GROUND-WATER SURVEY OF THE MAKOTI AREA

WARD COUNTY, NORTH DAKOTA

SWC PROJECT NO.1470

NORTH DAKOTA GROUND-WATER STUDIES

NO. 72

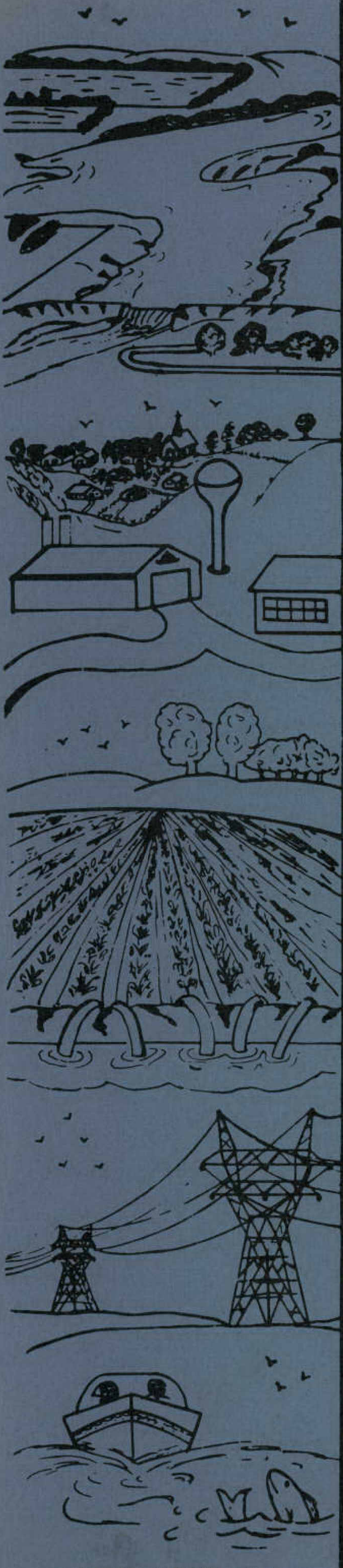
By

Charles E. Naplin
Ground-Water Geologist

Published By

North Dakota State Water Commission
State Office Building
900 Boulevard
Bismarck, North Dakota 58501

- 1968 -



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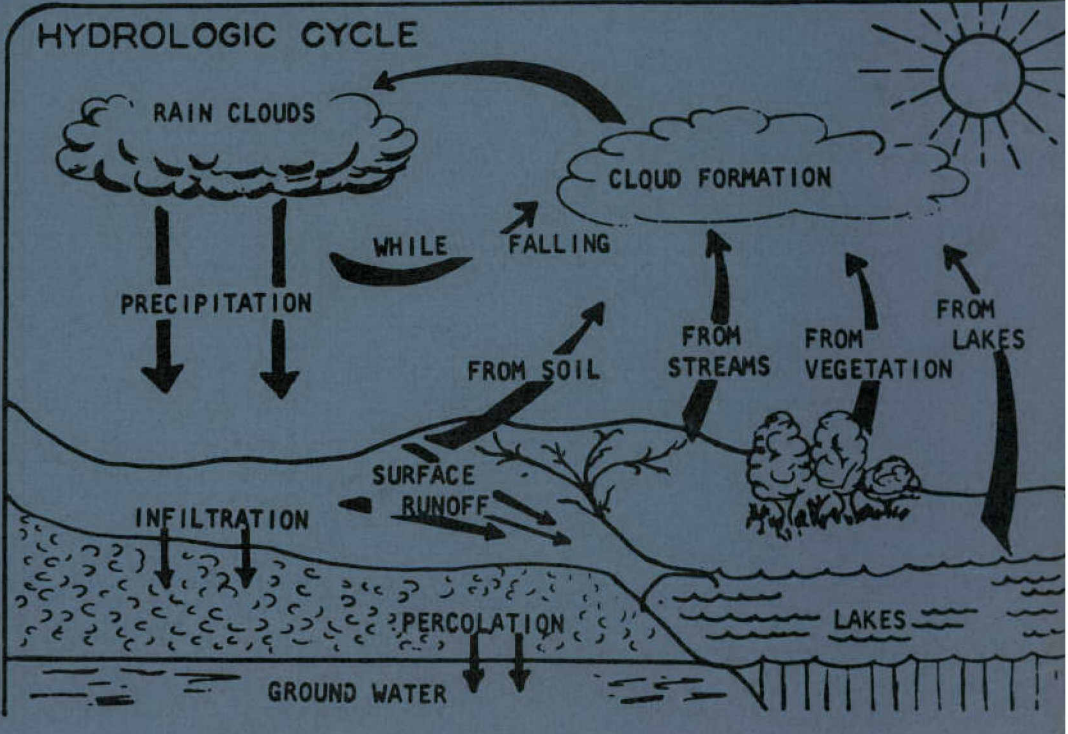

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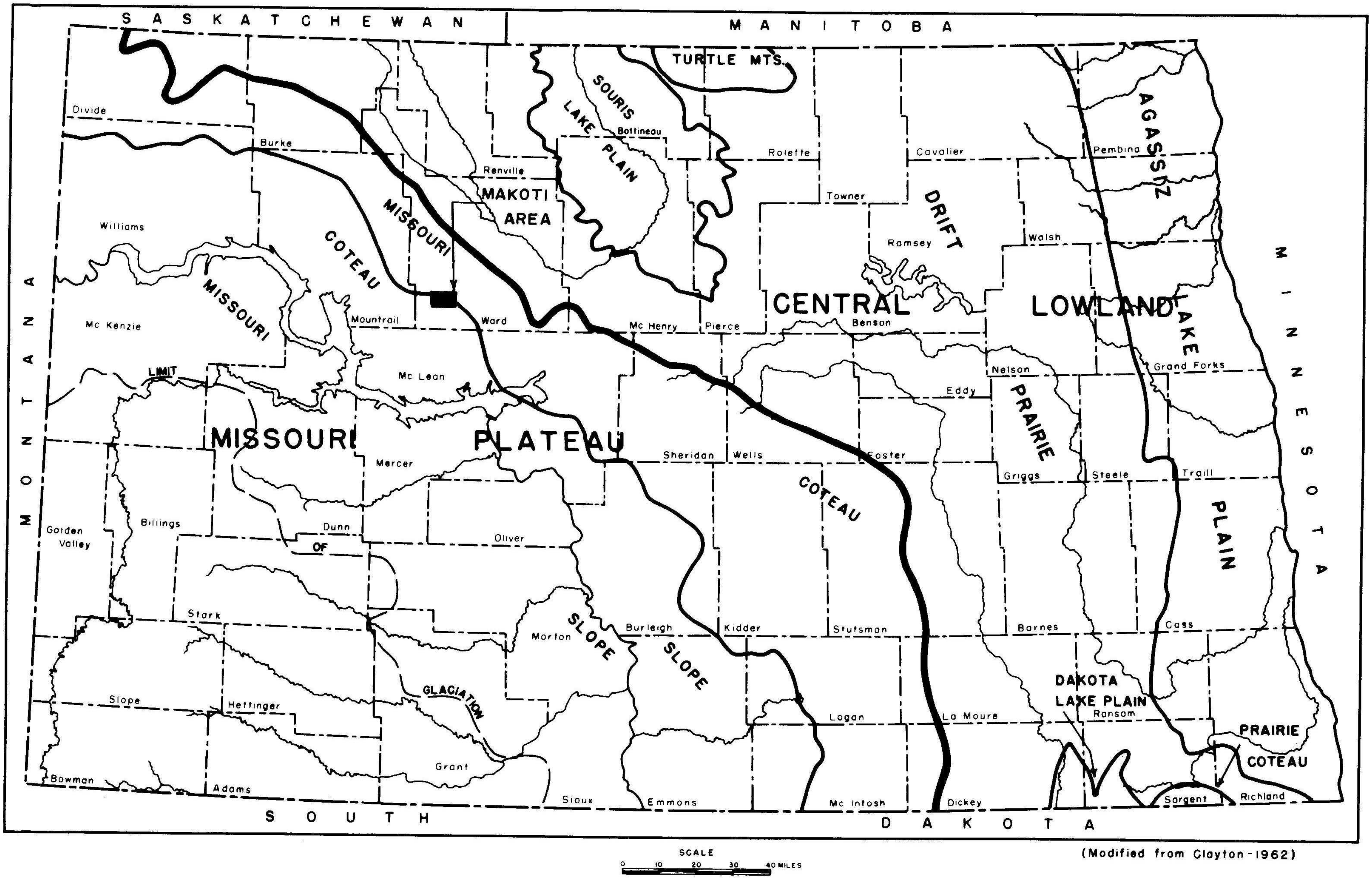
INTRODUCTION

PURPOSE AND SCOPE

On June 6, 1967 the Village Board of Makoti passed a resolution requesting the North Dakota State Water Commission to conduct a ground-water survey for the city. The necessary financial requirements were fulfilled in July, 1967, and the investigation was conducted in the latter part of September of the same year.

The survey consisted of test drilling, installation of observation wells, a partial well inventory, a pumping test, the chemical analyses of selected water samples, and preparation of this report. Twenty-seven test holes were drilled with the State-owned hydraulic rotary drilling machine to determine the presence and characteristics of subsurface strata. Supplemental information acquired from aerial photographs, highway maps, geologic reports, and an altimeter survey of the area was used in addition to data obtained from subsurface exploration in compilation of this report.

Test drilling and associated field work was under direct supervision of the author. Test drilling was done by Lewis Knutson and Hugh Jacobson. Chemical analyses were performed by Donald Delzer and Garvin Muri, State Water Commission Chemists at the North Dakota State Laboratories in Bismarck. An altimeter survey of selected observation well locations was conducted by David Donaldson, Ground-Water Technician, and the author. Special acknowledgement is extended to Mr. Loren Quandt, Village Clerk, for his information regarding present municipal water facilities.



(Modified from Clayton - 1962)

FIGURE I--PHYSIOGRAPHIC PROVINCES OF NORTH DAKOTA AND LOCATION OF MAKOTI AREA

LOCATION AND GENERAL FEATURES

The Makoti area, as described in this report, consists of 28 square miles in a portion of Township 152 North, Ranges 86 and 87 West in southwestern Ward County. The area is situated within the Missouri Coteau and Coteau Slope divisions of the Missouri Plateau Physiographic Province of North Dakota as shown in Figure 1. Surface elevations range from approximately 2,114 feet above mean sea level in the NW$\frac{1}{4}$ of Section 13, Township 152 North, Range 87 West to approximately 2,045 feet above mean sea level at observation well 2,825 in the SE$\frac{1}{4}$ of Section 9, Township 152 North, Range 87 West. Topographic relief increases towards the northeastern portion of the area due to the presence of the Missouri Coteau.

Because no rivers or streams have developed in the area the predominant drainage pattern is non-integrated. Runoff of annual precipitation generally follows poorly developed channels and collects in numerous sloughs and marshes.

Makoti, population 214 in 1960, is an agricultural community. The village, located one mile south of North Dakota Highway 23 (in the NW$\frac{1}{4}$ of Section 27, Township 152 North, Range 87 West) is served by the Soo Line Railroad. At present (1968) Makoti does not have a municipal water system. However, the village does have a network of sewer mains and a waste disposal facility which is located approximately 1/4 mile east of the village. Water for the sewerage system is provided in small quantities from numerous shallow private wells. Water for drinking and culinary purposes is purchased from local farm residents and stored in cisterns.

Climatological data based on a 35-year period of record at the U. S. Weather Bureau Station in Parshall, North Dakota, shows the average annual precipitation to be 14.69 inches. The average annual temperature for the same station in 1965 was 37.5°F. (U. S. Department of Commerce, 1966).

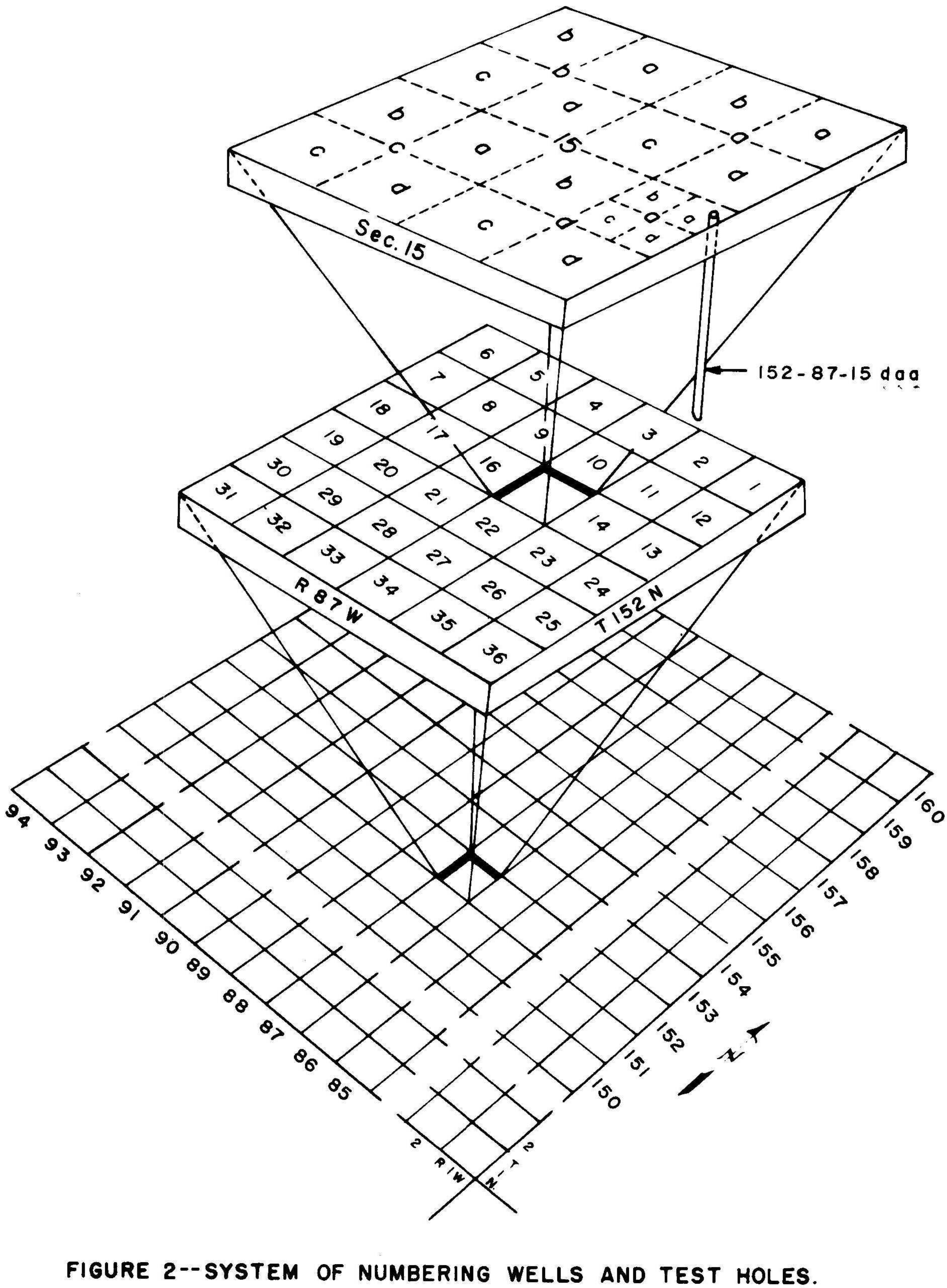


FIGURE 2--SYSTEM OF NUMBERING WELLS AND TEST HOLES.

PREVIOUS INVESTIGATIONS

A general study of the Ward County geology and ground-water resources was made by Simpson (1929, pp. 250-262, 304-305) in which he discusses the water-bearing strata and areas of artesian flow in the county. Simpson also lists a well inventory of selected municipal and farm wells and the chemical analyses of a few water samples.

In late 1963, a study of the geology and ground-water resources of Ward County was initiated. The investigation was a cooperative program between the U. S. Geological Survey, the North Dakota State Water Commission, the North Dakota Geological Survey, and the Ward County Water Management District. Information acquired during the course of this study will soon be available in a published report.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report is based upon the location of the well in the Federal system of rectangular surveys of public lands. The first number denotes the township north of the base line which passes laterally through the middle of Arkansas; the second number denotes the range west of the fifth principal meridian; the third number denotes the section in which the well is located. The letters a, b, c and d designate respectively the northeast, northwest, southwest and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). Consecutive terminal numerals are added if more than one well is located in a 10-acre tract. Thus, well 152-87-15daa is in the NE$\frac{1}{4}$ NE$\frac{1}{4}$ SE$\frac{1}{4}$ Section 15, Township 152 North, Range 87 West (Figure 2).

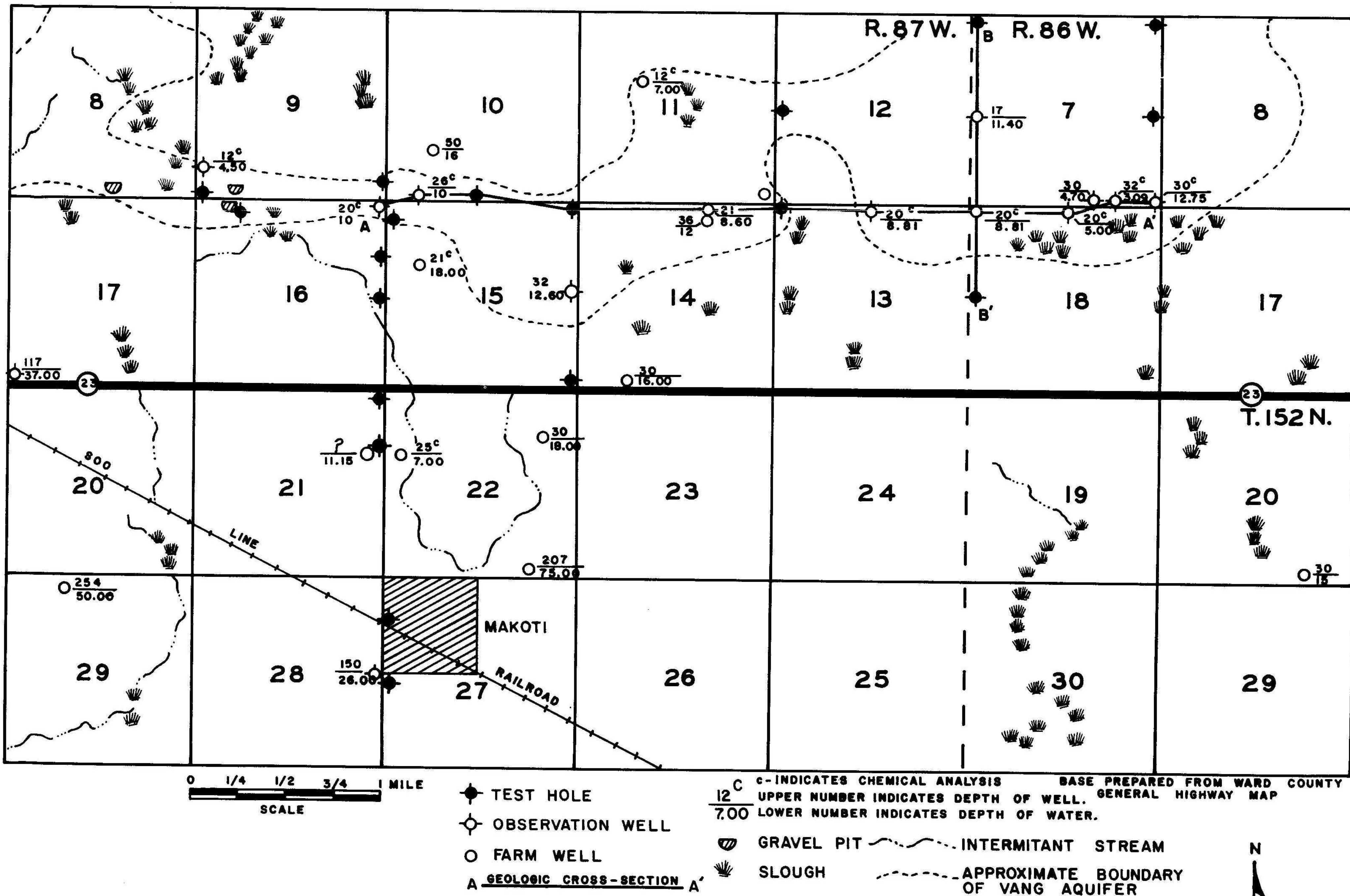


FIGURE 3--LOCATION OF WELLS, TEST HOLES, GEOLOGIC SECTIONS AND RELATED FEATURES IN THE MAKOTI AREA.

GEOLOGY AND OCCURRENCE OF GROUND WATER

GLACIAL GEOLOGY

Widespread glaciation is known to have taken place over much of the North American Continent during the Pleistocene Epoch. This Epoch in geologic time occurred approximately 1,000,000 years to less than 10,000 years ago. Four major glacial stages, from oldest to youngest: Nebraskan, Kansan, Illinoian, and Wisconsin, took place during the Pleistocene time interval. Glaciers, in the form of large continental ice sheets, advanced southward from Canada into Central North America. Glacial debris - clay, silt, sand, pebbles, cobbles and boulders - broken loose and transported within the slowly moving ice was deposited as drift during periods when moderating temperatures forced the retreat of glaciers. Glacial drift in the Makoti area was deposited during the Wisconsin period of glaciation.

The Missouri Coteau district which transverses Ward County from northwest to southeast (Figure 1) is an undulating plateau with numerous sloughs and swampy depressions. The Coteau du Missouri is essentially a bedrock "high" mantled with glacial drift that may exceed 300 feet in thickness (Pettyjohn, 1967). The drift cover on the Coteau is a combination of several types of glacial deposits. A large portion of the Coteau has been referred to as the "Altamont Moraine", "Terminal Moraine", and "Max Moraine". However, the recent ground-water study of Ward County has revealed that glacial deposits encountered in this area do not represent a single end moraine but probably several end or recessional moraines, some ground moraine, and a considerable amount of dead-ice moraine (Pettyjohn, 1967). Exposed drift cover in the Makoti area is mostly of ground moraine origin with some deeply collapsed, dead-ice morainal topography in the northeast and northwest portions of the area described in this report.

Till and Associated Sand and Gravel Deposits:

The glacial drift which mantles the Makoti area is predominantly composed of till. Till is defined as an unconsolidated, unstratified, heterogeneous mixture of clay, silt, sand, gravel, cobbles and boulders. These materials were deposited directly by melting ice with little or no transportation by water. Till, or "blue clay" as it is frequently referred to, is olive gray in color when encountered below the water table. Oxidized till, or "yellow clay" occurs above the water in the zone of oxidation where the slow infiltration of ground water has produced leaching and consequent weathering. Till is not a good source of ground water because of its lithologic composition. Clay and silt, the two predominant constituents of till, are extremely fine-grained, relatively impermeable, and will not readily yield water to wells.

Eight test holes completely penetrated the drift in the Makoti area. Thicknesses of drift encountered range from 36 feet in test hole 2826 (152-87-16bba) to 213 feet in test hole 3196 (152-87-27cbb) with an average thickness of 106 feet. Drill cuttings indicated a buried zone of yellowish brown, oxidized till in 21 of 32 test holes. The oxidized zone of till varies in depth and thickness. Test hole 2826 (152-87-16bba) penetrated 15 feet of oxidized till from 21 feet to 36 feet below land surface. Test hole 3196 (152-87-27cbb) penetrated 178 feet of oxidized till from 35 feet to 213 feet below land surface.

Pettyjohn (1967) states that there are two drift sheets present in the Makoti area. The Blue Mountain drift sheet is the oldest glacial deposit. The Blue Mountain drift has not been dated and indications are that organic materials in the till may be too old for radiocarbon dating methods. A younger drift sheet, the Makoti drift sheet, overlies Blue Mountain drift in the area described in this report and is exposed along road ditches.

Samples of wood, white spruce cones, and grass from till of Makoti age were dated by radiocarbon methods. Estimates of age are 10,330 ± 300 years B.P. (before present) to 10,350 ± 300 years B.P. These dates indicate that the Makoti drift sheet was deposited during the latter part of the Wisconsin stage of Pleistocene glaciation.

Test hole data, which indicated the presence of a buried oxidation zone, supports all previous information pertaining to the older oxidized Blue Mountain drift which underlies the younger Makoti drift sheet. Lithologically, the Makoti till and Blue Mountain till are similar, except for a greater percentage of lignite chips in the latter.

Sand and gravel are frequently associated with till. Data from several test hole logs indicated the presence of numerous thin stratified lenticular deposits of sand and gravel in the till. Figures 4 and 5 show some of the test holes where these deposits of sand and gravel were encountered. These deposits may provide water for farm wells, but would not yield sufficient quantities of water for a municipality, due to their limited areal extent and complete dependence upon infiltration of ground water through the surrounding till for recharge.

Alluvial and Outwash Deposits:

Alluvial and outwash materials consist of sand and/or gravel which has been deposited by meltwater streams emerging from the receeding ice front. In the Makoti area there are two major deposits of this depositional origin.

The Vang aquifer, situated north of Makoti, is a collapsed outwash deposit that partly fills a topographic sag. Fine-grained to coarse-grained gravelly sand ranging in thickness from 2 feet in test hole 2852 (152-86-7bbb) to 36 feet in test hole 2853 (152-86-7ddd) was encountered. The aquifer possesses good permeability and its surficial stratigraphic position permits rapid periodic recharge from the infiltration and percolation of precipitation. The aquifer occupies an area of approximately 5½ square miles in Orlien Township and extends northeastward into Anna, Linton, and Vang Townships (Pettyjohn, written communication).

Hiddenwood Lake aquifer, a buried alluvial deposit of fine-grained to coarse-grained sand and fine to medium gravel, extends northward from McLean County into Ward County. The deposit arcs northwest from the Village of Makoti and underlies portions of Township 152 North, Range 87 West in Sections 20, 21, 27 and 28. Materials common to Hiddenwood Lake aquifer are permeable, but the poor quality of ground water contained therein forestalls development of the aquifer as a favorable source of water for either domestic or municipal use.

BEDROCK GEOLOGY

The Makoti area is situated within the east central portion of the Williston Basin, a structural basin containing a thick sequence of sedimentary rocks. The stratigraphic column in this portion of North Dakota contains strata representing all systems of geologic time with exception of the Permian and Pennsylvanian Systems. Oil well test hole data indicates that thicknesses of stratified sedimentary rocks range from slightly less than 9,000 feet to greater than 11,000 feet in Ward County. (North Dakota Geological Survey Oil Test Circulars #68 and #110)

The Tongue River Formation of Lower Tertiary age stratigraphically underlies the glacial drift. Eight test holes penetrated the Formation to depths ranging from 4 feet in test hole 2826 (152-87-16bba) to 26 feet in test hole 3318 (152-87-16aaa). Drill cuttings of the Tongue River Formation indicated that its composition varies from medium olive gray, non-calcareous shale to clayey, light bluish gray, non-calcareous sandstone. Evidence of a thin zone of oxidization in the upper few feet of the Formation was observed in three test holes. As much as 10 feet of the upper Tongue River Formation is oxidized in outcrops in southwestern Ward County. In the Makoti area the maximum oxidized thickness penetrated was 7 feet in test hole 3318 (152-87-16aaa).

HYDROLOGIC CONCEPTS

Subsurface explorations have revealed that almost all continental areas are underlain at varying depths with porous materials saturated with water. Any formation of porous sedimentary rock or stratified deposit of sand and gravel that will yield water to wells in sufficient quantity to be of importance as a source of supply is called an "aquifer".

Characteristics of Aquifers:

There are two fundamental types of aquifers, artesian and water-table. Materials composing these two aquifer types may be lithologically similar, but differences in stratigraphic position, fluid pressure, water-yielding capabilities and conditions for recharge and discharge are dissimilar.

Artesian aquifers are permeable formations or deposits in which the water is confined by impermeable strata. Water occupying pore spaces between grains in aquifers of this type is said to be under "artesian" conditions because the water in a well tapping the aquifer rises above the top of the formation or deposit. The confined volume of materials saturated with ground water is subject to hydrostatic pressure. Withdrawal of ground water from an artesian aquifer by the pumping of a well will lower the water well level, but the aquifer will remain saturated if ideal artesians conditions exist. Preservation of total saturated thickness in artesian aquifers depends upon the volume of water removed by pumping wells, the rate of recharge, the amount of fluid expansion that occurs as hydrostatic pressure is removed, and the permeability of composite materials.

If the water in an aquifer is not confined by impermeable strata, the water is considered to occur under water-table conditions. Water held in storage may be removed from a water-table aquifer by lowering the water level, as in the vicinity of a well being pumped, which results in gravity drainage. The quantity of water stored is dependent upon material porosity and the volume of the aquifer. The "specific yield" is the volume of water that will drain by gravity from a unit volume of saturated aquifer thickness. However, the saturated thickness of water-table aquifers is dependent upon the water-table level which reflects seasonal changes in precipitation.

Recharge and Discharge:

Recharge, water entering an aquifer, occurs when water infiltrates porous materials either by direct absorption of precipitation at the surface of an aquifer or by percolation from streams, lakes and ponds. Recharge also occurs to a limited extent through relatively impermeable clay and silt overlying sand and gravel deposits, but the rate of recharge is slow.

Discharge, water leaving an aquifer, occurs when ground water is removed from porous materials by surface evaporation from soils, lakes, ponds, sloughs, as transpiration from vegetation, by seepage to streams, or by springs. Discharge may also be through pumping wells, although some of the water removed from an aquifer for domestic, stock and irrigation purposes eventually returns to the aquifer in form of recharge.

The Vang Aquifer:

The Vang aquifer, a surficial collapsed outwash deposit covering portions of Vang, Linton, Anna and Orlien Townships, ranges from about 350 yards to slightly more than 2 miles in width (Pettyjohn, written communication). Test hole data indicated that the aquifer ranges from slightly less than 1/4 mile to 1 1/4 miles in width and possesses an areal extent of approximately 5 1/2 square miles in Orlien Township.

The outwash material is predominantly a fine to coarse-grained gravelly sand. Generally, the sand is subangular to subrounded, moderately well sorted and slightly oxidized to oxidized above the water-table.

Test hole and altimeter data acquired during the course of this investigation indicate that the water-level gradient is toward the southwest. However, elevations of the water-table in the vicinity of test hole 2856 (152-86-7ddc) indicate that the water-table gradient is southeast toward a low marshy area in portions of Sections 17 and 18, Township 152 North, Range 86 West. Observation wells in the vicinity of test hole 2856 constitute the control points used in the determination of the water-table gradient in this area (Figure 4).

TABLE 1 -- WATER LEVELS IN THE VANG AQUIFER

WATER LEVELS ARE REFERRED TO LAND SURFACE DATUM

Obs. Well Number	Location	Water Level 2/68	Water Level 9/67	Difference in Water Levels + = Rise - = Decline
2851	152-86-7cbb	11.90	11.40	- 0.50
2856	152-86-7ddc	3.87	3.09	- 0.78
2853	152-86-7ddd	13.55	12.75	- 0.80
2830	152-86-18abb	5.00	5.00	0.00
2829	152-86-18bbb	9.20	8.81	- 0.39
2821	152-87-10cdc	9.58	10.00	+ 0.42
2849	152-87-13abb	8.30	7.80	- 0.50
2818	152-87-15add	13.70	12.60	- 0.70
3318	152-87-16aaa	9.00	9.80	+ 0.80

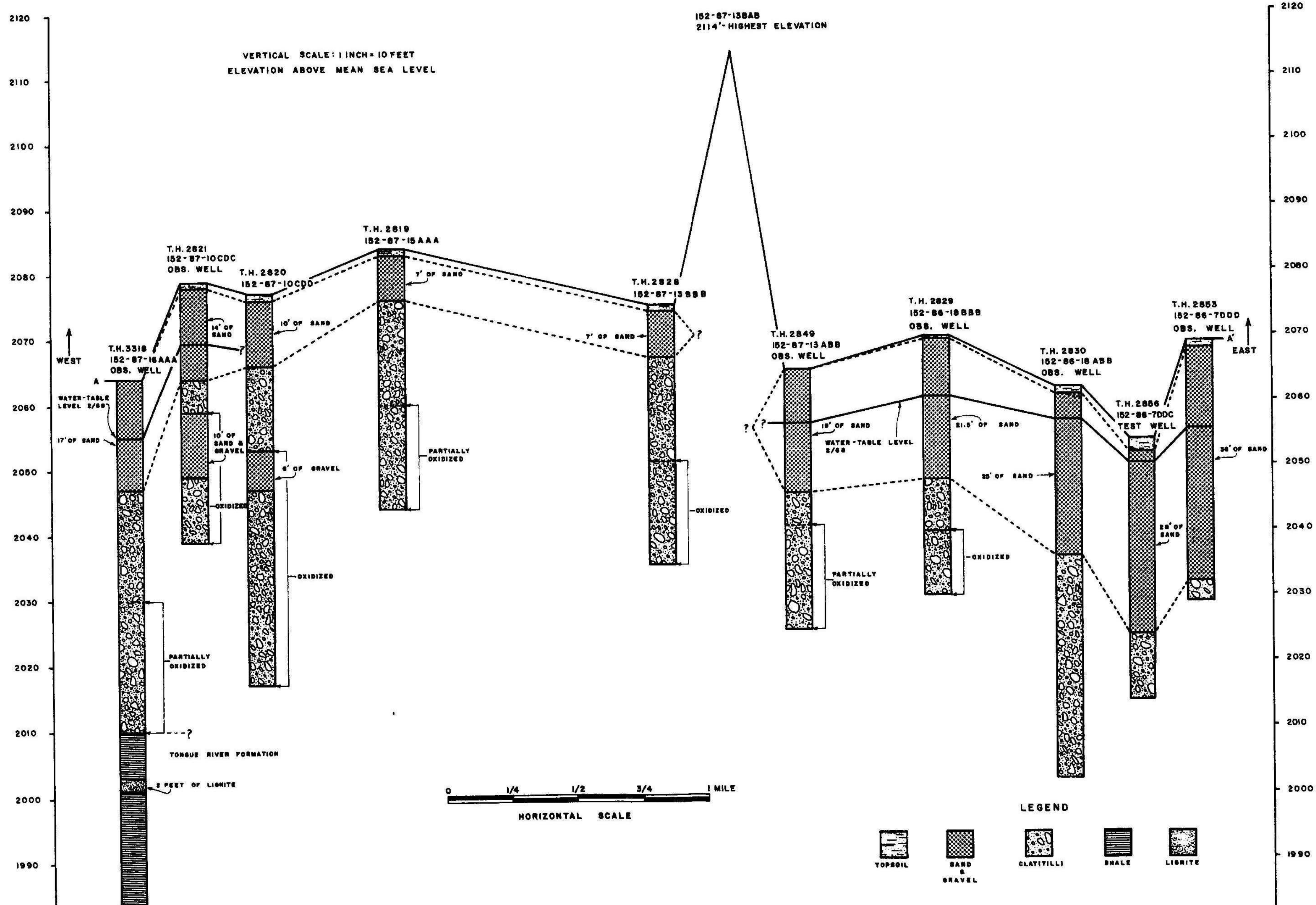


FIGURE 4 --GEOLOGIC CROSS-SECTION A-A' IN THE MAKOTI AREA

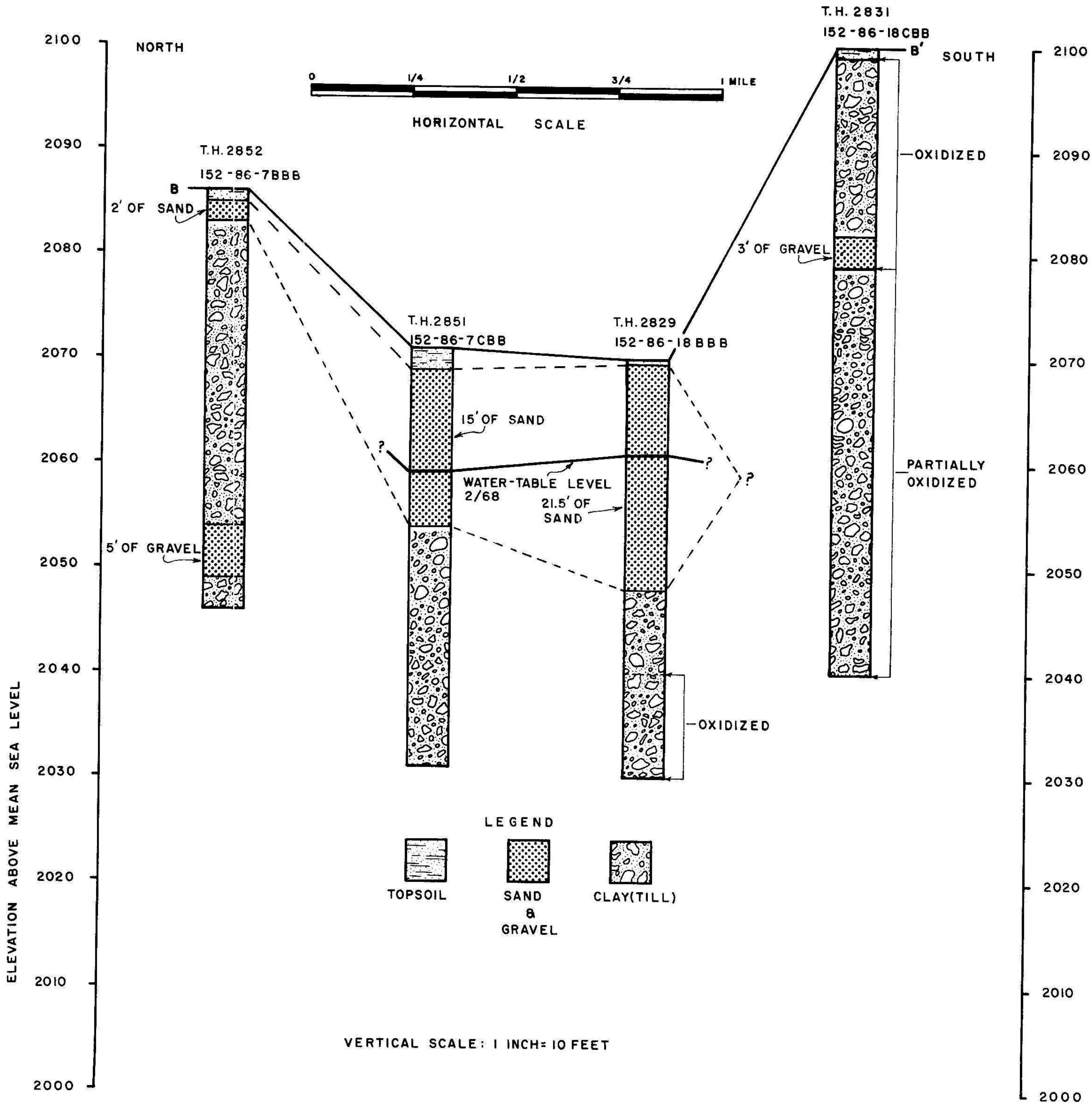


FIGURE 5 --GEOLOGIC CROSS-SECTION B-B' IN THE MAKOTI AREA

Water-level measurements of observation wells in the Vang aquifer indicate a general decline from September, 1967 to February, 1968 (Table 1). It is not uncommon for the water level in a water-table aquifer to decline during periods of limited recharge, especially in the winter months when infiltration and percolation of ground water is minimal. Below average precipitation during the warmer months of 1967 apparently had little effect on water levels common to the Vang aquifer. However, a prolonged period of drought would probably have an adverse effect on water levels because recharge to the aquifer is primarily dependent upon precipitation and local runoff.

During the investigation a test well (Test Hole 2856, 152-86-7ddc) was completed with 32 feet of 4-inch diameter plastic casing with the bottom 8 feet slotted. The well was pumped at 60 gpm (gallons per minute) for 3 hours and 10 minutes. The water level in the pumped well declined from 3.09 feet below land surface to about 22.00 feet below land surface during the pumping period. The test well had some installation shortcomings in that no screen was used and it was probably not properly developed. Drawdown recorded at two observation wells, test hole 2853 (152-86-7ddd) 712 feet east of the test well and test hole 2857 (152-86-7ddc) 200 feet west of the test well was 1.45 feet and 0.60 feet respectively.

Outwash materials composing the Vang aquifer in the vicinity of Makoti appear quite permeable. The thickness of outwash is quite variable, but the deposit appears to be continuous (Figure 6). Elevations determined during the altimeter survey and water level measurements indicate that all areas of the outwash may not contain intervals of sand saturated with water, even though sand is present.

WATER QUALITY

Ground water is derived from rainfall and snowmelt. The mineral content of ground water, often referred to in chemical terminology as total dissolved solids,

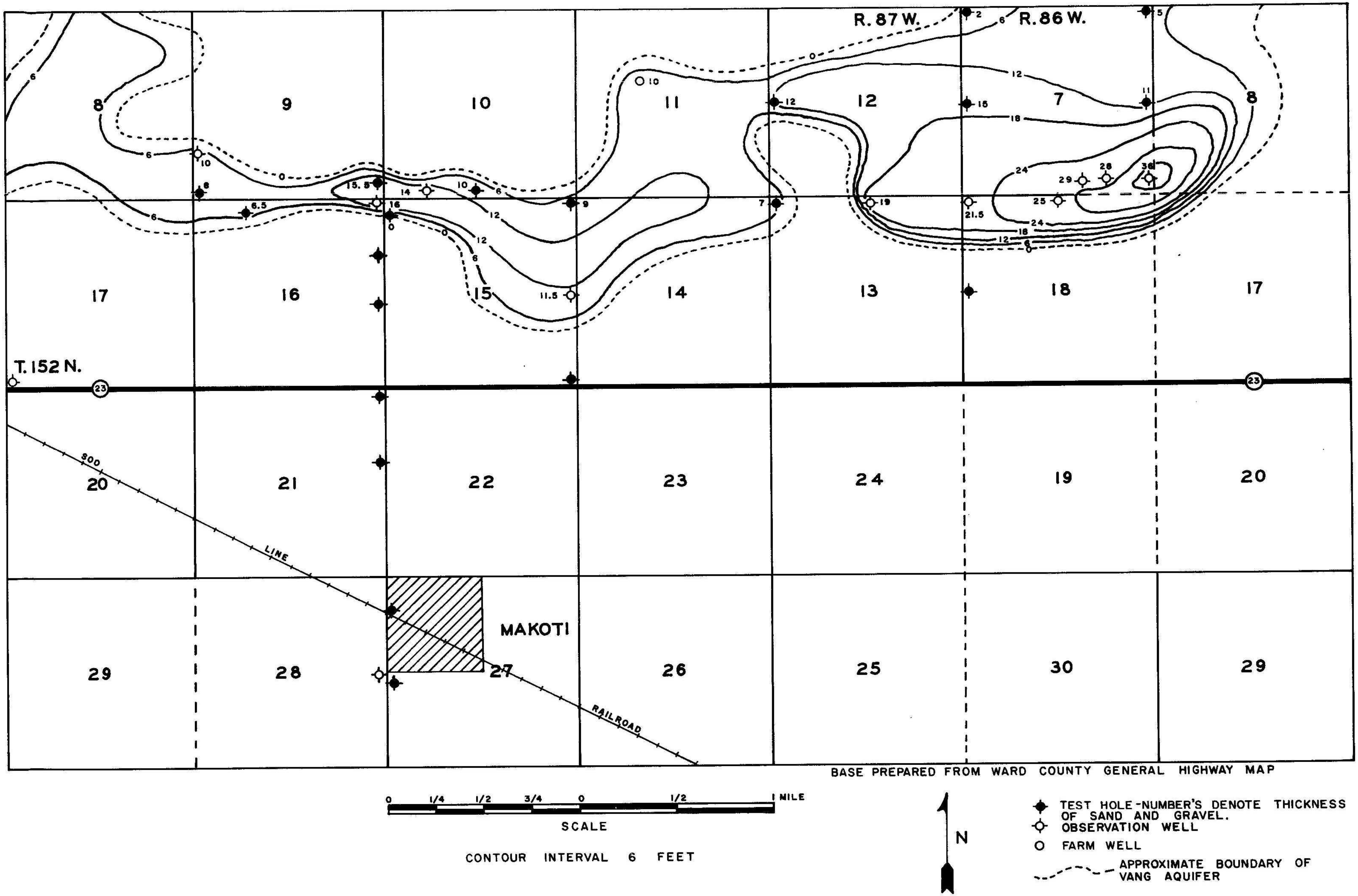


FIGURE 6 --THICKNESS MAP OF THE VANG AQUIFER IN THE MAKOTI AREA

is related to the chemical and physical composition of rocks coming into contact with ground water, duration of contact, temperature, pressure, and gases and minerals already in solution.

During the investigation at Makoti, ten water samples were collected for complete chemical analysis. Table 2 lists the chemical analyses of 13 water samples from the Makoti area. Nine samples represent ground water collected from wells constructed in the Vang aquifer. Three samples indicate the quality of ground water common to lenticular deposits of sand and gravel and one water sample represents the quality of ground water obtained from the Hiddenwood Lake aquifer.

The following summary gives the significance of selected constituents of water for a domestic or municipal water supply in North Dakota. (Schmid, unpublished report, March, 1965):

Silica (SiO_2):

No physiological or esthetic significance.

Iron (Fe):

Over .3 ppm iron may cause staining of laundry fixtures. Over .5 ppm may be tasted by persons unaccustomed to water with a high iron content. A water with a high iron content will adversely affect the taste of coffee and tea made from such water. Iron removal systems are available.

Calcium and Magnesium (Ca) and (Mg):

Are the primary causes of hardness. Over 125 ppm magnesium may have a laxative effect on persons unaccustomed to this type of water.

Sodium (Na):

No physiological or esthetic significance except for persons on salt-free diets.

Potassium (K):

Small amounts are essential to animal nutrition.

TABLE 2 - CHEMICAL ANALYSES *

(Analytical results in parts per million except as indicated

Location	Depth of Well (Feet)	Aquifer	Date of Collection	Silica (SiO_2)	Total Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Total Dissolved Solids	Hardness as $CaCO_3$ Calcium Magnesium	Hardness as $CaCO_3$ Noncarbonate	% Sodium	Sodium-absorption-ratio	Specific Conductance (micromhos 25°C)	pH
152-86-7ddc	32	V Sand	9-29-67	27	4.30	68	37	58	9.0	333	0.0	163	8.2	0.1	2.0	0.00	528	323	50	27	1.4	805	7.6
152-86-7ddd	30	V Sand	9-28-67	27	1.70	57	21	17	4.1	239	0.0	58	3.8	0.1	0.0	0.00	278	227	31	14	0.5	469	7.9
152-86-18abb	20	V Sand & Gravel	9-20-67	26	0.08	66	29	29	4.6	282	0.0	112	3.0	0.1	0.2	0.00	413	285	54	18	0.7	632	7.8
152-86-18bbb	20	V Sand & Gravel	9-20-67	26	1.20	72	23	17	2.9	257	0.0	95	2.0	0.1	0.2	0.00	365	275	65	12	0.4	565	7.9
152-87-9ccb	12	V Sand	9-20-67	28	4.60	91	40	23	4.7	293	0.0	82	3.1	0.1	140	0.10	587	390	150	11	0.5	820	7.9
152-87-10cdc	26	L Sand	9-19-67	27	3.10	147	72	119	6.0	405	0.0	555	8.1	0.2	0.5	0.20	1200	663	331	28	2.0	1530	7.8
152-87-11bdb	12	V Sand	8-9-66	27	0.26	68	33	14	2.0	233	0.0	56	0.8	0.3	104	0.03	396	305	114	9	0.3	639	8.0
152-87-13abb	20	V Sand & Gravel	9-28-67	23	1.10	93	28	24	3.6	307	0.0	129	4.5	0.1	14	0.00	446	348	97	13	0.6	714	7.9
152-87-15add	32	V Sand	9-19-67	23	0.66	68	22	7.3	2.5	269	0.0	49	1.6	0.2	0.2	0.00	301	260	40	6	0.2	494	7.7
152-87-15bcd	21	L Gravel	9-14-67	19	0.02	270	145	86	6.3	373	0.0	1060	30	0.3	1.4	0.14	2000	1270	965	13	1.0	2190	7.7
152-87-16aaa	20	V Sand	8-9-66	29	2.70	100	45	39	5.2	435	0.0	147	4.6	0.2	0.5	0.00	584	435	78	16	0.8	892	8.0
152-87-22bcb	25	L Gravel	9-14-67	29	0.08	376	224	100	18	434	0.0	1350	142	0.4	146	0.14	2800	1860	1510	10	1.0	3080	7.6
152-87-28daa	150	H Sand & Gravel	6-1-65	14	0.40	218	107	1220	15	1030	0.0	2650	67	0.4	0.7	0.55	4740	985	141	73	17.0	6080	8.1

* Analyses by the North Dakota State Laboratories Department

H Analysis of water sample from Hiddenwood Lake aquifer

V Analyses of water samples from Vang aquifer

L Analyses of water samples from lenticular sand and gravel deposits

Bicarbonate and Carbonate (HCO_3 and CO_3):

No definite significance in natural water, there are, however, certain standards to be maintained in water treatment plants. A water with high bicarbonate content will tend to have a flat taste.

Sulfate (SO_4):

A 250 ppm limit is set by the U. S. Public Health Service, however, a survey by the North Dakota State Health Department indicates no laxative effect is noticed until sulfates reach 600 ppm. Over 750 ppm there is generally a laxative effect. The following is a classification established by the North Dakota State Department of Health:

0 - 300 ppm SO_4	Low
300- 700 ppm SO_4	High
Over 700 ppm SO_4	Very High

Chloride (Cl):

Over 250 ppm may have a salt taste to persons unaccustomed to high concentrations. People may become accustomed to higher concentrations.

Fluoride (F):

It is believed to prevent decay in children's teeth within the limits of 0.9 to 1.5 ppm in North Dakota. Higher concentrations may cause mottled teeth.

Nitrate (NO_3):

Over 45 ppm can be toxic to infants, much larger concentrations can be tolerated by adults. Nitrate in excess of 200 ppm may have a deleterious effect on livestock health.

Boron (B):

No physiological or esthetic significance.

Total Dissolved Solids:

500 to 1,000 ppm is the limit set by the U. S. Public Health Service;

persons may become accustomed to water containing 2,000 ppm or more total dissolved solids. The following is a classification established by the North Dakota State Department of Health Survey:

0 - 500 ppm	Low
500 - 1400 ppm	Average
1400 - 2500 ppm	High
Over 2500 ppm	Very High

<u>Hardness:</u>

Calcium and magnesium are the primary causes of hardness. Hardness which increases soap consumption can be removed by a water softening system. The following is a general hardness scale established by the North Dakota State Department of Health:

0 - 200 ppm (as $CaCO_3$)	Low
200 - 300 ppm (as $CaCO_3$)	Average
300 - 450 ppm (as $CaCO_3$)	High
Over 450 ppm (as $CaCO_3$)	Very High

<u>pH:</u>

Should be between 7.0 and 9.0 for domestic consumption.

<u>Percent Sodium; Sodium Absorption Ratio; Specific Conductance:</u>

Are factors used in determining irrigation feasibility.

In general, water quality does not vary to any considerable degree within the Vang aquifer in the vicinity of Makoti. The water is a hard, calcium, bicarbonate type. The water quality can be summarized as average to very high in hardness, low in sulfate content, and low to average in total dissolved solids. However, there is considerable variation in iron and nitrate content throughout the aquifer. Analyses of two water samples from wells adjacent to low marshy areas contained nitrates in excess of accepted nitrate standards. The infiltration and percolation of nitrogeneous material into the aquifer from decaying organic residue in sloughs and potholes is the probable cause of excessive nitrate concentration. Iron content in water sampled from the test well (152-86-7ddc) is above the recommended level for domestic and culinary purposes.

CONCLUSION AND RECOMMENDATIONS

The municipal ground-water investigation served to partially define the thickness and areal extent of outwash materials common to the Vang aquifer in the Makoti area. Thicknesses of sand and gravel encountered during test drilling vary considerably throughout the aquifer. The most favorable area of the aquifer with regard to thickness of sand and gravel is in the vicinity of test hole 2856 (152-86-7ddc). Generally, the south portion of Section 7, Township 152 North, Range 86 West and the extreme north portion of Section 18, Township 152 North, Range 86 west constitute the area worthy of consideration as a possible source of municipal water.

It is suggested that prior to installation of a pipeline from the vicinity of test hole 2856 (152-86-7ddc) to the Village of Makoti, that a properly constructed test well be installed and a pumping test run for several days in order to accurately determine the water-yielding capabilities of the aquifer. The ability of the Vang aquifer to provide a sustained quantity of water for Makoti should be determined before the final arrangements are completed for a pipeline and municipal water facility.

Water quality within the Vang aquifer is acceptable for public use. However, because hardness and excessive concentrations of iron are not desirable for domestic and culinary purposes, the treatment and/or removal of these constituents would enhance water quality.

TABLE 3 - RECORDS OF WELLS AND TEST HOLES

Depth to Water: Measured water levels in feet and tenths or hundredths; reported water levels in feet.

Type of Well: Dr, drilled; Du, dug; Dv, driven; Bo, bored; g.p.m., gallons per minute.

Depth of Well: Measured depths in feet and tenths; reported depths in feet.

Use of Water: D, domestic; U, unused; PS, public supply; S, stock; T, test hole.

Remarks: Sp. Cond.: Specific Conductance (micromhos at 25°C) C.A., Chemical Analysis; A.Q.: Aquifer Test.

Location No. (1)	Owner (2)	Depth (feet) (3)	Diameter (inches) (4)	Type (5)	Date Completed (6)	Depth to water below land surface (feet) (7)	Date of Measurement (8)	Use of Water (9)	Aquifer (10)	Remarks (11)
152-86-7aaa	Test Hole 2855	40	4 3/4	Dr	1967			U		See Log
152-86-7add	Test Hole 2854	20	4 3/4	Dr	1967			U		See Log
152-86-7bbb	Test Hole 2852	40	4 3/4	Dr	1967			U		See Log
152-86-7cbb	Test Hole 2851	17	1 1/4	Dr	1967	11.40	9-67	T	Sand	See Log
152-86-7dcd	Test Hole 2857	30	1 1/4	Dr	1967	4.70	9-67	T	Sand	See Log
152-86-7ddc	Test Hole 2856	32	4	Dr	1967	3.09	9-67	T	Sand	See Log, C.A., A.Q.
152-86-7ddd	Test Hole 2853	30	1 1/4	Dr	1967	12.75	9-67	T	Sand	See Log, C.A.
152-86-18abb	Test Hole 2830	20	1 1/4	Dr	1967	5.00	9-67	T	Sand	See Log, C.A.
152-86-18bbb	Test Hole 2829	20	1 1/4	Dr	1967	8.81	9-67	T	Sand	See Log, C.A.
152-86-18cbb	Test Hole 2831	60	4 3/4	Dr	1967			U		See Log

TABLE 3 - RECORDS OF WELLS AND TEST HOLES (Cont.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
152-86-20dcc	H. Kruger	30	36	Du	1929	15.00	5-66	D,S	Sand	Sp. Cond. 1000-2000
152-87-9ccb	Test Hole 2825	12	1 1/4	Dr	1967	4.50	9-67	T	Sand	See Log, C.A.
152-87-9ccc	Test Hole 2824	40	4 3/4	Dr	1967			U		See Log
152-87-9ddd	Test Hole 2823	40	4 3/4	Dr	1967			U		See Log
152-87-cda$_1$	Lloyd Hanson	50	36	Bo	1947	16.00	9-67	S	Sand & Clay	Moderately Hard
152-87-10cda$_2$	Lloyd Hanson	30	6	Dr	1965			D	Sand	Leaves Salt Residue
152-87-10cdc	Test Hole 2821	26	1 1/4	Dr	1967	10.00	9-67	T	Sand	See Log, C.A.
152-87-10cdd	Test Hole 2820	60	4 3/4	Dr	1967			U		See Log
152-87-11bdb	E. Ouradnik	12	48	Du	1954	7.00	8-66	D	Sand	C.A.
152-87-11ddd	J. Bigelow	28	48	Du		20.00	5-66	S	Sand	Sp. Cond: < 2000
152-87-12bcc	Test Hole 2850	40	4 3/4	Dr	1967			U		See Log
152-87-13abb	Test Hole 2849	20	1 1/4	Dr	1967	8.81	9-67	T	Gravel	See Log, C.A.
152-87-13bbb	Test Hole 2828	40	4 3/4	Dr	1967			U		See Log
152-87-14bcb$_1$	L. Bergeson		24	Bo		8.60	9-67	D,S		
152-87-14bcb$_2$			36	Bo		12.00	9-67	D,S	Sand	
152-87-14cdc	Harold Grinde	30			1957	16.00	9-67	D	Sand & Gravel	Hard
152-87-15aaa	Test Hole 2819	80	4 3/4	Dr	1967			U		See Log
152-87-15add	Test Hole 2818	32	1 1/4	Dr	1967	12.60	9-67	T	Sand	See Log, C.A.
152-87-15bbb	Test Hole 2822	40	4 3/4	Dr	1967			U		See Log

TABLE 3 - RECORDS OF WELLS AND TEST HOLES (Cont.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
152-87-15bcd	L. Beyer	21	6	Du	1956	18.00	5-66	S	Gravel	C.A.
152-87-15ddd	Test Hole 2817	80	4 3/4	Dr	1967			U		See Log
152-87-16aaa	Test Hole 3318	20	1 1/4	Dr	1966	10.00	5-66	U	Sand	See Log, C.A.
152-87-16add	Test Hole 2816	60	4 3/4	Dr	1967			U		See Log
152-87-16bba	Test Hole 2826	40	4 3/4	Dr	1967			U		See Log
152-87-16daa	Test Hole 2815	60	4 3/4	Dr	1967			U		See Log
152-87-17ccc	Test Hole 3197	117	1 1/4	Dr	1966	37.00	12-65	U	Gravel	See Log
152-87-21aaa	Test Hole 2814	100	4 3/4	Dr	1967			U		See Log
152-87-21ada	Test Hole 2827	60	4 3/4	Dr	1967			U		See Log
152-87-21add			6			11.15	9-67	U		
$152\text{-}87\text{-}22adb_1$	Henry Fedje	90		Dr	1933			S	Sandstone & Lignite	Corrosive, rusty
$152\text{-}87\text{-}22adb_2$	Henry Fedje	30	24	Bo	1958	18.00	9-67	D	Sand	
152-87-22bcb	T. Lampert	25	18	Bo	1965	7.00	5-66	D,S	Gravel	C.A.
152-87-22dcd	T. Zieman	207	6	Dr		75.00	4-64	S		
152-87-27bbc	Test Hole 3196A	175	4 3/4	Dr	1965			U		See Log
152-87-27cbb	Test Hole 3196	235	4 3/4	Dr	1965			U		See Log
152-87-28add	Test Hole 1470-1	150	1 1/4	Dr	1965	26.00	12-65	U	Sand & Gravel	See Log, C.A.
152-87-29baa	J. Stafslien	254	4	Dr	1960	50.00	-60	S	Sandstone	

TABLE 4 - LOGS OF TEST HOLES

The following test hole logs are a summary of data from the driller's logs, geologist's sample descriptions, and the resistivity and potential electric logs.

All colors used in the sample descriptions are of wet samples. (Goddard and others, 1963.)

Grain size classification is C. K. Wentworth's scale from Pettyjohn (1957).

Elevations are based on mean sea level datum from an altimeter survey of selected locations in the Makoti area.

152-86-7aaa
Test Hole 2855
Elevation 2073 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ---	1	0	1
	Sand, fine to medium grained, subangular to rounded, moderately well sorted, mostly quartz, limestone, dolostone and granitics ------------------------	5	1	6
	Clay, silty, sandy, gravelly, yellowish brown, moderately cohesive, plastic, oxidized (till) ----------------------	17	6	23
	Clay, silty, sandy, pebbly, lignitic, olive gray, cohesive, moderately plastic, calcareous (till) ---------------	17	23	40

152-86-7add
Test Hole 2854
Elevation 2068 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ---	1	0	1
	Sand, gravelly (approximately 25-35% fine to medium, angular to subrounded gravel), fine to coarse, subangular to subrounded, moderately well sorted, mostly quartz, limestone, dolostone and granitics -----------------------------	11	1	12
	Clay, silty, sandy, pebbly, olive gray, moderately cohesive, moderately plastic, calcareous (till) ---------------------	8	12	20

152-86-7bbb
Test Hole 2852
Elevation 2086 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial Drift:				
	Topsoil, silty, brownish black -----------	1	0	1
	Sand, fine to medium, angular to subrounded, moderately well sorted, mostly quartz, limestone, and granitics, oxidized ------------------------------	2	1	3
	Clay, silty, sandy, pebbly, olive gray, cohesive, moderately plastic, calcareous (till) -----------------------	23	3	26
	Clay, gravelly, sandy, silty, olive gray, cohesive, moderately plastic, gravel occurs as thin layers (till) ---------	6	26	32
	Gravel, fine to coarse, angular to subrounded, fair sorting, mostly limestone, dolostone and granitics --------------	5	32	37
	Clay, silty, sandy, olive gray, moderately cohesive, plastic (till) -------------	3	37	40

152-86-7cbb
Test Hole 2851
Elevation 2071 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial Drift:				
	Topsoil, very silty, sandy, gravelly, brownish black ------------------------	2	0	2
	Sand, gravelly (approximately 20-30% fine to coarse gravel), fine to coarse, subangular to rounded, moderately well sorted, mostly quartz, limestone, and granitics, oxidized ------------------	15	2	17
	Clay, silty, sandy, lignitic, olive gray, moderately cohesive, plastic, calcareous (till) --------------------------	23	17	40

Observation Well

152-86-7dcd
Test Hole 2857

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, gravelly brownish black	2	0	2
	Sand, gravelly (approximately 10-15% fine, angular to subrounded gravel), fine to very coarse, angular to rounded (predominantly subrounded), moderately well sorted, approximately 45-55% quartz, 10-15% shale, 20-30% limestone and dolostone, remainder being light-colored granitics	29	2	31
	Clay, silty, sandy, olive gray, cohesive slightly to moderately plastic, calcareous (till)	9	31	40

Observation Well

152-86-7ddc
Test Hole 2856
Elevation 2054 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, gravelly, brownish black	2	0	2
	Sand, gravelly (approximately 10-15% fine, angular to subrounded gravel), fine to very coarse, angular to rounded (predominantly subrounded), moderately well sorted, approximately 40-50% quartz, 10-15% shale, 20-30% limestone and dolostone, remainder being light-colored granitics with a very small amount of gneiss and sandstone	28	2	30
	Clay, silty, sandy, olive gray, calcareous, cohesive, slightly plastic (till)	10	30	40

Test Well

152-86-7ddd
Test Hole 2853
Elevation 2069 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ----	1	0	1
	Sand, gravelly (approximately 20-30% fine to medium, subangular to subrounded gravel), fine to coarse, subangular to rounded, moderately well sorted, mostly quartz, limestone, dolostone and granitics ----------------------------	20	1	21
	Sand, very gravelly (approximately 30-40% fine to medium, subangular to subrounded gravel), fine to coarse, subangular to rounded, moderately well sorted, mostly quartz, limestone, dolostone and granitics ---------------------------------	16	21	37
	Clay, silty, sandy, olive gray, moderately cohesive, moderately plastic, calcareous (till) --------------------------	3	37	40

Observation Well

152-86-18abb
Test Hole 2830
Elevation 2062 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ----	1	0	1
	Sand, gravelly (approximately 20-30% fine to medium, angular to subrounded, moderately well sorted), fine to very coarse, angular to rounded, moderately well sorted, approximately 45-55% quartz, 15-20% limestone and dolostone, 5-10% shale, remainder being granitics and lignite, oxidized upper 8-12 feet of section ---------------------------	25	1	26
	Clay, silty, sandy, olive gray to medium dark gray, moderately cohesive, plastic, lignitic (till) ----------------------	34	26	60

Observation Well

152-86-18bbb
Test Hole 2829
Elevation 2070 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, grayish black -----	½	0	½
	Sand, gravelly lower 3-4 feet of section, fine to very coarse, angular to rounded, fair sorting, approximately 45-55% quartz, remainder being limestone, dolostone, shale, lignite, and light-colored granitics, oxidized upper 12-15 feet of section ----------------------	21½	½	22
	Clay, silty, sandy, olive gray to medium gray, moderately cohesive, plastic, calcareous (till) --------------------	8	22	30
	Clay, silty, sandy, dusky yellow to moderate yellowish brown, moderately cohesive, plastic, calcareous, oxidized (till) ------------------------------	10	30	40

Observation Well

152-86-18cbb
Test Hole 2831

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ----	1	0	1
	Clay, silty, sandy, moderate yellowish brown to dusky yellow, moderately cohesive, slightly plastic, oxidized (till) ------------------------------	17	1	18
	Gravel, fine to coarse (predominantly medium) angular to rounded, poorly sorted, mostly limestone, dolostone, and shale, remainder being granitics, oxidized ----------------------------	3	18	21
	Clay, silty, sandy, olive gray to dark yellowish brown, cohesive, moderately plastic, slightly oxidized, calcareous (till) ------------------------------	39	21	60

152-87-9ccb
Test Hole 2825

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, gravelly, brownish black	1	0	1
	Clay, silty, sandy, moderate yellowish brown, slightly cohesive, plastic, oxidized (till)	2	1	3
	Sand, gravelly lower 7 feet of section, fine to very coarse grained, angular to rounded, fair sorting, oxidized	10	3	13
	Clay, silty, sandy, olive gray, moderately cohesive, slightly plastic, unoxidized, (till)	8	13	21
	Sand, fine to very coarse, angular to rounded, moderately well sorted, approximately 50-60% quartz, remainder being shale, limestone, dolostone, and lignite, oxidized	2	21	23
	Clay, silty, sandy, lignitic, olive gray, cohesive, slightly plastic, calcareous, unoxidized (till)	17	23	40
	Clay, silty, sandy, gravelly, lignitic, olive gray to dark greenish gray, moderately cohesive, slightly plastic, calcareous, unoxidized (till)	20	40	60

Observation Well

152-87-9ccc
Test Hole 2824

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, gravelly, brownish black	1	0	1
	Clay, silty, sandy, moderate yellowish brown, moderately cohesive, plastic, oxidized (till)	3	1	4
	Sand, gravelly lower 3-4 feet of section, medium to very coarse, angular to rounded, fair sorting, approximately 40-50% quartz, remainder being limestone, dolostone, and shale	8	4	12
	Clay, silty, moderate yellowish brown, moderately cohesive, plastic, oxidized (till)	9	12	21
	Clay, silty, sandy, olive gray, moderately cohesive, plastic, unoxidized (till)	2	21	23

152-87-9ccc
Test Hole 2824 (Cont.)

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Gravel, fine to coarse, angular to subrounded, poorly sorted, approximately 45-55% limestone and dolostone, 10-20% shale, remainder being light-colored granitics and quartz	8	23	31
	Clay, silty, sandy, moderate yellowish brown with a few olive gray layers and moderate reddish brown concretions, cohesive, slightly plastic, calcareous, oxidized (till)	9	31	40

152-87-9ddd
Test Hole 2823

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, brownish black	½	0	½
	Sand, gravelly lower 10 feet of section, fine to very coarse grained, angular to rounded, moderately well sorted, oxidized, approximately 55-65% limestone and dolostone, remainder being light-colored granitics, shale, lignite	15½	½	16
	Clay, silty, sandy, moderate yellowish brown, moderately cohesive, plastic, calcareous, oxidized (till)	7	16	23
	Clay, silty, sandy, olive gray to moderate yellowish brown, cohesive, slightly plastic, calcareous, slightly oxidized to unoxidized (till)	37	23	60

152-87-10cdc
Test Hole 2821
Elevation 2079 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, brownish black	1	0	1
	Sand, gravelly lower 3 feet of section, fine grading to very coarse grained towards bottom of section, subangular to rounded, moderately well sorted, approximately 55-65% quartz, remainder being limestone, dolostone, light-colored granitics, lignite, and shale	14	1	15
	Clay, silty, sandy, olive gray, cohesive, plastic (till)	5	15	20

152-87-10cdc
Test Hole 2821 (Cont.)
Elevation 2079 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Sand, medium to very coarse, subangular to rounded, moderately well sorted, approximately 45-55% quartz, 25-35% shale, remainder being limestone and dolostone, oxidized	10	20	30
	Clay, silty, sandy, moderate yellowish brown, cohesive, plastic, calcareous, oxidized (till)	10	30	40

Observation Well

152-87-10cdd
Test Hole 2820
Elevation 2077 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, brownish black	1	0	1
	Sand, gravelly (approximately 20-30% fine, angular to subrounded gravel), medium to very coarse grained, angular to rounded, fair sorting, mostly quartz and granitics with some shale, limestone, and dolostone	10	1	11
	Clay, silty, sandy, olive gray to medium gray, slightly cohesive, very plastic (till)	13	11	24
	Gravel, sandy (approximately 15-25% coarse to very coarse, subangular to rounded sand), clayey, lignitic, fine to coarse (predominantly medium), subangular to rounded, fair sorting, approximately 45-55% limestone, dolostone with remaining portion granitics, shale and quartz, oxidized	6	24	30
	Clay, silty, moderate yellowish brown to dusky yellow, cohesive, semi-plastic, oxidized (till)	30	30	60

Electric Log

152-87-12bcc
Test Hole 2850

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, brownish black -----------	1	0	1
	Clay, silty, sandy, yellowish brown, moderately cohesive plastic, oxidized (till) --------------------------------	4	1	5
	Gravel, sandy (approximately 25-35% fine to coarse sand), fine to coarse, angular to subrounded, moderately well sorted --------------------------------	12	5	17
	Clay, silty, sandy, lignitic, olive gray, cohesive, moderately plastic, calcareous (till) --------------------------	23	17	40

152-87-13abb
Test Hole 2849
Elevation 2065 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Gravel, sandy (approximately 20-30% fine to coarse sand), fine to medium, subangular to subrounded, fair sorting, mostly limestone, dolostone, and granitics ----------------------------	19	0	19
	Clay, silty, sandy, yellowish brown, moderately cohesive, moderately plastic, oxidized (till) ----------------------	5	19	24
	Clay, silty, sandy, olive gray to moderate olive brown, cohesive, slightly plastic, calcareous (till) --------------------	16	24	40

Observation Well

152-87-13bbb
Test Hole 2828
Elevation 2075 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ----	1	0	1
	Gravel, sandy (approximately 20-30% coarse to very coarse, angular to subrounded sand), fine to medium, angular to rounded, poorly sorted, oxidized ------	7	1	8
	Clay, silty, sandy, olive gray to medium gray, cohesive, moderately plastic, calcareous (till) --------------------	16	8	24
	Clay, silty, sandy, dusky yellow with a few light brown layers, moderately cohesive, moderately plastic, numerous angular lignite grains, granules and a few pebbles, oxidized (till) ----------	16	24	40

152-87-15aaa
Test Hole 2819
Elevation 2084 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ----	1	0	1
	Sand, fine to coarse (predominantly medium grained), angular to rounded, fair sorting, estimate 45-55% quartz with remainder being limestone, dolostone and shale ----------------------------	7	1	8
	Clay, silty, sandy, moderate yellowish brown, cohesive, plastic, calcareous, limestone, shale, and lignite fragments present, oxidized (till) --------------	7	8	15
	Clay, silty, sandy, olive gray to dark greenish gray becoming dusky yellow (oxidized) toward bottom of section, cohesive, slightly plastic (till) -----	15	30	45
	Clay, silty, sandy, pebbly, olive gray to medium dark gray, very cohesive, slightly plastic (till) ---------------	35	45	80

Electric Log

152-87-15add
Test Hole 2818

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ----	$\frac{1}{2}$	0	$\frac{1}{2}$
	Sand, fine to coarse, subangular to rounded, moderately well sorted, oxidized to moderate brown, approximately 55-65% quartz, remainder being limestone, dolostone, shale, and lignite ---------	$3\frac{1}{2}$	$\frac{1}{2}$	4
	Clay, silty, sandy, dark yellowish orange to moderate yellowish brown, cohesive, slightly plastic, numerous limestone, dolostone, and shale grains, granules, and a few pebbles present, oxidized (till) --------------------------------	$12\frac{1}{2}$	4	$16\frac{1}{2}$
	Sand, fine to medium grading to very coarse at bottom of section, subangular to rounded, moderately well sorted, approximately 25-35% shale, 40-50% quartz, remainder being limestone and dolostone ----------------------------	$11\frac{1}{2}$	$16\frac{1}{2}$	28
	Clay, silty, olive gray to dark greenish gray, moderately cohesive, slightly plastic, numerous limestone and shale grains and granules present in clay matrix (till) -----------------------	6	28	34
	Clay, silty, moderate yellowish brown, cohesive, slightly plastic, oxidized (till) ------------------------------	6	34	40

Electric Log
Observation Well

152-87-15bbb
Test Hole 2822

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ----	½	0	½
	Gravel, sandy (approximately 20-25% coarse to very coarse sand), fine to medium, angular to subrounded, poorly sorted, oxidized, mostly limestone, dolostone, with some shale and granitics ---------	3½	½	4
	Clay, silty, sandy, moderate yellowish brown, moderately cohesive, slightly plastic, oxidized (till) --------------	13	4	17
	Gravel, fine to medium, angular to subrounded, poorly sorted, mostly limestone and dolostone (oxidized), some shale and granitics ------------------	1	17	18
	Clay, silty, sandy, moderate yellowish brown, cohesive, semi-plastic, calcareous, oxidized (till) ----------------	3	18	21
	Sand, medium to coarse, angular to rounded, poorly sorted, approximately 50-60% quartz, 15-25% shale, remainder being limestone and dolostone --------------	3	21	24
	Clay, silty, sandy, moderate yellowish brown top 10-12 feet of section (oxidized) to olive gray, cohesive, slightly plastic, calcareous, a few thin moderate reddish brown layers (till) ------------------------------	16	24	40

152-87-15ddd
Test Hole 2817

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, grayish black -----	1	0	1
	Gravel, very clayey, fine to coarse, angular to subrounded, poorly sorted, oxidized, mostly limestone, dolostone, shale, and light-colored granitics ----	2	1	3
	Clay, silty, sandy, moderate yellowish brown, moderately cohesive, plastic, limestone, dolostone, and shale grains and granules present, oxidized (till) -	20	3	23
	Clay, silty, sandy, olive gray to dark greenish gray, moderately cohesive, plastic, calcareous (till) ------------	6	23	29
	Clay, silty, sandy, moderate yellowish brown with a few light brownish gray streaks, cohesive, slightly plastic, numerous limestone, dolostone, and shale grains and granules present in clay matrix, oxidized (till) ----------	21	29	50

152-87-15ddd
Test Hole 2817 (Cont.)

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Sand, slightly gravelly, fine to coarse angular to subrounded, poorly sorted, mostly weathered, soft, medium dark gray shale some quartz, limestone, dolostone, and lignite present -------	4	50	54
	Clay, silty, sandy, moderate yellowish brown, cohesive, slightly plastic, numerous limestone, shale, dolostone grains and granules present, oxidized (till) ----------------------------	4	54	58
	Sand, fine to very coarse, angular to subrounded, poorly sorted, mostly shale, quartz and limestone, with some lignite and dolostone ---------------	4	58	62
	Clay, silty, sandy, moderate yellowish brown, cohesive, slightly plastic, limestone, shale and dolostone grains and granules present in clay matrix, oxdized (till) ----------------------	8	62	70
	Clay, silty, sandy, olive gray to dark greenish gray, cohesive, non-plastic, calcareous (till) -------------------	10	70	80

Electric Log

152-87-16aaa
Test Hole 3318
Elevation 2064 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Sand, fine to very coarse with fine to medium gravel, moderately well sorted, subangular to subrounded, oxidized ---	17	0	17
	Clay, silty, some sand, pebbly, a few cobbles and boulders, yellowish gray to moderate olive brown, moderately soft, cohesive, oxidized (till) ------	17	17	34
	Clay, silty, slightly sandy, pebbly, a few cobbles, olive brown to olive gray, moderately soft, cohesive, partially oxidized (till) ----------------------	20	34	54
Tongue River Formation:				
	Shale, yellowish gray, slightly indurated, non-calcareous, oxidized ------------	7	54	61
	Shale, medium olive gray, slightly indurated, non-calcareous ----------------	2	61	63
	Lignite, black -------------------------	2	63	65
	Shale, medium olive gray, slightly indurated, smooth, slippery --------------	15	65	80

Electric Log
Observation Well

152-87-16add
Test Hole 2816

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial Drift:				
	Topsoil, silty, sandy, grayish black ----	1	0	1
	Clay, silty, moderate yellowish brown, cohesive, plastic, limestone, shale, and lignite grains and granules present in clay matrix, oxidized (till) ------------------------------	8	1	9
	Clay, silty, sandy, olive gray to medium gray, cohesive, moderately plastic, calcareous, numerous limestone, shale, and lignite grains, granules, and a few pebbles present in clay matrix (till) ------------------------------	15	9	24
	Gravel, fine to coarse, subangular to rounded, poorly sorted, mostly limestone, dolostone, shale, and lignite -	2	24	26
	Clay, silty, moderate yellowish brown, cohesive, slightly plastic, calcareous, a few thin light bluish gray layers toward bottom of section, numerous limestone, shale, and lignite grains and granules present, oxidized	21	26	47
Tongue River Formation:				
	Sandstone, clayey, light greenish gray to light bluish gray, top 5-6 feet of section is moderate brown and oxidized, consolidated, non-calcareous ---------	13	47	60

Electric Log

152-87-16bba
Test Hole 2826

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial Drift:				
	Topsoil, gravelly, brownish black -------	½	0	½
	Sand, fine to very coarse, angular to rounded (predominantly subrounded), poorly sorted, mostly quartz and limestone, some shale, oxidized ----------	6½	½	7
	Clay, silty, sandy, olive gray to dark greenish gray, cohesive, slightly plastic, calcareous, unoxidized (till)	14	7	21
	Clay, silty, gravelly from 23-24 feet, moderate yellowish brown, moderately cohesive, plastic, oxidized (till) ---	15	21	36
Tongue River Formation:				
	Sandstone, moderate yellowish brown to dusky yellow, fine to medium grained, consolidated, well oxidized, calcareous, oxidized ----------------------	4	36	40

152-87-16daa
Test Hole 2815

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, grayish black ------	1	0	1
	Clay, silty, sandy, pebbly, moderate yellowish brown, cohesive, moderately plastic, calcareous, numerous limestone, shale, quartz, and lignite grains, granules, and pebbles present in clay matrix, oxidized (till) -----------------------	59	1	60

Electric Log

152-86-17ccc
Test Hole 3197

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, pebbly clay loam, dark brown -----	1	0	1
	Clay, silty, sandy, pebbly, dusky yellow to moderate olive brown, moderately cohesive, soft, gravelly in places, oxidized (till) -----------------------	19	1	20
	Clay, silty, sandy, pebbly, moderate olive brown to light olive gray, cohesive, soft, partially oxidized (till) --------	15	20	35
	Clay, sandy, silty, pebbly, olive gray, cohesive, compacted, numerous lignite and limestone pebbles (till) -----------	49	35	84
	Gravel, fine, sandy, subrounded, well sorted, oxidized ----------------------	2	84	86
	Clay, silty, olive gray, cohesive, plastic, laminated ----------------------------	5	86	91
	Sand, fine to coarse with small amount of fine gravel, subangular to subrounded, moderately well sorted, predominantly quartz and lignite --------------------	23	91	114
	Gravel, medium, subrounded, well sorted, mostly limestone and shale ------------	4	114	118
Tongue River Formation:				
	Shale, sandy in places, greenish gray, cohesive, very tight ------------------	17	118	135

Observation Well

152-87-21aaa
Test Hole 2814

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, grayish black -----	1	0	1
	Clay, silty, moderate yellowish brown, moderately cohesive, slightly plastic, calcareous, numerous limestone, shale, and lignite grains and granules present, oxidized (till) ----------------------	59	1	60
	Clay, silty, sandy, moderate yellowish brown, sand occurs as poorly sorted, clayey lenses, cohesive, moderately plastic, calcareous, oxidized (till) --	22	60	82
Tongue River Formation:				
	Shale, siliceous, medium bluish gray, indurated, non-calcareous ---------------	18	82	100

Electric Log

152-87-21ada
Test Hole 2827

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, clayey, grayish black ----	1	0	1
	Clay, silty, sandy, moderate yellowish brown to dusky yellow, cohesive, plastic, oxidized (till) --------------	7	1	8
	Gravel, sandy (approximately 20-30% coarse to very coarse sand), fine to medium, angular to subrounded, poorly sorted, approximately 55-65% limestone and dolostone, remainder being shale, light-colored granitics and quartz ----------	$8\frac{1}{2}$	8	$16\frac{1}{2}$
	Clay, silty, sandy, olive gray to dark greenish gray, cohesive, slightly plastic, unoxidized (till) ------------	$13\frac{1}{2}$	$16\frac{1}{2}$	30
	Clay, silty, sandy, moderate yellowish brown, cohesive, slightly plastic, oxidized (till) ----------------------	10	30	40
	Clay, silty, sandy, pebbly, olive gray to medium gray, cohesive, non-plastic, calcareous (till) ---------------------	20	40	60

Electric Log

152-87-27bbc
Test Hole 3196-A

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial Drift:				
	Clay, silty, sandy, grayish yellow, soft, slightly cohesive, oxidized (till) ----	5	0	5
	Clay, silty, sandy, pebbly, yellowish gray to moderate olive brown, moderately soft, moderately cohesive, oxidized (till) ------------------------------	10	5	15
	Clay, silty, sandy, pebbly, light olive gray, partially oxidized (till) -------	11	15	26
	Clay, silty, olive gray, cohesive, plastic, moderately soft, slightly sticky, tight	9	26	35
	Clay, silty, sandy, pebbly, moderate olive brown to light olive gray, cohesive, moderately soft, occasional thin layers of sand and gravel, oxidized (till) ---	32	35	67
	Gravel, fine, sandy, subangular to subrounded, well sorted, oxidized --------	3	67	70
	Clay, silty, moderate olive brown, soft, cohesive, plastic, oxidized -----------	7	70	77
	Clay, silty, sandy, pebbly, light olive gray to olive gray, moderately soft, cohesive (till) -----------------------	19	77	96
	Boulder, sandstone, greenish gray, indurated ---------------------------------	$1\frac{1}{2}$	96	$97\frac{1}{2}$
	Clay, silty, sandy, pebbly, olive gray, moderately soft, cohesive (till) ------	$37\frac{1}{2}$	$97\frac{1}{2}$	135
	Gravel, fine to medium, dark brown, angular to subangular, poorly sorted --	15	135	150
Tongue River Formation:				
	Shale, various shades of gray, moderately indurated to indurated, cohesive, interbedded with sandy clay lenses ---------	25	150	175

152-87-27cbb
Test Hole 3196

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial Drift:				
	Topsoil, pebbly clay loam, black ---------	1	0	1
	Clay, silty, sandy, pebbly, grayish yellow, slightly cohesive, soft ---------------	4	1	5
	Clay, silty, sandy, pebbly, dusky yellow, moderately cohesive, soft, oxidized (till) --------------------------------	10	5	15
	Clay, silty, sandy, pebbly, moderate olive brown, oxidized (till) ---------------	5	15	20

152-87-27cbb
Test Hole 3196 (Cont.)

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Clay, sandy, silty, pebbly, olive gray, moderately cohesive (till) -----------	5	20	25
	Clay, silty, olive gray, cohesive, plastic, sticky ---------------------	10	25	35
	Clay, very sandy, silty, pebbly, dusky yellow to moderate olive brown, moderately soft, cohesive, oxidized (till)	20	35	55
	Clay, silty, very sandy, pebbly, olive gray to moderate olive gray, cohesive, moderately soft, a few thin layers of detrital lignite and fine gravel (till) ----------------------------	49	55	104
	Gravel, fine with coarse sand, subrounded, moderately well sorted, mostly limestone, shale, and lignite ------------	11	104	115
	Clay, silty, sandy, pebbly, olive gray, very cohesive, moderately soft (till)	15	115	130
	Gravel, fine with medium to very coarse sand, subrounded, well sorted, mostly shale, limestone, and lignite --------	15	130	145
	Sand, with some fine gravel, fine to coarse, subangular to subrounded, well sorted, mostly quartz, shale, lignite, and limestone ----------------------	25	145	170
	Gravel, sandy, fine, subangular to subrounded, moderately well sorted, mostly shale, limestone and lignite --	6	170	176
	Clay, silty, sandy, pebbly, olive gray, cohesive, moderately soft (till) -----	37	176	213
Tongue River Formation:				
	Shale, sandy, light greenish gray to medium gray, moderately soft, cohesive	3	213	216
	Lignite, black, brittle, fissile --------	9	216	225
	Shale, medium gray, slightly indurated, tight ------------------------------	10	225	235

152-87-28add
Test Hole 1470-1

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Clay, silty, pebbly, yellowish gray, slightly cohesive, oxidized (till) ---	5	0	5
	Clay, silty, sandy, pebbly, a few cobbles present, dusky yellow to moderate olive brown, cohesive, slightly plastic, oxidized (till) -------------	15	5	20

152-87-28add
Test Hole 1470-1 (Cont.)

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Clay, silty, olive gray, moderately soft, cohesive, plastic	15	20	35
	Clay, silty, sandy, pebbly, moderate olive brown to olive gray, moderately soft, cohesive, moderately plastic, partially oxidized (till)	20	35	55
	Clay, silty, some sand grains, pebbly olive gray with a few moderate olive brown streaks, moderately soft, cohesive, some detrital lignite (till)	25	55	80
	Clay, silty, sandy, pebbly, olive gray, thin layers of sand and gravel, moderately plastic, very cohesive (till)	62	80	142
	Sand, medium to coarse, subangular to subrounded, well sorted, mostly quartz and lignite	7	142	149
	Gravel, fine to medium, angular to subangular, moderately well sorted, oxidized to brown color	2	149	151
Tongue River Formation:				
	Sandstone, clayey, light greenish gray, slightly cohesive, very fine-grained, slightly consolidated	4	151	155

Observation Well

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