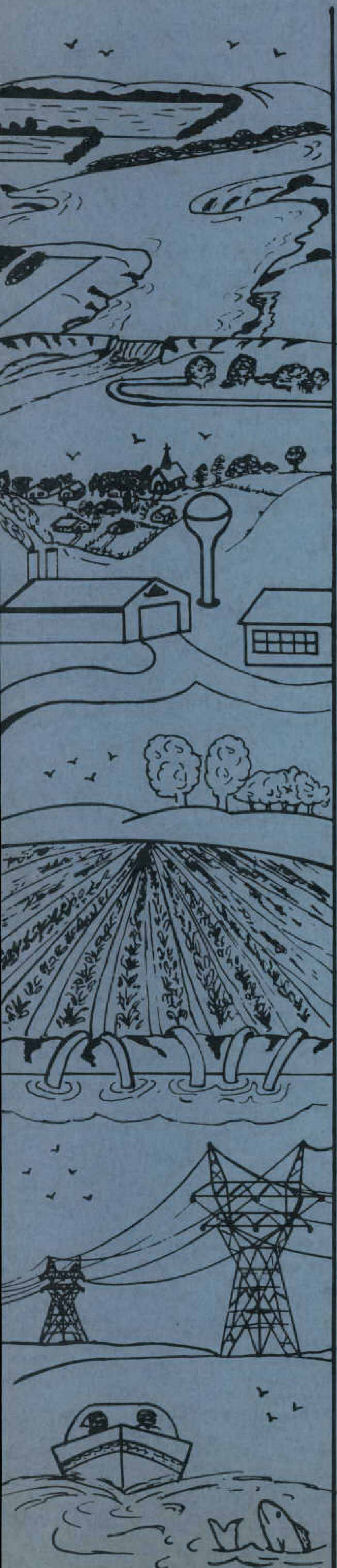

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GEOLOGY AND GROUND WATER RESOURCES OF THE MICHIGAN CITY AREA NELSON COUNTY, NORTH DAKOTA

By

Saul Aronow and P. E. Dennis, Geologists
and
P. D. Akin, Engineer
Geological Survey
United States Department of the Interior

NORTH DAKOTA GROUND WATER STUDIES

NO. 21

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

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

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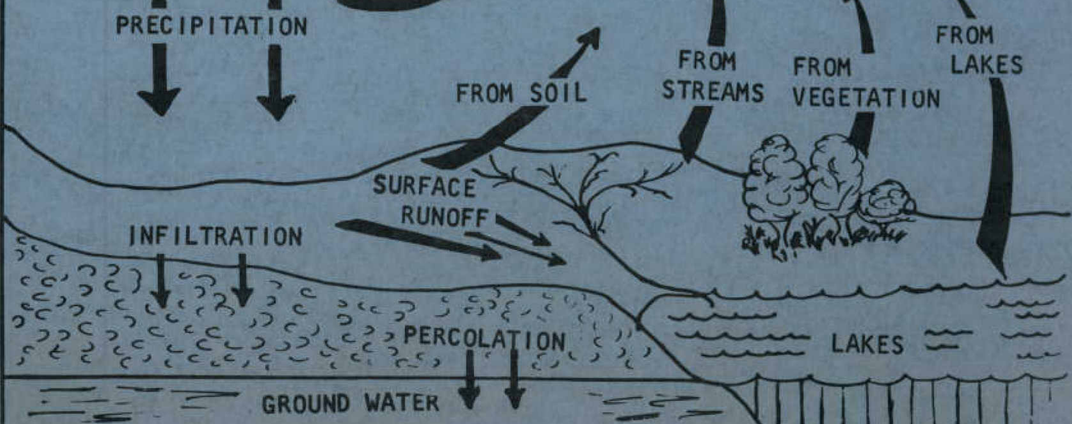

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OF THE MICHIGAN CITY AREA

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GEOLOGY AND GROUND-WATER RESOURCES OF THE MICHIGAN CITY AREA, NELSON COUNTY, NORTH DAKOTA

By

Saul Aronow, P. E. Dennis, and P. D. Akin

ABSTRACT

The Michigan City area is in the northeastern part of Nelson County, N. Dak., and, as considered in this report, comprises 112 square miles in parts of six townships.

The surface material in the area is glacial drift of the Mankato substage of the Wisconsin stage of the Pleistocene series. The immediately underlying bedrock is the Pierre shale of Late Cretaceous age. The Pierre shale has not been completely penetrated by wells in or near the area; therefore, the thickness of the shale and the presence of underlying formations are not known certainly. It is believed, however, that the Niobrara formation, the Benton shale, and the Dakota formation are present in the area. Also, it is likely that rocks of earlier Mesozoic and of Paleozoic age are present. Pre-Cambrian rocks underlie the entire area.

The glacial drift, as it was found in USGS test holes, ranges in thickness from 17 to 135 feet. In most places it was less than 35 feet thick, and well data indicate that it generally is not more than 40 feet thick.

Aquifers in the glacial drift furnish water to only about a quarter of the wells in the area. The aquifers include: (1) deposits of sand and gravel associated with the till that are not readily assigned to one of the following categories, (2) sorted deposits of overriden outwash, (3) deposits in the glacial spillways, and (4) deposits in the recognizable ice-contact features.

Most of the wells that tap aquifers in the drift are either dug or bored. They yield only small supplies of water for farm and domestic use.

No aquifer in the glacial drift is believed to be sufficiently productive of water to supply Michigan City adequately from one well or even from a field of two or three wells. However, certain aquifers in the glacial drift might warrant more thorough investigation as possible sources of supplemental supplies.

Aquifers in the Pierre shale furnish water to about three-quarters of the wells, in almost every part of the area. Although the exact physical nature of the aquifers in the shale is not known, their occurrence in the area is known to be quite general. The wells tapping these aquifers range in depth from 70 to 185 feet.

Pumping tests on wells tapping aquifers in shale in Michigan City indicate a coefficient of transmissibility on the order of 450 gallons per day per foot (gpd/ft) and a coefficient of storage on the order of 4×10^{-4} for the aquifer in that locality.

In general, it is unlikely that wells tapping aquifers in shale would yield more than about 10 gpm for any appreciable length of time. It is believed, however, that a system of wells, properly spaced so as to produce reasonably small interference with one another, could be developed that would yield a considerable amount of water. Individual wells probably could be expected to yield 7,000 to 14,000 gpd.

Some experimentation is warranted to determine whether wells constructed so as to allow water from the shallow drift aquifers to move to the aquifers in the shale might be beneficial in increasing the amount of water that could be taken economically from the area over a long period of time.

The aquifers of the Dakota formation would be reached at a depth of 1,200 to 1,300 feet below the land surface at Michigan City. They would be likely to yield more water than is needed by the city, but the water would be highly mineralized and unsuitable for general use. Wells tapping such aquifers at Michigan City probably would not flow naturally and the water would have to be obtained by pumping.

There is a possibility that aquifers may occur in some formations between the Dakota formation and the pre-Cambrian basement complex. However, it is believed that water in any deeper aquifers would be inferior in chemical quality even to that found in the Dakota formation.

All the water from the Michigan City area that was sampled for chemical analysis was found to be harder or more highly mineralized than is generally desirable for most domestic uses.

In five samples of water from the glacial drift, dissolved solids ranged from 540 to 3,190 parts per million (ppm) and averaged 1,320 ppm; hardness ranged from 160 to 1,410 ppm and averaged 510 ppm. The sodium concentration ranged from 18 to 71 percent and averaged 53 percent.

In 20 samples of water from the Pierre shale, dissolved solids ranged from 820 to 3,790 ppm and averaged 1,740 ppm; hardness ranged from 25 to 770 ppm and averaged about 210 ppm. In one water sample the sodium concentration was 34 percent, but in the other samples the sodium concentration ranged from 75 to 97 percent.

In addition to their generally high sodium percentage, most of the water samples from the area contained sufficient carbonate and bicarbonate, as compared to the calcium and magnesium present, to make the water of questionable value for general irrigation purposes.

INTRODUCTION

Purpose and Scope of the Investigation

The following is a progress report on the general study of the geology and ground-water resources of Nelson County being made by the United States Geological Survey, in cooperation with the State Water Conservation Commission and the State Geological Survey, as one of a series of investigations of different counties in North Dakota. These general studies are being made to determine the occurrence, movement, discharge, and recharge of the ground water, and the quantity and quality of such water available for all purposes, including municipal, domestic, irrigation, and industrial. However, the most critical need at the present time is for adequate and perennial water supplies for numerous towns and small cities throughout the State which are attempting to construct municipal water-supply systems for the first time or to expand present facilities. For this reason, the county studies are being started in the vicinity of those towns that have requested the help of the State Water Conservation Commission and the State Geologist. Progress reports are being released as soon as possible in order that the preliminary data may be available for use in the solution of water-supply problems in the towns, as well as for general reference, before the general studies can be completed. The area described in this report comprises about 112 square miles and is that part of Nelson County in which water may be available for municipal and other uses in the vicinity of Michigan City.

The investigation was made under the general supervision of A. N. Sayre, Chief of the Ground Water Branch, Water Resources Division, of the U. S. Geological Survey. The field work and test drilling were done under the direct supervision of P. E. Dennis, former District Geologist, and, later, under P. D. Akin, District Engineer.

Field work in the area was done chiefly from June to September, 1947, from May to October 1948, and in June 1949. It consisted of the following: (1) gathering information on most of the existing wells, including measurements of depths and water levels where possible, (2) mapping geologic features using aerial photographs and topographic maps, (3) drilling 55 test holes to depths of 20 to 140 feet for a total of about 2,400 feet of hole and taking ditch samples and cores of the earth materials, (4) determining land-surface altitudes at almost all the test holes, (5) collecting for chemical analysis water samples from water-bearing beds penetrated by test holes and existing wells, and (6) test pumping the wells to determine quantitatively the capacities of the water-bearing materials.

Locations of the test holes are shown in figures 3,5, and 6, the geologic sections in figure 4, and the data regarding the wells are given on pages 80a - 90b . The locations of the wells are shown in figures 5 and 6, and the logs of wells and test holes are given on pages 91-106.

Location and General Features of the Area

Michigan City, population 488 (1950 census), is in the northeastern part of Nelson County, 10 miles east of Lakota and about 53 miles west of Grand Forks. The city is served by two important highways, U. S. Highway 2 from east to west and State Highway 35 which originates in Michigan City and goes north. A branch of the Great Northern Railway passes through the city. The small community of Mapes is 5 miles west of Michigan City, at the western edge of the area.

The Michigan City area is in the part of the Central Lowland physiographic province (Fenneman, 1938, p. 559-588) that has been called the Drift Prairie by Simpson (1929, p. 4). (See fig. 1).

According to climatic maps by Bavendick (1946) the temperature in the Michigan City area ranges from an average of about 2°F in January to an average of about 67°F in July. Thus the area is characterized by cold winters and fairly warm summers. The average annual precipitation is about 19 inches. The growing season is about 120 days, during which most of the precipitation

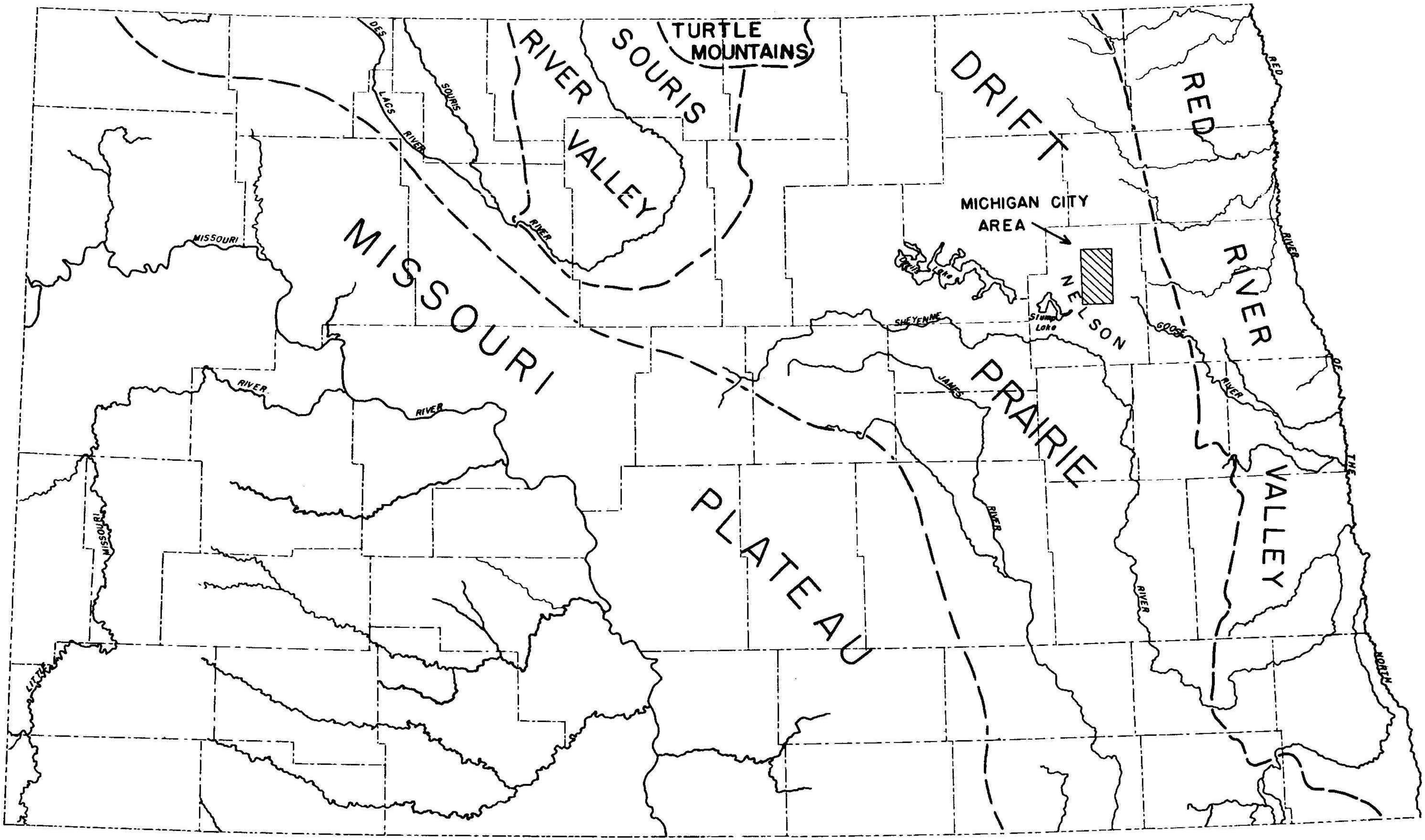

FIGURE I.—MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC DIVISIONS, AS MODIFIED FROM SIMPSON, AND LOCATION OF THE MICHIGAN CITY AREA.

occurs.

The principal occupation of the area is farming, with wheat, flax, oats, barley, and hay the principal crops. Some beef cattle and dairy cows are raised.

Several more or less distinct physiographic units form the topography of the area, as shown in figures 3 and 5. Most prominent are two end moraines, one in the northeast and the other in the southcentral part of the area. The limits of the southern moraine, which has a typical knob-and-kettle topography, are much more distinct than those of the northeastern one, whose principal features are northwest-trending morainal ridges with few, if any, intervening steep-sided depressions. Northeast of the southern moraine are two former glacial spillways, referred to in this report as the Goose Creek and Lindsey Lake spillways. At the present time they drain into the basin of the Red River of the North. Two large kettle chains, the main axes of which are more or less alined and strike north, lie west of the moraines. The northern kettle chain is referred to as the Lake Laretta chain and the southern is called the Bitter Lake chain. A third kettle chain, smaller and unnamed, lies just northwest of Michigan City.

The rest of the area consists of flat to rolling ground moraine and overridden outwash, which could not be differentiated in the field without more intensive and detailed mapping than could be done in the short time available.

Previous Work and Acknowledgments

The only previous geologic work done in the Michigan City area was by Upham (1896, pls. 18, 19, and 20), who mapped the morainal tracts of eastern North Dakota in a reconnaissance fashion. Simpson (1929, p. 177-181) discussed the geology and ground-water resources of Nelson County but he did not investigate the Michigan City area specifically. Some of the well data and chemical analyses contained in the present report were taken from Simpson's report. Other well data and chemical analyses were taken from Abbott and Voedisch (1938, p.68-69).

In 1938 and 1939 the Works Projects Administration made a State-wide well inventory, the results of which were never published but have been circulated in typescript copies. The bulk of the well data given in the table "Records of wells" in the present report was adapted from this inventory. For more than half the wells, the depths and aquifers were checked with the local well driller, Otto Anunson. The information in the table is therefore fairly accurate, the most serious errors being in the names of the current owners.

Prof. R. F. Flint, of Yale University, made a number of pertinent suggestions concerning the geology of the area in an office discussion with the senior author.

The present study was facilitated by the ready cooperation of the townspeople and farmers in the area. Special thanks are due Delbert and Lloyd Wright, who twice flew the senior author over the area, and those residents who gave the authors data concerning their wells or permitted measurements of depths and water levels in their wells and test drilling on their land. Thanks are due also to Otto Anunson, driller.

Many of the chemical analyses given in the present report were made by the North Dakota State Department of Health and by the North Dakota State Laboratories Department.

Present Water Supply and Future Needs

By far the greatest use of ground water in the Michigan City area is for farm supplies. Almost all the dug and bored wells in the area tap aquifers in the thin drift blanket over the Pierre shale. A few deeper, drilled wells enter drift aquifers in "lows" in the shale. The drift wells in the Michigan City area range from about 10 to 110 feet in depth. Generally the water from the drift is of poor quality for drinking and culinary purposes and is almost invariably hard. Most of the drilled wells and at least one dug well tap aquifers in the Pierre shale. These wells range in depth from about 40 to 185 feet. The quality of the water from the shale is locally reputed to be potable and soft. As contrasted with drift wells, which sometimes failed in the drought years of the 1930's, these wells are locally reputed to have furnished perennial supplies of water. The capacity of the shale wells generally is satisfactory for most farm, domestic, and stock needs, as long as there is no demand for large-scale supplies, as for irrigation.

At the start of this investigation Michigan City had no public water-supply and sewer system. It was estimated that the city would need a water supply of about 50,000 gpd. Water for use in the city was obtained from numerous private wells, almost all of which end in the Pierre shale (see fig.6). Although the quality of water obtained from the shale is considered satisfactory locally, wells developed in the shale generally have a capacity of less than 15 gpm. This low capacity is not satisfactory for large supplies for municipal or industrial uses.

In 1945 the Great Northern Railway drilled three test holes into the Pierre shale (see fig. 6). The quantity of water in these test holes was deemed insufficient for its needs. The railway then constructed a small reservoir with a fairly impervious drift bottom by deepening a "slough" at the east edge of the city (see fig. 6). The "slough" has a catchment area large enough to fill the reservoir in the spring of each year.

The only other single user of large amounts of water in the city is the creamery, which obtains water from two shale wells. These wells have capacities of less than 10 gpm. The peak use of water by the creamery is in the summer, and is about 8,000 gpd.

It has been decided to proceed with the construction of a water-supply and sewage-disposal system, using several small-capacity wells in shale as the source of water supply. It is realized, of course, that the supply of water from this source will be considerably smaller than is desirable, but it probably will meet minimum domestic requirements. The logs and locations of these new supply wells, drilled by the city, are included in this report.

Well-Numbering System

The well-numbering system used in this report is based upon the location of the well with respect to the land-survey divisions used in North Dakota. The first number is that of the township north of the baseline that extends laterally across the middle of Arkansas. The second number is that of the range west of the fifth principal meridian. The third number is that of the section within the designated township. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarter sections, quarter-quarter sections, and quarter-quarter-quarter sections. If more than one well occurs in a 10-acre tract (quarter-quarter-quarter section), consecutive numbers are given to them as they are scheduled. The number follows the letters. Thus, well 153-58-32ddc6 (fig.6) is in Township 153 North, Range 58 West, section 32. It is in the southwest quarter of the southeast quarter of the southeast quarter of that section and is the sixth well scheduled in that 10-acre tract. Similarly, well 151-58-7add (USGS test 22, fig. 3) is in the southeast quarter of the southeast quarter of the northeast quarter of sec. 7, T. 151 N., R. 58 W. Numbers for wells not

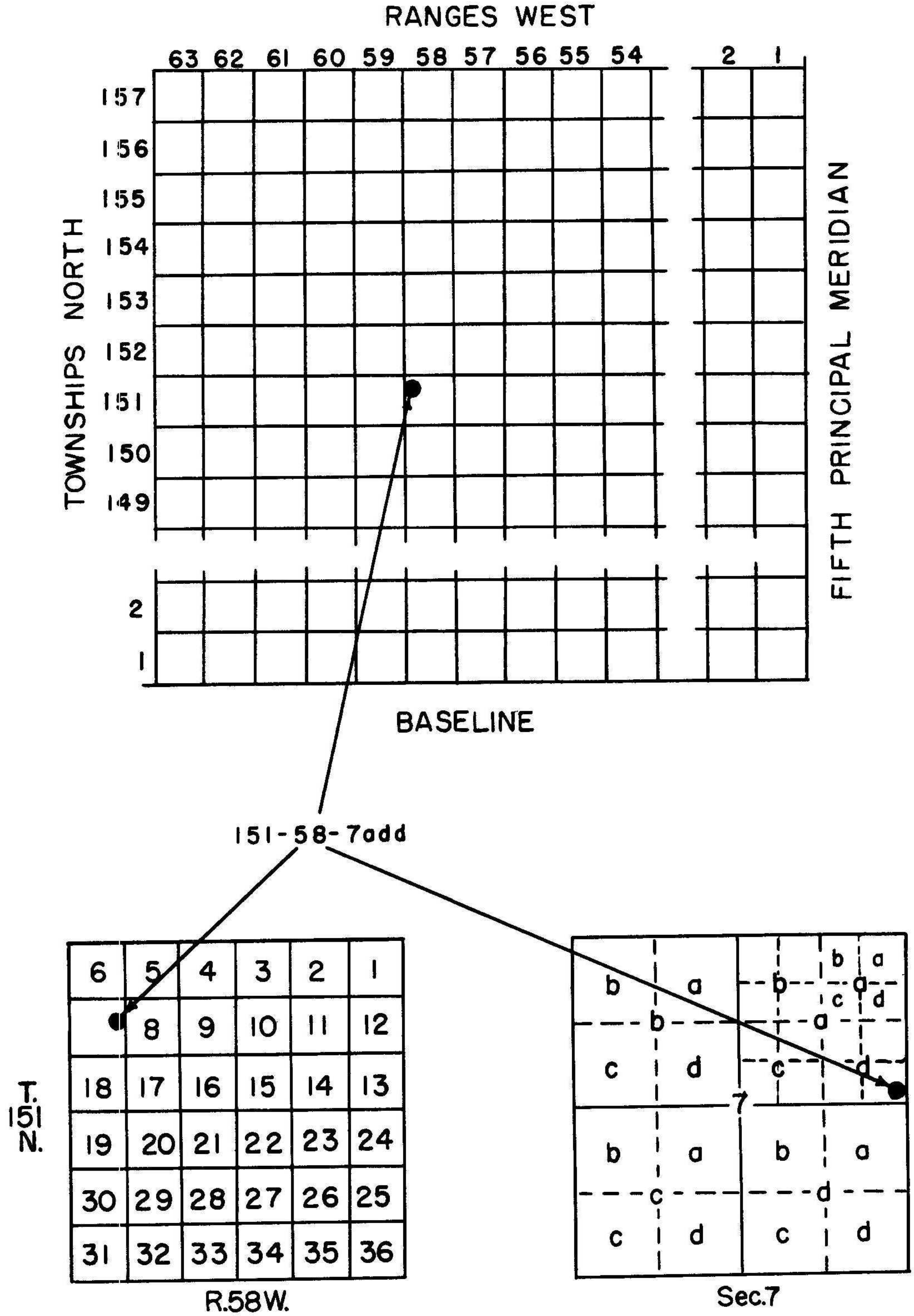

Figure 2 --Sketch illustrating well-numbering system.

accurately located within the section may contain only one or two letters after the section number, indicating that the locations of such wells are accurate only to the quarter section or quarter-quarter section. Figure 2 illustrates the application of this numbering system.

The test holes drilled under the supervision of the U. S. Geological Survey were given serial numbers in the field. These serial numbers with the prefix USGS, have been retained in the report for purposes of reference and for ease of recognition by the local people. Certain other wells and test holes, such as those drilled by the Great Northern Railway and Michigan City, are shown by special symbols on the illustrations for easy reference and identification.

GEOLOGY

Rock Units

The surface material in the Michigan City area is glacial drift of the Mankato substage of the Wisconsin stage of the Pleistocene series. The immediately underlying bedrock is the Pierre shale of Late Cretaceous age. No wells in the area or in the immediate vicinity penetrate the entire thickness of the Pierre shale and therefore the thickness of the formation at Michigan City is unknown. There is good reason to believe that the Niobrara formation, the Benton shale, and the Dakota formation also underlie the area. The evidence for the possible occurrence of these formations in the Michigan City area will be discussed later in this section.

Information regarding the glacial drift and the Pierre shale was obtained from test holes drilled under the supervision of the U. S. Geological Survey during the investigation from several test holes and wells drilled by Michigan City, from private wells, and from surface exposures. Data on the formations below the Pierre shale were obtained from published well logs.

No stratigraphic column is given in this report because the inclusion of one might imply greater certainty than is warranted concerning the occurrence of formations below the Pierre shale.

Glacial Drift

The glacial drift in the Michigan City area, as it was found in USGS test holes, ranges in thickness from 17 feet (USGS test 54) to 135 feet (USGS test 53). In most test holes it was found to be less than 35 feet thick (see fig. 4), and well data indicate that generally it is not more than 40 feet thick (figs. 5 and 6, and table on p.61).

Glacial drift is usually divided, lithologically, into (a) till and (b) stratified drift. In general the glacial drift in any one area is derived principally from the local bedrock. In the Michigan City area the local bedrock is the Pierre shale, which appears in the drift as brittle flat pebbles or as calcareous clay.

In fresh well cuttings the color of the drift generally changes from a yellow brown to a blue gray at depths of about 10 to 20 feet below the surface, where the oxidized zone ends. This change, if present, is indicated in the geologic sections by an oblique arrow at each test hole. In desiccated samples, such as are examined in the laboratory, the change is from a dull brown or buff to a light or dark gray.

The till is a heterogeneous mixture of clay, silt, sand, gravel, and boulders, which has no distinct or prominent stratification. The till seen at or near the surface in road cuts or similar exposures in the Michigan City area usually has some or all of the following characteristics:

(a) A composition largely of a gritty silt and clay plus materials of all size ranges.

(b) An over-all color of yellow brown.

(c) A rough blocky fracture, tending to flakiness when dry.

(d) A highly calcareous component which causes effervescence in dilute hydrochloric acid.

(e) Boulders and pebbles of shale, limestone, and dolomite, as well as those of granite and gneiss which may fall apart at the touch.

(f) Tiny, distinct, red-orange rust flecks.

(g) Platy crystals of gypsum, generally less than a quarter of an inch in longest dimension.

The till does not yield water to wells, but it functions as a confining bed for water contained in associated glacioaqueous deposits.

Stratified drift is a term applied to material that is stratified and sorted to some extent. Till and stratified drift grade into one another, depending on the extent to which flowing water was involved in their deposition. The term "glacioaqueous" is used in this report to refer to all stratified drift resulting from glaciation. It includes glaciofluvial (glacial-stream), glaciolacustrine (glacial-lake), and ice-contact deposits. The glaciofluvial or "channel" deposits make the best aquifers because of their better sorting, the comparative absence of clay and silt fines, and their continuity in channel directions. The scrambled structure and lack of continuity of materials in the ice-contact deposits do not permit as rapid transmission of water as do the channel deposits. No glaciolacustrine deposits were found in the area.

Bedrock

Information on the depth to and thickness of the Pierre shale, Niobrara formation, Benton shale, and the Dakota formation (p.14) was obtained from logs of wells outside the Michigan City area, and their indicated thicknesses in the area are based on extrapolation of the data. The wells of which logs were used for extrapolation are:

1. A municipal supply well in the city of Devils Lake in Ramsey County, about 34 miles west-northwest of Michigan City. This well taps aquifers in the Dakota formation. Part of the log is, roughly, as follows: 50 feet of glacial drift, 560 feet of Pierre shale, 120 feet of Niobrara formation, 590 feet of Benton shale, and 191 feet of Dakota formation. The Dakota formation was entered at a depth of 1,320 feet below the surface (Laird, 1941, p. 25-27).

2. A private well in the northeastern part of Griggs County, W$\frac{1}{2}$ sec. 28, T. 148 N., R. 58 W., about 29 miles south of Michigan City. This well penetrated 40 feet of drift and ended in shale at 704 feet without encountering any water (Simpson 1929, p. 143). The shale penetrated probably is the Pierre and possibly other shale of Late Cretaceous Age.

3. A private well in the southwestern part of Grand Forks County, N$\frac{1}{2}$ sec. 19, T. 149 N., R. 54 W., about 31 miles southeast of Michigan City. This well passed through 100 feet of lake deposits and other glacial drift, 506 feet of shale, probably Late Cretaceous, and ended in a white sand thought to be Dakota sandstone (Simpson, 1929, p. 138).

The Pierre shale, a marine deposit, is probably less than 500 feet thick in the Michigan City area and it immediately underlies all the drift in the area. As found in the test holes the shale is a gray compact, fissile rock which contains occasional thin layers of richly calcareous material. Bentonitic beds a few inches to a few feet in thickness were encountered in some test holes in other areas, and this may be the material described by local drillers as "soapstone." Local drillers report that the uppermost parts of the shale may be fairly soft and clayey. The log of the well in the city of Devils Lake, referred to above, indicates that in the portions not penetrated by the USGS test holes the shale may be tan in places, and that it contains varying amounts of sand, lignite, gypsum, and sulfur.

The Pierre shale is the most important aquifer in the Michigan City area. Most of the water for farm supplies is obtained from the upper 100 feet of the formation (see table, p. 61).

The Niobrara formation and the Benton shale are reported to be 120 and 590 feet thick, respectively, in the Devils Lake well. They probably are thinner in the Michigan City area. In samples from the Devils Lake well, the Niobrara formation was found to be gray or tan and to contain gypsum, lignite, and selenite. The Benton shale there is gray and contains pyrite, gypsum, selenite, and sulfur. No water is obtained from these formations in the Michigan City area. It is reported that some aquifers are present in the formations in the Edgeley and La Moure quadrangles in south-central North Dakota (Hard, 1929, p. 45-46).

Concerning the Dakota formation Simpson (1929, p. 40) noted that, for the convenience of his report, "the entire group of water-bearing sandstone beds below the Benton, with the intervening shaly or calcareous beds, is called the Dakota sandstone, though it may include earlier Cretaceous rocks, especially in the western part of the State." In the present report the term Dakota formation is used to designate the group of beds referred to be Simpson in this instance. Simpson described the Dakota sandstone proper (p. 40-41) as "a gray ferruginous sandstone, very poorly cemented and interbedded with thin layers of clay and shale. In places it includes beds of fine, incoherent nearly white sand."

The data on the three wells noted at the beginning of this section were plotted on a structure-contour map of the Dakota sandstone prepared by Laird (1949). Assuming that the material found in the last well was correctly identified as Dakota sandstone, it is concluded that the formation may lie under the Michigan City area at a depth of 1,200 to 1,300 feet below the surface.

Pre-Cambrian rocks underlie the entire area but have not been reached by drilling there.

It is likely that rocks of early Mesozoic and Paleozoic ages are present between the Dakota formation and the pre-Cambrian crystalline basement complex.

A Note on the Subdrift Topography

The general character of the subdrift topography is shown on the geologic sections, figure 4. Both the north-south sections (A-A''') and the east-west section (C-C') show the surface of the shale to be nearly flat to gently rolling. The few depressions encountered by the test holes appear to be rather narrow and steep sided. The general evenness of the surface and the narrow steep-sided depressions may be partly or wholly the result of the smoothing and scouring action of the ice, respectively. However, because these features of the sub-drift topography are known to be common to much of North Dakota and adjacent States, it is believed more likely that they were produced largely by stream erosion prior to the glaciation, in which case a newly incised erosion surface is suggested.

Glacial Geology

End Moraines

In general, end moraines are expressed in the topography as more or less continous topographic "highs" having an irregular surface with varying degrees of relief. These "highs" are built up when the melting of the ice sheet at its terminus keeps pace with its general forward motion. Glacial ice usually has entrained considerable debris, which is dumped when the transporting ice melts. Sometimes this debris is later ridged-up by subsequent forward motion of the ice. It is this partly dumped and partly ridged material that forms the moraine. Most of the material is unsorted-that is, till. Some sorted material may be present in a moraine, however, depending on the quantity of melt water available. The last ice that forms the moraine, when no longer active, may deposit, as it melts, partly sorted material over previously deposited material. This material is "ablation moraine."

The two end moraines in the Michigan City area are not named, or referred to by name, in this report. The area was first mapped geologically by Upham (1896, pls. 18, 19, and 20). Since his work, a number of moraines in the Devils Lake-Stump Lake region to the west have been remapped and renamed. At the present time it is not clear if Upham's correlations between the Michigan City area and the area to the west are valid.

The southern moraine differs in appearance from the northern moraine and seems to have had a somewhat different genesis. In ground plan, it is roughly wedge-shaped, the apex pointing north (fig. 3). It is approximately bounded on the north and northeast by the Goose Creek spillway and partly bounded on the west by the Bitter Lake kettle chain. Except for the group of northwest-striking ridges on the northeast, the surface of the moraine consists mainly of knobby hills and steep-sided depressions. It has been suggested 1/ that the steep-sided kettles, together with certain other topographic features outside the moraine area, may indicate the remains of a preglacial or interglacial drainage system.

Local relief and topography similar to those in the end-moraine area (fig. 3) also characterize the Bitter Lake kettle chain, but this kettle chain is not included in the southern moraine area because it does not form a topographic "high."

1/ Flint, R. F., 1950, Oral communication.

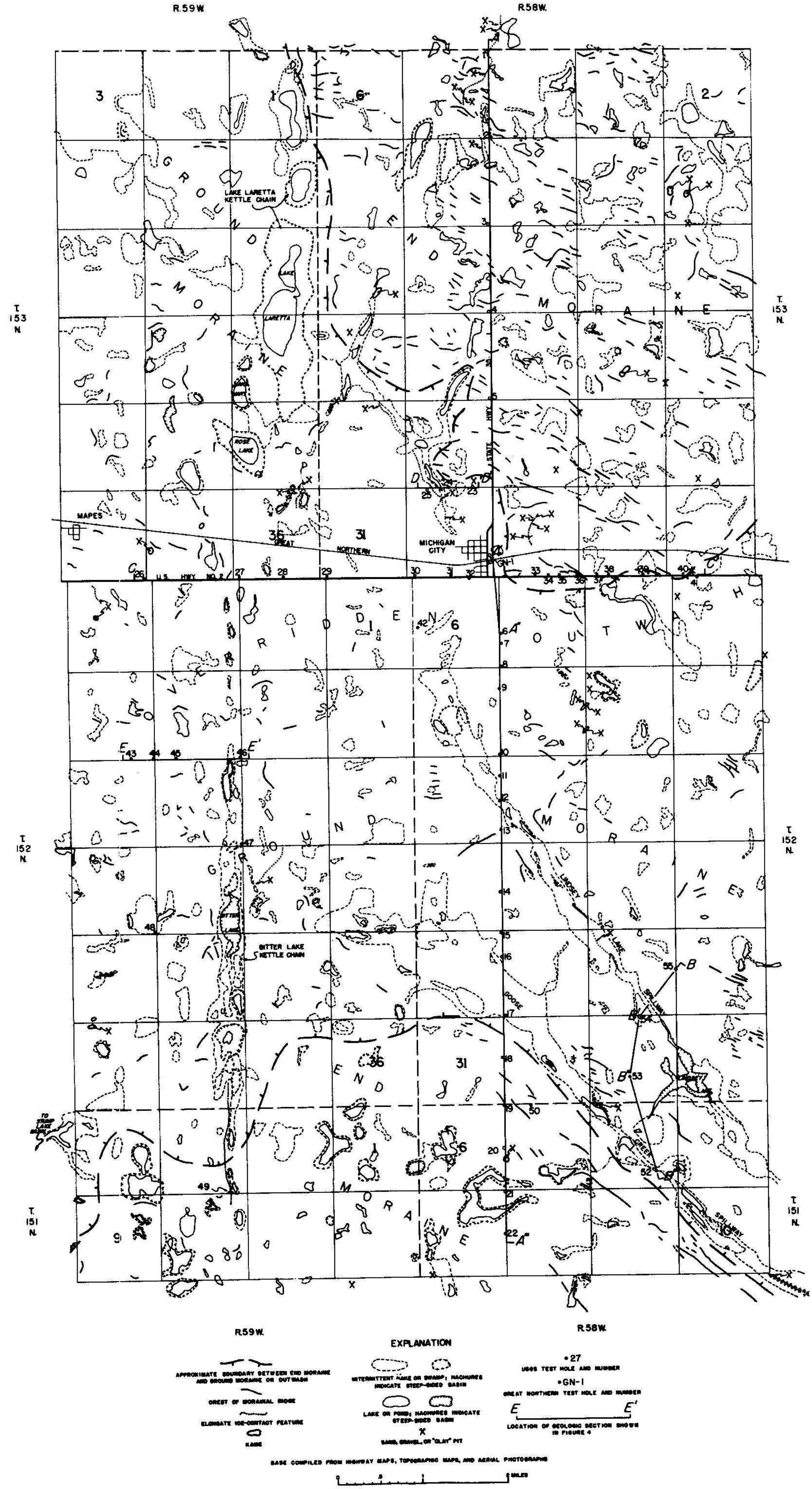

FIGURE 3.—MAP OF MICHIGAN CITY AREA SHOWING GLACIAL GEOLOGY AND LOCATIONS OF TEST HOLES AND GEOLOGIC SECTIONS.

The knob-and-kettle topography of the southern moraine betokens a lengthy stay of active ice and the continual burial of ice blocks whose melting made the depressions or kettles. The final retreat of the ice from the site of the moraine was probably more halting and slower in the northeast than in the northwest direction, as indicated by the presence of the northwest-trending morainal ridges. These ridges, a few of which are north of the Goose Creek spillway in secs. 32 and 33, T. 152 N., R. 58 W., were probably among the last features formed as the active ice front retreated. USGS test 51, drilled in one of these ridges to a depth of 52 feet, did not reach bedrock. The upper 15 feet was a sandy silt and may represent a shallow crevasse filling whose presence here might be explained as follows: The morainal ridge, one of the higher topographic features of the area, may have had its crest first exposed after the ice began to waste downward. The top of the ridge would be fringed with ice which formed a small basin into which the sandy silt was deposited from the contiguous ice.

As shown in geologic section A-A''', figure 4, there seem to be two layers of sorted material underlying the southern moraine: one at about 1,500 feet and a lower one between 1,460 and 1,480 feet. The lower one appears in the section as if it might be continuous with the sorted material found in USGS test 17, under the Goose Creek spillway. The continuity is problematical, however, as will be discussed in the section on Spillways.

The apparent continuity and generally increasing thickness of the sorted materials of the moraine toward the south suggest that they may be outwash deposited in front of stationary or moving ice. They may have been overriden later and partly modified as the ice moved south and built the moraine.

USGS test 21, drilled in one of the larger and deeper kettles in the moraine, showed the presence of a "low" in the bedrock surface.

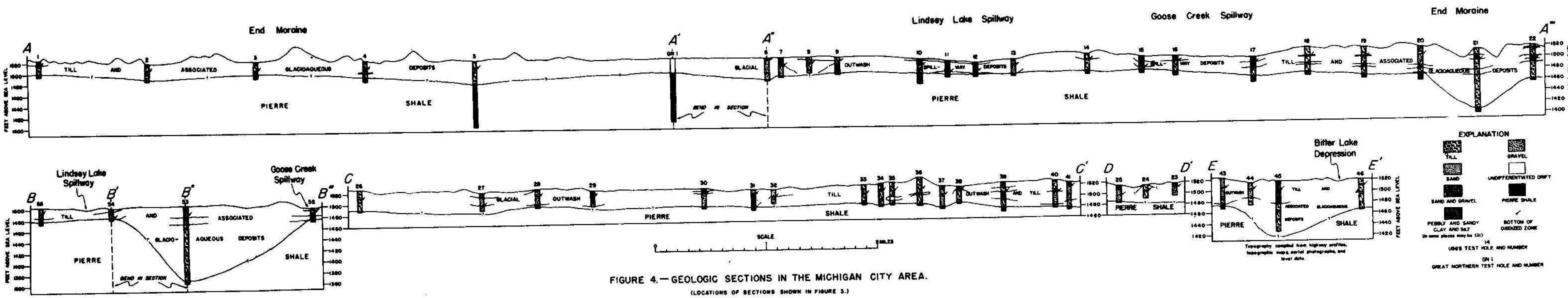

FIGURE 4.—GEOLOGIC SECTIONS IN THE MICHIGAN CITY AREA.

(LOCATIONS OF SECTIONS SHOWN IN FIGURE 3.)

The relationship of the kettle, the "low", and the relatively thick sorted deposits is not clear. However, it is suggested that the bed-rock "low" probably was floored with till before the deposition of the sorted materials. The depression in the till may have collected a thicker section of sorted material than the flatter topography to the north. Also, the till-lined basin may have permitted the emplacement or burial of a large ice block or group of ice blocks which upon melting formed the present kettle.

West-northwest of the kettle mentioned above, in sec. 6, T. 151 N., R 58 W., and in secs. 1 and 2, T. 151 N., R. 59 W. (fig. 3) is a group of deep, steep-sided kettles. A comparison of figure 3 with figure 5 indicates that drift more than 110 feet thick is associated with this rough alinement of kettles. This "low" in the bedrock may be continuous with the one penetrated by USGS test 21. In sec. 9, T. 151 N., R. 59 W., another "low" in the bedrock, associated with large kettles, is indicated by well data.

The fact that wells have been developed in the "lows" may indicate the presence of sorted material in a stratigraphic sequence similar to that found in USGS test 21.

The questions as to whether the places of thick drift can be "tied together" to form a coherent drainage net or whether the occurrence of large deep kettles in the Michigan City area uniformly indicates thick drift can be settled only by obtaining more detailed subsurface data than are available at the present time. However, the apparent association of the large kettles with thick drift deposits suggests a means of explaining the specific locations of some of the kettles. The kettles may have been formed as the result of relatively thick ice accumulating in bedrock swales. The swale fillings then may have been buried in drift deposited by a later, minor readvance of the glacier after the ice that had accumulated in them was melted.

The deep-drift occurrences have been referred to previously as "lows" or swales in the bedrock to avoid any commitment concerning their origin. They may represent parts of a drainage net developed just prior to the deposition of the latest drift, the base of which is impossible to ascertain at the present time. The drainage net may have been developed partly in the shale bedrock and partly in the drift. It may never be possible to outline the drainage net completely, as it may prove to be difficult to distinguish the older drift in which the valley was formed from the younger drift at the surface.

On the other hand, the bedrock "lows" may be parts of a drainage net developed entirely in the bedrock and later partly obliterated by glacial erosion; or they may represent a drainage net that was scoured out, widened, and deepened by glacial ice to a varying extent in different localities.

The northern moraine, as shown in figure 3, lacks the chaotic knob-and-kettle appearance of the southern moraine. The main features are a series of generally northwest trending ridges easily seen on aerial photographs. However, the regular trend of the ridges is not easily discovered by "on-the-ground" investigation. The limits of the moraine are not so clearly defined as are parts of those of the southern moraine. The southern limit of the northern moraine was indicated on the map, rather arbitrarily, as the southern boundary of the large ridges. (However, sizable ridges do occur outside of the area indicated as end moraine, as, for example, in sec. 17, T. 152 N., R. 58 W.) The same is true of the western limit. The Lake Laretta kettle chain, like the Bitter Lake kettle chain, is not high topographically and, hence, was not included in the end-moraine area.

The surface topography shown in cross section A-A''' is rougher in the northern than in the southern moraine. The relief in the northern moraine is greater but the topographic features are more numerous in the southern moraine. The northern moraine is weakly developed in part and includes some rather flat areas.

The uppermost material found in USGS tests 3 and 4 seems to be partly sorted and probably is ablation moraine.

The presence of the more or less oriented ridges seems to indicate that the ice retreated in a halting fashion to the northeast, but with little or no readvance and overriding or burial of detached masses of ice, thus resulting in a lack of steep-sided depressions.

The thickest drift in the northern moraine area is that reported in two drilled wells, in secs. 14 and 34, T. 153 N., R. 58 W. The drift in these wells was reported to be about 60 feet thick (fig. 5). The well in sec. 34 was drilled on top of a morainal hill which is about 20 or 30 feet above the surrounding topography. This, rather than a "low" in the shale bedrock, may account for the thicker drift.

The bedrock topography beneath the moraine is fairly flat, so far as can be discerned from the test-hole data. However, in the northern part of geologic section A-A''' the test holes were drilled a mile apart, and "lows" such as the one found at the extreme south end of the geologic section may be present between the test-hole locations.

The lack of large steep-sided kettles in the northern moraine is consistent with the flat bedrock surface, if it is assumed that depressions in the bedrock had a tendency to catch and preserve large blocks of ice which later melted and formed kettles. A relation of the kettles to the irregular bedrock surface was suggested in the case of the southern moraine. Well data available from the northern moraine support the hypothesis of that relationship.

Ground Moraine

Ground moraine is flat to rolling topography underlain largely by till. It may originate from drift overridden and plastered down by moving ice, or from ablation moraine. In glacial geology, ground moraine is a fairly generalized category in which are placed types of topography underlain by till that do not readily fall into any other category.

The occurrence of ground moraine in the Michigan City area is shown in figure 3. It has less than 20 feet of relief and is confined to the areas west of and between the two end moraines, including those west of the Lake Laretta kettle chain and those east and west of the southern part of the Bitter Lake kettle chain. It was not possible, in the field, to find the contact between the ground moraine and what appears to be outwash that was laid down and later overridden by ice.

Ice-Contact Features

The locations of ice-contact features in the Michigan City area are shown on figure 3. None are very long nor do they have much relief. They were formed by melt water in or under cavernous and fissured ice that temporarily or permanently stopped moving. They are usually composed of sorted material. As noted by Flint (1947, p. 143), "The sediments of ice-contact stratified drift have three general characteristics that distinguish them from proglacial sediments: extreme range and frequent and abrupt changes in grain size; intimate association with till; and deformation." The specific types of ice-contact features are identified by their shape, lithology, and relation to other features.

The principal types of ice-contact features may be defined as follows: Eskers are sinuous, steep-sided ridges which are thought to be the deposits of streams beneath or within the ice. Crevasse fillings are even-crested ridges which have been formed in fissures or crevasses open to the sky. Kames are ideally conical but may be short, flat-topped, or wedge-shaped ridges. They may originate as alluvial fans down a steep ice face, or as deposits in openings in the ice. Kame terraces commonly are formed of material deposited between an ice face and a valley wall or hillside. The materials of all ice-contact features are subject to collapse and deformation when the retaining ice walls melt.

Many of the ice-contact features in the area have a rather amorphous topographic expression, which leads to some difficulty in delimiting the sorted material. On figure 3 they are generally indicated only by the "gravel pit" symbol. Most of these amorphous features are probably kames or kame terraces. The kamelike ones tend to splay out, with few if any sharp contours. Those kame-like terraces are generally located on the sides of large hills, which apparently are composed chiefly of till. Examples of the latter can be found in sec. 28, T. 153 N., R. 58 W., and in sec. 7, T. 151 N., R 58 W.

The only esker in the Michigan City area that has the typical knobby crest and sinous ground plan crosses State Highway 35 in the extreme northern part of the area, in secs. 3 and 4, T. 153 N., R 58 W., and sec. 33, T. 154 N., R. 58 W. The relief of the esker is generally less than 25 feet. It seems to end in the south in a group of high morainal ridges. USGS test 1 was drilled in a flank of the esker and penetrated about 6 feet of sand and gravel.

The location of the esker among a group of morainal ridges may appear to be somewhat unusual, because morainal ridges are formed by active ice and ice-contact features are characteristic of stagnant or wasting ice. However, the esker probably was formed after the ice that formed the morainal ridges had become detached from the main mass of active ice.

An esker in secs. 29, 30 and 32, T. 153 N., R. 58 W., with probably less than 20 feet of relief, has a slightly knobby crest and is somewhat sinuous in ground plan. It is interrupted by a swamp in the NW$\frac{1}{4}$ sec. 29. The southeastern part of the esker is poorly developed and is barely perceptible as a low, continuous rise in which are two gravel pits. Sand and gravel is exposed in a road cut just east of USGS test 25. The 27 feet of sorted material in USGS test 25 probably is related to the esker. The low relief of the esker at this point may indicate that it is partly buried in till.

The presence of the esker in and paralleling the spillwaylike depression northwest of Michigan City may indicate that any surface drainage of melt water through the depression was preceded by sub or englacial drainage. It is suggested that the subglacial channel in which the esker was deposited was later enlarged and opened to the sky.

Another feature that may be an esker was found in a setting similar to that of the one discussed above. It is in the SE$\frac{1}{4}$ sec. 27, the E$\frac{1}{2}$ sec. 34, T. 152 N., R. 59 W., and NE$\frac{1}{4}$ sec. 3, T. 151 N., R. 59 W This is a long, fairly straight ridge that begins in the north by partly bisecting the Bitter Lake group of depressions and continues south, still partly flanked by these depressions. It is more or less even crested in some places but in other places it has the knobby crest characteristic of eskers. It has the characteristic steep sides of a hill composed of sand and gravel.

USGS test 49 was drilled at the southern end of the feature with rather ambiguous results. At the test hole, the uppermost 24 feet is material that may be either till or a clayey pebbly sand; that material is underlain to a depth of 57 feet by sorted material. The surface relief of the feature is greater than the 24 feet of material that may be till.

It is believed that the Bitter Lake kettle chain is the remains of a sub- or englacial drainage system. It is possible, therefore, that till was let down onto the feature by the collapse of an ice roof.

A number of other eskers were observed in the Michigan City area: in sec. 33, T. 153 N., R. 58 W., in sec. 36 T. 153 N., R. 59 W., and in secs. 4 and 23, T. 152 N., R. 59 W.

Several features that may be crevasse fillings were found in the area. One, in sec. 8, T. 153 N., R. 58 W., may be related to the esker north of it in sec. 5. This feature is fairly straight. Its relief was difficult to estimate because most of the contents had been excavated, but it appears to have had about 10 or 15 feet of relief and a fairly flat crest.

Three other crevasse fillings that were studied are in the spillways. One, in the Lindsey Lake spillway, is in sec. 28 T. 152 N., R. 58 W. The other two are in or near the Goose Creek spillway: one is in sec. 4, T. 151 N., R. 58 W., just outside the limits of the spillway as shown on the map, and the other is in sec. 14, T. 151 N., R. 58 W., just outside the extreme southeastern corner of the map area.

The structure of the crevasse fillings was either poorly exposed or not definitive, and it is not certain that they are truly ice-contact features. Possibly they were initially ice-contact features whose contents were reworked into "bars" or they may be primary "bar" deposits.

The short ridge in the SE$\frac{1}{4}$ sec. 11, T. 152 N., R. 59 W., which is shown as morainal in figure 3, may also be a crevasse filling.

Kames are the commonest type of ice-contact feature in the Michigan City area. They generally have no characteristic form and the symbol on the map usually only approximates their shape. The kames that have better conical or wedgelike shapes may be found in sec. 35, T. 153 N., R. 59 W., and in secs. 28 and 33, T. 152 N., R. 59 W.

As is apparent from the geologic map (fig. 3) and the preceding discussion, most of the ice-contact features are in the eastern half of the area, and most of these are in the vicinity of the northern moraine. The reason is not clear, but the concentration there of ice-contact features may be related to the presence of an active but retreating ice front. Greater quantities of melt water and glacial debris were available there than in the western half of the area which, it is believed, was occupied by large masses of less vigorously moving or stagnant ice. Concurrent development of morainal ridges and ice-contact features probably explains why many of the ice-contact features are not typically developed, as they have been distorted and partially obliterated.

In general there is little difference in the mineral constituents or grain sizes of the materials constituting the eskers, crevasse fillings, and kames. Most particles are less than 1½ inches in largest diameter, though all the deposits contain scattered cobbles and boulders. Sand is the predominant size fraction. The principal mineral constituents, roughly in decreasing order of frequency, are those derived from metamorphic and igneous rocks, limestone and dolomite, and shale.

Proglacial Deposits

The proglacial deposits in the Michigan City area are shown in figure 3 as overridden outwash and spillway sediments. Proglacial deposits are those that were deposited in front of and beyond the zone of active moving ice.

Outwash deposits are usually those that were laid down in front of a moraine by short shifting streams which headed in the moraine. In the ground plan, the long axis of the outwash body as a whole commonly parallels the outer edge of the moraine. The outwash deposits are believed to have been overridden by readvances of the ice shortly after deposition and are generally covered with a thin veneer of till.

Spillway sediments were deposited by more definitely channeled streams of melt water which may or may not have headed in the outwash.

In the Michigan City area, widespread and more or less continuous deposits of sorted material with less than 20 feet of relief are believed to be overridden outwash deposits and spillway deposits. The overridden outwash deposits were discovered almost entirely by test drilling. The spillways can be identified on the surface as shallow, elongate depressions. Although the sediments of the overridden outwash and spillways are probably continuous with one another, they will be discussed separately.

Overridden Outwash Deposits

Overridden outwash deposits underlying parts of the Michigan City area were discovered mainly by the test drilling. In the absence of data obtained from test drilling, the outwash would have been thought to be ground moraine. The surface exposures of the outwash deposits are patchy and not easily classified; the surface topography in the outwash areas appears to be identical to that of the ground moraine. Among the areas that may be underlain by outwash are those north and east of the Bitter Lake kettle chain, especially along U. S. Highway 2. Those areas are not discriminated on the map (fig. 3) because sufficient evidence for indicating any contacts are lacking except in the places that were test drilled.

The surface of the area of overridden outwash is dotted with numerous small, shallow, undrained depressions. The amount of relief in the areas indicated as overridden outwash is generally less than 20 feet.

The material exposed in most road cuts along U. S. Highway 2 in the western part of the area could not be definitely correlated with the uppermost material found in the test holes (USGS tests 27 to 31, geologic section C-C', fig. 4). The samples from the test holes show sorted material immediately below the surface. The road cuts show mainly a pebbly, sandy clay and silt that may be interpreted as till or ablation moraine.

Exposures of material similar to that penetrated in the test holes were examined in (a) a road cut, (b) several gravel pits, and (c) a large excavation.

(a) The road cut is on the south side of U. S. Highway 2, about four-tenths of a mile west of the intersection with State Highway 35. The material is mainly sand.

(b) The gravel pits are in the SW$\frac{1}{4}$ sec. 35, T. 153 N., R. 58 W., in the NW$\frac{1}{4}$ sec. 3, T. 152 N., R. 58 W., and in the SW$\frac{1}{4}$ sec. 2, T. 152 N., R. 58 W. Considerable sand and gravel has been removed from the pits but the assortment and bedding, and the structure are not readily determinable because the pits have not been worked for several years and are now filled with water. The sorted material may continue beyond the limits of the pits; at least the slopes around the sides of the pits seem more or less continuous with the flatter topography beyond the areas of excavation.

(c) The excavation, made in the summer of 1950 for the Michigan City sewage-lift station, is near the north side of U. S. Highway 2, about two-tenths of a mile east of the intersection with State Highway 35. It is about 25 feet deep and more than 30 feet in diameter. The materials seen in the upper 10 feet consist of a pebble-free silt and clay, and a pebbly silt and sand. Both types of sediments are light brown and they grade into one another both laterally and vertically. Bedding is obscure or absent. A few boulders and large pebbles are present. The next lower 2 feet consists of coarse, poorly sorted, clayey light-brown sand, which makes a sharp contact with the overlying material. The rest of the material to the bottom of the excavation is blue-gray till.

The uppermost material probably is a thin bed of partly water-worked till and ablation moraine. The sand below probably is a thin lens of outwash. The sand is water bearing to the extent of necessitating continuous pumping to enable work to be done in the bottom of the excavation.

The outwash was penetrated by USGS tests 6, 7, and 9, geologic section A-A''', USGS tests 27, 28, 29, 30, 31, 32, 37, 39, 40, and 41, section C-C', and USGS tests 43, 44, 45, section E-E', figure 4. The principal basis for designating as outwash the sorted material found in these test holes is the widespread distribution and apparent continuity of the material. The lack of continuity in the eastern end of geologic section C-C', at least in the plane of the section, can be explained when considered in relation to the other glacial features.

Because most of the test holes were drilled in borrow pits along the margins of roads, much of the uppermost till or ablation moraine had been removed at the test-hole sites prior to the drilling. Thus in USGS test 27, 28, 30, 31, 32, 43, and 44, only a thin veneer of the material was penetrated by the drilling (see logs; some of this material is too thin to be represented in the geologic sections). Thicker sections were found in USGS test 29, 37, 39, 40, 41, and 45.

The outwash, in addition to being overlain by till, in places terminates against till, as seen in the eastern end of geologic section C-C', and in USGS tests 7, 8, and 9, section A-A''', figure 4. The material found in the road cut and gravel pits is similarly enclosed.

The bulk of the outwash material ranges from very fine and very coarse sand to fine gravel and medium gravel. It contains much interstitial clay and silt, which markedly decreases its permeability, thus making it a poor aquifer. The main constituent of the coarser outwash material is detrital shale. Among the other constituents are limestone, dolomite, and several types of igneous and metamorphic rocks.

The outwash as a whole probably was not simply deposited as a unit and then overridden by later ice. The information yielded by test drilling indicates that at least in some places it was deposited in a fairly complex manner. The test holes in the eastern part of geologic section C-C', and USGS test 6 to 9, section A-A''' (fig. 4), were drilled at or close to the arbitrary edge of the northern and moraine. The ice that deposited the moraine retreated slowly and in oscillatory fashion. This suggests that some of the outwash at the edge of the moraine was deposited among previously existing morainal ridges. Other portions of the outwash may have been partly or completely removed by a readvance of the ice whose prior melting had deposited it. The outwash that survived was then covered with a final veneer of till or ablation moraine. The material in some gravel pits may be saucer-shaped deposits of outwash lying in basins in the till. That exposed in others may extend downward and be continuous with a larger body of outwash that has considerable lateral extent. Thus, the material in the gravel pit near USGS test 41 is probably continuous with the outwash material in both USGS test 40 and 41.

The pitted surface of the buried outwash in some places probably is the result of its deposition on an uneven till or bedrock surface. In other places it may also be the result of the overriding of pitted outwash in which the buried ice masses were not completely melted before the readvance of the ice, as suggested by Thwaites (1926, p. 314).

An alternative, but less likely, interpretation of the outwash has been considered by the authors and will be only mentioned here. Except, perhaps, for places like the eastern end of the geologic section C-C', where fairly thick till overlies the outwash, the material called ablation moraine may actually be outwash. If the last outwash was laid down by feebly moving water, the material may have been fairly fine-grained and contained much silt and clay. If this material were reworked by frost action, plants, and animals, it might simulate ablation moraine or partly waterworked till. This hypothesis would place the "overridden" area in the category of a pitted outwash plain. However, this hypothesis is considered unlikely because of, among other reasons, the widespread occurrence of boulders over the supposed outwash, the lack of steep-sided kettles, and the absence of any remnant of a smooth upland surface. Criteria suggested by Thwaites (1948, p. 49) for discrimination of pitted overridden and pitted unstratified outwash are not all applicable here because of the possibly fine-grained character of the original outwash.

Spillway Deposits

The principal spillways are in the southeastern part of the Michigan City area. The northern spillway is referred to in this report as the Lindsey Lake spillway and the southern one as the Goose Creek spillway. At the present time they drain southeast into Goose Creek which flows into the Goose River, a tributary of the Red River of the North.

Where they begin, the spillways are wide and have gently sloping sides. They narrow to the southeast. They contain numerous subbasins which become apparent only when the spring runoff has passed. The spillways also contain two ice-contact deposits, in the NW$\frac{1}{4}$ sec. 28, T. 152 N., R. 58 W., and in the NW$\frac{1}{4}$ sec. 14, T. 151 N., R. 58 W., respectively.

The lateral limits of the spillways extend beyond those shown on the map (fig. 3), on which only the limits of the more conspicuous poorly drained or swampy places are indicated. A topographic map with a 20 foot contour interval covering the southern half of the Michigan City area is available, but probably a map with a 5-foot contour interval would be necessary to draw accurate limits.

Because the spillways are swampy and low-lying no surface exposures of the material underlying them were available for examination.

Two geologic sections were drilled across the spillways. The first is that part of section A-A''' (fig. 4) in which USGS tests 10 to 13 and 15 to 17 are located. The second, B-B''', is roughly parallel to the first and crosses the narrower, lower reaches of the spillways. In this section only USGS test 52 and 54 were actually in the spillways.

The uppermost material penetrated in drilling across the spillways was a pebbly, sandy clay and silt. Although this material as it appeared in the drill cuttings has a slight resemblance to till, 2/ it is believed actually to represent thin, alternating layers of sand, gravel, and silt and clay that were mixed up by the rotary drilling. This kind of material lines the spillways in several other areas that have been test drilled.

The greatest thicknesses of this material were penetrated in geologic section A-A''' by USGS test 15, 16, and 17, in the Goose Creek spillway, where they are as much as 8 feet. Underlying the upper material, the coarser sorted material such as sand and gravel are thickest in the Lindsey Lake spillway, where in USGS tests 10 and 13, they are about 24 feet thick. These coarser deposits, like those in the overridden outwash, were found to be rather clayey.

The uppermost pebbly and sandy clay and silt found in the drill cuttings probably have been deposited since late Pleistocene time as more or less seasonal deposits. The sand and gravel in these deposits probably were, and are, laid down in the spring when the water in the spillways has the greatest

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2/ Surface exposures of this material have also been seen by the authors in other areas in North Dakota. It is thought that an alternative hypothesis, the opposite of that proposed for overridden outwash, cannot be considered for the deposition of this material. There is no reason to believe that ice re-advanced over the spillways.

carrying power; the clay and silt, in the summer and fall under lacustrine conditions, when the spillways break up into subbasins.

The thicker sections of the upper clayey and silty material in the Goose Creek spillway indicate greater very late Pleistocene and post-Pleistocene deposition in this spillway than in the Lindsey Lake spillway. On the other hand, the thicker sections of coarse material in the Lindsey Lake spillway probably indicate greater Pleistocene sedimentation. This may be explained by the areal location of the spillways. The Goose Creek spillway was not as close to the active ice front in the northeastern part of the area as was the Lindsey Lake spillway, which probably intercepted the larger portion of melt water.

The presence and orientation of the two spillways may indicate two minor halts in the retreat of the ice front. At least a small part of the stratigraphically lower portions of the spillway deposits actually may be glacial outwash. Later the spillways probably functioned solely to drain water and sediments from the outwash farther north which was not yet overridden. The overridden outwash in USGS test 9 (see geologic section A-A''', fig. 4) is continuous with the spillway deposits in USGS test 10.

Kettle Chains

The features classified as kettle chains are groups of elongate depressions whose long axes are more or less alined. The three major kettle chains in the Michigan City area, shown on figure 3, are (1) the Lake Laretta chain, (2) the Bitter Lake chain, and (3) an unnamed chain northwest of Michigan City.

(1) The Lake Laretta chain consists of several depressions, most of them steep-sided, which are alined more or less north-south, and which extend from sec. 1 to sec. 26 T. 153 N., R. 59 W. All the depressions contain lakes, the largest of which is Lake Laretta.

(2) The Bitter Lake chain is essentially one large basin which extends

north-south from sec. 10, T. 152 N., R. 59 W., to sec. 3, T. 151 N., R. 59 W. At the northern and southern terminations of the basin, and in a line with its major axis, are a number of separate depressions, which extend into sec. 3, T. 152 N., R. 59 W., on the north and into sec. 10, T. 151 N., R. 59 W., on the south. The basin itself contains a number of subbasins, in the largest of which is Bitter Lake. The southern end of the depression is partly bisected by what may be an esker. (See p. 23.)

The walls of both these kettle chains seem to be composed almost entirely of till. Aside from ice-contact features, no large deposits of sorted material were found in or near the chains.

(3) The unnamed chain is roughly N-shaped and lies northwest of Michigan City. The west arm of the "N" runs south-southwest, from sec. 18, T. 153 N., R. 58 W., to sec. 36, T. 153 N., R. 59 W. The crossbar of the "N" extends southeastward from sec. 19 to sec. 32, T. 153 N., R. 58 W. The east arm of the "N" starts in sec. 20 and extends in a south-southwest direction to sec. 29, T. 153 N., R. 58 W. This group of depressions consists mostly of a branching elongate trough with subbasins containing water or swamps. The southern part of the west leg, however, is a kettle chain.

Two eskers parallel parts of this chain. The first is near the southern end of the western arm. The second, the longer one, parallels a part of the crossbar.

The Lake Laretta and Bitter Lake chains may be the surface expressions of "lows" in the bedrock. Data from test holes and wells are available only for the Bitter Lake group. A section, E-E' (fig. 4), was drilled across its narrow, shallow northern termination, the deepest part of which, as found by USGS test 45 in sec. 10, is about two-thirds of a mile west of the axis of the depression. Bedrock was not reached by this test hole, which is 92 feet deep. However, a deeper portion of the section may lie farther east, between USGS test 45 and 46. This "low" is probably an elongate depression or valley, but it is not known if the section is exactly transverse to it. A well in sec. 15, about half a mile southeast of USGS test 45 (fig. 5), was reported to be 108 feet deep and to end in drift. The data from the other wells and test holes south of section E-E' all indicate shallow depths to shale. The evidence of a relationship between a bedrock "low" and the Bitter Lake chain is fairly definite in the vicinity of section E-E', but where the "low" trends from that point is not clear.

This "low" may extend to the area underlying the Lake Laretta chain. USGS test 27 and 29, geologic section C-C', either of which might have established or refuted such a connection, did not penetrate to the bedrock. No deep wells in the drift are reported in the vicinity of the Lake Laretta chain.

Probably the present form of the basins in the Lake Laretta and Bitter Lake chains is of kettle origin. Such origin is suggested by their size, depth, and steep sides. The steep sides may be largely the result of wave action in the bigger basins, but that is unlikely in the smaller ones. In the Lake Laretta chain, the lack of sorted material and the presumably thin drift cover suggests that the parent ice blocks were the remnants of thicker ice that moved through previously existing hollows in the drift.

For the Bitter Lake chain a similar hypothesis may be considered, with the added condition that originally the drift hollow was the distorted surface representation of a bedrock "low". The possible esker at the southern end of the chain may be interpreted as evidence of some subglacial drainage associated with the chain before the ice blocks melted sufficiently to break up a continuous channel floor.

The two chains, considered together with the previously mentioned unalined group of deep kettles in the southern moraine (p. 15-19) probably represent a partly obliterated drainage system. The system developed in its entirety in an earlier drift, the southern portion having consisted of partly drift filled bedrock "lows." The southern portions of the drainage may have flowed partly on the bedrock after the earlier drift was considerably eroded, rather than on the drift itself. This north-south portion of the system may have been tributary to the portion represented by the east-west group of deep kettles in the moraine (p. 16). The east-west segment may have then passed through the "low" found by USGS test 53, in sec. 33, T. 152 N., R. 58 W.

The N-shaped, unnamed kettle chain northwest of Michigan City apparently had an origin different from that of the other two. It seems to be almost entirely related to a late phase in the history of the last Mankato ice. The continuous, more or less unbroken, floor of portions of the chain and the presence of the eskers may indicate drainage that was sub- or englacial and that later was open to the sky. The tunnel in which the long southeast-striking esker was deposited may have enlarged, opened to the sky, and continued somewhat as a surface drainage channel. The interrupted alinement of the east arm of the "N" in the moraine may be interpreted as the result of surface drainage, perhaps between stagnant ice blocks, that was disrupted by a readvance of the ice. The lower portion of the western arm of the "N" may have been the site of an ice tunnel in which no longer esker or other large ice-contact feature was deposited. The collapse of the roof with its entrained debris and possible melting of a floor composed partly of ice may account for the present appearance of the feature.

The path of disposal of the melt water presumably collected by the unnamed group of depressions is not clear. The obvious destination must have been the Lindsey Lake spillway, but any surface connection is very obscure. The melt water may have spread out over a fairly wide area, say a mile or two, before being funneled into the spillway. This melt water may have deposited some of the outwash found in the test drilling south of this group.

Some of the melt water collected by the unnamed chain may have been disposed of by way of the Bitter Lake chain, which has some of the characteristics of the unnamed group. Among these characteristics are the small, shallow depressions at the north and south ends and a possible alined esker. However, the "chopped-up" nature of the floor would mean, if anything, that any drainage through the chain passed over an ice floor, which may have been partly subglacial and partly englacial or open to the sky. This hypothesis, of course, does not explain the kettle origin of the Bitter Lake chain, but merely some of its subsidiary features.

Summary of Glacial History

It is not known how many glaciations prior to the Mankato are represented by the drift mantle in the Michigan City area. The ice that deposited the surface drift is believed to be of Mankato age. At least prior to the last ice, there may have been a drainage system in the Michigan City area which was cut partly in drift and partly in the then-exposed shale bedrock. The present remnants of this system may be the Lake Laretta and Bitter Lake kettle chains, a group of kettles in the southern moraine, and several bedrock "lows" indicated by test drilling and by well data.

The ice that retreated and downwasted in the Michigan City area had only one major and fairly prolonged halting place, which was at the site of the southern moraine. The ice that built the moraine apparently overrode outwash previously deposited in front of it. After the deposition of the moraine, the ice front in the eastern part of the area retreated haltingly to the northeast and out of the area. The rate of retreat of the ice front was considerably slower in the northeastern part of the area, and numerous northwest-trending ridges were deposited, which make up the northern moraine.

The abundance of melt water during the deposition of the northern moraine apparently gave rise to numerous small ice-contact features in the moraine area. Outwash deposited just south of the moraine was in most places overriden by re-advances of the ice front.

The ice in the western part of the area apparently retreated at a faster rate, and resurged less vigorously, than that in the eastern part. This seems to be evidenced by the paucity of groups of morainal ridges with distinct orientations.

During this period of retreat and downwasting, the area was drained to the southeast by the two large spillways and possibly by the N-shaped chain northwest of Michigan City. It is likely that some melt water drained to the south and southwest into the Devils Lake-Stump Lake basin, partly through the unnamed N-shaped kettle chain and partly through the Bitter Lake kettle chain. The presence of these two kettle chains and their attendant ice-contact features suggest that some sub- and englacial drainage may have developed during and after the final retreat of the ice from the area.

In recent time, the spillways have drained into tributaries of the Red River of the North. Numerous lakes and swamps occupying basins of glacial origin dot the surface of the area. A thin soil, generally less than a foot thick, has developed over most of the area.

HYDROLOGY

Some Principles of the Occurrence of Ground Water and Hydrologic Concepts

Geologically speaking, all the solid materials in the earth's crust are called rocks whether they are hard like granite or slate, soft like shale or clay, consolidated like sandstone, or unconsolidated like loose sand and gravel.

The rocks that form the earth's crust in the Michigan City area may be divided into two kinds: the sedimentary rocks that overlie the basement complex and the basement complex itself, which is of igneous and metamorphic origin.

The sedimentary rocks of the area, especially the glacial drift, the shales, and the Dakota formation were formed by the accumulation of small fragments of rock materials by mechanical means with, perhaps, a minor amount of chemical action to cause partial cementation or consolidation of some of the materials. Because of the shapes and sizes of the individual rock particles, a considerable amount of open space occurs in the rocks. The rocks are therefore said to be "porous". The quantitative measure of the open space- its percentage of the whole volume of the rock - is called the "porosity."

Below the water table in the area, under natural conditions, the open or pore spaces in the sedimentary rocks are filled with water. The porosity of a rock material is therefore a measure of its capacity to store water when saturated. However, the capacity of a rock to yield water to wells by gravity drainage may be much less than would be indicated by its porosity, because part or all of the water may be held in the pore spaces by molecular attraction of the water to the rock material. If the pore spaces are large, as in coarse gravel, practically all the water stored in them can be removed by gravity drainage. If the individual particles composing the rock are small, as in clay or shale, practically none of the stored water can be removed by gravity drainage, although the porosity of the rock may be considerable. The volume of water, expressed as a percentage, that will drain by gravity from a unit volume of the saturated rock material is called its "specific yield"; the volume that remains behind is the "specific retention."

Another characteristic of a rock material that is important, insofar as water supply is concerned, is the difficulty or ease with which water can move through the material. If the pore spaces are relatively large, as in coarse gravel, the resistance to the movement of water through the material is not great and the rock is said to be permeable. However, if the pore spaces are small, as in clay or shale, the resistance to the movement of water may become very great and the rock is said to be impermeable or to have low "permeability." Permeability is expressed quantitatively for field use, as the number of gallons per day that will flow through a cross-sectional area of 1 square foot under unit or 100-percent hydraulic gradient, at the local temperature of the ground water.

Any rock formation that will yield water to wells in sufficient quantity to be of importance as a source of water supply is called an "aquifer" (Meinzer, 1923, p. 52). As would be indicated by the above discussion, the rocks that are composed mostly of sand and gravel would constitute the most productive aquifers, whereas those composed mostly of clay or shale might not yield enough water to be called aquifers. However, in the Michigan City area, there are aquifers in the upper part of the Pierre shale that are more important than the local sand and gravel aquifers in the glacial drift, not because of greater permeability but because the aquifers in the shale occur over a wider area and therefore are more generally available.

If the water in an aquifer is not confined by an impermeable stratum above, the water is said to occur under water-table conditions. In such case, water may be obtained from storage in the aquifer by causing a lowering of the water level, as in the vicinity of a pumped well, which results in gravity drainage of the surrounding rock material.

If the water is confined in the aquifer by an overlying impermeable stratum, however, so that the water in a well rises above the top of the aquifer under hydraulic pressure, the water is said to occur under artesian conditions. It is not necessary that the well flow for it to be classed as artesian under this definition. Water is yielded, at least temporarily, because of its own expansion and because of the compression of the aquifer due to lowered pressure, rather than by gravity drainage. The water-yielding capacity is called the "coefficient of storage." The coefficient of storage is defined as the volume of water that will be released from storage in each vertical column of the aquifer having a base of 1 square foot when the artesian pressure falls 1 foot. The amount of water released from storage in an aquifer with a given lowering of water level will be much less - of the order of a hundredth or a thousandth - for artesian conditions than for gravity drainage under water-table conditions, other factors such as permeability, thickness, and areal extent being equal. The term "coefficient of storage" may be applied to water-table as well as artesian conditions, in which case it is essentially equal to the specific yield.

In the Michigan City area, both artesian and water-table aquifers occur in the sedimentary rocks, but the artesian aquifers, especially those in the Pierre shale, are of much greater importance because of their larger areal extent and consequent accessibility to a greater number of users.

It is evident from the foregoing discussion that the suitability of an aquifer to furnish a water supply for any given purpose will depend upon the permeability of the materials composing the aquifer and upon its volume and capacity to store water. In addition, there must be adequate recharge to the aquifer if the water-supply development is to last indefinitely; for it is apparent that even a small draft will eventually deplete the water in storage unless there is adequate recharge. There have been instances where aquifers composed of materials having rather good permeability, but having only small areal extent and being completely enclosed in relatively impermeable material, have been pumped nearly dry in a comparatively short time, to the detriment and disappointment of those concerned. The rather high initial yield of the wells gave the erroneous impression that a great volume of water would be available from the aquifer indefinitely.

Recharge to the various aquifers in the Michigan City area is discussed in the sections dealing with the several formations.

In some rocks, fractures and solution openings form the permeable passageways through which water moves from the formation to a well or natural outlet such as a spring. It is possible that the permeability of some of the aquifers in the Pierre shale is due to fractures. If there are limestones of Paleozoic age below the Dakota formation in the area, some of them may yield water through solution openings. Even the upper part of the pre-Cambrian complex may yield small amounts of water through fractures.

Aquifers in the Glacial Drift

Aquifers in the glacial drift furnish water to only about a quarter of the wells in the Michigan City area (figs. 5 and 6). The aquifers include: (1) the deposits of sand and gravel in or associated with the till that are not readily assigned to one of the following categories, (2) the sorted deposits of the overriden outwash, (3) the deposits in the glacial spillways, and (4) the deposits in the ice-contact features.

Aquifers in the End-Moraine and Ground-Moraine Areas

The till with its associated deposits of sand and gravel is the most widespread glacial material in the Michigan City area. The till itself is a heterogeneous mixture of materials ranging in size from clay to boulders and lacking stratification in any degree. Because of its high clay and silt content, the till is not an aquifer. However, the deposits of sand and gravel included in or otherwise associated with the till constitute aquifers of varying importance, depending upon their thickness, areal extent, permeability, and accessibility to recharge. It is believed that the sand and gravel and other sorted deposits associated with

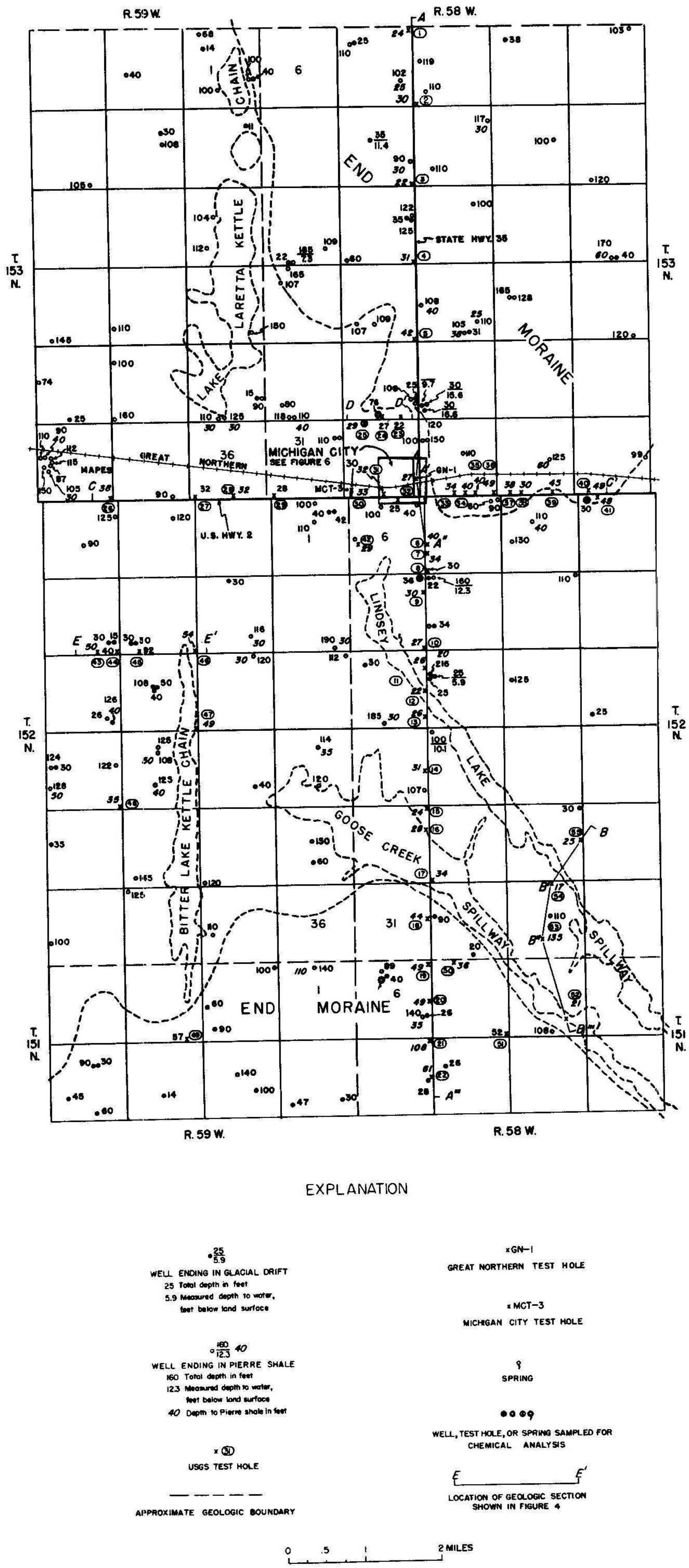

FIGURE 5.—GEOLOGIC SKETCH MAP OF THE MICHIGAN CITY AREA SHOWING LOCATIONS OF SPRING, WELLS, TEST HOLES, AND GEOLOGIC SECTIONS.

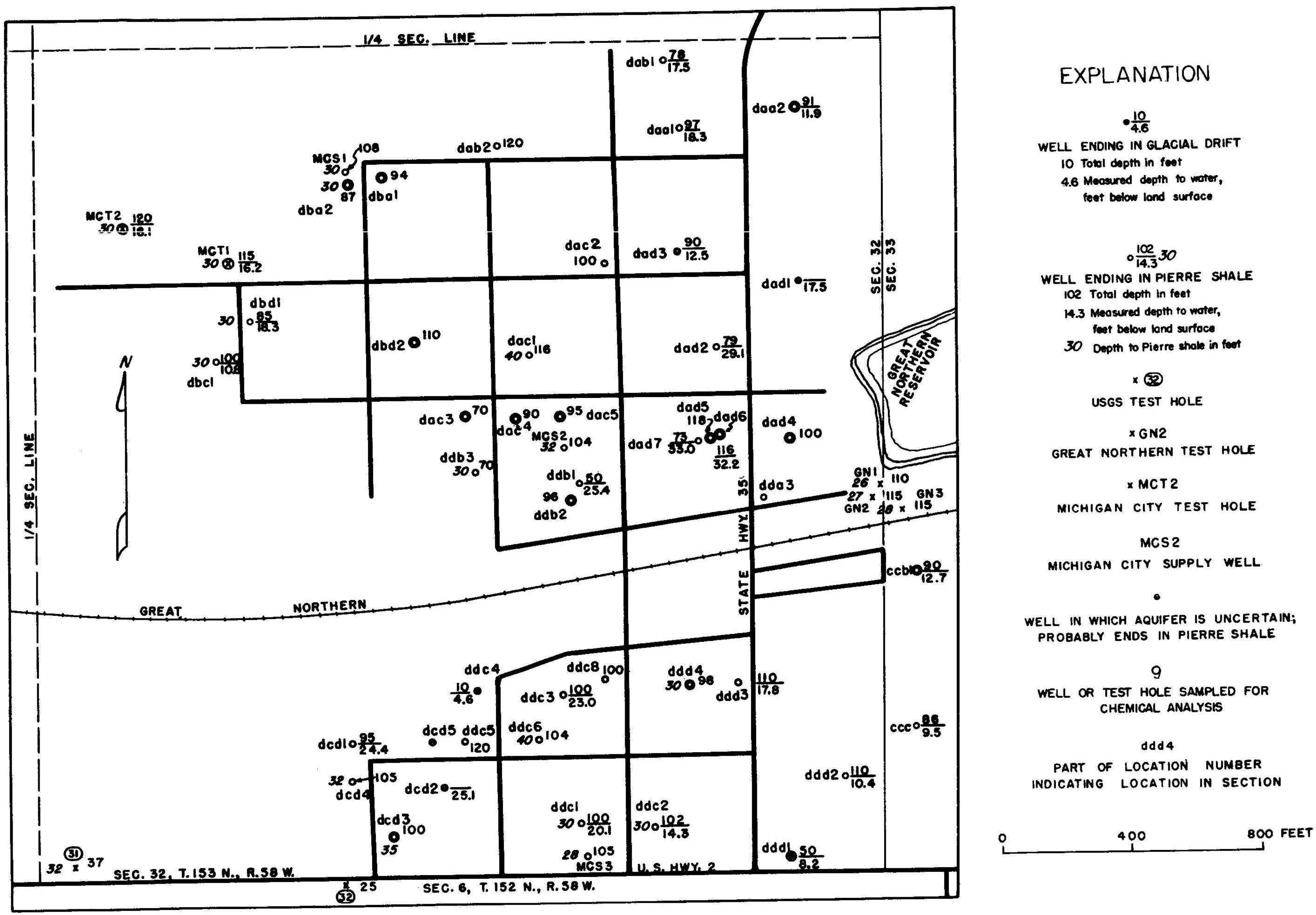

FIGURE 6.—SKETCH MAP OF MICHIGAN CITY SHOWING LOCATIONS OF WELLS AND TEST HOLES.

(LOCATION OF THIS AREA SHOWN IN FIGURE 5.)

the till were originally channel fillings, outwash, glacial-lake deposits, or ice-contact deposits that were modified or partly destroyed by glacial action after deposition. Some of the deposits may have been moved short distances and redeposited as a very gravelly till. In some places the sorted materials of large ice-contact deposits, outwash deposits, and channel fillings have been buried by till and at least partly protected against subsequent action of the glacial ice, and these may form important aquifers. The overridden outwash in the central part of the Michigan City area is an example of that type of material that has been only partly disturbed by glacial action since deposition.

Aquifers in or associated with the till in the end-moraine and ground-moraine areas supply water to about 70 percent of the wells that tap drift aquifers in the Michigan City area. Of the wells in aquifers related to the till, most are in the end-moraine areas. It is thought that the aquifers generally are small bodies of sand and gravel that may be more or less isolated from each other by the surrounding till. Inasmuch as the till is not entirely impermeable, however, and as these small bodies of sorted material may be numerous and partly interconnected in some areas, the entire till sheet may function as a poor aquifer.

In the southern end-moraine areas wells ranging in depth from 14 to 90 feet tap aquifers in the glacial drift. With one exception (well 152-59-15bdd1), the deepest wells that tap drift aquifers in the Michigan City area are found in the southern moraine.

The general presence of at least thin deposits of sorted material in the southern moraine area is shown by the logs of USGS tests 18, 19, 20, 21, 22, and 50 (see sec. A-A''', figs. 4 and 5). Furthermore, there is a suggestion that one and perhaps two of the sections of sorted materials may represent aquifers of some lateral continuity. Thus the 11 feet of sand in USGS test 21, between elevations of 1,460 and 1,480 feet above sea level, may be continuous with the lower sorted materials found in USGS test 18, 19, and 20, which occur at similar elevations. Lesser thicknesses of an upper sorted material were penetrated in USGS tests 18 and 19 at an elevation of about 1,500 feet. At about the same elevation, 9 feet of sorted material was found in USGS test 21, and about 11 feet, the lower sorted material,in USGS test 22. Although continuity of these aquifers is not proved by the relatively small number of test holes drilled, the rather general presence of sorted materials in this part of the southern moraine is demonstrated. It seems likely that wells having moderate capacities (say 25 to 40 gpm) could be obtained in the vicinity of USGS test 21 and 22.

Several shallow drift wells near the southern end of geologic section A-A''' probably tap one or the other of the two aquifers found at the test holes. Some of these were reported to be inadequate in the drought years of the 1930's. This suggests that a perennial supply for municipal or industrial purposes cannot be obtained from these aquifers. Additional test drilling in this moraine area west of geologic section A-A''' may disclose thicker sections of sorted material and possibly some connections between the two aquifers and the aquifer penetrated in the deeper drift wells in secs. 2 and 9, T. 151 N., R.59 W.

The deeper wells referred to above may tap drift aquifers in subdrift channels, the sides of which may be almost vertical. One instance of the occurrence of a relatively great difference in the thickness of the drift in a relatively short distance is near USGS test 18 (152-58-31add). At the test hole, only 44 feet of drift was found above the shale bedrock, but a well just across the road, perhaps 150 feet away, taps a drift aquifer at a depth of 90 feet (fig. 5). There is no noticeable difference in the surface topography that might give a clue as to the presence of the thicker drift.

A similar occurrence was observed by the authors near Lakota, about 10 miles west of Michigan City. A Geological Survey test hole had been drilled through

33 feet of till and 52 feet of sand and gravel. The Pierre shale bedrock was reached at 85 feet. Later, while attempting to develop the aquifer in the sand and gravel for municipal use, the city of Lakota drilled a test hole about 75 feet southwest of the first one. There the shale bedrock was reached at 38 feet, and only 3 feet of sand and gravel was above the shale. Another was drilled approximately 140 feet north of the Geological Survey test hole. It penetrated between 30 and 35 feet of till and then 55 feet of sand and gravel. A screen was installed between 61 and 85 feet. In that area, also, there was no indication in the surface topography of the presence of the thicker drift deposits.

In the northeast moraine, in the Michigan City area, no deep drift wells are reported. All the deeper wells are believed to end in shale. It would appear that drift aquifers capable of supporting even farm wells are not generally present there. The lack of thick and continuous aquifers is consistent with the very small size of the ice-contact features in the area. It appears that the ice front never paused in one place long enough to permit the development of thick or continuous aquifers there. The results of the test drilling (see northern part of geologic section A-A',fig. 4) at least partly confirm this conclusion.

In the ground-moraine area most of the wells are dug or bored and are less than 50 feet deep. They yield only small supplies of water for farm use. A few drilled wells more than 50 feet deep tap drift aquifers in the ground-moraine area. In fact, well 152-59-15bdd1, 108 feet deep, is the deepest well in the Michigan City area that taps a drift aquifer. The well taps an aquifer described as clay and gravel and is reported to have furnished an inadequate supply of water for farm needs during the drought years. The thick drift at this well probably is associated with a "low" that may have some surface expression in the Bitter Lake kettle chain (see sec. E-E', fig. 4).

Aquifers in the Overridden Outwash

The overridden outwash consists essentially of sand or sand-and-gravel deposits, generally with considerable interstitial clay and silt that make for low permeability of the material. The deposits probably are not more than 50 feet thick anywhere in the area and are much thinner in most places where found in the Geological Survey test holes.

The contact between the overridden outwash and the surrounding ground moraine could not be mapped from surface indications. The outwash deposits were found in USGS test holes 6,7,8,9,27,28,29,30,31,32,35,36,37,40,41,43,44, and 45 (fig.4).

About 30 percent of the wells tapping drift aquifers apparently obtain water from the overridden outwash deposits. Insofar as could be ascertained, all these wells are dug or bored. None of the wells known to tap the outwash deposits are drilled. The wells yield only small supplies of water for farm and domestic use.

In geologic section C-C' (fig. 4), the thickest and apparently most continuous outwash deposits were found in USGS tests 27, 28, 29, and 30. In these test holes the constituent material of the deposits varied from sand to sand and gravel to gravel with considerable amounts of clay and silt. The thickest sections of gravel were found in USGS tests 28 and 30.

On the basis of the material found in USGS test 30, the Michigan City council contracted with Otto Annunson, the local well driller, to put down a test hole (MCT3, fig. 5) about 100 feet north of the Geological Survey test. The material encountered in that test hole, drilled with a cable-tool machine, did not appear to be as clean as the material from the Survey test hole obtained with a hydraulic-rotary drilling machine. It was not necessary to case the hole to prevent caving and the open hole was easily bailed dry.

On September 4, 1947, a short pumping test was attempted on well 152-59-1a1, a 36-inch-diameter bored well that presumably obtains water from the overridden outwash. The well was equipped with a pump jack and cylinder pump. The pump jack was powered by a small gasoline engine.

The well was pumped for 7 hours and 15 minutes but a constant pumping rate could not be maintained. The measured pumping rate varied from $3\frac{1}{4}$ to $5\frac{1}{2}$ gpm. The resulting data, therefore, were not particularly good for computing the coefficients of transmissibility 3/ and storage. These were estimated by using the drawdown data obtained during the pumping. No measurements were made of the recovery of the water level after pumping.

The coefficient of transmissibility was estimated to be between 800 and 1,000 gpd per foot and the coefficient of storage was estimated to be between 0.1 and 0.2. It is not known how closely these figures represent the conditions in the outwash at the well itself or in general; but, at the well site, the coefficients probably are not lower than the smaller figures given - that is, 800 gpd per foot and 0.1, respectively. The results obtained from the city test hole near USGS test 30 would indicate that the transmissibility of the outwash deposits there is considerably less than 800 gpd per foot.

It is estimated that, under water-table conditions, an aquifer of large areal extent, having a saturated thickness of 30 feet, a coefficient of transmissibility of 800 gpd per foot and a coefficient of storage of 0.1, would be capable of

3/ The "coefficient of transmissibility" is generally more convenient to use in ground-water studies than the "coefficient of permeability" (p. 38-39) to express quantitatively the ease or difficulty with which water can move through an aquifer. The coefficient of transmissibility is the average field coefficient of permeability multiplied by the thickness of the aquifer in feet.

The coefficient of transmissibility, as used here, may be defined as the number of gallons of water that will pass in 1 day through a vertical strip of the aquifer 1 foot wide under a unit hydraulic gradient (1 foot per foot) and with the water at field temperature. It may also be thought of as the number of gallons of waterthat will pass in 1 day through a vertical strip of the aquifer 1 mile wide under a hydraulic gradient of 1 foot per mile and with the water at field temperature.

yielding about 8,500 gpd to a 1-foot-diameter well for a period of 1 year without benefit of recharge to the aquifer. This would amount to about 6 gpm with continuous pumping. With the possibility of a natural lowering of water levels in the outwash deposits during drought cycles, even this small yield could not be depended on.

The outwash deposits found in USGS tests 6, 7, 8, and 9 in section A-A''' have characteristics similar to those found in section C-C'. The thickest sections of the outwash deposits were found in USGS tests 43, 44, and 45 in section E-E'. It is not known whether the deposits in section E-E' have greater permeability than those found in section C-C'. However, the deposits are quite similar in character and it may be assumed that not much greater yields from wells could be expected.

Aquifers in the Glacial Spillways

None of the wells in the Michigan City area are known to derive water from the deposits in the Lindsey Lake and Goose Creek spillways, although a few of the shallow wells along the boundaries of the spillways may obtain water from deposits associated with them. The material found in the Geological Survey test holes drilled in the spillways ranges from a pebbly clay to fairly clean gravel.

The sand and gravel deposits found in the test holes drilled in and adjacent to the spillways ranged in thickness from 3 to 24 feet. A piece of 4-inch standard pipe, the lower end of which was slotted with a torch, was installed in USGS test 10 and an attempt was made to pump water from the test hole. However, it would yield only about $\frac{1}{2}$ to 1 gpm and no further tests were made on it. A slotted 4-inch pipe was installed in USGS test 12 also, and a short pumping test was made on that hole. The hole was pumped for a period of about $3\frac{1}{2}$ hours. The pumping rate varied from 3.5 to 4.1 gpm, the average being about

3.7 gpm.

As in the pumping test on well 152-59-1al in the overridden outwash, the data obtained were not particularly good for calculating the coefficients of transmissibility and storage because of the varying pumping rate and because no other observation wells were used. Although the test hole yielded water at a very slow rate, the coefficient of transmissibility was estimated to be on the order of 6,000 gpd per foot, which is a fairly high figure compared to the results obtained from other aquifers in the area.

It is estimated that, under water-table conditions, an aquifer of large areal extent, having a saturated thickness of 16 feet, a coefficient of transmissibility of 6,000 gpd per foot, and a storage coefficient of 0.2, would be capable of yielding about 30,000 gpd to a 1-foot-diameter well for a period of 1 year without benefit of recharge to the aquifer. This would amount to about 20 gpm with continuous pumping. As was stated in regard to the outwash deposits, a yield of this amount could not be depended on if there were considerable lowering of water levels due to natural ground-water discharge during the drier years.

The casing was left in USGS test 12 so that water-level measurements could be made there. Weekly water-level measurements were obtained for a period of about 3 years, before the casing was destroyed by a road grader. The data will be discussed in the section dealing with recharge to the aquifers in the glacial drift.

Aquifers in the Ice-Contact Deposits

No wells in the Michigan City area are known to obtain water from aquifers in the ice-contact deposits. Well 151-58-6dad1 may tap an aquifer in the southwest extension of the kame that straddles the section line between secs. 5 and 6, T. 151 N., R. 58 W. The well is reported to be 26 feet deep and to tap a "clay and sand" aquifer, which yields inadequate amounts of water for general farm use.

Some of the larger ice-contact deposits in the Michigan City area would yield water supplies of sufficient magnitude for general farm and household use. Often, the bulk of the deposits are above the general water table, only a relatively thin saturated zone being present in their lower part. With natural lowering of the water-table during drought cycles, the deposits may dry up completely. It is believed that none of the ice-contact deposits found in the Michigan City area would furnish water in sufficient quantity for municipal use, although, if it became necessary, the water available in some of the deposits might be used as a supplemental supply.

Of the ice-contact deposits in the Michigan City area, only two appear to offer any possibility of producing sufficient water for supplemental municipal use or light industrial use. These are (a) the possible esker at the south end of the Bitter Lake depression and (b) the esker just northwest of Michigan City. USGS test 49 was drilled in the deposits at the south end of the Bitter Lake depression. It passed through 33 feet of sand and sand and gravel between 24 and 57 feet, which probably is water bearing. USGS test 23, 24, and 25 (sec. D-D', fig. 4) were drilled along the section line north of Michigan City. The bulk of the material found in USGS tests 23 and 25 was poorly sorted, clayey sand and gravel. Only till was found in USGS test 24.

If needs arise for water supplies larger than required for domestic and stock use, these and other ice-contact deposits in the area warrant study in greater detail. In other areas in the State, some of the larger ice-contact deposits have furnished considerable amounts of water for municipal purposes but, in general, they have been unable to supply the full municipal demands.

Possible Interconnection of Aquifers in the Glacial Drift

Although the aquifers occurring in the principal types of glacial deposits have been discussed separately, there doubtless is a considerable degree of interconnection, hydrologically, between the various aquifers. The ice-contact deposits, for instance, quite likely intersect, overlie, or otherwise contact sand and gravel deposits in the till sheet that are of different origin. These contacts permit the relatively free movement of water from one body of sand and gravel to another, so that both function essentially as a single aquifer. Even where two bodies of sand and gravel are not actually in contact, there may be significant movement of water between them, especially where the intervening till is thin or somewhat more permeable than is general.

Likewise, the deposits in the glacial spillways may be in physical contact with aquifers in the till and with aquifers in the overridden outwash deposits. The overridden outwash deposits, too, doubtless are in physical contact with many of the smaller aquifers in the till, especially any around the edges of the outwash or immediately underlying it. In many instances, therefore, a well ostensibly in one of the smaller aquifers in the till may actually draw water from storage in the outwash, or vice versa.

Also, a rather permeable stringer of gravel or sand and gravel of relatively small cross section but with considerable linear extent would act somewhat as a natural infiltration gallery to collect the seepage from the less permeable surrounding material. Interconnection with other bodies of permeable material would, of course, widen its area of influence.

A well tapping such an aquifer might yield a great deal more water than could be guessed from the results of test drilling. Therefore, from the point of view of developing water supplies for municipal or light industrial purposes, any relatively thick section of permeable material probably would be worth testing by constructing a well and pumping, even though the material was not found in nearby test holes. The pumping tests should be long enough to reveal, by analysis of the results, the presence of impermeable boundaries and sources of recharge indicating interconnection with other aquifers.

The sand and gravel bodies in the deeper parts of the till would have little chance of being in direct contact with the shallow aquifers in the ice-contact features, glacial spillways, outwash, or even the shallower aquifers in the till. However, even in the deeper drift, the larger bodies of sand and gravel are likely to be interconnected with other sand and gravel bodies so as to widen materially the area from which they can receive significant amounts of water.

Even though some of the aquifers may yield a great deal more water than could be guessed from the results of the test drilling, because they are interconnected with other permeable materials, the interconnection cannot be assumed without adequate testing in the field. Some of the aquifers, especially in the deeper drift, doubtless are completely surrounded by thick deposits of relatively impermeable till, as explained on page 40. Such aquifers would receive seepage from the surrounding areas very slowly. Initial yields might be fairly large, but with continued use the water level would decline rapidly and the production rate would diminish to insignificant amounts within a relatively short time.

Such aquifers would be excellent for small demands such as ordinary farm and domestic use. In most such cases, the average rate of use probably would not exceed the rate of seepage into the aquifer from the surrounding till. The sand and gravel would furnish ideal conditions for the construction of a well, and intermittent yields would be large enough to supply temporary demands for watering stock, washing clothes, filling sprayer tanks, watering lawns and gardens, and other farm and household uses.

Recharge, Storage, and Natural Disposal of Water in the Glacial-Drift Aquifers

Recharge to the various aquifers in the glacial drift occurs principally by downward percolation of water from melting snow and rain, although certain aquifers may receive a larger part of their recharge by lateral percolation of water through the ground from adjacent areas.

The shallow sand and gravel deposits in the glacial spillways probably are the aquifers in the area that are best situated to receive recharge by the direct penetration of water from rain and melted snow. In years of heavy snowfall, a considerable amount of water will run off the areas adjacent to the spillways when the accumulated winter snows melt in the spring. This runoff water may produce sizable surface flows in the spillways at that time of the year, and the spillway deposits doubtless absorb about as much water as they are capable of holding.

During the period of snowmelt in the spring, evaporation and transpiration rates are low, and rainfall increases the rate of runoff to the spillways and so increases the amount of water available for recharge.

During the summer evapotranspiration rates are high and the lighter rains probably contribute little water to the ground-water supply in the deposits. Rains in the late fall contribute more, proportionately, as the evapotranspiration rates are again lower. Heavy or sustained rains may contribute considerable recharge at any season of the year.

Figure 7 shows a hydrograph of well 152-58-18daa covering approximately a 3 year period, 1948-51. This well taps deposits in the Lindsey Lake spillway. The illustration shows something of the complex relationship between recharge, precipitation, and temperature. A complete record is available for only 2 years; but for those 2 years the hydrograph shows the large rise in water level that generally results from the infiltration of melted snow in the spring, the lesser

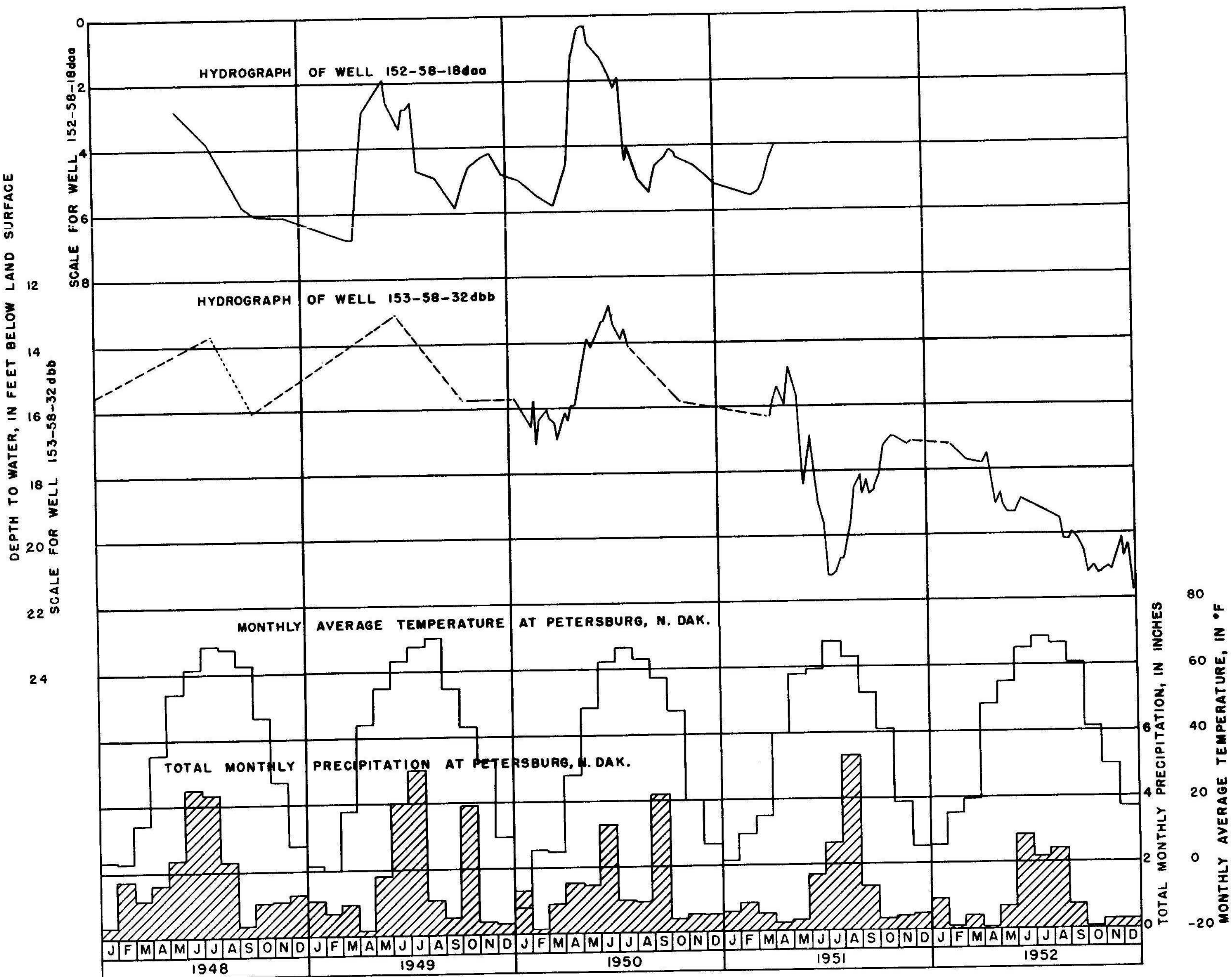

FIGURE 7.—HYDROGRAPHS OF TWO WELLS IN THE MICHIGAN CITY AREA AND GRAPHS SHOWING MONTHLY AVERAGE TEMPERATURE AND TOTAL MONTHLY PRECIPITATION AT PETERSBURG, N. DAK., FOR THE YEARS 1948-52, INCLUSIVE.

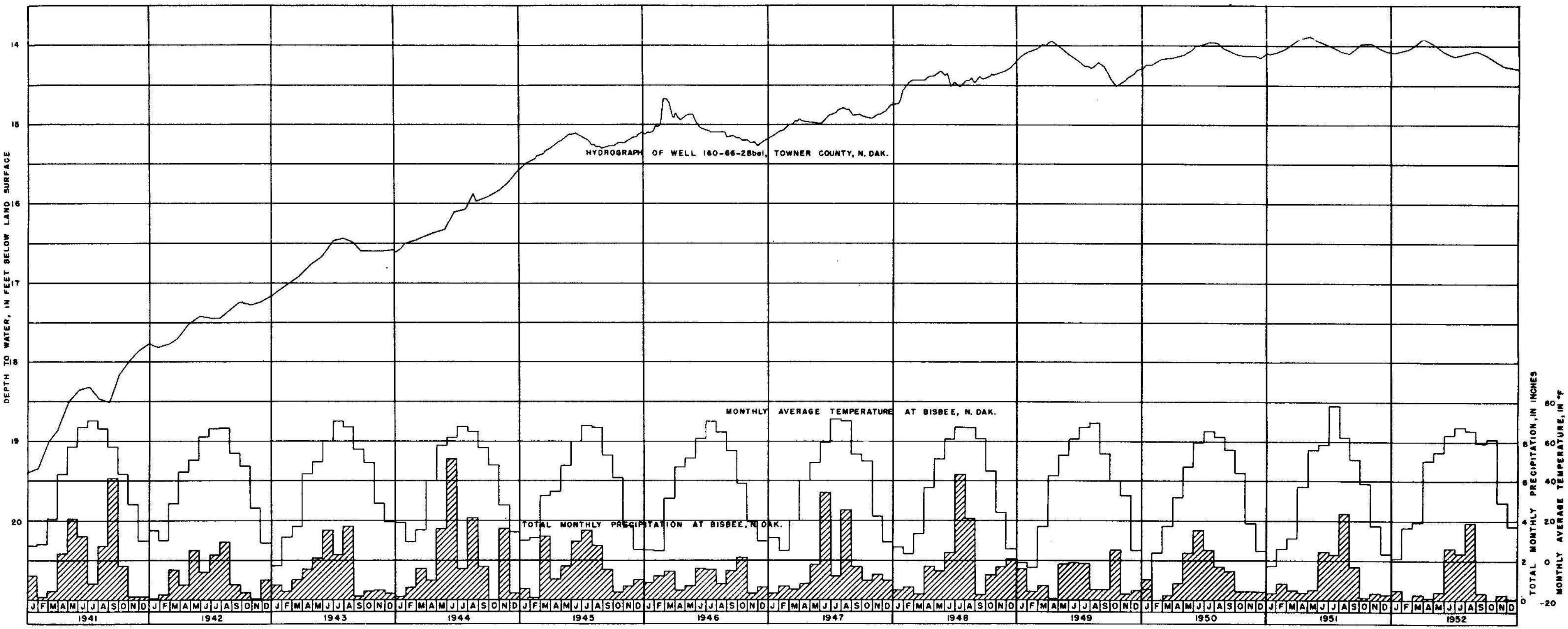

FIGURE 8.—HYDROGRAPH OF WELL 160-66-28bal, TOWNER COUNTY, N. DAK., AND GRAPHS SHOWING MONTHLY AVERAGE TEMPERATURE AND TOTAL MONTHLY PRECIPITATION AT BISBEE, N. DAK., FOR THE YEARS 1941-52, INCLUSIVE.

but significant rises resulting from rains in the fall, lesser rises resulting from heavier rains during the summer, and the persistent decline during the cold winter months when the ground is frozen and no significant amount of infiltration can occur.

The deposits in the ice-contact features and the exposed parts of the overridden outwash deposits receive recharge principally by downward percolation. In general, there is little surface runoff from adjacent areas to contribute additional water for recharge, as in the case of the deposits in the spillways. Some water doubtless percolates underground to these deposits from adjacent higher areas.

The deposits of sand and gravel included in the till are the aquifers least well situated to receive recharge. The water that reaches these aquifers by downward percolation generally must pass through a till cover of low permeability, and lateral movement into and out of the aquifers generally must occur at a very slow rate. The amount of recharge that may be received by the aquifers individually is partly dependent upon surface conditions unfavorable forrunoff. Where surface conditions are favorable for the collection of water in kettles and potholes, the water is held in these small basins for a considerable time, especially in the spring after the snow melts, and good opportunity is thus afforded for downward percolation of water. The actual amount of water that may seep into the ground is dependent upon the permeability of the materials under the small basins, which generally is quite low. In wet years many of the basins may contain water throughout the year, but in the dry years most of the water that collects in the basins in the spring may be lost by evapotranspiration by early summer.

The shallower aquifers in the till probably can receive recharge at a faster rate than the deeper aquifers. No water-level records are available for aquifers in the till in the Michigan City area. However, figure 8 contains a hydrograph for well 160-66-28bal, near Egeland, about 70 miles northwest of Michigan City. This well, in drift, is 135 feet deep and the hydrograph probably shows reactions to recharge typical of the deeper aquifers in the till. The period of record shown is 1941-52, inclusive. From 1941 to 1949 there was a continual general rise in the water level, which probably indicates a slow recovery from low stages reached during the dry years of the 1930's.

The seasonal water-level fluctuations at this well are markedly different from those observed at well 152-58-18daa in the Michigan City area and at other shallow wells in the State. There is little indication of immediate effects of recharge from the spring snowmelt. Generally the lowest water level occurs in the late fall, and a rise during the winter, Typically the rise continues until spring or early summer, after which the water level declines until late fall. There appear to be some small rises in the water level that may result from rains occurring several months before the rise in water level becomes significant.

The slow changes and the general character of the hydrograph are believed to indicate the very slow rate at which recharge can enter the deeper aquifers in the till.

The shallow aquifers in the till, covered by perhaps only a few feet of till, probably would react to rainfall and snowmelt in a fashion similar to that shown for well 152-58-18daa (fig. 7). The deeper aquifers probably would react in a fashion similar to that shown for well 160-66-28bal.

The amount of water stored in the aquifers in the glacial drift in the Michigan City area doubtless is large. However, it is believed that estimates based upon present knowledge of the area would not be particularly accurate or meaningful. It may be stated, however, that the sand and gravel deposits in the spillways, in the overriden outwash, and in the ice-contact deposits would yield more water to wells per unit of saturated volume, on the average, than would the till and its contained sand and gravel aquifers taken as a whole.

The manner of movement of the water in the glacial drift in the area is incompletely known and, therefore, a detailed accounting of the recharge, movement, and disposal of the ground water is not possible. The Lake Laretta and Bitter Lake kettle chains constitute lows in the western part of the area to which the ground water may move laterally from adjacent areas. From the lows of the kettle chains, the water is returned to the air by evaporation and by transpiration of plants.

In the southeastern part of the area, the two spillways form relatively permeable, though shallow, troughs through which the water may percolate rather readily. Water may percolate laterally from adjacent areas to the spillways, where a considerable part of the water probably is returned to the air by evapotranspiration.

How greatly these lows or troughs affect the general movement of ground water in the area is not known, but they undoubtedly receive only a minor portion of the total recharge to the ground water in the area. Much of the water that reaches the water table in the upland areas probably is disposed of later by evapotranspiration on lower ground. The part of the water that escapes evaporation and transpiration in the area probably percolates laterally in a southerly direction in the western part of the area and southerly and easterly in the eastern part.

Possibilities of Developing Water Supplies for Municipal or Light-Industrial Use from Aquifers in the Glacial Drift

No aquifer found in the glacial drift was believed to be sufficiently productive of water to furnish an adequate supply for municipal or sizable industrial use from one well or even from a field of two or three wells. Michigan

City has constructed wells in the Pierre shale with the thought that they would furnish an adequate amount of water for present uses, but with knowledge that the available supply is definitely limited. In time, therefore, more water probably will be required than can be furnished by the shale wells now in use. Certain of the aquifers in the glacial drift warrant more thorough investigation as possible sources of additional water for municipal or industrial use at Michigan City at such time as a supplemental supply will be needed. The possibility of obtaining additional water from the shale aquifers is discussed in a subsequent section, as is also the possibility of using the water in some of the drift aquifers as sources of artificial recharge to the shale aquifers.

Because of its proximity to the city, the possibility of developing a small water supply from the esker just north of the city may be worth investigating. This probably would involve detailed test drilling of the feature and the construction of a well in which pumping tests could be made.

A logical next step would be to investigate somewhat more thoroughly the possibility of developing wells in the sand and gravel deposits of the glacial spillways. This also probably would involve some detailed test drilling and, perhaps, the use of infiltration galleries rather than wells through which to obtain a usable supply of water.

The overridden outwash deposits in the vicinity of USGS tests 43, 44, and 45 appear suitable for yielding considerable quantities of water to wells. A test well drilled in that area would give additional needed information on the productiveness of the deposits.

Lastly, additional test drilling might be worth while to explore somewhat more fully the possibilities of obtaining additional water from deeper drift aquifers in bedrock channels. Drilling, perhaps supplemented by geophysical exploration, across the low areas of the Lake Laretta and Bitter Lake kettle chains would be in order. No aquifers of importance were found in the drilling during the present investigation, but additional testing might disclose the presence of moderately productive aquifers.

Aquifers in the Pierre Shale

Aquifers in the Pierre shale furnish water to about three-fourths of the wells in the Michigan City area (fig. 5). Because the water is softer than that generally obtained from aquifers in the glacial drift and because the wells in the shallow drift aquifers may not furnish sufficient water for use during long drought periods, the wells tapping shale aquifers are considered by the local residents to be the best obtainable. They are found in almost every part of the ar

Nature of the Aquifers in the Pierre Shale

The fine-grained, compact, and apparently impermeable nature of the Pierre shale, as described by well drillers and as seen in drill cuttings, would make it seem most unlikely that any aquifers of importance are present in the shale. The bulk of the shale, of course, does not function as an aquifer.

The exact physical nature of the aquifers in the shale has not been determined. Simpson (1929, p. 30) suggested that the aquifers were in weathered or creviced parts of the shale or in interbedded sandstone. The idea of percolation of water through fractures is well borne out by the appearance of the shale in exposures the authors have seen near the Sheyenne River in the Devils Lake area of North Dakota. In addition to horizontal breaks along bedding and lamination planes, there are numerous vertical joints, so that the rocks exhibit a kind of polygonal pattern of cracks. These effects become marked as the exposures weather. They seem, however, to be the result of desiccation, and such fractures probably do not persist to any great depth.

Well drillers in the Michigan City area, and in other parts of North Dakota where the drift is underlain by the Pierre shale, only rarely find water in the upper part of shale that may have been exposed to weathering processes. Although some drillers state that a "brown," "yellow," or "reddish" zone may be found at the top of the shale in some localities, the occurrence of such a zone does not necessarily signify the presence of an aquifer.

The aquifers in the shale generally occur at depths of more than 20 or 30 feet below the top of the shale. Zones of angular fragments overlain and underlain by unbroken shale have been reported by one driller. Most drillers report the complete absence of sand, and all agree that there is no definite sandy bed within a given area from which water is obtained. In some places where angular fragments and sandy beds were penetrated, no aquifers were found.

Most drillers classify the shale beds as "soft" or "hard" or as "slate." There is general agreement that water is more likely to be found in the "hard" shale than in the "soft." However, some wells are reported to obtain water from "soft" shale beds, and water is not always found in the "hard" beds.

Cores of a hard light-colored calcareous shale were recovered from USGS test holes drilled near a well (outside the Michigan City area) where the driller had logged "hard light-colored shale." Similarly, cores at a horizon logged by the drillers as "soft, white soapstone" proved to be bentonitic shale. There is no assurance that other drillers use the same terminology, but the results of test drilling indicate that the harder parts of the shale are generally calcareous but not sandy. The shale in USGS tests 5 and 10 was cored from 50 to 120 feet and from 40 to 46 feet, respectively. Core recovery was generally less than 50 per cent. However, the core failed to show any sand or sandy layers, oxidized zones, or brecciated or otherwise broken zones. It is possible that very thin sand layers in the shale might have been washed out in the process of taking the core. However, sandy partings should have been preserved, and none were detected. Likewise, broken zones might be partly washed out in the drilling process and the fragments interpreted to be shale cuttings. A core from the only unusual zone in the shale was taken from a depth of 100 to 110 feet and contained about a foot of very silty shale.

The possibility that calcareous zones in the shale may contain crevices that have been enlarged by solution, has been considered, but no such conduits were observed in the shale cores that were recovered.

It has been suggested that, in view of the fact that the aquifers are nearly always associated with hard layers of shale, the water-bearing openings are fractures caused by earth stresses. Such fractures generally would not be formed or maintained in the softer, more plastic shale. Stresses set up by the overriding glacial ice might have fractured brittle layers to a depth of 100 feet or more. Such fractures may have been enlarged to some extent by solution of the calcareous content by percolating water.

Whatever the exact physical nature of the aquifers in the shale, they do not appear to be extensive in any given horizontal plane; note the varying depths of the wells that tap shale aquifers. However, even though the aquifers occur at different elevations at different wells, those that occur within 120 feet or so of the land surface appear to be hydrologically connected and to form a rather extensive hydrologic unit, as evidenced by the manner in which the pumping of one well will influence the water level in another (p. 62-64). There is evidence also that the aquifers in the shale, at least in the area near Michigan City, receive recharge from downward percolation of rain and melted snow more readily than might be expected (p.64-66). Also, the water derived from these aquifers is of comparatively good chemical quality, which would appear to indicate rather free circulation of the water in the aquifers and replenishment by recharge.

Water-bearing beds in the shale are present at depths considerably greater than 120 feet below the land surface. However, these deeper aquifers contain more highly mineralized water than the shallow aquifers, the mineralization increasing as the depth to the aquifer increases. It is probable that these deeper aquifers are virtually cut off from recharge and, at least locally, that they have no important hydrologic connection with the shallow aquifers in the upper part of the shale.

The most detailed subsurface data available regarding the shale are for the area in and near Michigan City. A summary of the data for wells tapping shale aquifers in the entire area compiled from the well tables, is given on page 61. The data show that the drift under Michigan City ranges in thickness from 26 to 55 feet. The thickness of shale penetrated ranges from 30 to 92 feet, and at most of the wells it was 70 to 90 feet. The depths of the wells range from 70 to 120 feet.

In the outer part of the Michigan City area, excluding the area in and near the city itself, the wells for which the depth to shale is known range in depth from 90 to 190 feet. The drift cover ranges from 25 to 110 feet in thickness. The thickness of shale penetrated ranges from 30 to 160 feet. Among the extremes that may be noted in the data are those for well 152-59-12ddc, where the drift cover is 30 feet thick and the thickness of shale penetrated, 160 feet, as compared with well 151-59-1baa where the drift was 110 feet thick and the thickness of shale penetrated, 30 feet (fig. 5).

In general, the data on the wells in Michigan City suggest that locally there is a definite water-bearing zone between 70 and 90 feet below the top of the shale or, at least, that the most productive aquifers occur in that depth interval. The total depth of any particular well is not necessarily indicative

Depths to shale, thicknesses of shale penetrated, and depths of wells in Michigan City area

Location no.	Depth to shale	Thickness of shale penetrated	Depth of well
151-58-6dad2	35	105	140
151-59-1baa	110	30	140
152-58-4bd	40	70	110
152-58-18cdd	30	155	185
152-59-11dca	30	86	116
152-59-12ddc	30	160	190
152-59-14aba	30	90	120
152-59-16dd1	40	86	126
152-59-21cbc	50	78	128
152-59-22bad2	50	58	108
152-59-22cad	40	85	125
152-59-24abc	35	79	114
153-58-5da	25	77	102
153-58-8dad	30	60	90
153-58-9aad	30	87	117
153-58-14dcc1	60	110	170
153-58-21cbb	40	68	108
153-58-21d	25	85	110
153-58-21dc1	38	67	105
153-58-30cdc2	40	70	110
153-58-32dac1	40	76	116
153-58-32dac6	32	72	104
153-58-32dba2	30	57	87
153-58-32dba3	30	78	108
153-58-32dbb	30	90	120
153-58-32dbc1	30	70	100
153-58-32dbd1	55	30	85
153-58-32dcd4	32	73	105
153-58-32dda1	26	84	110
153-58-32dda2	27	88	115
153-58-32ddb3	30	40	70
153-58-32ddc1	30	70	100
153-58-32ddc2	30	72	102
153-58-32ddc6	40	64	104
153-58-32ddc7	28	80	108
153-58-33ccb2	28	92	120
153-58-34dba	60	65	125
153-59-25cdd1	30	80	110
153-59-25cdd2	30	95	125
153-59-34bca2	40	50	90
153-59-34cba2	30	75	105

of the actual depth to the aquifer from which it derives its water. Some wells are drilled below the aquifer to provide storage and others tap more than one aquifer. A shallower water-bearing zone is present in a number of wells and test holes, as indicated by well depths, but apparently it is not as productive locally as the lower ones. Michigan City test hole 2 penetrated a water-bearing bed at 30 feet below the top of the shale. All the Great Northern test holes obtained water in the shale at 55 feet or less below the top of the shale. In the Michigan City area as a whole, more than half the wells for which data are available apparently tap aquifers within the 70 - to 90 - foot range.

Results of Pumping Tests on Aquifers in the Shale

Three pumping tests were made on wells in Michigan City that tap shale aquifers. In the first of these tests, well 153-58-32dad5 was pumped and wells dad6 and dad7 were used as observation wells in which water levels were measured during the pumping and subsequent recovery. The pumping test was begun in the afternoon of April 21, 1947. The well was pumped at an average rate of 7.4 gpm for a period of 5 hours and 19 minutes; the rate varied from about 7.7 to 7.3 gpm. Water-level measurements were made in the observation wells during the pumping ing period and for 9 hours and 35 minutes after pumping stopped. Measurements were not made in the pumped well.

The pumped well is 118 feet deep. It is cased with steel pipe to a depth of 50 feet and with a light steel perforated liner to its full depth. The depths at which various aquifers in the shale were penetrated are not known.

Well dad6 is 23.8 feet northeast of the pumped well. It is 116 feet deep and is finished in the same way as the pumped well.

Well dad7 is 43.2 feet west of the pumped well. It is only 73 feet deep. The manner in which this well was finished is not known but it probably was cased to a depth of about 50 feet, with also a perforated liner extending to the bottom of the well, as were wells dad5 and dad6.

The water-level data obtained in wells dad6 and dad7 during the pumping and recovery periods were analyzed for the coefficients of transmissibility and storage (p.40 and 46), by means of the nonequilibrium formula (Theis, 1935, p. 519-524; Wenzel, 1942, p. 87-89).

The data obtained from well dad7 gave a good plot, as required for use of the formula, but the data from well dad6 did not. Therefore, only data from well dad7 were used in making computations. The coefficient of transmissibility computed from the data is 490 gpd per foot and the coefficient of storage is 6.2×10^{-4}.

In the second pumping test, well 153-58-32dbc2 was pumped and wells dbb, dbc1, and dbd1 were used as observation wells (fig. 6). The pumping test was begun in the morning of April 24, 1947. The well was pumped for 96 hours and 40 minutes at an average rate of 6.6 gpm; the rate varied from 10.7 gpm at the beginning of the test to 5.6 gpm for a short time during the test. At one time during the test a motor fuse was blown, and the pump was off for about 50 minutes until repairs could be made. The data obtained during the test were, of course, affected by the shutdown period and by the changes in pumping rate. However, in the analysis by means of the Theis nonequilibrium formula, about half the data were plotted on a fairly even curve and these were used in making the computations for the coefficients of transmissibility and storage. The coefficient of transmissibility was computed as 420 gpd per foot and the coefficient of storage was computed as 3.8×10^{-4}.

A third short pumping test was begun May 23, 1949, using the same wells that were used in the second test described above. Well 153-58-32dbc2 was pumped for 26 hours and 35 minutes at a rate which averaged 19.8 gpm for the entire run. However, the pumping rate at the beginning of the test was 25.6 gpm and dropped off to about 20 gpm after about 7 hours of pumping. Near the end of the run, the water level in the pumped well was drawn below the pump intake, about 105 feet below the land surface at the well, so that air was admitted to the pump and surging effects began.

Many of the data obtained during this test were discarded after they were plotted for analysis, but the remaining data were used to make computations for the coefficients of transmissibility and storage. The data were analyzed by means of the modified nonequilibrium formula (Cooper and Jacob, 1946, p. 526-534), the Theis recovery formula (Theis, 1935, p. 522), and the Theis nonequilibrium formula. The results varied from well to well and with the method used. Computed values of the coefficient of transmissibility ranged from 490 to 900 gpd per foot and averaged 710 gpd per foot. Computed values of the coefficient of storage ranged from 2.8×10^{-4} to 5.8×10^{-4} and averaged 4.2×10^{-4}.

Although the data obtained from these tests were not entirely reliable, it is believed that the results of the computations show fairly well the order of magnitude of the coefficients of transmissibility and storage of the combination of aquifers in the upper 90 feet of shale in the Michigan City area. In making theoretical computations (see a subsequent section of this report) for drawdowns likely to result from pumping wells that tap shale aquifers, a coefficient of transmissibility of 450 gpd per foot and a coefficient of storage of 4×10^{-4} are used. These figures are believed to be somewhat conservative, on the whole, for the magnitude of the coefficients for the aquifers in the upper part of the shale in the area near Michigan City.

Recharge, Storage, and Movement of Water in the Aquifers in the Shale

Intermittent water-level measurements have been made in well 153-58-32dbb since 1947. A hydrograph showing the data available is given in figure 7. Although the available record is relatively short and somewhat sketchy, there is evidence that seasonal recharge to the aquifers in the shale does occur. The part of the hydrograph for 1950 is closely correlative with the 1950 hydrograph for well 152-58-18daa and suggests that, as for the shallow aquifers in the glacial drift, the principal recharge occurs in the spring after the melting of the winter snow.

The manner in which the recharging water reaches the aquifers in the shale is not known. Because of the impermeable nature of the bulk of the shale, it might seem almost impossible that any great amount of water could reach the aquifers by direct downward percolation. However, the correlation between the 1950 hydrographs, for the wells mentioned above, suggests that there is definite interconnection between the shallow aquifers in the glacial drift and the aquifers in the shale.

The amount of recharge that reaches the aquifers in the shale cannot be computed from present data. Assuming an interconnection with shallow aquifers in the drift, the height to which water in the shale aquifers can rise is controlled by the elevation of the water table in the glacial drift in the recharge areas. Under natural conditions, then, the magnitude of the rise of water levels in wells tapping aquifers in the shale would depend on the amount of recharge received by the aquifers in the glacial drift in the recharge areas. Possibly a greater amount of recharge than would occur naturally could be induced to aquifers in the shale by pumping them to bring water levels to a comparatively low stage at about the time of the spring thaw. In this way some water that might be rejected under natural conditions possibly would be saved because of the greater storage capacity available in the aquifer. However, using a coefficient of storage of 4×10^{-4} as computed from the pumping tests, a change in water level of 1 foot in the aquifers in the shale would represent a change in storage of only about 80,000 gallons per square mile. A similar change in water level in shallow water-table aquifers in the glacial drift, especially if composed principally of sand and gravel, might represent a change in storage of several tens of millions of gallons per square mile of aquifer.

By lowering the water levels sufficiently, at least part of the aquifers in the shale could actually be drained of water. The amount of water that could be recovered by such drainage cannot be estimated from present information, but it probably is not more than a small percentage of the volume of the rocks.

The manner of movement of the water in the aquifers in the shale is not known. However, because of the comparatively good quality of the water, it must be assumed that reasonably vigorous movement does occur. The movement of the water is controlled to some extent by the shape of the water table in the overlying glacial drift and by the relative permeabilities of the glacial-drift materials that may be near or in actual contact with permeable parts of the shale. Recharge to the shale must be derived from water that has passed through the glacial drift. The water then moves through the permeable parts of the shale and is again discharged to the glacial drift at some lower elevation.

Possibilities of Developing Water Supplies for Municipal and Industrial Use From Aquifers in the Pierre Shale

Because of the rather low transmissibility of the aquifers in the shale, it is unlikely that most wells would yield much more than 10 gpm for relatively long periods of time. However, in the Michigan City area, the aquifers appear to be present over most or all of the area and probably can be considered to form an areally extensive system. It is believed, therefore, that a system of wells, properly spaced so as to produce only slight interference with each other, might be developed to yield a considerable amount of water. Individual wells probably would yield between 5 and 10 gpm, or about 7,000 to 14,000 gpd.

In order to assist in determining the best arrangement for wells in such a field, the following table has been prepared:

Theoretical Drawdowns, in Feet, at Various Distances From a Well Pumped at 5 gpm From an Areally Extensive Aquifer

(Coefficient of transmissibility, 450 gpd per foot; coefficient of storage, 4×10^{-4})

Time since pumping started	Drawdowns (feet)								
	Distance from pumped well (feet)								
	10	100	300	500	700	1,000	3,000	5,000	10,000
1 day	10.3	4.5	1.9	0.9	0.4	0.1	0.0	0.0	0.0
10 days	13.2	7.4	4.6	3.4	2.6	1.8	.1	.0	.0
100 days	16.2	10.3	7.5	6.2	5.4	4.5	1.9	.9	.1
1 year	17.8	12.0	9.2	7.9	7.0	6.1	3.4	2.2	.8
2 years	18.7	12.9	10.0	8.8	7.9	7.0	4.2	3.0	1.4
3 years	19.2	13.4	10.6	9.3	8.4	7.5	4.7	3.5	1.8
5 years	19.8	14.0	11.2	9.9	9.1	8.2	5.4	4.1	2.4
7 years	20.3	14.4	11.7	10.3	9.5	8.6	5.8	4.5	2.8
10 years	20.6	14.9	12.1	10.8	9.9	9.0	6.2	5.0	3.3

The theoretical drawdowns, computed by means of the Theis nonequilibrium formula (Wenzel, 1942), are based on the assumptions that the aquifer is areally extensive, is homogeneous and isotropic throughout, (equally permeable in all directions) and has constant coefficients of transmissibility and storage at every time and place. It is assumed, also, that all water pumped is removed from storage in the aquifer without benefit of seasonal recharge. How well these assumptions correspond to actual conditions in the aquifer is questionable. It appears that the aquifers form a rather extensive system, but there doubtless is considerable variability in the coefficients of transmissibility and storage from one place to another. Also, at least in some localities, the transmissibility may be greater in one direction than in another. The coefficient of storage may vary somewhat in time as well as from place to place. Additional data on the coefficients of transmissibility and storage are needed from other parts of the area in order to determine just how well the coefficients used would approach the actual conditons.

Moreover, it appears that there is seasonal recharge to the aquifers in the shale, especially after the spring thaw, except in years of comparatively little winter precipitation. Also, it appears that water temporarily stored in the shallow aquifers in the drift is able to move into the shale aquifers to some extent, and this movement could be increased by lowering the water levels in the shale by pumping.

In using the table, the drawdown effects at any place from the pumping of one well are simply added to the effects at the same place from pumping another well, in order to determine the combined effects of pumping both wells. Likewise, if more than two wells are involved, the effects of each well at any particular place are simply added together to give the combined effects.

The drawdowns are directly proportional to the pumping rate, so that the effect at any place and time of pumping 10 gpm would be twice that of pumping 5 gpm as listed in the table.

The drawdown to be expected in a pumped well cannot be foretold with accuracy, but in 6-inch wells and at a pumping rate of 5 gpm, the drawdowns generally would be 10 to 15 feet more than those shown in the table for wells 10 feet away.

In the overridden-outwash area just south and west of Michigan City, some experimentation might be done to increase the flow of water from the shallow aquifer to the aquifers in the shale by installing screens opposite all aquifers in a series of wells. Pumping could then be done in a nearby well that would tap only the aquifers in the shale. When the water level in the lower aquifers is lowered, water would flow from the shallow aquifer to the shale aquifers through the connecting wells. By inducing recharge to the lower aquifers in this manner, it might be possible to increase materially the yield of a well tapping them. Also, the additional storage available in the shallow aquifer and its greater accessibility to seasonal recharge would be of material benefit in a long-range water-supply program.

Dakota Formation

The presence of the Dakota formation (p. 14) in the Michigan City area has not been established by drilling. However, because it has been found in adjacent areas and is known to occur throughout most of North Dakota, it is believed to be present in the Michigan City area. If present, it probably would be reached at a depth of 1,200 to 1,300 feet below the land surface.

In the city of Devils Lake, about 40 miles west of Michigan City, wells tapping the Dakota formation are used for municipal supplies. These wells are pumped at a rate of about 300 gpm. When not pumped, the wells flow at a rate in excess of 100 gpm. It is not known if flowing wells could be obtained from the Dakota formation in the Michigan City area. Simpson's map (1929, pl. 1) of the areas of artesian flow in North Dakota indicates that the northeastern part of Nelson county, in which the Michigan City area lies, is not in the area of artesian flow.

The artesian water in the city of Devils Lake is highly mineralized, containing about 3,700 ppm of dissolved solids. It is highly charged with sodium chloride, sulfate, and bicarbonate. This water is undesirable for domestic use as well as for most agricultural and industrial purposes, except perhaps for cooling and washing processes.

Other Bedrock Aquifers

There is a possibility that rocks of earlier Mesozoic and Paleozoic ages are present in the area between the Dakota formation and the pre-Cambrian rocks. Some of these rocks, if present, may be sufficiently permeable to yield considerable quantities of water to wells. However, it is believed that water in any deeper aquifers would be inferior in chemical quality even to that found in the Dakota formation.

CHEMICAL QUALITY OF THE WATER FROM WELLS AND SPRINGS IN THE MICHIGAN CITY AREA

In order that the reader may more easily understand the significance of the chemical analyses, a partial list of chemical standards required by the U. S. Public Health Service for drinking water used on interstate carriers is given here.

Chemical constituent	Maximum concentration permitted ppm
Dissolved solids	500 (1,000 if necessary)
Chloride (Cl)	250
Sulfate (SO_4)	250
Magnesium (Mg)	125
Fluoride (F)	1.5
Iron and Manganese together (Fe + Mn)	.3

The presence of nitrate in ground water may indicate organic contamination. Also, water containing more than about 45 parts per million (ppm) of nitrate may be injurious to infants (Comly, 1945; Silverman, 1949). The presence of fluoride in drinking water in excess of 1.5 ppm may cause mottling of the enamel of the teeth in growing children.

Soft water is desirable for washing clothes or for any washing operation where soap is used. Practically all natural water contains calcium and magnesium, which cause a hardness of varying degree, depending upon the concentration of these constituents. Water having a hardness of more than about 100 ppm as $CaCO_3$ is generally considered to be fairly hard.

For general irrigation of crops or for watering lawns, trees and gardens, water containing a large percentage of sodium, with respect to the total cation concentration, is undesirable because it causes the soil to become impermeable. Water containing more than 50 to 60 percent of sodium (as indicated in the table of chemical analyses) would be harmful to the soil if applied continuously for a long time. This would be especially true if the soil were heavy and subsurface drainage poor. In a porous soil with good subsurface drainage, the effects would not be so marked.

Eaton (1950, p. 123-133) has shown that if water containing relatively large amounts of carbonate and bicarbonate as compared to the calcium and magnesium present is used for irrigation, a soil-water solution containing principally sodium salts may result. The danger of developing a soil solution of high-sodium content is increased if the water is applied sparingly and if good soil drainage is not provided. If the soil solution contains considerable sodium carbonate or sodium bicarbonate, a black-alkali soil may result.

All the waters from the Michigan City area that were sampled for chemical analysis were found to be harder or more highly mineralized, or both, than is generally desirable for most domestic uses. However, in areas where water of the better classification cannot be obtained with reasonable economy, the acceptability of the harder and more mineralized water will depend largely upon the tolerance of the local users. They may become accustomed to the poorer water and find it quite acceptable for general use.

Chemical analyses of 25 samples of ground water from the Michigan City area are given in the table on page 74. These samples were collected from wells, test holes, and one spring in the area. Five of the samples are of water from aquifers in the glacial drift and the rest are of water from aquifers in the Pierre shale.

In the water samples from aquifers in the glacial drift, the dissolved solids ranged from 540 to 3,190 ppm and hardness ranged from 160 to 1,410 ppm. The average concentration of dissolved solids in the 5 samples is 1,320 ppm and the average hardness is 510 ppm. The sodium percentage ranged from 18 to 71 and exceeded 60 in 3 out of 5 samples.

All the water samples from aquifers in the Pierre shale were obtained from a relatively small area in or adjacent to Michigan City. The depths of the wells or test holes sampled range from 50 to 120 feet. The analyses, therefore, probably should not be considered to be representative of the water in the Pierre shale in the entire area and especially in the deeper aquifers.

In the 20 water samples from aquifers in the Pierre shale, the dissolved solids ranged from 820 to 3,790 ppm and averaged 1,740 ppm. The hardness in these samples ranged from 25 to 770 ppm and averaged about 210 ppm. In one sample (153-58-32dbb) the percentage of sodium was 34, but in the other samples the sodium percentage ranged from 75 to 97. There is no apparent relation between the depth of the wells from which the samples were obtained and the dissolved solids, hardness, or percentage of sodium.

Most of the water samples from the area contained sufficient carbonate and bicarbonate, as compared to the calcium and magnesium present, to make the water of questionable value for general irrigation.

Generally the iron content of the water from the drift is higher than that of the water from shale. The iron content of the water from the drift ranged from 0.3 to 7.3 ppm as compared with a range of 0.4 to 3.5 ppm for the water from shale.

Although the water samples obtained from aquifers in the glacial drift were too few to permit a satisfactory comparison of the chemical quality of the water from the drift and the Pierre shale, indications are that, on the whole, the water from the glacial drift is harder but less highly mineralized than the water from the Pierre shale.

In general, the higher mineralization of the water in the Pierre shale appears to be due to greater proportions of sodium, sulfate, and chloride, although some of the samplesof water from the shale contained relatively small amounts of chloride. Other samples contained relatively small amounts of calcium and magnesium and relatively large amounts of sodium. These suggest the following possibilities: (1) Some of the wells tapping the shale aquifers may obtain some water from overlying aquifers in the glacial drift by seepage around the well casing; thus the water sampled may be a composite of water from the drift and the shale. (2) Aquifers in the Pierre shale may receive recharge from aquifers in the glacial drift by lateral or downward percolation. The percolation may be somewhat freer in certain areas than in others, resulting in differing proportions of the minerals being dissolved. (3) Water passing through the glacial drift to or through the shale may pass, in places, through zones containing minerals that have base-exchange capacity which absorb some of the calcium and magnesium from the water and release an equivalent amount of sodium.

Source of analysis: AV; Abbott and Voedisch (1938), p. 68-70;
DH; State Dept. of Health, Bismarck; Simpson (1929), p. 292-293;
SL; State Laboratories Dept., Bismarck, N. Dak.

Location number	Owner or name	Source of analysis	Date	Depth	Aquifer	Iron (fe)	Calcium (Ca)	Magnesium (Mg)
151-58-6bac	Gordon Spring1/	S	4-30-21	-	D	-	110	33
152-58-3bbb	George Norman	SL	6-18-47	30	D	2.4	46	48
152-58-7aaa	M.S. Swanson Est	SL	7-11-47	36	D	.3	88	12
152-58-18daa	USGS Test 12	DH	5-29-48	26	D	3.1	32	19
153-58-29cdd	Lloyd Wright	SL	7-11-47	76	S	1.2	160	13
153-58-32bba	USGS Test 25	DH	8-29-47	32	D	7.3	300	160
153-58-32daa2	M.C. Milligan	SL	4-2-47	91	S	.8	170	85
153-58-32dac3	W. Lamb2/	AV	1937-38?	100	S	.6	25	33
153-58-32dac4	V. A. Theison	AV	1937-38?	90	S	.8	16	5
153-58-32dac5	Michigan Fire-house	SL	7-11-47	95	S	.7	58	27
153-58-32dad4	K. L. Wright	AV	1937-38?	100	S	1.2	18	22
153-58-32dad5	Orren Lee	SL	7-11-47	118	S	.9	18	14
153-58-32dad6	.....do....	SL	7-11-47	116	S	1.2	70	36
153-58-32dba1	George Peuka	SL	4-2-47	94	S	.8	29	9
153-58-32dba2	B. Smith3/	S	4-30-21	87	S	.13	29	14
153-58-32dbb	Michigan City Test 2	DH	8-29-47	120	S	.64	130	65
153-58-32dbc2	Michigan City Test 1	SL	7-11-47	60	S	..9	5	3
....do......	.....do.....	SL	7-11-47	100	S	.9	7	5
153-58-32dbd2	Michigan City School	SL	7-11-47	100	S	.4	32	18
....do......	.....do.....	AV	1937-38?	100	S	.4	21	25
153-58-32dcd3	Carl Dahl	SL	4-2-47	100	S	1.8	8	4
153-58-32ddb2	Orvick Supply Co.	SL	7-11-47	96	S	.9	27	18
153-58-32ddd1	Standard Service Station	SL	4-2-47	50	S?	3.5	50	11
153-58-32ddd4	J.W. Lamb and E. W. Ryall	SL	4-2-47	98	S	2.2	38	16
153-58-32ccb1	P. Hall	SL	4-2-47	90	S	.7	25	11

1/ Owner listed as J. W. Cecka by Simpson (1929, p. 292).
2/ Owner listed as Bert Hagen in Abbott and Voedisch (1938, p. 70)
3/ Owner listed as K. L. Wright by Simpson (1929, p. 292).

IN THE MICHIGAN CITY AREA, N. DAK.
million)

Aquifer; D, drift; S, Pierre shale

Sodium (Na)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum)	Hardness (as $CaCO_3$)	Percent sodium
42	0	410	160	2	-	1.0	540	410	18
260	0	540	380	31	-	-	1,030	310	64
280	58	150	570	38	-	-	1,120	270	69
180	0	280	200	130	0.03	-	700	160	71
1,240	130	440	540	1,490	-	-	3,790	450	86
520	0	630	1,670	220	-	-	3,190	1,410	44
1,050	110	570	40	1,670	-	-	3,410	770	75
660	0	790	140	590	2.0	7.9	1,850	200	88
680	0	780	390	340	0.4	0.0	1,820	60	96
590	110	490	540	290	-	-	1,860	260	83
480	0	700	210	270	0.2	11	1,360	140	88
550	110	550	230	360	-	-	1,550	100	91
520	62	600	380	330	-	-	1,690	320	78
780	79	480	800	320	-	-	2,250	110	94
420	0	660	210	210	-	4.5	1,210	130	86
140	0	490	440	35	-	-	1,050	590	34
360	46	410	340	33	-	-	990	25	96
610	46	540	360	330	-	-	1,630	38	97
520	72	490	470	210	-	-	1,560	150	88
500		600	470	180	1.0	6.7	1,510	160	87
680	84	690	40	540	-	-	1,700	36	97
760	150	560	130	680	-	-	2,040	140	92
250	50	410	180	78	-	-	820	170	76
470	31	670	200	270	-	-	1,360	160	86
470	120	420	260	220	-	-	1,310	110	90

SUMMARY OF GROUND-WATER CONDITIONS IN THE MICHIGAN CITY AREA

Aquifers in the glacial drift furnish water to only about a quarter of the wells in the Michigan City area. The aquifers include: (1) the deposits of sand and gravel associated with the till that are not readily assigned to one of the following categories, (2) sorted deposits of overridden outwash, (3) the deposits in the glacial spillways, and (4) the deposits in the ice-contact features.

Aquifers in or associated with the till supply water to about 70 percent of the wells that tap drift aquifers in the Michigan City area. About 20 percent of the wells that tap drift aquifers are in the ground-moraine area and about 50 percent are in the end-moraine areas. Most of the wells are dug or bored and are less than 50 feet deep. They yield only small supplies of water for farm use.

It is thought that the aquifers in or associated with the till generally are small bodies of sand and gravel that may be more or less isolated from each other by the surrounding till. Inasmuch as the till is not entirely impermeable, however, and as these small bodies of sorted material may be numerous and partly interconnected in some areas, the entire till sheet may function as a poor aquifer.

About 30 percent of the wells tapping drift aquifers in the area apparently obtain water from the overridden outwash deposits. Most - perhaps all - of the wells are dug or bored and yield only small supplies of water for farm and domestic use.

The overridden outwash consists essentially of sand or sand-and-gravel deposits, generally with considerable interstitial clay and silt which makes for low permeability of the material. The deposits probably are not more than 50 feet thick anywhere in the area and are much thinner at most locations where they were penetrated by test drilling.

None of the wells in the area are known to tap aquifers formed by the deposits in the Lindsey Lake and Goose Creek spillways, although a few of the shallow wells along the boundaries of the spillways may penetrate them. The material found in the Geological Survey test holes drilled in the spillways ranges from a pebbly clay to fairly clean gravel. The sand-and-gravel deposits found in the test holes drilled in and adjacent to the spillways range in thickness from 3 to 24 feet.

No wells in the area are known to obtain water from the ice-contact deposits, although some of the larger deposits would yield supplies sufficient for general farm and household use. In many places the bulk of the deposits is higher than the water table and only a relatively thin saturated zone is present in their lower part. With natural lowering of the water table during drought cycles, the deposits may dry up completely.

It is believed that not any of the ice-contact deposits in the area would furnish water in sufficient quantity for municipal or other large-scale use, although, if it became necessary, the water in some of the deposits might be used as a supplemental supply. Only two of the ice-contact deposits in the area appear to offer possibilities for such development.

There doubtless is a considerable degree of interconnection hydrologically, between the various aquifers in the glacial drift, which may permit the relatively free movement of water from one body of sand and gravel to another, so that both function essentially as a single aquifer. For this reason, any aquifer in the drift might yield a great deal more water than could be guessed from the results of general test drilling. In a search for large supplies of water, any relatively thick section of permeable material probably would be worth testing by constructing a well and making a thorough pumping test, even though similar material was not found in nearby test holes.

Recharge to the various aquifers in the glacial drift occurs principally by downward percolation of water from melted snow and rain, although certain aquifers may receive a larger proportion of their recharge by lateral percolation through the ground from adjacent areas.

The sand and gravel deposits in the glacial spillways, ice-contact features, and the exposed parts of the overridden outwash are best situated to receive recharge by direct penetration of water from rain and melted snow. The sand and gravel deposits included in the till are less well situated to receive recharge in that manner.

No aquifer found in the glacial drift was believed to be sufficiently productive of water to supply Michigan City from one well or even from a field of two or three wells. However, certain of the aquifers in the glacial drift might warrant more thorough investigation as possible sources of small or supplemental supplies. Such aquifers include some of the ice-contact deposits, deposits in the glacial spillways, certain parts of the overridden outwash, and some deeper drift aquifers situated in bedrock channels.

Aquifers in the Pierre shale furnish water to about three-quarters of the wells in that area. Because the water is softer than that generally obtained from aquifers in the glacial drift and because the wells in the shallow drift aquifers may not furnish sufficient water for use during long droughts, the wells tapping shale aquifers are considered by the local residents to be the best obtainable in the area.

The exact physical nature of the aquifers in the shale has not been determined. However, their occurrence in the area is quite general and wells in the shale are found in almost every part of the area. The wells range in depth from 70 to 185 feet.

Pumping tests on wells tapping shale aquifers in Michigan City indicate a coefficient of transmissibility on the order of 450 gpd per foot and a coefficient of storage on the order of 4×10^{-4} for the aquifer there.

Water-level records of a well tapping shale in Michigan City appear to indicate seasonal recharge to the shale aquifers, but the manner in which the recharging water reaches the aquifers and its amount are not known.

Because of the rather low transmissibility of the shale, it is unlikely that wells generally could be obtained that would yield much more than 10 gpm for any appreciable length of time. It is believed, however, that a system of wells, properly spaced so as to cause only slight interference with one another, could be developed to yield a considerable amount of water. Individual wells probably could be expected to yield 7,000 to 14,000 gpd.

It is suggested that some experimentation might be done toward artificially recharging the aquifers in the shale with water from higher aquifers in the glacial drift by installing screens opposite both aquifers in a series of wells. Pumping could then be done from a nearby well that would tap only the lower shale aquifers. In this way, it might be possible to increase materially the amount of water that could be taken from the area economically over a long period of time.

The aquifers of the Dakota formation probably would be reached at a depth of 1,200 to 1,300 feet below the land surface at Michigan City. They probably would yield more water than is needed by the city but it would be highly mineralized and unsuitable for general use. Wells tapping the aquifers at Michigan City probably would not flow naturally and the water would have to be obtained by pumping.

There is a possibility that aquifers may occur in some formations between the Dakota formation and the basement complex. However, it is believed that water in any deeper aquifers would be inferior in chemical quality even to that found in the Dakota formation.

Most of the water from the Michigan City area that was sampled for chemical analysis was found to be harder or more highly mineralized than is generally desirable for most domestic uses.

In 5 samples of water from the glacial drift, dissolved solids ranged from 540 to 3,190 ppm and averaged 1,320 ppm; hardness ranged from 160 to 1,410 ppm and averaged 510 ppm. The sodium concentration ranged from 18 to 71 percent and was above 60 percent in 3 out of 5 samples.

In 20 samples of water from the Pierre shale, dissolved solids ranged from 820 to 3,790 ppm and averaged 1,740 ppm; hardness ranged from 25 to 770 ppm and averaged about 210 ppm. In one water sample the sodium concentration was 34 percent, but in the other samples it ranged from 75 to 97 percent.

Most of the water samples from the area contained sufficient carbonate and bicarbonate, as compared to the calcium and magnesium present, to make the water of questionable value for general irrigation. A further deterrent for most of the sources is excessive amounts of dissolved solids and high percentages of sodium.

Type of well: B, bored; Dr, drilled; Du, dug.

Aquifer: D, glacial drift; S, Pierre shale.

Depth to water: Measurements given to hundredths or tenths are measured water levels; those given in whole numbers are reported.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date completed
151-58					
4dca	USGS test 52	25	5	Dr	1948
4dcc	Minn. Land Bank	108	6	Dr	1936
5bab	USGS test 50	40	5	Dr	1948
5ddd	USGS test 51	52	5	Dr	1949
6aaa	USGS test 19	55	5	Dr	1948
6ba1	John Orvik	89	5	Dr	1926
6ba2	....do....	40	48	Du	1921
6bac	Gordon Spring	...			
6daa	USGS test 20	60	5	Dr	1948
6dad1	Mrs. L. Kjorsvik	26	36	Du	1910
6dad2	....do....	140	5	Dr	1938
7aaa	USGS test 21	115	5	Dr	1948
7add	USGS test 22	65	5	Dr	1948
7daa	Bert Swenseth	28	36	Du	1906
8bc	J. P. Lamb Est.	26	36	Du	1910
151-59					
1baa	Lamb Land Co.	140	5	Dr	1926
2aaa	....do....	100	5	Dr	1926
2cbb	B. Helgeson	60	27	B	1906
2cc	Chas. Simons	90	6	Dr	1929
3ddc	USGS test 49	57	5	Dr	1949
9acb1	Henry Rusid	90	6	Dr	1918
9acb2	....do....	30	36	Du	1935
9cbd	Hans Nelson	45	48	Du	1933

Date of measurement: For measured depths to water, this is date of measurement. For reported depths, this is date of report, not date of measurement by reporter.

Use of water: D, domestic; I, industrial; M, municipal; O, observation; S, stock; T, test holes, U, unused.

Aquifer	Depth to water (feet below land surface)	Date of measurement	Use of water	Remarks
...	.....	....	T	See log. Hole refilled.
S	28	1938	D,S	Water reported adequate.
...	.....	....	T	See log. Hole refilled.
...	.....	....	U	Do.
...	.....	....	T	Do.
S	30	1938	D,S	Water reported adequate.
D	37	1938	S	Water reported inadequate; aquifer, clay.
D			S	See chemical analysis.
...	.....	....	T	See log. Hole refilled.
D	24	1938	S	Water reported inadequate; aquifer, clay, sand.
S	25	1938	D,S	Water reported good; shale at 35 feet.
...	.....	....	T	See log. Hole refilled.
...	.....	....	T	Do.
D	11	1938	D,S	Water reported inadequate; aquifer, gravel.
D?	25	1938	D,S	Water reported inadequate.
S	.....	....	D,S	Water reported good; shale at 110 feet.
D	.....	....	D,S	Water reported good; aquifer sand and gravel
D	40	1938	D,S	Water reported adequate; aquifer, gravel.
D	60	1938	D,S	Water reported adequate; aquifer, sand.
...	.....	....	T	See log. Hole refilled.
D	80	1938	D	Water reported inadequate; aquifer, "sandstone."
D	20	1938	D,S	Water reported adequate; aquifer, gravel.
D	42	1938	D,S	Water reported inadequate; aquifer, sand.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date completed
151-59 - Cont.					
9dcc	Peter Bakke	60	24	B	1915
10cad	Paul Ruud	14	24	Du	1916
11bdd	Nels Berg	140	6	Dr	1914
11db	J. P. Reep	100	5	Dr	1921
12cc	S. Smogge	47	36	Du	1910
12d	J. Franzen Est.	30	18	B	1935
152-58					
3bba	USGS test 41	50	5	Dr	1947
3bbb	George Norman	30	24	B	....
4bd	J. S. Lamb	110	5	Dr	1918
4cb	S. Tibbett	130	5	Dr	1926
5aaa1	George Peuka	60	6	Dr	....
5aaa2	....do.....	90	6	Dr	1916
5cbb	USGS test 6	42	5	Dr	1947
5cbc	USGS test 7	36	5	Dr	1947
5ccc	USGS test 8	30	5	Dr	1947
6aaa	Marie Erickson	40	48 by 48	Du	1916
6aba	USGS test 32	25	5	Dr	1947
6baa	S. E. Rio	100	5	Dr	1918
6cbb1	....do....	...	....	Dr	....
6cbb2	USGS test 42	35	5	Dr	1948
7aaa	M. S. Swanson Est.	36	30	B	....
7aad	USGS test 9	32	5	Dr	1947
7ddd	USGS test 10	46	5	Dr	1947
8bb1	Nelson Nearing	22	24	Du	....
8bbb2	....do....	160	5	Dr	1934
8cbc1	Lloyd Floren	...	5	Dr	....
8cbc2	....do....	34	36 by 36	Du	1911
9aaa	Mrs. Cubash	110	6	Dr	1910

Aquifer	Depth to water (feet below land surface)	Date of measurement	Use of water	Remarks
D	35	1938	D,S	Water reported adequate; aquifer, sand, gravel.
D	12	1938	D,S	Water reported adequate; aquifer
S	40	1938	D,S	Water reported surplus.
S	50	1938	D,S	Do.
D	1	1938	S	Water reported inadequate; aquifer, sand, gravel.
D	20	1938	S	Water reported adequate; aquifer, gravel.
...	.....	....	T	See log. Hole refilled.
D	.....	....	...	Water reported hard; see chemical analysis.
S	20	1918	D,S	Water reported good; shale at 40 feet.
S	20	1926	D,S	Water reported adequate.
S?	.....	....	...	Water reported soft.
S	10	1916	S	Reported never pumped dry.
...	.....	...	T	See log. Hole refilled.
...	.....	....	T	Do.
...	.....	....	T	Do.
S	10	1916	D,S	Water reported adequate, hard; was originally soft.
...	.....	....	T	See log. Hole refilled.
S	.....	....	D,S	Water reported soft, adequate.
S?	.....	....	U	Well abandoned; water re-reported soft.
...	.....	....	T	See log. Hole refilled.
D	6	1938	D,S	Water reported hard, adequate; aquifer, sand and gravel. See chemical analysis.
...	.....	....	T	See log. Hole refilled.
...	.....	....	T	Do.
D?	.....	....	D,S	Water reported hard.
S	12.34	5-28-48	U	Well abandoned; water reported soft, salty.
...	.....	....	...	
D	32	1938	D,S	Water reported adequate; aquifer, sand and gravel.
S?	60	1938	D,S	Water reported adequate; aquifer, sand.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date completed
152-58 - Cont.					
15cc	F. Wright	25	48 by 48	Du	1932
16bc	Anton Danda	125	6	Dr	1917
17bcb1	O. Narum	25	48 by 48	Du	1934
17bcb2	....do....	216	6	Dr	1915
17bcb3	....do....	25	48 by 48	Du	1939
18aad	USGS test 11	30	5	Dr	1948
18b	C. Peters	30	36	B	1916
18cdd	W. Fowler	185	6	Dr	1937
18daa	USGS test 12	26	5	Dr	1948
18dda	USGS test 13	30	5	Dr	1948
19daa	USGS test 14	36	6	Dr	1948
19dda	Floyd Anderson	107	6	Dr	1929
20bbb	John Reineke	100	5	Dr	1918
28aaa	K. Wright	30	48 by 48	Du	....
28add	USGS test 55	30	5	Dr	1948
29ccc	USGS test 17	45	5	Dr	1948
30aaa	USGS test 15	30	5	Dr	1948
30ada	USGS test 16	35	5	Dr	1948
31add	USGS test 18	50	5	Dr	1948
32bcc	Nelson Elvick	90	....	Dr	1918
32dcc	O. Okstad	20	36 by 36	Du	....
33abb	USGS test 54	20	5	Dr	1948
33acc	Lamb Land Co.	110	6	Dr	1931
33cad	USGS test 53	140	5	Dr	1948
152-59					
1a1	W. H. Lamb	40	36	B	1898
1a2	....do....	42	36	B	1898
1abb	Lamb Estate	100	5	Dr	1937

Aquifer	Depth to water (feet below land surface)	Date of measure-ment	Use of water	Remarks
D	22	1938	D,S	Water reported adequate; aquifer, sand.
S	20	1917	D,S	Water reported adequate, salty.
D	5.90	5-28-48	S	Water reported hard.
S	20	1915	D	Water reported hard, inadequate; shale at 20 feet.
D?	.....	....	D,S	Water reported hard.
...	.....	....	T	See log. Hole refilled.
D	25	1938	S	Water reported adequate; aquifer, sand.
S	30	1937	S	Water reported hard, salty, inadequate; shale at 30 feet.
...	.....	....	0	See log. See chemical analysis.
...	.....	....	T	See log. Hole refilled.
...	.....	....	T	Do.
S	20	1929	D,S	Water reported soft, adequate.
S	10.05	5-28-48	D,S	Do.
D	.....	....	...	Water reported adequate; aquifer, sandy clay.
...	.....	....	T	See log. Hole refilled.
...	.....	....	T	See log. Hole refilled.
...	.....	....	T	Do.
...	.....	....	T	Do.
...	.....	....	T	Do.
D	20	1948	D,S	Water reported fairly soft, adequate; aquifer, sand and gravel.
D?	19	1938	...	Water reported inadequate.
...	.....	....	T	See log. Hole refilled.
S	50	1938	...	Water reported adequate.
...	.....	....	T	See log. Hole refilled.
D	10.50	9-4-47	S	Water reported inadequate; aquifer, clay.
D	22	1938	...	Water reported adequate; aquifer, clay.
S?	22	1938	S	Water reported hard, unpotable.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date completed
152-59 - Continued					
1acb	Lamb Estate	110	...	Dr	....
3abd	....do....	120	6	Dr	1916
4aad	Luther Day	125	6	Dr	1912
4dbb	Anderson	90	6	Dr	1908
9dd1	H. Leike	30	18	D	1911
9dd2	....do....	150	6	Dr	1920
9dcd	USGS test 43	55	5	Dr	1947
9ddd	USGS test 44	40	5	Dr	1947
10cc1	H. Leike	30	18	B	1912
10cc2	....do....	30	36	B	1937
10ccd	USGS test 45	92	5	Dr	1947
10ddd	USGS test 46	55	5	Dr	1947
11baa	W. Young	30	36	B	1880
11dca	W. Young	116	...	Dr	1935
12ddc	Lamb Estate	190	5	Dr	1944
13aaa	....do....	112	6	Dr	1922
14aba	Curtis Wright	120	6	Dr	....
15bdd1	C. Webber	108	6	Dr	1935
15bdd2	....do....	50	24	B	1912
15bdd3	....do....	40	24	B	1915
15ddd	USGS test 47	51	5	Dr	1947
16dd1	N. Master	126	6	Dr	1917
16dd2	....do....	26	24	B	1909
21add	....do....	122	6	Dr	1925
21bcc1	R. H. Andrew	30	48	Du	1898
21bcc2	....do....	124	6	Dr	1912
21cbc	O. L. Neshein	128	58	Dr	1936
21ddd	USGS test 48	37	5	Dr	1947
22bad1	E. Fox	125	6	Dr	1911
22bad2	....do....	108	5	Dr	1949

Aquifer	Depth to water (feet below land surface)	Date of measurement	Use of water	Remarks
S	.....	....	S	Water reported soft, unpotable.
S	30	1938	D,S	Water reported soft, adequate.
S?	30	1938	D,S	Water reported adequate, soft, slightly salty.
S	80	1938	D,S	Water reported inadequate.
D	25	1938	S	Water reported inadequate; aquifer, clay.
S	135	1938	D,S	Water reported inadequate.
...	.....	....	T	See log. Hole refilled.
...	.....	....	T	Do.
D	28	1938	...	Water reported inadequate.
D	22	1938	...	Water reported inadequate; aquifer, gravel.
...	.....	....	T	See log. Hole refilled.
...	.....	....	T	Do.
D	28	1938	D,S	Water reported inadequate; aquifer, clay and sand.
S	18	1935	D,S	Water reported adequate; shale at 30 feet.
S	.....	....	S	Water reported inadequate; salty; shale at 30 feet.
S	110	1938	D,S	Water reported adequate.
S	.....	....	D,S	Water reported adequate; shale at 30 feet.
D	108	1938	...	Water reported inadequate; aquifer, clay and gravel.
D	15	1938	S	Water reported inadequate; aquifer, clay.
D	10	1938	S	Do.
...	.....	....	T	See log. Hole refilled.
S	30	1938	D,S	Water reported adequate; good well; shale at 40 feet.
D	10	1938	D	Water reported inadequate; aquifer, clay.
S	80	1938	D,S	Water reported adequate.
D?	20	1938	S	Water reported inadequate.
S	60	1938	D,S	Do.
S	28	1938	D,S	Water reported adequate; shale at 50 feet.
...	....	....	T	See log. Well refilled.
S	25	1938	D,S	Water reported adequate.
S	.....	....	D	Water reported soft, adequate; shale at 50 feet.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date completed
152-59 - Continued					
22cad	F. National Bank	125	6	Dr	1925
23dbd	J. Liodal	40	18	B	1918
24abc	H. Greenlee	114	6	Dr	1947
24dbc	A. Fuhrman	120	6	Dr	1911
25bdd	S. M. Kallstead	150	6	Dr	1908
25cad	J. C. Kallstead	60	6	Dr	1925
26ccc	C. A. Bunde	120	6	Dr	1918
27cc	G. Sparks	145	6	Dr	1912
28bcc	H. Severson	35	18	B	1900
33cbc	J. R. Johnson	100	6	Dr	1913
34bbb	G. Sparks	125	6	Dr	1917
35cb	S. Reep	110	6	Dr	1918
153-58					
2aab	E. Hauge	103	6	Dr	1910
3b	G. Nomen	38	36	Du	1935
4bcc	Oscar J. Olson	119	...	Dr	1925
4c	E. Rice	110	6	Dr	1918
4ccc	USGS test 2	32	5	Dr	1948
5aaa	USGS test 1	30	5	Dr	1948
5b1	O. B. Simon	25	36	Du	1908
5b2	H. W. Edden	110	6	Dr	1912
5da	O. Olson	102	6	Dr	1949
8bdd	L. E. Daws	35	30	B	....
8dad	L. J. Scheifford	90	24 to 6	Dr	1934
8ddd	USGS test 3	30	5	Dr	1948
9aad	C. Anderson	117	5	Dr	1935
9c	T. H. Smith	110	6	Dr	1910
10adc	Lamb Land Co.	100	6	Dr	1915
11cdc	B. B. Benson	120	6	Dr	1910
14dcc1	Mrs. Wheeler	170	5	Dr	1936
14dcc2	....do....	40	48	Du	....
16a	A. Dusbabek	100	5	Dr	1925
17add1	L. E. Daws	35	30	B	1902

Aquifer	Depth to water (feet below land surface)	Date of measure-ment	Use of water	Remarks
S	.....	....	S	Water reported adequate; shale at 40 feet.
D	40	1938	D,S	Water reported inadequate.
S	10	7-47	S	Shale at 35 feet; see log.
S?	100	1938	D,S	Water reported inadequate
S	80	1938	D,S	Water reported adequate.
D	40	1938	D,S	Water reported adequate, aquifer, gravel.
S	50	1938	D,S	Water reported adequate.
S	100	1938	D,S	Water reported inadequate
D?	20	1938	S	Do.
S	40	1938	D,S	Water reported adequate.
S	110	1938	S	Do.
S	40	1938	S	Do.
S	15	1938	...	Water reported adequate.
D	16	1938	...	Water reported adequate; aquifer, clay and sand.
S	.....	....	D,S	Water reported adequate; soft, slightly salty.
S	60	1938	S	Water reported adequate.
...	.....	....	T	See log. Hole refilled.
...	.....	....	T	Do.
D	24	1938	...	Water reported inadequate aquifer, sand.
S	70	1938	S	Water reported inadequate
S	6	1949	S	Water reported adequate, soft, shale at 25 feet.
D?	11.41	5-27-48	S	Water reported inadequate hard, unpotable.
S	36	1938	...	Water reported adequate; shale at 30 feet.
...	.....	....	T	See log. Hole refilled.
S	27	1938	S	Water reported adequate; shale at 30 feet.
S?	60	1938	S	Water reported adequate.
S?	60	1938	S	Water reported adequate.
S?	80	1938	S	
S	120		...	Water reported adequate; shale at 60 feet.
D?	39	1938	...	Water reported inadequate.
S?	60	1938	...	Water reported adequate.
D?	14	5-27-48	U	Well abandoned; water reported hard, alkali.

LOCATION number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date completed
153-58 - Continued					
17add2	....do....	122	6	Dr	1941
17add3	....do....	125	6	Dr	1910
7ccc	K. Narum	60	6	Dr	1930
7ddd	USGS test 4	39	5	Dr	1948
8cdc1	W. Fowler	22	36	Du	....
8cdc2	W. Fowler	185	40 & 6	Du & Dr	1935
8dd	J. Knutson	109	6	Dr	1918
9b	O. Gunderson	107	6	Dr	1935
9bab	W. Fowler	165	6	Dr	1940
0c	J. Gunderson	107	6	Dr	....
0cda	L. Wright	109	6	Dr	1905
0ddd	USGS test 5	120	5	Dr	1948
21cbb	Carl Narum	108	5	Dr	1951
21d	Lamb Land Co.	110	5	Dr	1919
21dc1	R. Zacha	105	5	Dr	1938
21dc2	....do....	31	36	B	1912
22bcd1	J. P. Lamb	165	6	Dr	1935
22bcd2	J. Summerfield	128	6	Dr	1920
23ddc	Lamb Land Co.	120	5	Dr	1918
28ccb1	Mark Garver	...	26	Du	....
28ccb2	....do....	30	26	Du	....
28ccb3	....do....	30	26	Du	1895
29ccd	USGS test 24	27	5	Dr	1947
29cdd	Lloyd Wright	76	6	Dr	1927
29dad1	George Reed	25	24	Du	1898
29dad2	....do....	108	6	Dr	1940
29dad3	....do....	120	6	Dr	1908

Aquifer	Depth to water (feet below land surface)	Date of measurement	Use of water	Remarks
S?	18	1941	D	Water reported adequate, soft, said to taste of iodine.
S?	18	1948	S	Water reported inadequate, soft, salty; said to taste of iodine.
S	40	1938	S	Water reported adequate.
...	.....	....	T	See log. Hole refilled.
D?	.....	....	D	Water reported inadequate, hard.
S?	7.26	5-28-48	S	Water reported adequate, hard, alkaki.
S	40	1938	...	Water reported adequate.
S	50	1938	...	Do.
S?	.....	....	S	Water reported inadequate, hard, salty.
S	40	1938	...	Water reported adequate.
S?	60	1938	...	
...	.....	....	T	See log. Hole refilled.
S	.....	....	...	Water reported soft, potable; shale at 40 feet.
S	20	1919	D,S	Water reported adequate; shale at 25 feet.
S	.....	....	...	Water reported adequate; shale at 38 feet.
D?	25	1938	S	Water reported adequate.
S	25	1938	...	Water reported adequate.
S	60	1938	...	Do.
S	60	1938	...	Do.
D?	9.70	5-28-48	U	Well abandoned, partly caved in; water reported hard.
D?	15.55	5-28-48	S	Water reported adequate, hard, alkali, contains iron.
D?	16.58	5-28-48	D	Water reported adequate, hard, alkali.
...	.....	....	T	See log. Hole refilled.
S?	.....	....	D,S	Water reported adequate, soft, slightly salty. See chemical analysis.
D?	12	5-24-48	U	Well abandoned; water reported inadequate, hard, alkali.
S?	20	1940	D	Water reported adequate, soft, slightly salty.
S	.....	....	S	Do.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date completed
153-58 - Continued					
29ddc	USGS test 23	22	5	Dr	1947
30c	D. Wright	80	6	Dr	1924
30cdc1	Jack Meneschum	118	6	Dr	1922
30cdc2	....do....	110	5	Dr	1949
31aad1	E. H. Greenlee	110	36	B	1916
31aad2	....do....	...	...	Dr	....
31ccd	USGS test 29	28	5	Dr	1947
32bba	USGS test 25	32	5	Dr	1947
32ccd1	USGS test 30	36	5	Dr	1947
32ccd2	Michigan City test 3	30	4	Dr	1947
32daa1	Albert Steen	97	5	Dr	1918
32daa2	M.C. Milligan	91	6	Dr	1944
32dab1	J. O. Sonsteng	78	6	Dr	1916
32dab2	A. D. Chaffee	120	...	Dr	1926
32dac1	Michigan City Hospital	116	5	Dr	1949
32dac2	Steven Hofer	100	5	Dr	1920
32dac3	W. Lamb	100	6	Dr	....
32dac4	V. A. Theison	90	5	Dr	1932
32dac5	Michigan City Firehouse	95	6	Dr	1909
32dac6	Michigan City Supply 2	104	6	Dr	1950
32dad1	John Cacha	...	...	Dr	....
32dad2	Julia Larson	79	...	Dr	1910
32dad3	Albert Dusbabek	90	5	Dr	....

Aquifer	Depth to water (feet below land surface)	Date of measurement	Use of water	Remarks
...	.....	....	T	See log. Hole refilled.
S	20	1938	...	Water reported adequate.
S	18	1922	S	Water reported soft, adequate.
S	.....	....	...	Water reported soft, adequate; shale at 40 feet.
S	33	1938	S	Water reported soft, slightly salty.
S?	.....	....	D	Water reported adequate, hard;said to taste of iodine.
...	.....	....	T	See log. Hole refilled.
...	.....	....	T	See log. Hole refilled. See chemical analysis.
...	.....	....	T	See log. Hole refilled.
...	.....	....	T	Do.
S	18.31	11-6-46	D	Water reported adequate, soft, salty, unpotable.
S	11.92	11-6-46	D,S	Water reported adequate, slightly salty. See chemical analysis.
S	17.47	11-6-46	D	Water reported adequate, salty.
S	.....	....	D	Water reported soft, adequate.
S	.....	....	D	Water reported adequate,soft and potable; shale at 40 feet.
S	.....	....	D	
S	.....	....	D	See chemical analysis.
S	.....	....	D	Do.
S	.....	....	M	Water reported potable. See chemical analysis.
S	.....	....	M	Water reported soft, potable; shale at 32 feet.
S?	17.52	11-6-46	U	Water reported potable, soft.
S	29.06	11-6-46	D	Water reported adequate, soft, and slightly salty.
S	12.48	11-6-46	D	Water reported inadequate, hard. Reported to have been soft at one time.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date completed
153-58 - Continued					
32dad4	K. L. Wright	100	6	Dr	1915
32dad5	Orren Lee	118	6	Dr	1926
32dad6	...do....	116	6	Dr	1926
32dad7	...do....	73	5	Dr	....
32dba1	George Peuka	94	5	Dr	1944
32dba2	B. Smith	87	4	Dr	1918
32dba3	Michigan City supply 1	108	6	Dr	1950
32dbb	Michigan City test 2	120	5	Dr	....
32dbc1	O'Hara	100	6	Dr	....
32dbc2	Michigan City test 1	115	5	Dr	....
32dbd1	E. Desatall	85	5	Dr	1931
32dbd2	Michigan City School	100	6	Dr	1910
32dcc	USGS test 31	37	5	Dr	1947
32dcd1	C. Anderson	95	5	Dr	1946
32dcd2	Langstaff	...	5	Dr	....
32dcd3	Carl Dahl	100	5	Dr	1946
32dcd4	Henry Rude	105	5	Dr	1950
32dcd5	John Hagen	...	6	Dr	....
32dda1	Great Northern test 1	110	6	Dr	1945
32dda2	Great Northern test 2	115	6	Dr	1945
32ddb1	Orvick Supply Co.	50	5	Dr	1917
32ddb2	....do....	96	5	Dr	1919

Aquifer	Depth to water (feet below land surface)	Date of measurement	Use of water	Remarks
S	.....	....	D	See chemical analysis.
S	.....	....	I	Well at creamery. See chemical analysis.
S	32.18	4-21-47	I	Well at creamery. See chemical analysis.
S	33.03	4-21-47	U	Well at creamery.
S	18	1944	D	Water reported adequate, soft, potable. See chemical analysis.
S	.....	....	D	Shale at 30 feet. See chemical analysis.
S	.....	....	M	Water reported soft and potable; shale at 30 feet. See log.
S	18.1	4-24-47	O	Shale at 30 feet. See chemical analysis.
S	10.8	4-24-47	D,O	Water reported adequate, soft, and potable. Shale at 30 feet.
S	16.2	4-24-47	T	Shale at 30 feet. See chemical analysis.
S	18.3	4-24-47	D,O	Water reported adequate, soft, and potable; shale at 30 feet.
S	.....	....	D	Water reported adequate, soft and potable. See chemical analysis.
...	.....	....	T	See log. Hole refilled.
S	24.41	10-31-46	D	
S?	25.14	10-31-46	D	
S	18	12-46	D	Shale at about 35 feet. See log and chemical analysis.
S	.....	....	D	Water reported adequate, potable and soft; shale at 32 feet.
S	.....	....	U	
...	.....	....	T	Shale at 26 feet; hole refilled, see log.
S	.....	....	T	Shale at 27 feet; hole refilled, see log.
S	25.40	10-31-46	U	
S	.....	....	I	Water reported adequate. See chemical analysis.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date completed
153-58 - Continued					
32ddb3	Marvin Kruger	70	6	Dr	1916
32ddc1	Otto Anunson	100	6	Dr	1919
32ddc2	Carl Hanson	102	5	Dr	1944
32ddc3	J. A. Lamb	100	5	Dr	1936
32ddc4	L. A. Haatvedt	10	24	Du	....
32ddc5	....do....	120	5	Dr	....
32ddc6	E. Lamb	104	5	Dr	1949
32ddc7	Michigan City supply 3	108	6	Dr	1950
32ddc8	J. Lamb	100	4	Dr	1922
32ddd1	Standard Service	50	5	Dr	.....
32ddd2	P. J. Hilman	110	6	Dr	1910
32ddd3	Curtis Wright	110	5	Dr	1914
32ddd4	J. W. Lamb and E. W. Ryall	98	5	Dr	1916
33acc	A. P. Brandberry	110	6	Dr	1936
33bcb1	E. G. Sommerfiled	100	6	...	....
33ccb1	P. Hall	90	5	Dr	1910
33ccb2	Great Northern test 3	120	6	Dr	1945
33ccc	Bessie Bogart	86	5	Dr	1916
33cdd	USGS test 33	36	5	Dr	1947
33dcc	USGS test 34	42	5	Dr	1947
33dcd	USGS test 35	42	5	Dr	1947
33ddd	USGS test 36	50	5	Dr	1947
34ccd	USGS test 37	40	5	Dr	1948
34cdc	USGS test 38	32	5	Dr	1947
34dba	Leo Danda	125	5	Dr	1947
34dcc	USGS test 39	52	5	Dr	1947

Aquifer	Depth to water (feet below land surface)	Date of measurement	Use of water	Remarks
S	.....	....	D	Water reported adequate, soft and potable, shale at 30 feet.
S	20.07	10-31-46	D	Do.
S	14.34	10-31-46	...	Water reported soft; shale at 30 feet.
S	23.04	10-31-46	D	Used to water lawn and garden.
S	4.46	10-31-46	U	
S	.....	....	D	Water reported soft, unpotable.
S	.....	....	D	Water reported soft, potable; shale at 40 feet.
S	.....	....	M	Water reported soft, potable; shale at 28 feet. See log.
S	.....	....	D	Water reported adequate, soft, potable.
S?	8.16	10-31-46	D,I	Water reported adequate. See chemical analysis.
S	10.38	10-31-46	D	Water reported soft and potable.
S	17.80	10-31-46	D	Water reported potable.
S	15	1916	D	Water reported adequate. soft and potable, See Chemical analysis.
S	20	1938	S	Water reported inadequate.
S	.....	....	D	Water reported just adequate, soft, slightly salty.
S	12.73	10-31-46	D,S	Water reported inadequate, potable. See chemical analysis.
S	.....	....	T	Shale at 28 feet; hole refilled, see log.
S	9.49	10-31-46	D	Water reported soft, and potable.
...	.....	....	T	See log. Hole refilled.
...	.....	....	T	See log. Hole refilled.
...	.....	....	T	Do.
...	.....	....	T	Do.
...	.....	....	T	Do.
...	.....	....	T	Do.
S	.....	....	S	Water reported adequate, soft; shale at 60 feet.
...	.....	....	T	See log. Hole refilled.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date completed
153-58 - Continued					
35ccd	USGS test 40	50	5	Dr	1947
35daa	F. Vilson Est.	99	6	Dr	1933
36ccc	USGS test 27	32	5	Dr	1947
153-59					
1b	Gronna Ins. Co.	14	4 ft. sq.	Du	1923
1bba	Albert Monson	68	6	Dr	1919
1cda	Ole Thorson Est.	100	6	Dr	1926
1da1	Olaf Thorson	40	18	B	1908
1da2	....do....	100	6	Dr	1923
2cab	J. P. Lamb Land Co.	40	6	Dr	1912
10ddc	J. Hancock Ins.	105	6	Dr	1920
11ac1	H. W. Paul	30	4 ft. sq.	Du	1900
11ac2	....do....	108	6	Dr	1914
12a	E. R. Barid, Rec.	11	4 ft. sq.	Du	1938
13bdd	John Thorson	104	6	Dr	1912
13cdb	Julius Johnson	112	6	Dr	1926
22ccd	Myrtle Beck	145	6	Dr	1920
23ccb	W. E. Zemman	110	...	Dr	1918
24dd	G. Wierwell	150	6	Dr	1930
25cdd1	Lamb Estate	110	6	Dr	1920
25cdd2	....do....	125	6	Dr	1918
25dad1	Chalmer Olson	90	6	Dr	1928
25dad2	....do....	15	4 ft. sq.	Du	1936
26bbc	Johnson Bros.	100	6	Dr	1917
26ccc	Joe Lamb Est.	160	6	Dr	1910
27bcc	John Lamb	74	...	Dr	1937
27cdd	U. C. Life Ins.	25	...	Du	1933
34bca1	Nelson County	110	6	Dr	1912
34bca2	E. Heller	90	5	Dr	1949
34bcd1	Leo Hoynes	112	6	Dr	1923
34bcd2	....do....	115	6	Dr	1926
34cba1	Bill Hoynes	87	6	Dr	1923

Aquifer	Depth to water (feet below land surface)	Date of measurement	Use of water	Remarks
...	.....	....	T	See Log. Hole refilled.
S?	30	1938	...	Water reported adequate.
...	.....	....	T	See log. Hole refilled.
D?	12½	1938	S	Water reported adequate.
S?	25	1938	D,S	Do.
S?	25	1938	D,S	Do.
D?	.....	....	...	Water reported inadequate.
S?	.....	....	D,S	Do.
S?	18	1938	D,S	Water reported adequate.
S?	95	1938	D,S	Water reported inadequate.
D?	28	1938	D,S	Do.
S?	30	1938	S	Do.
D?	8	1938	S	Water reported adequate.
S?	30	1938	D,S	Water reported surplus
S?	60	1938	...	Water reported adequate.
S?	.....	....	D,S	Do.
S?	25	1938	D,S	Water reported adequate.
S?	.....	....	D,S	Do.
S	.....	....	S	Water reported adequate, hard, unpotable for cattle; shale at 30 feet.
S	.....	....	S	Do.
S	20	1948	D,S	Water reported adequate, soft.
D?	13	1938	...	Water reported adequate.
S?	20	1938	D,S	Water reported surplus.
S?	.....	....	...	Water reported adequate.
S?	18	1938	D,S	Water reported adequate.
D?	.....	....	S	Water reported inadequate.
D?	.....	....	D,S	Water reported adequate.
S	15	1949	D	Water reported adequate, soft; shale at about 40 feet.
S?	.....	....	D,S	Water reported adequate, soft.
S	12	1926	U	Well abandoned; water reported adequate.
S?	.....	....	D	Water reported adequate,soft.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date completed
153-59 - Continued					
34cba2	Mapes Public School	105	5	Dr	1951
34cbb	Peter Bakke	150	6	Dr	1925
34ddd	USGS test 26	40	5	Dr	1948
35ddc	Ronnie	90	6	Dr	1932
36ccc	USGS test 27	32	5	Dr	1947
36dcc	USGS test 28	34	5	Dr	1947

Aquifer	Depth to water (feet below land surface	Date of measurement	Use of water	Remarks
S	.....	....	...	Water reported adequate; shale at 30 feet.
S?	.....	....	S	Water reported adequate.
...	.....	....	T	See log. Hole refilled.
S?	.....	....	...	Water reported adequate.
...	.....	....	T	See log. Hole refilled.
...	.....	....	T	Do.

LOGS OF WELLS AND TEST HOLES IN THE MICHIGAN CITY AREA, N. DAK.

151-58-4dca
USGS test 52

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, gray, silty and sandy	2	3
Sand and gravel, light-brown	2	5
Till, gray-brown	4	9
Till, gray	5	14
Sand, gray, medium to very coarse, and shale gravel, medium	7	21
Pierre shale, gray	4	25

151-58-5bab
USGS test 50

Material	Thickness (feet)	Depth (feet)
Till, light-brown	16	16
Till, gray	14	30
Sand and gravel, gray	6	36
Pierre shale, gray	4	40

151-58-5ddd
USGS test 51

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Silt, light-brown, sandy and clayey	14	15
Till, light-brown	20	35
Till, gray	6	41
Sand, gray, gravelly and clayey	6	47
Till, gray	5	52

151-58-6aaa
USGS test 19

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Till, light-brown	14	15
Sand	1	16
Till, gray	14	30
Sand, gray, fine to medium, silty	5	35
Till, gray	14	49
Pierre shale, gray	6	55

151-58-6daa
USGS test 20

Material	Thickness (feet)	Depth (feet)
Topsoil, black	2	2
Till, gray	2	4
Till, light-brown	10	14
Till, gray	19	33
Sand, gray, coarse, and shale gravel, fine, very silty and clayey	6	39
Till, gray	8	47
Shale sand, gray, medium to coarse, silty and clayey	2	49
Pierre shale, gray	11	60

151-58-7aaa
USGS test 21

Material	Thickness (feet)	Depth (feet)
Topsoil, black	2	2
Till, light-brown	9	11
Sand, light-brown, fine to medium, and shale gravel, silty	9	20
Till, gray	17	37
Sand, gray, medium to coarse, and some gravel, very clayey	11	48
Till, gray	60	108
Pierre shale, gray	7	115

151-58-7add
USGS test 22

Material	Thickness (feet)	Depth (feet)
Till, light-brown	4	4
Sand and gravel, light-brown	2	6
Till, light-brown	13	19
Sand, light-brown, medium, and gravel, fine, clayey	6	25
Gravel, fine to medium, and sand, very coarse	5	30
Till, gray	31	61
Pierre shale, gray	4	65

151-59-3ddc
USGS test 49

Material	Thickness (feet)	Depth (feet)
Till, light-brown, sandy, or sand, very gravelly and clayey	24	24
Sand and gravel, gray, mostly shale	9	33
Sand, gray, mostly shale	4	37
Sand and gravel, gray, mostly shale	15	52
Sand, gray, mostly shale	5	57

152-58-3bba
USGS test 41

Material	Thickness (feet)	Depth (feet)
Clay, gray, silty and sandy	1	1
Gravel, light-brown, medium, fairly free of clay	7	8
Shale gravel, gray, medium to coarse, clayey	14	22
Shale and limestone gravel, gray, very clayey	12	34
Till, gray	12	46
Shale gravel, gray, medium	2	48
Pierre shale, gray	2	50

152-58-5cbb
USGS test 6

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, light-brown, silty and sandy	3	4
Sand, gray, fine to very coarse, clayey and gravelly	23	27
Shale gravel, gray	13	40
Pierre shale, gray	2	42

152-58-5cbc
USGS test 7

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, light-brown, silty, sandy and gravelly	4	5
Sand, light-brown	2	7
Gravel, light-brown, sandy and silty	7	14
Shale sand, gray, medium to very coarse	20	34
Pierre shale, gray	2	36

152-58-5ccc
USGS test 8

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, light-brown, silty and sandy	5	6
Till, light-brown	6	12
Till, gray	18	30

152-58-6aba
USGS test 32

Material	Thickness (feet)	Depth (feet)
Clay, light-brown, gravelly	2	2
Gravel, light-brown, mostly shale, sandy and clayey	10	12
Till, gray, upper part gravelly	13	25

152-58-6cbb2
USGS test 42

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Till, gray	2	3
Till, light-brown	12	15
Till, gray	10	25
Sand and gravel, gray	3	28
Boulder	1	29
Pierre shale, gray	6	35

152-58-7aad
USGS test 9

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, light-brown, silty and sandy	5	6
Till, gray	6	12
Sand, gray, medium to coarse, and shale gravel, fine	16	28
Till, gray	2	30
Pierre shale, gray	2	32

152-58-7ddd
USGS test 10

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, light-brown, silty and sandy	2	3
Shale sand and gravel, light-brown	7	10
Sand, gray, very coarse, clayey, mostly shale	10	20
Gravel, gray, fine to medium, coarser material shale	7	27
Pierre shale, gray	19	46

152-58-18aad
USGS test 11

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, light-brown, sandy, silty, and gravelly	2	3
Sand, gray, medium to coarse, clayey and gravelly	12	15
Sand and gravel, light-brown, very clayey	5	20
Till, gray, sandy and gravelly	6	26
Pierre shale, gray	4	30

152-58-18daa
USGS test 12

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, gray, silty and sandy	2	3
Clay, light-brown, silty and sandy	1	4
Sand, gray-brown, medium, and shale gravel, silty	11	15
Gravel, medium to coarse, and sand, very coarse, free of clay	5	20
Till, gray	2	22
Pierre shale, gray	4	26

152-58-18dda
USGS test 13

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, light-brown, gravelly	1	2
Sand, light-brown, fine to coarse, clayey	8	10
Sand, gray, very fine to coarse, and gravel, fine, silty and clayey	16	26
Pierre shale, gray	4	30

152-58-19daa
USGS test 14

Material	Thickness (feet)	Depth (feet)
Topsoil, black	2	2
Clay, light-brown, silty and sandy	7	9
Sand and gravel, light-brown	1	10
Till, gray	21	31
Pierre shale, gray	5	36

152-58-28add
USGS test 55

Material	Thickness (feet)	Depth (feet)
Topsoil, black	2	2
Till, light-brown	7	9
Till, gray	9	18
Sand and gravel, gray	7	25
Pierre shale, gray	5	30

152-58-29ccc
USGS test 17

Material	Thickness (feet)	Depth (feet)
Topsoil, black	2	2
Clay, gray, silty and sandy	4	6
Sand, light-brown, very gravelly and clayey	3	9
Sand, gray, very fine to very coarse, and gravel, fine, clayey	11	20
Till, gray	14	34
Pierre shale, gray	11	45

152-58-30aaa
USGS test 15

Material	Thickness (feet)	Depth (feet)
Topsoil, black	2	2
Clay, brown-gray, silty and sandy	7	9
Sand, light-brown, fine to very coarse, and gravel, fine to medium	11	20
Till, gray	4	24
Pierre shale, gray	6	30

152-58-30ada
USGS test 16

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, light-brown, silty and sandy	8	9
Sand, gray, clayey and gravelly	19	28
Pierre shale, gray	7	35

152-58-31add
USGS test 18

Topsoil, black	1	1
Till, light-brown	15	16
Sand and gravel, light-tan	1	17
Till, gray	11	28
Sand and gravel	3	31
Till, gray	13	44
Pierre shale, gray	6	50

152-58-33abb
USGS test 54

Topsoil, black	2	2
Clay, light-brown, sandy and gravelly	2	4
Sand, light-brown, very fine to very coarse, and some gravel, very clayey	13	17
Pierre shale, gray	3	20

152-58-33cad
USGS test 53

Topsoil, black	2	2
Till, gray	3	5
Till, light-brown	11	16
Till, gray	3	19
Sand, gray, very fine to coarse, clayey	13	32
Till, gray	87	119
Sand, very coarse, and gravel, fine to very coarse	7	126
Till, gray	9	135
Pierre shale, gray	5	140

152-59-9dcd
USGS test 43

Material	Thickness (feet)	Depth (feet)
Sand, light-brown, gravelly and clayey	17	17
Sand, gray, very gravelly and clayey	20	37
Gravel, gray, shale, sandy and clayey	10	47
Till, gray	3	50
Pierre shale, gray	5	55

152-59-9ddd
USGS test 44

Material	Thickness (feet)	Depth (feet)
Topsoil, black	4	4
Sand, light-brown, fine to coarse, very gravelly and clayey	8	12
Gravel, gray, very sandy and clayey	15	27
Till, gray	13	40

152-59-10ccd
USGS test 45

Material	Thickness (feet)	Depth (feet)
Topsoil, black	2	2
Sand, light-brown, clayey	5	7
Sand, light-brown, and gravel, some shale, very clayey	10	17
Shale gravel, gray, and sand, very clayey; upper and lower contacts transitional	25	42
Till, gray, gravelly	15	57
Till, gray	35	92

152-59-10ddd
USGS test 46

Material	Thickness (feet)	Depth (feet)
Till, light-brown	12	12
Till, gray, sandy	10	22
Till, gray	32	54
Pierre shale, gray	1	55

152-59-15ddd
USGS test 47

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Till, light-brown	10	11
Sand, light-brown, fine to coarse, gravelly and sandy	10	21
Sand, gray, fine to coarse, and gravel, fine, free of clay	28	49
Pierre shale, gray	2	51

152-59-21ddd
USGS test 48

Till, light-brown	13	13
Till, gray	9	22
Gravel, gray, sandy and very clayey	13	35
Pierre shale, gray	2	37

152-59-24abc
H. Greenlee

Yellow clay (till)	15	15
Blue clay (till)	16	31
Gravel	4	35
Shale	79	114

153-58-4ccc
USGS test 2

Topsoil, black	1	1
Till, light-gray	3	4
Till, light-brown	8	12
Till, gray	18	30
Pierre shale, gray	2	32

153-58-5aaa
USGS test 1

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Sand, light-brown, very fine to very coarse, and gravel, medium	6	7
Till, gray	17	24
Pierre shale, gray	6	30

153-58-8ddd
USGS test 3

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, light-brown, silty	3	4
Till, light-brown	11	15
Till, gray	7	22
Pierre shale, gray	8	30

153-58-17ddd
USGS test 4

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, light-brown, silty	4	5
Till, light-brown	11	16
Sand and gravel, gray	1	17
Till, gray	4	21
Sand and gravel, gray	3	24
Till,gray	7	31
Pierre shale, gray	8	39

153-58-20ddd
USGS test 5

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Till, light-brown	13	14
Till, gray	28	42
Pierre shale, gray	78	120

153-58-29ccd
USGS test 24

Material	Thickness (feet)	Depth (feet)
Till, light-brown	10	10
Till, gray	17	27

153-58-29ddc
USGS test 23

Material	Thickness (feet)	Depth (feet)
Sand, light-brown, and gravel, medium, well-sorted and free of clay	7	7
Shale gravel, light-brown, very sandy and clayey	15	22

153-58-31ccd
USGS test 29

Material	Thickness (feet)	Depth (feet)
Clay, gray-brown, silty and sandy	3	3
Sand, light-brown	4	7
Sand, gray, fine to medium, and shale gravel, fine, slightly clayey	13	20
Shale gravel, gray, coarse, some limestone, sandy	8	28

153-58-32bba
USGS test 25

Material	Thickness (feet)	Depth (feet)
Sand, light-brown, and gravel, medium, clayey	7	7
Sand, light-brown, coarse, and some shale gravel, fine	10	17
Gravel, gray, medium, and some sand, clayey	12	29
Pierre shale, gray	3	32

153-58-32ccd1
USGS test 30

Material	Thickness (feet)	Depth (feet)
Sand, light-brown	5	5
Gravel, light-brown, some shale, fairly free of clay	4	9
Shale gravel, gray, fine to coarse, very clayey	24	33
Pierre shale, gray	3	36

153-58-32ccd2
Michigan City test 3

Material	Thickness (feet)	Depth (feet)
Yellow clay with sand and gravel (till?)	17	17
Sand and gravel, clayey (till?)	7	24
Blue clay, sticky, mixed with shale gravel (gravelly till?)	6	30

153-58-32dac6
Michigan City supply 2

Material	Thickness (feet)	Depth (feet)
Yellow clay (till)	10	10
Blue clay (till)	22	32
Shale	72	104

153-58-32dba3
Michigan City supply 1

Material	Thickness (feet)	Depth (feet)
Yellow clay (till)	10	10
Blue clay (till)	20	30
Shale	78	108

153-58-32dbc2
Michigan City test 1*

Material	Thickness (feet)	Depth (feet)
Till, light-brown	29	29
Till, gray	1	30
Pierre shale, gray	85	115

153-58-32dcc2
USGS test 31

Material	Thickness (feet)	Depth (feet)
Sand, light-brown, medium	7	7
Gravel, gray, fine to medium, and sand	25	32
Pierre shale, gray	5	37

* Samples examined by USGS personnel.

153-58-32dcd3
Carl Dahl*

Material	Thickness (feet)	Depth (feet)
Till, light-brown, with layers of silty sand and gravel	20	20
Till, gray	8	28
Gravel, medium to coarse	1	29
Gradational contact between till and shale	6	35
Pierre shale, gray	65	100

153-58-32dda1
Great Northern test 1

Material	Thickness (feet)	Depth (feet)
Sand and clay (till)	24	24
Dirty sand with water	2	26
Shale	44	70
Shale with water	5	75
Shale	35	110

153-58-32dda2
Great Northern test 2

Material	Thickness (feet)	Depth (feet)
Sand and clay (till)	25	25
Sand with surface water	2	27
Shale	45	72
Loose shale with water	6	78
Shale	37	115

153-58-32ddc7
Michigan City supply 3

Material	Thickness (feet)	Depth (feet)
Soil	3	3
Yellow clay and some sand and gravel (till)	12	15
Blue clay, till	11	26
Sand and gravel	2	28
Shale	80	108

*Samples examined by USGS personnel.

153-58-33ccb2
Great Northern test 3

Material	Thickness (feet)	Depth (feet)
Sand and clay (till)	25	25
Sand with surface water	3	28
Shale	35	63
Shale with a little water	1	64
Shale	12	76
Loose shale with water	4	80
Shale	30	110
Gray shale	10	120

153-58-33cdd
USGS test 33

Topsoil, black	2	2
Till, light-brown	14	16
Till, gray	18	34
Shale, gray	2	36

153-58-33dcc
USGS test 34

Topsoil, black	1	1
Clay, light-brown, silty and sandy	3	4
Till, light-brown	8	12
Till, gray	28	40
Pierre shale, gray	2	42

153-58-33dcd
USGS test 35

Topsoil, black	2	2
Till, light-brown	14	16
Till, gray	11	27
Sand, gray, coarse, and shale gravel, fine	7	34
Till, gray	6	40
Pierre shale, gray	2	42

153-58-33ddd
USGS test 36

Material	Thickness (feet)	Depth (feet)
Clay, light-brown	5	5
Till, light-brown	16	21
Till, gray	8	29
Shale gravel, medium, clayey	3	32
Till, gray	17	49
Pierre shale, gray	1	50

153-58-34ccd
USGS test 37

Material	Thickness (feet)	Depth (feet)
Clay, light-brown, silty and sandy	5	5
Sand, light-brown, very fine to very coarse, clayey	10	15
Shale sand, gray, very coarse, clayey	23	38
Pierre shale, gray	2	40

153-58-34cdc
USGS test 38

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, light-brown, silty and sandy	5	6
Till, gray	24	30
Pierre shale, gray	2	32

153-58-34dcc
USGS test 39

Material	Thickness (feet)	Depth (feet)
Clay, light-brown, silty and sandy	9	9
Till, light-brown	8	17
Sand, gray, coarse, and gravel, fine, very clayey.	13	30
Till, gray	15	45
Pierre shale, gray	7	52

153-58-35ccd
USGS test 40

Material	Thickness (feet)	Depth (feet)
Till, light-brown	17	17
Till, light-gray	5	22
Shale gravel, gray, clayey	22	44
Till, gray	5	49
Pierre shale, gray	1	50

153-59-34ddd
USGS test 26

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Till, light-brown	15	16
Till, gray	22	38
Pierre shale, gray	2	40

153-59-36ccc
USGS test 27

Material	Thickness (feet)	Depth (feet)
Clay, light-brown, silty and sandy	2	2
Sand, light-brown, medium, clayey	6	8
Sand, light-brown, medium to coarse, some shale, clayey	15	23
Gravel, gray, fine to coarse, some shale	9	32

153-59-36dcc
USGS test 28

Material	Thickness (feet)	Depth (feet)
Clay, light-brown, silty and sandy	2	2
Gravel, light-brown, medium, slightly clayey	10	12
Gravel, gray, fine to coarse, clayey	15	27
Gravel, coarse	5	32
Pierre shale, gray	2	34

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