply 50,000 gallons a day, provided that the perennial recharge to the aquifer is sufficient. The principal recharge to the aquifer probably is from rainfall which seeps into the aquifer in the slough area and in the adjoining gravel-pit areas. The total amount of recharge to the area is, then, a function of the areal extent of the aquifer. Although the area of the aquifer is not known, there is both geologic and hydrologic evidence to indicate that it may be much smaller than the 350 acres estimated as necessary to furnish a perennial supply averaging 50,000 gallons a day.

No reasonable estimate of the safe perennial yield of the aquifer can be made until more basic data are at hand regarding the size of the aquifer and the manner and amount of recharge. The areal extent of the aquifer can be determined by an adequate test-drilling program. The manner and amount of recharge can be determined by a program of water-level measurements, in conjunction with careful measurements of water-table slopes and determinations of the coefficient of transmissibility and storage in other parts of the aquifer.

Rough estimates indicate that the areal extent of the aquifer necessary to produce a perennial supply equal to 50,000 gallons a day may be as much as 350 acres. Present data do not indicate an aquifer of this extent. If it should be desired to develop a supply of water less than 50,000 gallons a day, the estimated required area would be approximately $\frac{350 \times \text{required av. daily yield}}{50{,}000}$ acres. Thus, an areal extent of the aquifer over about 100 acres probably would be required for a safe perennial yield of the order of 14,000 to 15,000 gallons a day.

QUALITY OF THE WATER

By P. D. Akin

Table I gives chemical analyses of two ground waters in the Zeeland area. Analysis 1 is of a sample from the potential Zeeland supply well on the Edwin Boschee farm. This sample was collected on August 20, 1947, near the end of the pumping test described in this report, at which time approximately 280,000 gallons of water had been pumped from the well. The analysis was made by the Division of Laboratories, North Dakota State Department of Health, at Bismarck. The comments of the analyst regarding this water are as follows: "This sample is low in total dissolved minerals and would be excellent for domestic use. Removal of the hardness by chemical treatment would make this water superior as compared to other North Dakota supplies.

"The principal minerals present are iron, calcium bicarbonate and magnesium bicarbonate.

"This water should prove excellent to good for irrigation and should be suitable for most plants."

According to reports of residents, this probably is the best water for general purposes that has been found in the area, insofar as mineral content is concerned.

Analysis 2 is taken from North Dakota Geological Survey Bulletin 11. [11/]

This sample is from a shallow drilled well at the blacksmith shop in Zeeland. The water was indicated by Abbott and Voedisch as being derived from the Fox Hills sandstone but it is likely that it is derived from glacial sand and gravel at the base of the drift and overlying the Pierre shale. This water is very high in dissolved minerals and is very hard. It would be unfit for domestic use and for most other purposes. Although this sample probably contains more dissolved minerals than most of the water from shallow wells in the area, reports from local residents indicate that very high mineralization is not unusual in water derived from shallow wells in the immediate vicinity of Zeeland.

11/ Abbott, G. A., and Voedisch, F. W., The municipal ground-water supplies of North Dakota: North Dakota Geol. Survey Bull. 11, pp. 64-65, 1938.

Table I

Chemical Analyses of Two Ground Waters in the Zeeland Area

	Sample 1	Sample 2
Description of well:		
Location	NW¼ sec. 30, T. 129 N., R. 73 W	Sec. 21, T. 129 N., R.73 W.
Owner	Edwin Boschee	Blacksmith shop
Type	Drilled	Drilled
Depth	41 feet	44 feet
Aquifer	Sand and gravel	Sand
Chemical analyses:		
Date of collection	8-29-47	?
Date of analysis	9-6-47	?
Source of analysis	(a)	(b)
Total dissolved solids	252	4,025
Total alkalinity ($CaCO_3$)	174	376
Total hardness ($CaCO_3$)	180	1,485
Iron (Fe)	0.2	0.2
Calcium (Ca)	49	282
Magnesium (Mg)	14	189
Sodium (Na)	Absent	651
Bicarbonate (HCO_3)	212	459
Chloride (Cl)	Trace	128
Sulfate (SO_4)	Trace	2,235
Fluoride (Fl)	Absent	Absent

a/ Division of Laboratories, North Dakota State Department of Health, Bismarck, N. Dak.

b/ Abbott, G. A., and Voedisch, F. W., The municipal ground-water supplies of North Dakota: North Dakota Geol. Survey Bull. 11, pp. 64-65, 1938.

CONCLUSION

From the data obtained in the course of this study, a shallow water-bearing stratum yielding water of good quality was located about 2 miles west of Zeeland. A pumping test conducted on a single well in this aquifer shows that the stratum has a relatively high yield but that the well did not entirely recover after pumping had ceased. This would indicate that the aquifer has a limited extent. The data on hand suggest that a perennial yield of less than 50,000 gallons per day may be expected from this aquifer. It should be pointed out, however, that the test drilling in this aquifer was not extensive enough to condemn it entirely on the basis of the information on hand. It is suggested that more test drilling could profitably be done in the vicinity of the Boschee farm in sec. 30.

It also appears that a much more limited source of supply might be obtained in the SE$\frac{1}{4}$ sec. 29, on what is known as the Bauer farm, where a shallow pit might be dug to combine both the small amount of surface runoff and the waters in the shallow gravel occurring from 13.5 to 16.0 feet from the surface. Inasmuch as this would be partly surface water and also would be open to the air and subject to other possible sources of contamination not present in a well, this type of installation would have to include a treatment plant.

APPENDIX A

Logs of test holes drilled in Zeeland area

No. 1. Location - NW¼ sec. 29, T. 129 N., R. 73 W. Drilled by hand auger.

	Feet
Till, gray, iron-stained, mottled, sandy, very damp in lower part	0 - 7
Till, gravelly clay (?)	7 - 8.5
Till, sandy clay, fewer stones	8.5- 9.8
Till, stony, sandy clay, with many stones; this probably is the water horizon	9.8-11.4

Water 8 feet from ground surface after standing for 1 day.

No. 2. Location - SE¼NW¼ sec. 30, T. 129 N., R. 73 W, in the middle of the slough on the Edwin Boschee farm.

Clay and silt, dark gray, some few pebbles	0 - 3.8
Clay, light gray, mottled with light-brown iron spots	3.8- 8.8
Sand, very fine-grained, some pebbles struck at 10.6 but not brought up	8.8-13.0
Clay, till, sandy, gray, stony, with mottled spots	13.0-13.7
Gravel, fine, and coarse brown sand	13.7-15.3

Water level 2.4 feet from the surface.

No. 3. Location-SE¼NW¼ sec. 30, T. 129 N., R. 73 W., on the east side of the slough on the Edwin Boschee farm, 405 feet by pacing beyond No. 2.

Surface soil, slightly sandy, brown to gray clay, stony till	0 - 3.3
Clay, gray with red-brown mottling, till with abundant gypsum (?) crystals	3.3- 8.4

	Feet
Same as above but sandier, with a little water....	8.4- 9.5
Till, dark-gray clay with few stones; looks almost like Pierre shale	9.5-16.2

No. 4. Location - center of SE$\frac{1}{4}$ sec. 29, T. 129 N., R. 73 W., in the middle of the slough on the Bauer farm.

Surface clay and sand	0 - 3
Sand, brown-gray, iron-mottled, clayey	3.0- 8.5
Till, gray, sandy, stony	8.5- 9.4

Water 5.8 feet from surface. Too much water to finish, probably ended in same gravel as No.2 hole on Boschee farm.

No. 5. Location - center of SE$\frac{1}{4}$ sec. 29, T. 129 N., R. 73 W., 450 feet NE of No. 4 on the northeast edge of slough near gravel pit.

Surface clay and soil	0 - 2.5
Sand, coarse and clayey, stony till	2.5- 3.3

Hole abandoned because of rocks.

No. 6. Location - center of SE$\frac{1}{4}$ sec. 29, T. 129 N., R. 73 W., 66 feet S. of No. 5 in slough bottom.

Surface clay and sand	0 - 2.5
Sand, mottled gray and brown, with much clay, graded down to gravel	2.5- 3.3
Sand, gray, fine and coarse, with some pebbles, mainly fine sand	3.3- 4.2
Sand, very fine, almost silt	4.2- 6.5
Sand and gravel, coarse; could not get through stones	6.5- 7.5

Water level 4 feet from ground surface.

No. 7. Location - 1,320 feet S. of hole No. 1, NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 30, T. 129 N., R. 73 W.

	Feet
Surface dirt and sand	0 - 1.0
Sand and clay, light-brown to gray	1.0- 2.5
Sand, yellow-brown and fine-grained	2.5- 7.2
Sand, clayey (till?) with stones, almost a gravel	7.2- 8.6

Water at 8.0 feet from ground surface. Hole located in ditch about 2 feet below general land level.

No. 8. Location - NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 30, T. 129 N., R. 73 W., 552 feet S. of No. 7.

Surface sand and clay, much wash	0 - 6.1
Till, clay, slightly stony, slightly sandy, gray to black near top, elsewhere gray mottled with brown..	6.1- 9.2
Sand, clayey, with a few stones	9.2-10.2
Gravel, brown, fine-grained	10.2-10.8

Could not go farther because of water in gravel. Water level 9.8 feet from surface.

No. 9. Location - NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 33, T. 129 N., R. 73 W.

Surface clay and sand	0 - 2.2
Sand, brown clay, with some stones (till?)	2.2- 3.8
Gravel, brown, or gravelly till	3.8- 4.5
Sand, gray to brown, fine-grained, with some stones..	4.5- 6.5
Till, sandy clay, stony	6.5- 7.0

Water 5.6 feet from surface.

No. 10. First test well drilled with boring machine. Location - NE$\frac{1}{4}$ sec. 30, T. 129 N., R. 73 W., on Edwin Boschee farm. John J. Jangula, Jr., driller, Tony J. Klein, helper.

	Feet
Surface clay and soil	0 - 1.5
Sand, fine-grained	1.5- 4.7
Till clay with pebbles, stony, with some coarse sand and gravel; till rather sandy from 4.7 to 5.7 feet	4.7- 7.0
Big rock at 7.5 feet; also some gravel	7.0- 7.5
Till clay, hard, gray to yellow, stony; stones small	7.5-15.0
Till, blue clay, with fewer stones, some thin gravel lenses	15.0-24.5
Till, sandy, blue, with fewer stones	24.5-27.0
Till, blue clay, stony	27.0-29.0
Gravel, medium-grained	29.0-36.0

Water 3.7 feet from surface. Diameter was 2 feet from 9 to 8 feet, and 8 inches from 8 to 36 feet.

No. 11. Location - SE$\frac{1}{4}$ sec. 30, T. 129 N., R. 73 W., on the Kranzler farm.

Surface clay and sand	0 - 2.5
Clay, gray, sandy (till?)	2.5- 5.0
Till, gravelly	5.0- 7.0
Till, sandy clay, brown	7.0-16.0
Clay, blue, slightly stony till, slightly sandier at 27.5 and 42.5 feet	16.0-47.0
Gravel, fine-grained, or coarse sand, blue clay	47.0-49.0
Quicksand and brown stony clay till with sand lenses	49.0-54.0

Water level at 4.6 feet from the ground surface one day after drilling.

No. 12. Location - $NW\frac{1}{4}SE\frac{1}{4}$ sec. 33, T. 129 N., R. 73 W., about $\frac{1}{4}$ mile east of Andrew Knowles' farmhouse.

	Feet
Surface and clay and sand	0 - 2.5
Till, clay, yellow-gray, with few pebbles; pebbles appear weathered	2.5- 9.0
Till, blue-gray, with few pebbles, slightly sandy	9.0-12.5
Till, sandy clay, sand, fairly coarse, small pebbles	12.5-19.0
Quicksand, water at 19.0 feet	19.0-22.5
Till, blue clay, with Pierre shale pebbles, slightly sandy at top	22.5-29.0
Dark clay on bottom with Pierre shale pebbles Pierre shale	29.0-30.0

Water 6.5 feet from surface; pumped out quickly.

No. 13. Location - $NW\frac{1}{4}SE\frac{1}{4}$ sec. 33, T. 129 N., R. 73W., behind Andrew Knowles' barn.

Surface clay and silt	0 - 2.5
Till, gray clay, sandy, stony	2.5- 3.5
Till, sandy, gravelly; could be called a dirty gravel	3.5- 6.5
Gravel, medium-grained	6.5- 8.5
Till, sandy, yellow clay; less sandy below 9.0 feet	8.5-12.5
Till, blue clay, stony and slightly sandy, tough	12.5-24.0
Sand, coarse	24.0-25.0
Till, blue clay	25.0-34.0
Till, blue sandy clay	34.0-40.0

Quicksand probably in bottom. Hole abandoned at 40.0 feet as kettle would not take out sand. This well encountered no water except in upper gravel. This is only surface water which traveled down the hole when it was being drilled. Water did not rise in hole.

No. 14. Location - SE$\frac{1}{4}$ sec. 29, T. 129 N., R. 73 W. Bauer farm.

	Feet
Surface clay	0 - 3.0
Clay, yellow-brown, with few pebbles	3.0- 6.5
Sand and blue sandy clay, few pebbles	6.5- 9.0
Sand, light-gray, clayey, mottled with brown......	9.0-10.5
Till, darker-gray sandy clay with some gravels ...	10.5-13.5
Gravel, brown, medium-grained	13.5-15.5
Till, brown clayey gravel	15.5-16.0
Till, brown clay	16-0-18.5
Till, blue clay	18.5-21.0
Till, sandy clay	21.0-24.5
Pierre shale, blue, with fossils	24.5-25.5

Water 5 feet from ground surface. Practically all the water in this hole comes from the gravel at 13.5 to 16.0 feet. The water seems to come in fairly fast, but does not compare with No. 10 on the Boschee farm. The gravel here is too thin to give much water, but this probably would make a good farm well. Quicksand here was thin and apparently not saturated.

No. 15. About 9 feet ESE. of No. 10.

Surface clay and silt	0 - 1.5
Sand, coarse, and gravel; much water	1.5-13.5
Till, yellow clay	13.5-15.0

At 13 feet hit rock; did not continue.

No. 16. About 15 feet SE. of No. 10.

	Feet
Surface clay and silt	0 - 3.0
Sand, coarse, water-bearing	3.0 - 7.0
Till, sandy clay	7.0 - 8.0
Sand, coarse, and some gravel	8.0 -10.5
Till, brown clay	10.5 -14.0
Till, blue clay	14.0 -22.5
Gravel, very coarse, cobbles 3 to 4 inches in diameter	22.5 -31.0

Wood casing 18 inches in diameter to 24 feet; samples at 25.0, 27.5, 28.5 and 31.0 feet. Stopped at 31.8 feet; too much water; could not hold gravel in the kettle. Water level 3.6 feet from ground surface.

Zeeland drilled well.

	Feet
Sand, coarse, granite grains, limestone grains, pyrite, gneiss grains, sand grains rounded to subangular, very fine shale fragments; limestone grains and sand grains seem to be predominant. A few of the sand grains appear to have a frosted appearance	26 - 29
Sand, medium coarse to coarse, similar to sample above. Grains primarily white limestone and subangular to subrounded milky and clear quartz pebbles; some of the quartz grains are frosted. Other fragments include grains of gneiss, granite, and a chloritic schist. Several pyrite fragments also noted. One interesting fragment noted, which might be a sandstone with numerous grains of quartz and other green minerals in it, might conceivably also be a very fine grained igneous rock	29 - 33
Sand, fine to medium-grained, primarily subrounded to subangular quartz, few grains of granite and gneiss, with some fragments of schist, some few fragments of pyrite	33 - 37
Sand, fine to coarse sand; limestone and sand grains predominant; sand grains rounded to subangular; more shale fragments in this specimen than in any of the others	37 - 40

These cuttings were all taken from a well that was drilled with a jetting rig by the Independent Drilling Co. of Aberdeen, S. Dak. All the samples have a washed appearance and none of them contain any of the coarse material found in the original drilling that was done with the boring machine on test holes 10, 15, and 16. I do not know whether the gravel did not occur in this particular well or if the coarser material was ground up by the machine. For this well the record given by Wade Zick, City Auditor, on January 15, 1947, is as follows:

> The hole was drilled 12 feet, southwest from No. 16, which is the 2-foot well now boarded up. From 0 to 25 feet they had sand and clay, from 25 to 30 feet, coarse gravel, from 30 to 41 feet, coarse sand.

The samples on hand, from 29 to 40 feet, are the ones outlined in the more detailed log above. George Tolman, engineer in charge of the project, says that there was 31 feet of casing set above the 14-foot screen. Four feet of the casing is above ground.

Well data for

Location of well	Owner or farm tenant	Depth of well (feet)	Diameter (inches)	Type
129-72-30 b	Simon Metzell	15.0	36	Bored
129-73-1 ad	Joachim J. Meier	140	$2\frac{1}{2}$	Drilled
129-73-2 ca		73.7	30	Bored
129-73-3 b		54.1	30	do.
129-73-3 d	Mike Fiest	89		do.
129-73-4 ad	Mrs. Peter Fiest	18.3	36 x 36	Dug
129-73-5 bc		11.2	30	Bored
129-73-5 dd	Tony Fiest	23.4	30	do.
129-73-6 bb	John A. Fiest	100(?)		do.
129-73-9 bb	Anthony Fiest	31.4	30	do.
129-73-10 ba	Katy P. Fiest	72.6	30	do.
129-73-10 a	Frank A. Fiest	48.6	30	do.
129-73-11 ac	Mike Holzer	68.0	30	do.
129-73-12 ab	Jake Schumacher	88.6		do.
129-73-14 bb	John N. Fiest	84.0	24	do.
129-73-15 bd	Katy Fiest	8.7	48 x 48	Dug
129-73-15 dd	Katy Fiest	53.8	24	Bored
129-73-15 dd	Casper Schatz	67.5	24	do.
129-73-17 dc		76.0	30	do.
129-73-17 bd	Antone Schaffner	69.5	30	do.
129-73-18 ba		65.5	30	do.
129-73-19 c	Mike Salwei	64.3	30	do.
129-73-19 b	Joseph Young	26.2	30	do.

the Zeeland Area

Date completed	Depth to water below land surface (feet)	Date of measurement	Use 1/	Remarks
	3.4	6-30-46	S,D	Well flows. Reported to have been 98 feet deep originally, but has been filled with rocks to measured depth.
	120.0	7-10-46	S,D	Could not get into well for measurement. Depth and depth to water reported by occupant.
	29.5	do.	S,D	
	20.2	do.	S	
	69.0	do.	S,D	Could not get into well. Depth and depth to water reported by occupant. Goes dry in dry years. Pumps out quickly.
	4.5	do.	S,D	
	1.7	7- 9-46	S,D	
	52.0	do.	S,D	Depth not measured.
	7.8	7- 7-46	S,D	Reported good in dry years.
1944	10.6	do.	S,D	
	32.9	7-10-46	S,D	
	29.7	do.	S,D	
	45.7	do.	S,D	Pumps out easily. Aquifer reported as quicksand.
	44.1	do.	S,D	Aquifer reported as gravel
	53.8	7- 7-46	S,D	Aquifer reported as gravel.
	6.7	do.	Abd	Reported to be good well. Water hauled from this well to town at one time. Aquifer reported as gravel.
	37.3	do.	S,D	Aquifer reported as sand
	32.1	do.	S,D	Aquifer reported as sand, gravel, and clay.
	59.2	do.	S,D	
	43.2	do.	D	
1946 (?)	23.0	7- 1-46	S	Pasture well. Well pumping before reading was taken.
	23.3	7-10-46	S,D	Goes dry under heavy pumping
	16.8	7- 1-46	S,D	Could be pumped dry in dry years.

1/ S, stock use; D, domestic; Ind, industrial; Abd, abandoned

Location of well	Owner or farm tenant	Depth of well (feet)	Diameter (inches)	Type
129-73-20 a	John R. Pfeifer	58.0	30	Bored
129-73-20 aa		52.4	24	
129-73-21 c	John Haas	51.5	30	do.
129-73-21 c	Adam Aberle	69.4	30	do.
129-73-21 c	John Jangula	61.2	30	do.
129-73-21 c	Jacob Jangula	35.4	30	do.
129-73-21 c	John Jangula, Jr.	46.0	30	do.
129-73-21 c	Milwaukee R. R.	44.2	30	do.
129-73-21 c	John Pfeifer	18.0	30	do.
129-73-21 c	Tony Klein	56.0		
129-73-21 c	Wade Zick	40.0	30	
129-73-21 c	Jacob Stern	40.0	40	
129-73-21 c	Catholic Church	93.0	30	do.
129-73-21 c	Mrs. George Lacker	33.6	30	do.
129-73-21 c	Paul Welder	59.0	30	do.
129-73-21 c	Henry Delzer	67.0	30	do.
129-73-21 c	Martin Knowles	53	30	do.
129-73-21 c	Duke Herth	55.6	30	do.
129-73-21 c	Frank Fiest	37.7	30	do.
129-73-21 c	Ronnie Delzer	40.8	30	do.
129-73-21 c	John Haas	63.8	30	do.
129-73-21 c	John P. Schumacher	53.0	30	do.
129-73-21 c	M. M. Braun	50.0	30	do.
129-73-21 c	Edwin Boschee	49.0	30	do.
129-73-21 c	Henry Reiner	45.0	24	do.
129-73-24 aa	Mike Salwei	130 (?)	30	do.
129-73-27 ac	Mrs. Lugarda Est.	29.3	30	do.
129-73-27 d	Frank Metzell	33.0	30	do.
129-73-28 b	Edwin Bauer	41.0	30	do.
129-73-29 aa	Henry Reiner	57.0	30	do.

the Zeeland area (con't)

Date completed	Depth to water below land surface (feet)	Date of measurement	Use 1/	Remarks
1909	34.0	7- 8-46	S, D	Reported good in dry years
	8.6	do.	S	
1945	37.0	7-10-46	D	Shale reported at 14.0 feet.
	53.1	do.	S, D	Shale reported at 34.0 feet.
	29.4	do.	S, D	
	14.4	do.	D	
1945	13.5	do.	D	
	11.2	do.	Ind.	
	5.3	do.	D	
	19.8	do.		Unused.
	9.7	do.	D	
	17.4	do.	D	
	16.5	do.	D	
	12.2	do.	D	
	12.5	do.	D	
	33.0	do.	D	Bottom reported to be in shale. Water of very poor quality; cattle will not drink it.
	28.3	7- 6-46	S, D	Sand and gravel reported at 40 feet.
1940	19.5	do.	D	In shale (?).
	14.0	do.	S, D	
	20.0	do.	S	
	20.5	do.	D	
1942	22.1	do.	S, D	
1946	31.5	do.	Irr	
1921 (?)	12.0	6-30-46	Unused	
1934 (?)	17.0	do.	Ind	See analysis in Bull. 11, N.D.G.S. Reported to be in Lance formation.
	51.2	7- 1-46	S, D	Well had been pumping when measured. Did not go dry in dry years.
	22.9	7- 7-46	D	Reported in blue clay or shale. Three wells here and none has sufficient water.
	27.0	do.	S, D	
	28.0	do.	D	
	14.3	do.	S	Drillers log: Till ----- 0 - 43.0 feet Gravel ---43.0-45.0 feet Shale ----45.0-57.0 feet

1/ S, stock use; D, domestic; Ind, industrial; Irr, irrigation

Well data for

Location of well	Owner or farm tenant	Depth of well	Diameter (inches)	Type
129-73-29 dd	Mrs. Ed. Bauer	12.1	48 x 48	Dug
129-73-30 bb	Edwin Boschee	68.6	30	Bored
129-73-32 a	Emil Bauer	44.7	30	do.
129-73-33 b	Arthur Bauer	57.8	30	do.
129-73-33 c	Mrs. Christine Muench	41.0	30	do.
129-73-33 d	Andrew Knowles	20.0	30	do.
129-73-34 dd	S. P. Metzell	48.5		
129-73-35 d	Mike Schatz	45.2	30	do.
129-74-24 db	Ludwig Pfeifer	58.7	36	

APPENDIX B

the Zeeland area (con't)

Date completed	Depth to water below land surface (feet)	Date of measure-ment	Use 1/	Remarks
	5.5	6-30-46	S, D	Zeeland now buys water from this well.
1931	30.5	do.	S	When measured well had been pumping. Driller reports well bottom is quicksand. Drillers log: Yellow clay and sand -- 0 -15.0 feet Blue clay-15.0-30.0 feet Blue sand-30.0-68.0 feet Water hit at 45.0 feet.
	14.8	7- 7-46	S, D	
	44.0	do.	S, D	Aquifer reported to be sand and gravel.
	8.6	do.	S, D	
	3.1	do.	S	Aquifer reported to be gravel.
	18.2	do.	S, D	
	39.0	do.	S, D	
	24.5	do.	S, D	Never went dry in dry years.

1/ S, stock use; D, domestic; Ind, industrial; Irr, irrigation

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