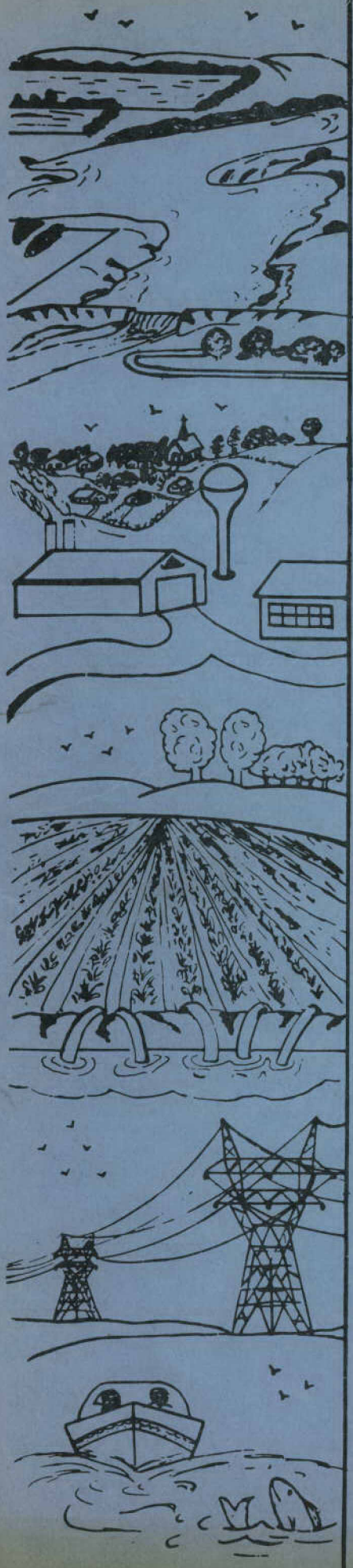

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GROUND-WATER SURVEY OF THE COLUMBUS AREA BURKE, COUNTY, NORTH DAKOTA

S.W.C. PROJECT NO. 745

NORTH DAKOTA GROUND-WATER STUDIES

NO. 73

By
Charles E. Naplin
Ground-Water Geologist

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North Dakota State Water Commission
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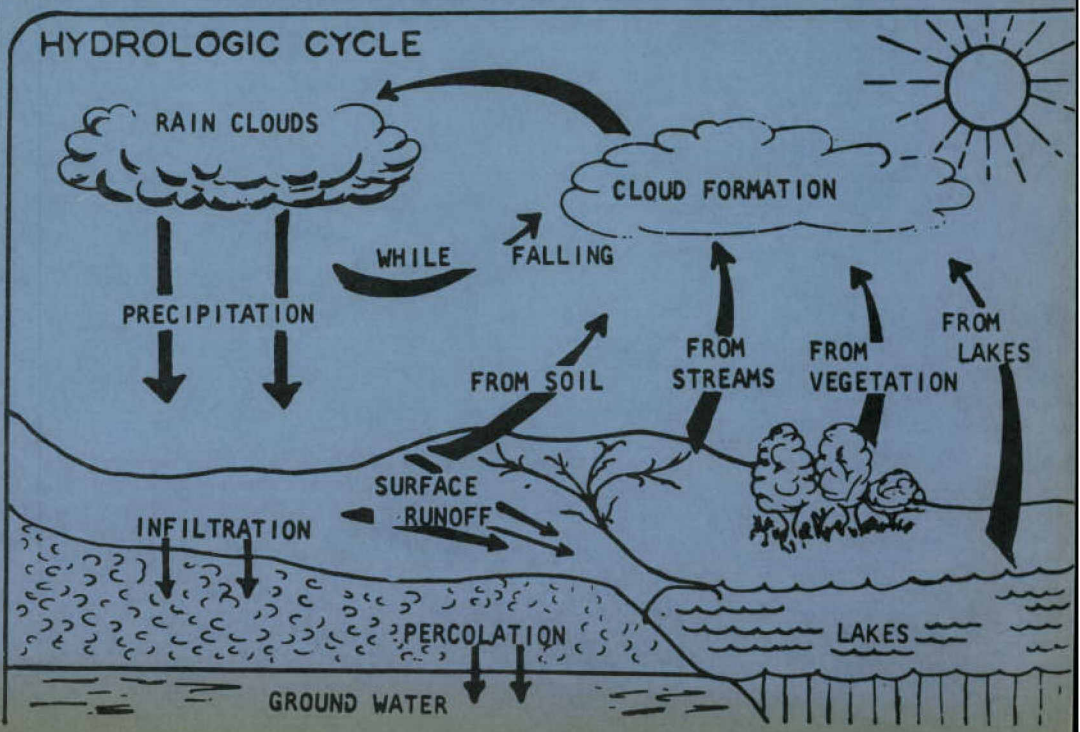

GROUND-WATER SURVEY OF THE COLUMBUS AREA BURKE COUNTY, NORTH DAKOTA

SWC Project #745

By
Charles E. Naplin, Ground-Water Geologist
North Dakota State Water Commission

NORTH DAKOTA GROUND-WATER STUDIES NO. 73

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Bismarck, North Dakota 58501

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BURKE COUNTY, NORTH DAKOTA

INTRODUCTION

PURPOSE AND SCOPE

The Columbus City Council passed a resolution on September 7, 1967 requesting the North Dakota State Water Commission to conduct a ground-water survey for the city. This study resulted from that resolution and its purpose was to locate and evaluate potential water supplies for the city of Columbus. Periodic water shortages in past years initiated the problem of finding a dependable supply of water for the municipality.

The survey consisted of test drilling, installation of observation wells, chemical analyses of selected water samples, a review of available data, and the preparation of this report. Well-inventory data were obtained from an open-file report of hydrologic data in the Crosby-Mohall area 1945-51 (LaRocque and others, 1963). Subsurface information obtained from 12 test holes drilled during the investigation was supplemented with data from 10 test holes drilled in conjunction with the Burke-Mountrail County ground-water study and 4 test holes drilled prior to the installation of the new city well northwest of Columbus. Additional information obtained from topographic maps and geologic reports supplemented the evaluation of ground-water conditions in the Columbus area. Field work began early in November and was completed in the first part of December 1967.

A preliminary oral report was made before the Columbus City Council on March 11, 1968. The report consisted of an explanation of the favorable areas where gravel was encountered during the test drilling phase of the investigation, and discussion of water quality with emphasis on iron, hardness, and sulfate content. The geohydrologic characteristics of

the channel deposit north of the municipality were discussed, and the possibility that the lower interval of gravel encountered may not be continuous was brought to the Council's attention. The city of Columbus was advised, should they decide to install a city well, that the State Water Commission would make available aquifer-testing equipment and personnel for an aquifer test.

Test drilling and associated field work was under direct supervision of the author. Lewis Knutson and Hugh Jacobson of the State Water Commission, accomplished the test drilling using a hydraulic-rotary drilling machine. Observation wells for the aquifer test and the new city well were installed by Mann Drilling Company of Dickinson. Chemical analyses were performed by Donald Delzer and Garvin Muri, State Water Commission Chemists, at the North Dakota State Laboratories in Bismarck. Special acknowledgment is extended to Norbert Kihle, Mayor of Columbus, for information concerning city wells and water facilities, and Clarence Armstrong of the U. S. Geological Survey, for supplying well-inventory and water-level data.

LOCATION AND GENERAL FEATURES

The Columbus area described in this report consists of 50 square miles in a portion of T. 163 N., Rs. 93 and 94 W. in northwestern Burke County. This area is located within the Central Lowland physiographic province of North Dakota, as shown in figure 1. Surface elevations range from 1,936 feet above mean sea level in the $SE\frac{1}{4}$, sec. 33, T. 163 N., R. 93 W. to less than 1,895 feet in the $NW\frac{1}{4}$, sec. 18, T. 163 N., R. 94 W.

Surface topography is gently undulating and slopes north toward the International Boundary. Drainage is semi-integrated with several intermittent streams following dendritic courses. These streams merge with

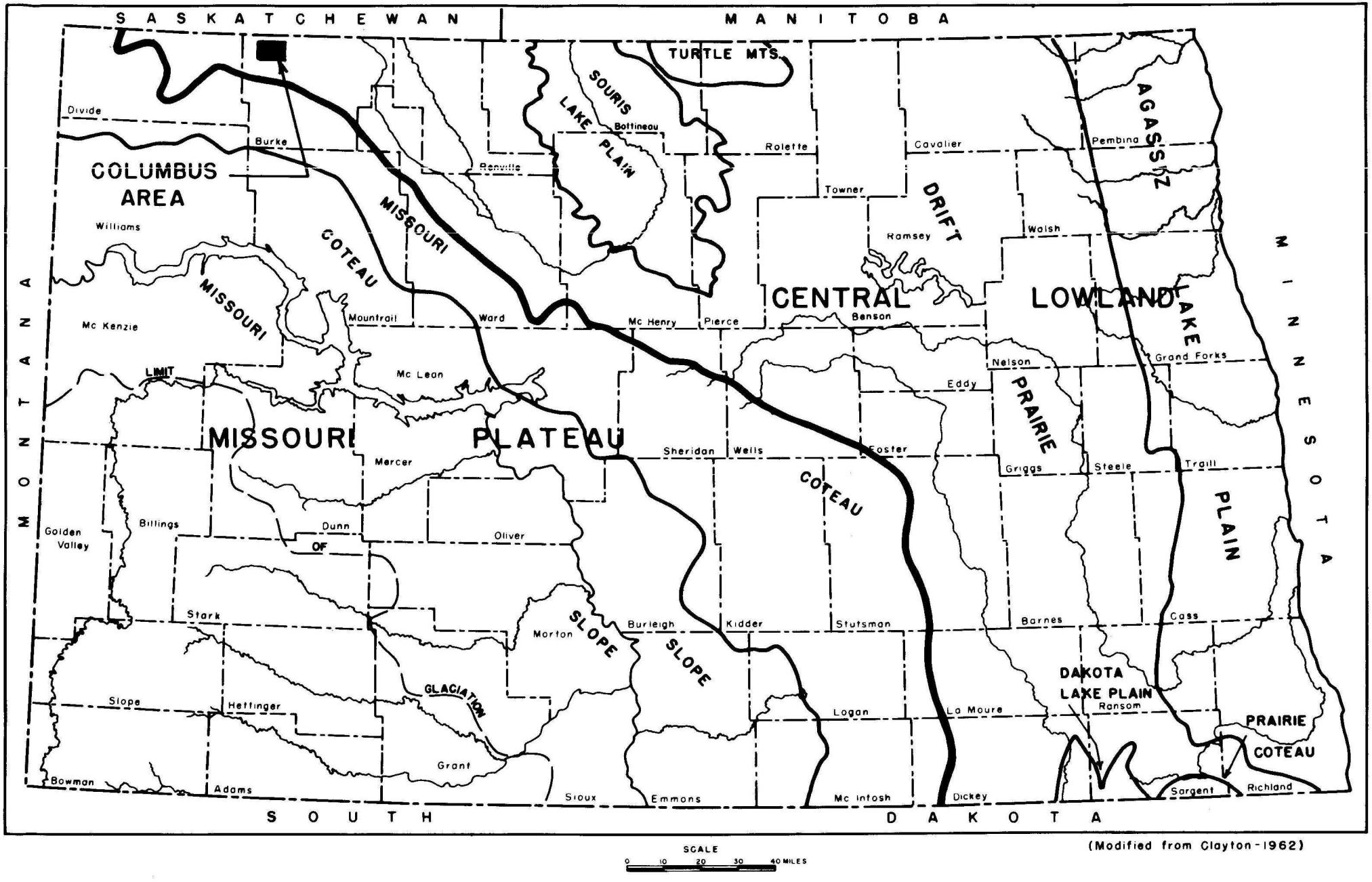
East Branch Short Creek and West Branch Short Creek, both of which flow northward into Saskatchewan, Canada.

The average annual temperature is 37.7° F, based on a 47 year period of record at the U. S. Weather Bureau Station in Portal, N. Dak., approximately 13 miles northeast of Columbus. The average annual precipitation is 13.71 inches at Columbus and is the 10-year mean for the period 1951-60 (U. S. Dept. of Commerce, 1965).

Columbus, population 672 (1960 Census), is predominantly an agricultural community; however, some local economic benefit is derived from nearby lignite and petroleum industries. The city is located in the NW¼, sec. 32, T. 163 N., R. 93 W. and is served by State Highways 5 and 40 and a branch line of the Great Northern Railway.

PRESENT WATER SUPPLY

The water system at Columbus consists of a network of water and sewer mains, a 70,000 gallon elevated storage tank, 4 wells and a sewerage lift station and disposal facility. City wells range in depth from 275 feet in city well 4 (163-93-32bdd$_2$) to 314 feet in city well 1 (163-93-32bcd). All wells are completed with 6-inch steel casing with the bottom few feet slotted. They are not gravel packed. A 5 hp (horsepower) electric motor powers a 4-inch diameter vertical turbine pump at city well 2 (163-93-32bdb) located near the fire hall. The pumping rate of this well has been estimated at 6 to 9 gpm (gallons per minute). The other 3 city wells are equipped with electric-powered 2 hp submersible pumps. Pumping rates at city well 1 (163-93-32bcd) and city well 4 have been estimated at 13 gpm, while city well 3 (163-93-32bdc) yields approximately 6 to 9 gpm. Total estimated gallonage for all 4 wells combined is about 38 gpm (Norbert Kihle, oral communication, 1968).



(Modified from Clayton-1962)

FIGURE 1--MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC PROVINCES AND LOCATION OF THE COLUMBUS AREA

The city of Columbus has experienced numerous problems in past years because wells would become inoperative due to excessive infiltration of fine sand into well casings. This problem is still acute and directly related to the slotted casing used in well construction. Wells constructed in formations of fine-grained materials, as is typical of the Tongue River Formation underlying the Columbus area, should be properly screened and gravel packed to minimize infiltration of fine-grained sand.

A gas problem has been reported in city well 3 (163-93-32bdc) where excessive corrosion has completely deteriorated one submersible pump, necessitating replacement. The corrosion problem may be a combination of several factors. Results of the chemical analysis of a mixture of water from the city wells indicate high concentrations of sodium (Na) and bicarbonate (HCO_3). Normally these substances remain in solution as ions in water under pressure. However, when pressure is removed, as occurs within a well bore, the bicarbonate constituent will disassociate and break down into hydroxl ions (OH) and carbon dioxide (CO_2), which is given off as a gas. In a well bore, therefore, an excessive concentration of hydroxl ions may accumulate and combine with free sodium ions to form the very corrosive basic substance sodium hydroxide (NaOH), which will deteriorate metals. Corrosion may also be due to iron-reducing bacteria or electrolysis caused by an electrical leak from a faulty pump-motor ground.

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 that passes laterally through the middle of Arkansas; the second number denotes the range west of the fifth principal meridian; the third number denotes the

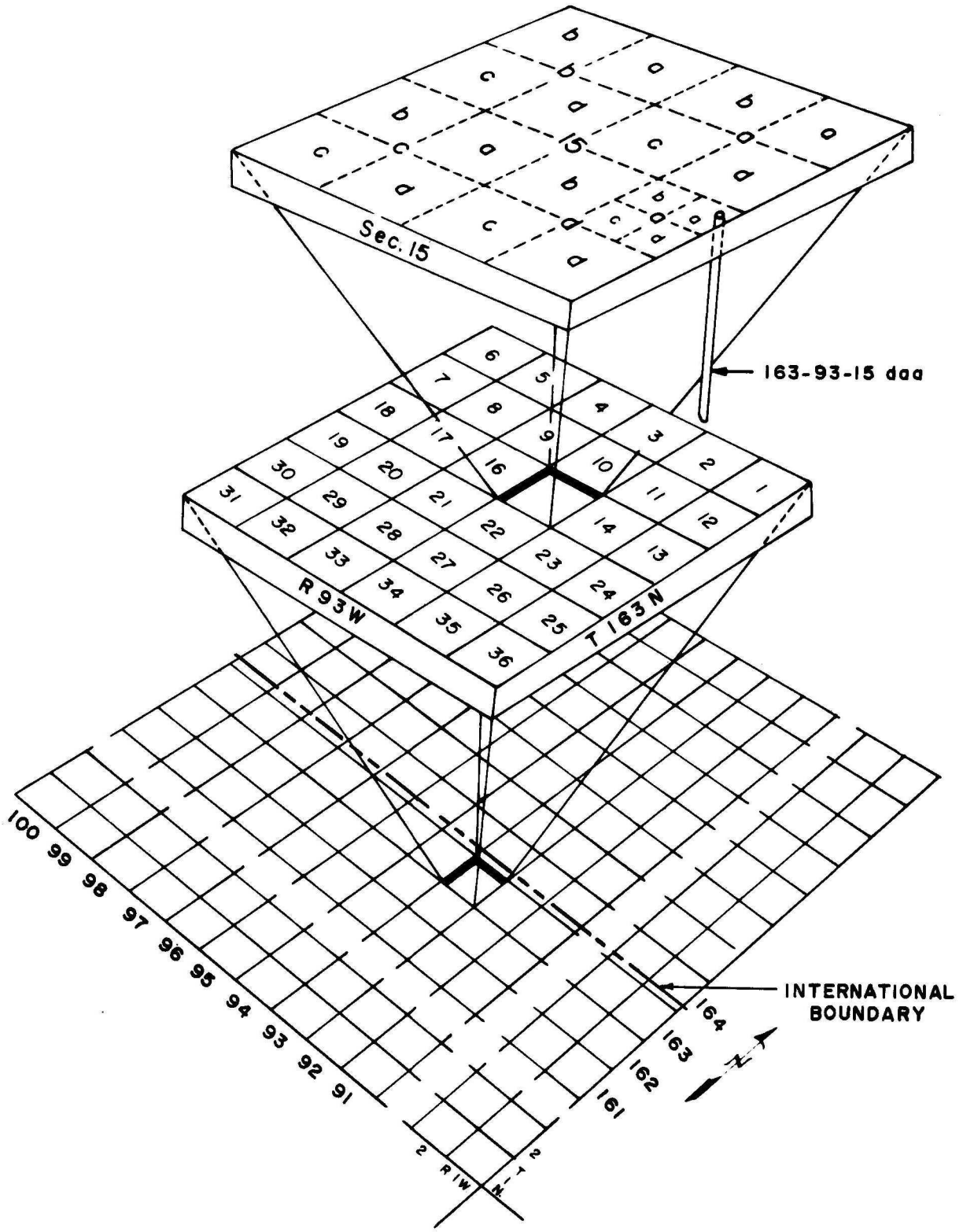


FIGURE 2--SYSTEM OF NUMBERING WELLS AND TEST HOLES.

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 163-93-15daa is in the $NE\frac{1}{4}NE\frac{1}{4}SE\frac{1}{4}$ sec. 15, T. 163 N., R. 93 W. (fig. 2).

PREVIOUS INVESTIGATIONS

A general study of the Burke County geology and ground-water resources was made by Simpson (1929, p. 90-94), in which he briefly discusses water-bearing strata and the quality of ground water. He also lists a well inventory of selected municipal and farm wells and the chemical analyses of two water samples from within the county.

In July 1965, a study of the geology and ground-water resources of Burke and Mountrail Counties was initiated as a cooperative program between the U. S. Geological Survey, the North Dakota State Water Commission, the North Dakota Geological Survey, and the Burke and Mountrail County Water Management Districts. Information acquired during this study is available, but will not be published until after the scheduled completion date in 1969. When completed, the published report may be obtained from the North Dakota State Water Commission in Bismarck and the North Dakota Geological Survey in Grand Forks.

GEOLOGY AND OCCURRENCE OF GROUND WATER

GEOLOGIC HISTORY

Prior to glaciation, the land surface in the Columbus area probably resembled the present-day topography of the Badlands area of southwestern North Dakota, with sedimentary rocks of Tertiary age exposed at the surface.

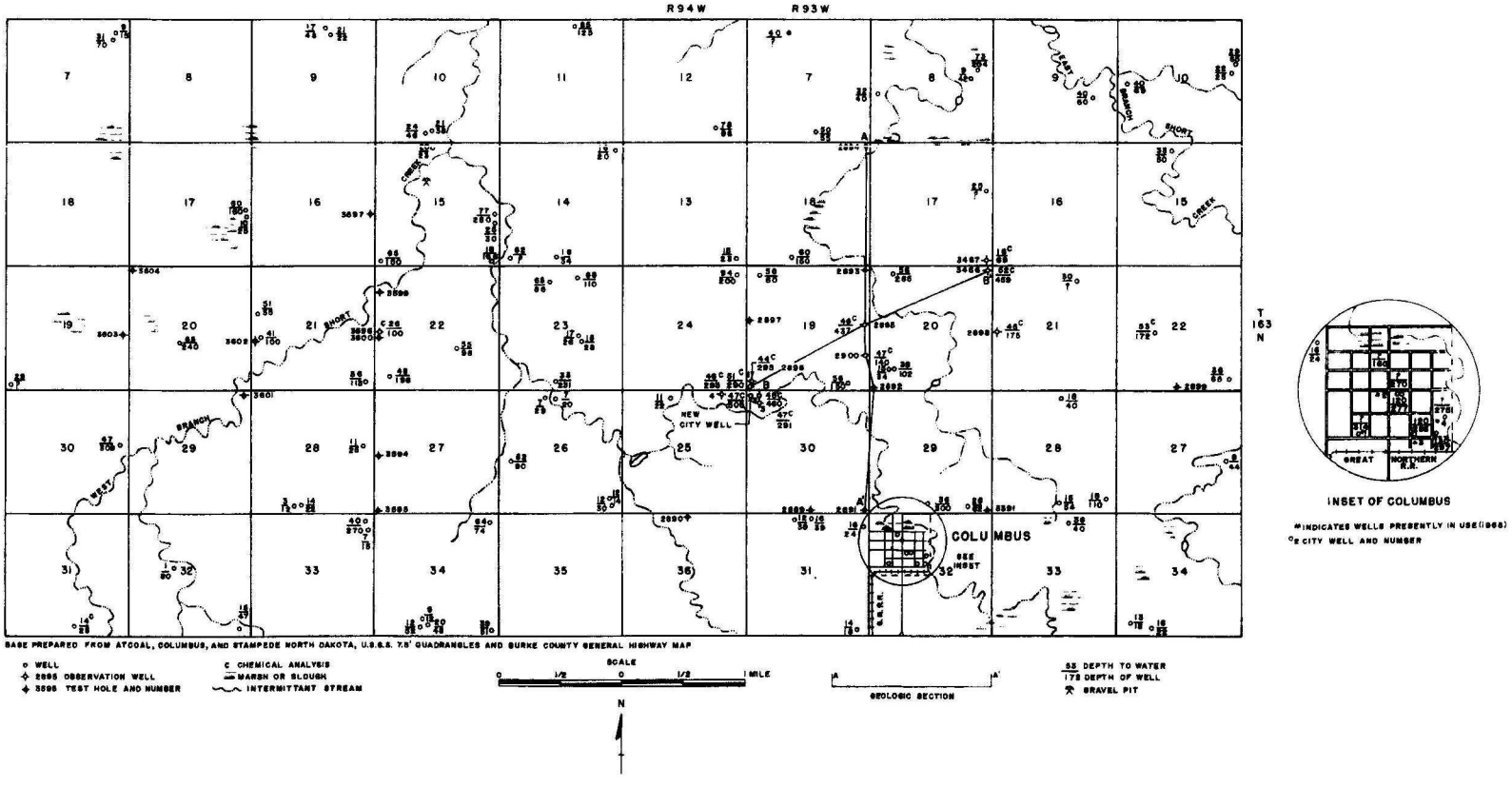


FIGURE 3--MAP OF COLUMBUS AREA SHOWING LOCATION OF WELLS, TEST HOLES, GEOLOGIC SECTIONS, AND RELATED FEATURES

Over a period of millions of years, mass-wasting agencies, such as the subsidence and upheaval of the earth's crust, and the erosional agents such as wind, rain, and thermal differentiation, influenced and determined topographic relief.

Information compiled from subsurface investigations during the Divide County ground-water survey indicates the preglacial drainage of northwestern North Dakota followed a northeast gradient (Armstrong, 1967, p. 7). Preglacial channels of the Missouri and Yellowstone Rivers are known to dissect portions of Divide County. The preglacial Yellowstone channel in the vicinity of Crosby, N. Dak., is located approximately 18 to 20 miles west of Columbus. The ancestral Missouri and Yellowstone channels are thought to merge approximately 14 to 15 miles west of Estevan, Saskatchewan and continue as one channel northeast into southern Manitoba (Christiansen and Parizek, 1961, p. 2). The buried channel in the Columbus area, encountered during this investigation, functioned as an eastward drainage trench while the Yellowstone channel was blocked with ice near Estevan, Saskatchewan.

Approximately 20 percent of the earth's surface was glaciated during the Pleistocene Epoch. This epoch lasted from about 1,000,000 years to less than 10,000 years ago. Four stages of glaciation - from oldest to youngest, Nebraskan, Kansan, Illinoian and Wisconsinan - took place during this time. Glacial stages have been subdivided into substages by geologists. Exposed glacial deposits in the Columbus area are believed to have been deposited in conjunction with the Mankato Substage of the Wisconsinan Stage of Pleistocene Glaciation. Pre-Wisconsinan glacial deposits in the Columbus area have either been removed by erosion or the action of younger ice.

BEDROCK

Underlying the mantle of glacial drift in the Columbus area are several thousand feet of stratified sedimentary rocks. Distinctive rock units that can be mapped areally and are consistent in lithologic composition are termed formations. Formations of sedimentary strata in the Columbus area represent a chronological order of deposition ranging from Cambrian to Tertiary time, with the exception of rocks of Permian age (Hansen, 1967, p.9).

The Tongue River Formation of Tertiary age stratigraphically underlies the cover of glacial drift. Twenty-one of 29 test holes shown on figure 3 penetrated thicknesses ranging from 4 feet in test hole 2895 (163-93-19add) to 47 feet in test hole 3602 (163-94-21cbb). Drill cuttings indicated a variable lithologic composition with light-bluish-gray, slightly calcareous shale and clayey, bluish-gray sandstone occurring as interbedded layers throughout the stratigraphic section. The shale is relatively impermeable and will not readily yield water to wells. The sandstone is permeable and yields water to wells but not readily, as is evidenced by the municipal wells at Columbus.

Calculated elevations of the top of the Tongue River Formation range from 1,435 feet above mean sea level in test hole 3466 (163-93-20aaa) to 1,877 feet in test hole 3601 (163-94-29aaa). The difference of 442 feet in relief is due to the presence of a channel eroded into the formation during one or more of the interglacial periods.

GLACIAL DRIFT

During the Pleistocene Epoch, continental ice sheets moved southward over the Columbus area several times. Slowly moving glacial ice became heavily laden with bedrock materials and glacial debris that had been broken loose and pulverized by the shearing force and overlying weight of accumulating ice. Glacial debris originating from source areas situated primarily in Canada was deposited as drift during periods when moderating temperatures forced the retreat of glaciers. Glacial drift refers to all stratified or unstratified materials deposited directly or indirectly by glacial action. Drift in the Columbus area ranges from 23 feet thick in test hole 3601 (163-94-29aaa) to 483 feet in test hole 3466 (163-93-20aaa). The surface of the glacial drift in the Columbus area is a ground moraine, which is a landform of low relief and gently undulating topography.

Till:

Glacial drift that overlies the Tongue River Formation in the Columbus area is composed mostly of till. Till is an unconsolidated, unstratified, heterogeneous mixture of clay, silt, sand, gravel, cobbles and boulders. These materials have been deposited directly by glacial 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 table in the "zone of oxidation" where air and the slow infiltration of ground water has produced leaching and consequent weathering. The oxidized zone of till in the Columbus area ranges in thickness from 11 feet in test hole 2893 (163-93-19aaa) to 39 feet in test hole 2891 (163-93-30ddd). 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.

Buried-Channel Deposits:

Test drilling during the Burke County ground-water study indicated the presence of a buried channel north of Columbus. Further test drilling data obtained during the municipal ground-water study at Columbus added to the previous information. Data from 17 of the 29 test holes drilled in the Columbus area indicated the channel was filled with materials consisting of till, lacustrine clay, sand and gravel. Several test holes drilled through the glacial drift encountered significant thicknesses of gravel in similar stratigraphic positions (figs. 4 and 5). Test hole 3466 (163-93-20aaa) encountered 100 feet of gravel from 383 feet to 483 feet below land surface. Test hole 2895 (163-93-19add) encountered 95 feet of sand and gravel from 380 feet to 476 feet and test hole 2896 (163-93-19ccc$_1$) penetrated 62 feet of gravel from 268 feet to 330 feet but did not penetrate the entire deposit. These test holes also encountered several smaller intervals of sand and (or) gravel above the basal channel deposit (figs. 4 and 5).

The channel itself was probably incised into the Tongue River Formation during a period when natural regional drainage to the northeast was blocked by ice. The preglacial Yellowstone channel, which followed a northeasterly course through Divide County and into Canada, is known to have been blocked by glacial ice west of Estevan, Saskatchewan (Christiansen and Parizek, 1961, p. 9). The preglacial Yellowstone channel became filled with water and a glacial lake was formed. Water overflowed from the lake and followed an easterly course from Divide County into western Burke County, cutting a diversion channel north of Columbus.

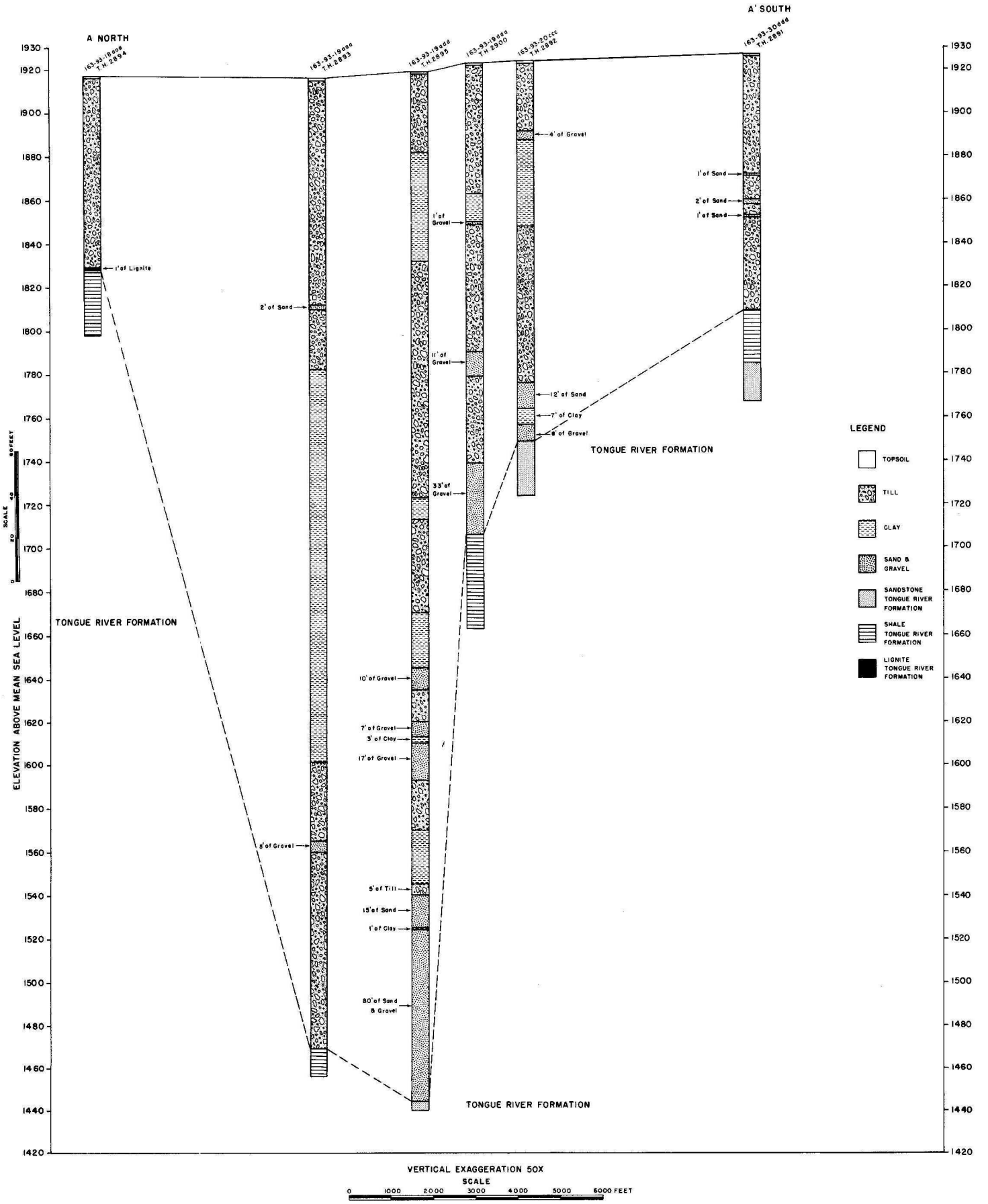


FIGURE 4--GEOLOGIC SECTION A-A' IN THE COLUMBUS AREA

(LOCATION OF SECTION A-A' SHOWN IN FIGURE 3)

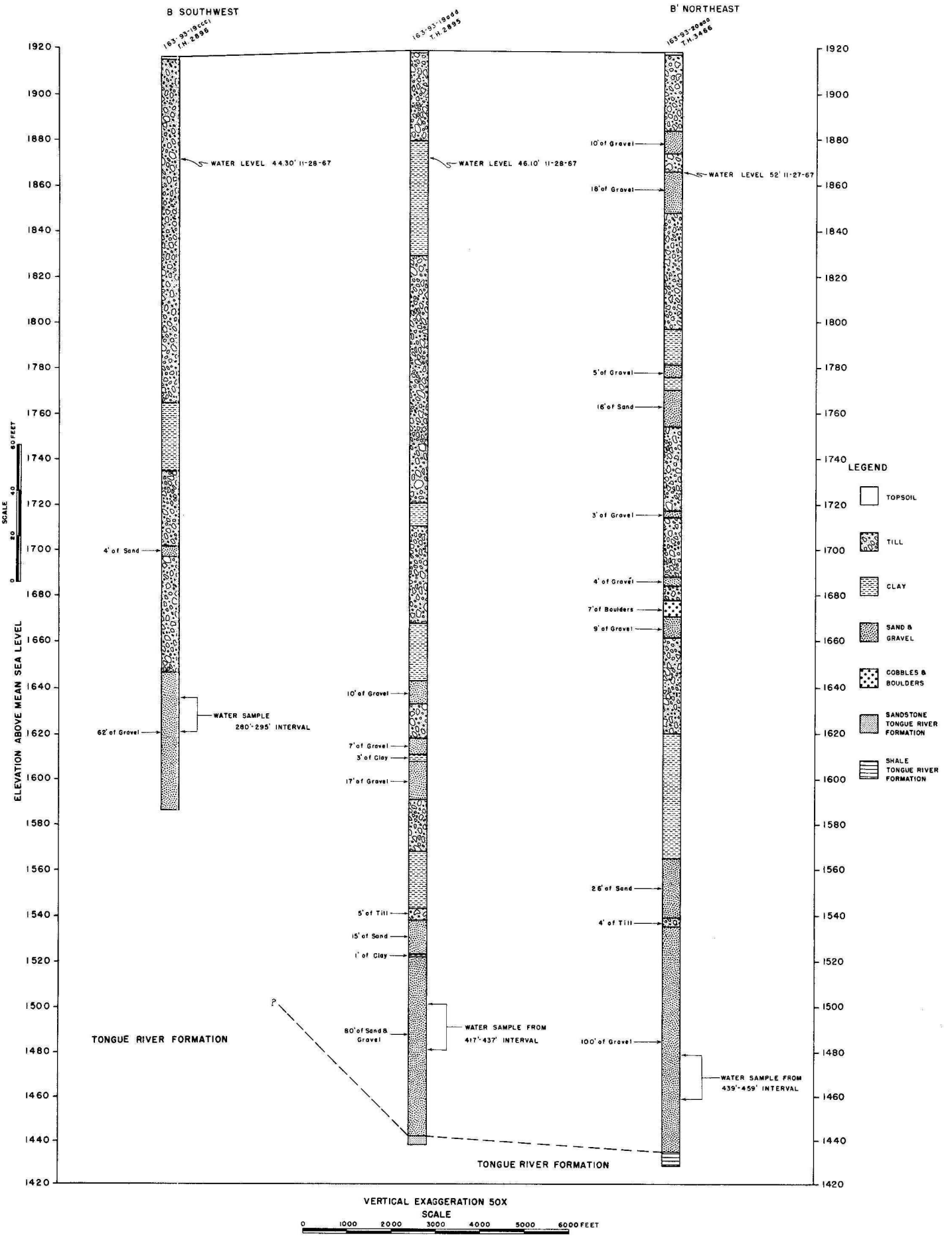


FIGURE 5--GEOLOGIC SECTION B-B' IN THE COLUMBUS AREA

(LOCATION OF SECTION B-B' SHOWN IN FIGURE 3)

Stratified materials deposited within the channel range from clay-size material to cobbles. Coarse materials, such as sand, gravel and cobbles, indicate times during which large volumes of rapidly flowing water sorted and deposited the sediments. Lacustrine clays and silts were deposited as lake sediment when the channel was temporarily blocked by ice or debris.

Subsurface data indicate the buried channel trends west to east-northeast in northwestern Burke County. The channel is approximately 1 to $1\frac{1}{2}$ miles wide and is more than 400 feet deep. Lemke (1960, p.119) referred to an eastward trending buried channel without surface expression in the northern part of Burke County. The existence of a buried channel in the Columbus area supports this assumption.

HYDROLOGY

Subsurface exploration has revealed that almost all continental areas are underlain at varying depths with porous materials that are saturated with water. Any formation of porous sedimentary rock or 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 Artesian Aquifers:

Artesian aquifers are permeable formations or deposits in which water is confined by overlying impermeable strata. Water occupying pore spaces between grains in aquifers of this type is said to be under artesian conditions if the water in a well tapping the aquifer rises above the top of the formation or deposit. The amount of water-level rise above the top of an aquifer is called "head." The water-level in a well constructed in

an artesian aquifer will seek its own level because of a difference in pressure between the top of the aquifer and the land surface. Table 1 illustrates artesian conditions in the buried-channel deposit north of Columbus.

Table 1 - Selected data on observation wells in Columbus area.

Well number	Location	Elev. of land surface*	Water level elevation 3-11-68*	Elev. at the top of gravel interval in which wells are completed*	Artesian head in feet (water level elev. minus gravel elev.)
2895	163-93-19add	1919	1873.4	1523	350.4
2896	163-93-19ccc$_1$	1916	1872.0	1648	224.0
2900	163-93-19dda	1923	1877.5	1739	138.5
3466	163-93-20aaa	1918	1870.0	1535	335.0
2898	163-93-21cbb	1916	1868.9	1762	106.9

* All elevations are in feet above mean sea level.

Withdrawal of ground water from an artesian aquifer by the pumping of a well will lower the pressure head, but the aquifer will remain saturated if sufficient artesian head exists. The quantity of water held in storage is related to the degree of porosity and the saturated volume of confined permeable materials.

Recharge and Discharge:

Recharge occurs when water infiltrates into porous materials either by direct absorption of precipitation or by percolation from streams, lakes, and ponds. Recharge also occurs, although slowly, through relatively impermeable clay and silt overlying sand and gravel deposits. In buried-channel deposits recharge may also occur through the vertical and horizontal

movement of ground water from underlying and surrounding sediments. Primary vertical recharge from the underlying Tongue River Formation and secondary horizontal recharge through the surrounding glacial drift constitute ground-water movement into the Columbus buried channel deposit.

Discharge occurs when ground water is removed from porous materials. Ground water may be lost through evaporation occurring at the surface of soils, lakes, ponds, sloughs, and as transpiration from vegetation, by seepage to streams, or by springs. Discharge may also occur through pumping wells. A few farm wells and the new municipal well (163-93-30bbb$_1$) are the primary sources of discharge occurring in the Columbus buried channel.

Ground-Water Potential In The Columbus Area:

The buried channel deposit encountered during this investigation is here called the Columbus aquifer. The lower interval of sand and gravel within the buried channel appears favorable as a potential source of water for the municipality. The porous materials encountered in test holes 2895 (163-93-19add), 2896 (163-93-19ccc) and 3466 (163-93-20aaa) (fig. 5) generally consist of fine to coarse, angular to rounded, very permeable, sandy gravel. Stratigraphically the gravel immediately overlies and is hydrologically connected with the Tongue River Formation. This hydrologic system is presently at equilibrium because water levels in the Tongue River Formation and the sand and gravel aquifer are essentially equivalent, as indicated by water levels recorded in table 1.

Cross-section A-A' (fig. 4) illustrates the extremely narrow width of gravel occupying the lowest interval in the channel. The aquifer consists of numerous lenses of sand and gravel stratigraphically positioned at different intervals. However, a pumping test conducted at the new city well indicates that the lenses are hydraulically connected to varying degrees.

Boundary conditions will be encountered in portions of the aquifer where permeable sand and gravel pinch out against silt and clay deposits in the channel or the valley walls. A well completed in a lense of sand and (or) gravel or near a valley wall will be subject to the influence of boundary conditions that may result in larger drawdown values. No-flow or restricted-flow boundary conditions will occur in confined aquifers when a well is completed in the aquifer near an impervious valley wall. These conditions will also occur when a well is completed in a lense of sand and (or) gravel bounded on all sides by clay.

Results of Aquifer Test:

An aquifer test was performed during August 1968 on a new city well located approximately $1\frac{1}{2}$ miles northwest of Columbus. The test was under the supervision of R. W. Schmid, ground-water hydrologist for the State Water Commission, with assistance from E. A. Wesolowski of the U. S. Geological Survey.

The test was started at 0800 hours on 22 August and a pumping rate of 398 gpm was maintained for 100 hours. Static water levels in different wells measured at the same time ranged from 26.25 to 51.40 feet below the measuring points, while the final water levels ranged from 26.48 to 66.96 feet. Water samples were taken from all the observation wells, and the production well was periodically sampled during the pumping period. Results of the chemical analyses are listed in table 2.

Locations of wells measured during the pumping test are as follows:

Location	Distance (in feet) from production well
163-93-19add	5,800' ENE
163-93-19ccc$_1$	250' N
163-93-19ccc$_2$	500' N

Location	Distance (in feet) from production well
163-93-19dda	5,300' ENE
163-93-20aaa	11,600' ENE
163-93-21cbb	10,800' ENE
$163\text{-}93\text{-}30bbb_1$	Production Well
$163\text{-}93\text{-}30bbb_2$	500' E
$163\text{-}93\text{-}30bbb_3$	500' E
163-94-22cbb	16,200' W
163-94-25aab	1,000' W

The production well and observation wells are shown on figure 3.

A graphic plot of the drawdown and recovery for the production well and selected observation wells is shown on figure 6. The drawdown and recovery illustration was constructed by plotting the decline in water levels at selected observation wells versus time. A larger decline in water levels occurs at observation wells located closer to the production well than at wells farther away because the degree of drawdown is greater in the immediate vicinity of the pumped well. However, the drawdown and recovery at observation well 2 ($163\text{-}93\text{-}30bbb_2$) was less than at ober-vation wells 1, 3, and 4. This is because observation well 2 was completed at a greater depth in the aquifer system, 460 feet bls (below land surface) compared to 305 feet bls for the production well; therefore, water-level fluctuations in this well reflect the degree of hydraulic connection to the sand and gravel in which observation wells 1, 3, and 4 are completed.

Data from the aquifer test indicate the sand and gravel in the aquifer will yield a sufficient quantity of water for the city of Columbus. The specific capacity of the pumped well was determined by using the formula:

$$S = \frac{Q}{(d_2-d_1)}$$

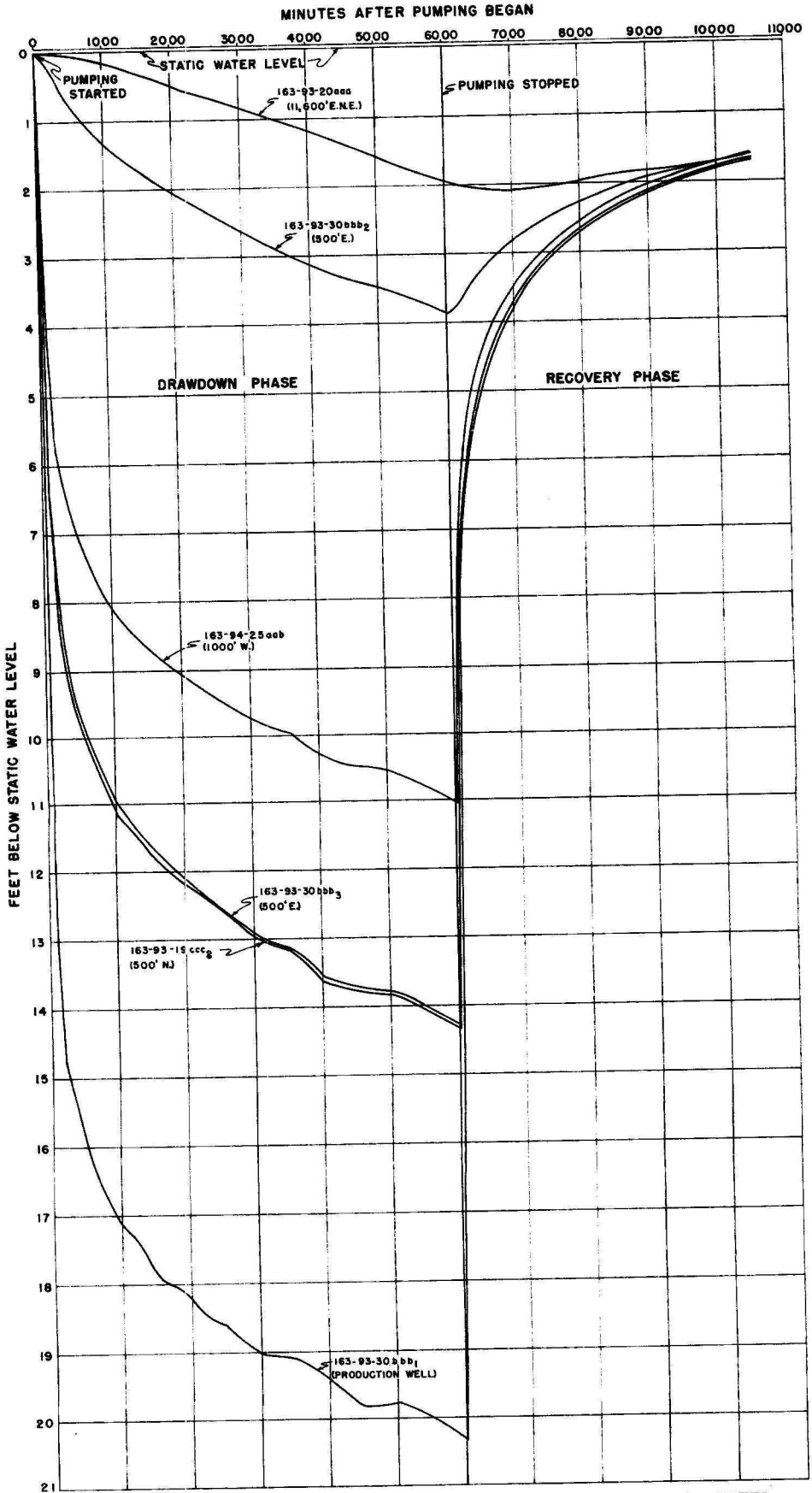


FIGURE 6-DRAWDOWN AND RECOVERY OF PRODUCTION WELL AND SELECTED OBSERVATION WELLS

Where

S = specific capacity in gallons per minute per foot of drawdown

Q = pumping rate in gallons per minute (gpm)

d_1= static water level in feet before pumping began

d_2= water level in feet after 24 hours of pumping at a constant rate

Using 398 gpm as the pumping rate, 46.60 feet as the static water level, and 64.40 feet for the water level after 24 hours of pumping, it was determined that

$$S = \frac{398\text{gpm}}{(64.40\text{ feet}-46.60\text{ feet})} = 22.36\text{gpm/foot of drawdown}$$

Fuctuations in water levels during the pumping period indicate hydraulic continuity within the lower interval of sand and gravel. Future development of the aquifer for industrial purposes is possible, but additional subsurface chemical-quality and aquifer-test data will be needed in order to properly ascertain the true potential. Technical data on transmissibilities, coefficients of storage, and specific yield are available from the State Water Commission (Schmid, 1968).

WATER QUALITY

Ground water is derived from rainfall and snowmelt. The mineral content of ground water, referred to as total dissolved solids, is related to the chemical and physical composition of rocks coming into contact with the ground water, the duration of contact, the temperature, pressure, and gases and minerals already in solution.

Seventeen water samples were collected for complete chemical analysis during the investigation at Columbus. Ten of these represent water quality in the lower portion of the aquifer system (table 2).

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

Silica (SiO_2):

No physiological or esthetic significance

Iron (Fe):

Over 0.3 ppm (parts per million) iron may cause staining of laundry fixtures. Over 0.5 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. It does have an affect on yard use of water.

Potassium (K):

Small amounts are essential to animal nutrition.

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, and may have an affect on yard use.

Sulfate (SO_4):

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

generally has 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:

A limit of 500 to 1,000 ppm is 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	-	1,400 ppm	Average
1,400	-	2,500 ppm	High
Over 2,500 ppm			Very high

TABLE 2 - CHEMICAL ANALYSES

(Analytical results in parts per million except as indicated)

Location	Well depth (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	Total hardness as $CaCO_3$	Total hardness noncarbonate	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos 25°C)	pH
163-93-17ddd	69	Sand	11-16-67	24	3.4	562	179	213	16	500	0.0	2080	20	0.1	0.0	0.30	3590	2140	1730	18	2.0	3630	7.6
163-93-19add	437	Gravel	11-21-67	24	2.9	94	30	532	6.1	1250	0.0	315	119	1.0	0.0	0.19	1760	356	0.0	76	12.0	2620	7.9
163-93-19ccc$_1$	295	Gravel	12- 4-67	27	0.2	35	22	580	7.4	1080	0.0	456	98	1.4	0.0	0.34	1760	180	0.0	87	19.0	2640	8.1
163-93-19ccc$_2$	290	Gravel	9-12-68	28	0.24	131	27	478	8.7	987	0.0	568	92	0.9	0.0	0.59	1850	438	0.0	70	9.9	2640	8.2
163-93-19dda	140	Gravel	12- 8-67	24	0.48	225	55	293	12	380	0.0	1100	25	0.1	0.0	0.44	2000	788	476	44	4.5	2440	7.8
163-93-20aaa	459	Gravel	6-28-67	23	2.4	56	22	572	7.2	1110	0.0	420	98	1.0	8.0	0.35	1760	230	0.0	84	16.0	2670	7.8
163-93-21cbb	175	Gravel	12- 6-67	24	2.0	80	80	631	9.2	981	0.0	960	101	1.6	0.0	0.34	2380	529	0.0	72	12.0	3300	8.0
163-93-22cab	172	Gravel	12- 7-67	9.9	3.1	113	45	729	8.6	575	0.0	1500	35	0.7	0.0	0.44	2800	468	0.0	77	15.0	3680	7.9
163-93-30bbb$_1$ ***	305	Sand & gravel	8- 9-68	23	0.24	57	15	622	7.7	1220	0.0	446	91	2.2	0.3	0.49	1870	205	0.0	86	19.0	2790	8.1
163-93-30bbb$_1$ ***	305	Sand & gravel	8-10-68					585				439										2780	
163-93-30bbb$_1$ ***	305	Sand & gravel	8-14-68																			2780	
163-93-30bbb$_1$	305	Sand & gravel	8-15-68																			2790	
163-93-30bbb$_1$ ***	305	Sand & gravel	8-22-68	22	0.07	63	15	639	7.6	1250	0.0	447	88	2.1	1.0	0.39	1890	218	0.0	86	19.0	2800	8.0
163-93-30bbb$_1$ ***	305	Sand & gravel	8-23-68																			2830	
163-93-30bbb$_1$	305	Sand & gravel	8-24-68					626				491										2870	

Table 2 - CHEMICAL ANALYSIS

(Analytical results in parts per million except as indicated)--continued

Location	Well depth (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	Total hardness as $CaCO_3$	Total hardness noncarbonate	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos 25°C)	pH
*** 163-93-30bbb$_1$	305	Sand & gravel	8-25-68																			2830	
163-93-30bbb$_1$	305	Sand & gravel	8-26-68	22	0.10	64	17	642	7.6	1180	0.0	536	83	1.9	0.0	0.44	1950	230	0.0	85	18.0	2850	8.0
163-93-30bbb$_2$	460	Gravel	9-12-68	29	1.0	54	8.6	676	7.2	1630	0.0	149	151	2.2	0.0	0.20	1810	170	0.0	89	23.0	2850	8.1
163-93-30bbb$_3$	291	Gravel	9-11-68	27	0.0	88	40	440	9.2	783	0.0	597	97	0.4	0.0	0.44	1680	385	0.0	71	9.8	2450	7.9
163-93-32bdb**	275	Sandstone	11-16-67	6.3	0.34	4.6	2.1	882	3.1	1960	0.0	2.1	236	2.9	0.0	0.07	2150	20	0.0	99	88.0	3360	8.2
163-94-22cbb1	100	Gravel	7-14-68	23	0.60	130	48	360	9.0	736	0.0	693	14	0.2	0.0	0.49	1750	523	0.0	59	6.8	2240	7.8
163-94-25aab	293	Gravel	9-11-68	28	0.06	85	26	553	8.5	1010	0.0	618	66	1.6	0.0	0.49	1900	321	0.0	78	13.0	2710	8.0
163-94-31dcc	25	Sand	4-19-67	17	0.62	151	38	489	4.0	663	0.0	982	41	0.1	22	0.23	2040	533	0.0	66	9.2	2780	8.1

*Chemical analysis by the North Dakota State Laboratories Department, Bismarck, North Dakota

**Chemical analysis of city wells (mixture)

***Partial analysis

Hardness:

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

pH:

Should be between 7.0 and 9.0 for domestic consumption.

Percent Sodium, Sodium Adsorption Ratio; Specific Conductance:

Are factors used in determining irrigation feasibility.

Ground-water quality in the buried channel varies considerably. Water samples from the bottom intervals of gravel encountered in the channel indicated a hard, sodium bicarbonate type of water. Water quality from test holes 2895 (163-93-19add), 2896 (163-93-19ccc$_1$), 3466 (163-93-20aaa) and the new city well (163-93-30bbb$_1$) can be summarized as low to high in hardness, high in sulfates, and high in total dissolved solids. The dissolved iron content ranges from 0.06 ppm in test hole 4 (163-94-25aab) to 3.4 ppm in test hole 3467 (163-93-17ddd).

Several water samples collected during the aquifer test at the new city well (163-93-30bbb$_1$) indicated a slight deterioration in water quality. This probably resulted from the migration of poorer quality water from a nearby lense of sand and gravel. Iron content at the start of the aquifer test was 0.24 ppm and at completion was 0.10 ppm. This is below the

recommended maximum level of 0.3 ppm; therefore, the water should not require treatment and removal of iron for municipal use. Because of high sodium and salinity hazards the water may be detrimental to lawns.

SUMMARY

A city well ($163\text{-}93\text{-}3\text{-}bbb_1$) was installed during late July and early August 1968 approximately 250 feet south of test hole 2896 ($163\text{-}93\text{-}19ccc_1$). The well is 305 feet deep and is completed with 280 feet of 8-inch diameter steel casing and 25 feet of 6-inch diameter #90-slot stainless-steel screen. A 10 hp electric motor powers a vertical turbine pump and supplies water to the city of Columbus at a rate of 100 gpm. The water is piped into Columbus through approximately $1\frac{1}{2}$ miles of 6-inch diameter transite (cement) pipeline.

Data from the pumping test performed on the new city well indicate the aquifer will yield a sufficient quantity of water for the city of Columbus. Water quality did deteriorate slightly during the aquifer test. The concentration of total dissolved solids increased from 1,870 ppm to 1,950 ppm and hardness increased from 205 ppm to 230 ppm. The dissolved iron content decreased from 0.24 ppm to 0.10 ppm and is below the recommended maximum tolerance of 0.30 ppm. Deterioration of water quality indicates the apparent migration of poorer quality water from other areas of the aquifer system to the vicinity of the new city well. Water quality, specifically hardness, could be improved by the installation of a municipal water-softening facility.

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.

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: C.A., chemical analysis; logs in table 4.

Location no.	Owner	Depth (feet)	Diameter (inches)	Type	Date completed	Depth to water below land surface (feet)	Date of measurement	Use of water	Aquifer	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
163-93-7ba			2 1/2	Dr.	1917	40	9-10-45	S		
163-93-7dc		55.0	24	Bo.	1919	50	5-22-46	S	Sand	
163-93-8ad$_1$	Russel Uleberg	204.0	5	Dr.	1918	73.08	5-23-46	S	Sandstone	
163-93-8ad$_2$	Russel Uleberg	42.0	12	Bo.	1916	9.05	5-23-46	D	Sand	
163-93-8cb	Henry Tyndall	40.0	18	Bo.	1913	32	9-10-45	D,S		
163-93-9da	Levi Nygaard	60.0	2	Dr.	1912	40	5-24-46	S	Lignite	
163-93-10ad$_1$	James Murphy	65.0	12	Bo.	1905	29.26	5-24-46	D,S		
163-93-10ad$_2$	James Murphy	25.0	18	Bo.	1912	22.01	5-24-46	U		
163-93-10cb		69.0	12	Bo.	1922	40.17	5-24-46	S	Sand	
163-93-15ba$_1$	J. Stompro	50.0	18	Bo.	1916	32.55	9-13-45	S		
163-93-15ba$_2$	J. Stompro		3	Dr.	1918			S		
163-93-17ad			10	Bo.	1917	24.99	5-23-46	S		
163-93-17ddd	Test hole 3467	69.0	1 1/4	Dr.	1967	16.20	11-28-67	T	Gravel	See log, C. A.
163-93-18aaa	Test hole 2894	120	4 3/4	Dr.	1967			T		See log
163-93-18cd		150	3	Dr.	1926	60	5-15-46	U		

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

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
163-93-19aaa	Test hole 2893	460	4 3/4	Dr.	1967			T		See log
163-93-19add	Test hole 2895	437	1 1/4	Dr.	1967	46.10	11-28-67	T	Gravel	See log, C. A.
163-93-19bb	E. Kihle	60	36	Du.	1921	56.16	5-15-46	S	Sand	
163-93-19bcc	Test hole 2897	265	4 3/4	Dr.	1967			T		See log
163-93-19ccc$_1$	Test hole 2896	295	1 1/4	Dr.	1967	44.30	11-28-67	T	Gravel	See log, C. A.
163-93-19ccc$_2$	Test hole 1	290	1 1/4	Dr.	1968	50.59	9-12-68	T	Gravel	See log, C. A.
163-93-19dd	John Salveson	150	3	Dr.	1924	56.07	5-15-46	S	Sandstone	
163-93-19dda	Test hole 2900	140	1 1/4	Dr.	1967	47	11-28-67	T	Gravel	See log, C. A.
163-93-20aaa	Test hole 3466	459	4	Dr.	1967	52	11-27-67	T	Gravel	See log, C. A.
163-93-20bb	Reves	265	3	Dr.	1925	56.06	5-23-46	D,S	Sandstone	
163-93-20cc$_1$	Selmer Salveson	102	12	Bo.	1926	39.01	5-15-46	S	Gravel	
163-93-20cc$_2$	Selmer Salveson	34	18	Bo.	1927	15.30	5-15-46	U		
163-93-20ccc	Test hole 2892	200	4 3/4	Dr.	1967			T		See log
163-93-21ab			12	Bo.	1924	30.07	5-15-46	U		
163-93-21cbb	Test hole 2898	175	1 1/4	Dr.	1967	46.50	11-28-67	T	Gravel	See log, C. A.
163-93-22cab	Henry T. Swenson	172	6	Dr.	1952	52.64	11-21-67	U	Gravel	C. A.
163-93-22cdd	Test hole 2899	240	4 3/4	Dr.	1967			T		See log
163-93-22dd	Henry T. Swenson	65	12	Bo.	1924	36.09	5-24-46	S	Gravel	
163-93-27da		44	12	Bo.	1930	8.08	5-24-46	U		
163-93-28ab	George Wanamaker	40	6	Bo.	1928	17.55	9-11-45	D		
163-93-28dc	E. Ely	54	12	Bo.	1927	15.07	5-24-46	S		
163-93-28dd	H. Ringwall	110	4	Dr.	1932	18	5-24-46	D,S		
163-93-29cd	Alfred A. Koppenlslon	200	5	Dr.	1927	36.07	5-23-46	S		
163-93-29dd	Mrs. Z. Kvnernum	82	12	Bo.	1929	28.09	5-23-46	D,S		
163-93-29ddd	Test hole 3391	140	4 3/4	Dr.	1967			T		See log
163-93-30bb	O. Hanson		18	Bo.	1917	15.62	5-22-46	D,S		
163-93-30bbb$_1$	New City Well	305	8	Dr.	1968	46.60	8-26-68	D	Sand & gravel	C. A.
163-93-30bbb$_2$	Test hole 2	460	1 1/4	Dr.	1968	48.00	9-12-68	T	Gravel	See log, C. A.
163-93-30bbb$_3$	Test hole 3	291	1 1/4	Dr.	1968	47.37	9-11-68	T	Gravel	See log, C. A.
163-93-30dcc	Test hole 2889	100	4 3/4	Dr.	1967			T		See log

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

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
163-93-30ddd	Test hole 2891	160	4 3/4	Dr.	1967			T		See log
163-93-31aa	Clarence Shepstad	24	24-12	Bo.	1927	16.13	5-22-46	D,S	Sand & Gravel	
163-93-31ba$_1$	Charles Darras	39	24	Bo.	1923	16.04	5-22-46	S		
163-93-31ba$_2$	Charles Darras	38	12	Bo.	1924	12.02	5-22-46	S		
163-93-31dd	G. Auran	18	36	Du.	1931	14	5-22-46	D,S		
163-93-32ab	Bonasness	40	18	Bo.	1932	36	5-24-46	S	Sand	
163-93-32ba		20	120	Du.				D	Sand	
163-93-32bbd	City of Columbus	160	6	Dr.	1925	9.28	9-11-45	U	Lignite	Abandoned
163-93-32bcd	City well 1	314	6	Dr.	1954			PS	Sandstone	Soft
163-93-32bdb$_1$	City of Columbus	270	6	Dr.	1928			U	Sandstone	Abandoned
163-93-32bdb$_2$	City well 2	277	6	Dr.	1954	120		PS	Sandstone	Soft
163-93-32bdc	City well 3	295	6	Dr.	1963	120		PS	Sandstone	Soft, some gas
163-93-32bdd$_1$	City of Columbus	297	6	Dr.	1949	130	3-68	U	Sandstone	Soft, some gas, abandoned
163-93-32bdd$_2$	City well 4	275	6	Dr.	1967			PS	Sandstone	Soft
163-93-34cc$_1$	Anton Vigen	18	48	Du.	1936	13.09	5-27-46	S		
163-93-34cc$_2$	Anton Vigen	22	18	Bo.	1936	16	5-27-46	U	Sand	
163-94-7aa$_1$	Norman Sims	70	36-18	Du.Bo.		31.16	5-17-46	S	Lignite	
163-94-7aa$_2$	Norman Sims	15	24	Du.		9.16	5-16-46	D	Sand	
163-94-9ab$_1$	Robert Slater	22		Bo.		21.00	5-20-46	U	Gravel	
163-94-9ab$_2$	Robert Slater	48	14	Bo.		17.25	5-20-46	D,S	Sand	
163-94-10cd$_1$	A. B. Peterson	46	36-18	Du.Bo.	1908	24.25	9-10-45	D,S	Sand	
163-94-10cd$_2$	A. B. Peterson	38	18	Bo.	1905	20.75	5-21-46	S		
163-94-11ab	L. Sorum	125	4	Dr.	1920	85.43	5-21-46	S		
163-94-12dc	O. Brenno	96		Dr.	1917	78.28	5-22-46	S	Sandstone	
163-94-13dd	Anton Brenno Estate	23	18	Bo.	1922	15.50	5-22-46	U		
163-94-14aa	John Brenno	20	12	Du.	1917	16.50	5-22-46	D,S	Sand	
163-94-14cc			5	Dr.	1918	62.21	5-21-46	U		
163-94-14cd		34	12	Bo.	1928	15.66	5-24-46	U		
163-94-15ba	A. B. Peterson	23	12	Bo.	1910	20.33	5- -46	D	Sand	
163-94-15cc	Amos Peterson	150	2 1/2	Dr.	1903	65.00	5-21-46	S	Sandstone	

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

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
163-94-15da$_1$	Carl Sorum	280	3	Dr.	1909	77.41	5-21-46	S	Sand	
163-94-15da$_2$	Carl Sorum	30	12	Bo.	1910	24.75	5- -46	S		
163-94-15dd	U.S. Geological Survey	166	4 3/4	Dr.	1907	18.16	8-25-47	T		
163-94-16daa	Test hole 3597	180	4 3/4	Dr.	1968			T		See log
163-94-17da$_1$	Anton Starr	160	2 1/2	Dr.		60.00	5-17-46	S	Sandstone	
163-94-17da$_2$	Anton Starr	25	24	Bo.		10.02	5-17-46	D	Gravel	
163-94-19cc	Louis Somerness		18	Bo.		29.33	5-16-46	S	Sand	
163-94-19daa	Test hole 3603	60	4 3/4	Dr.	1968			T		See log
163-94-20bbb	Test hole 3604	160+	4 3/4	Dr.	1968			T		See log
163-94-20ca	G. Dahl	240	6	Dr.		65.00	5-17-46	S	Sandstone	
163-94-21bc	State of North Dak.	55	36-14	Du.		50.66	5-17-46	D,S	Gravel	
163-94-21cb	J. Dalebout	100	14	Bo.		41.50	5-17-46	D		
163-94-21cbb	Test hole 3602	400	4 3/4	Dr.	1968			T		See log
163-94-21dd		113	3 1/2	Dr.		35.75	5-21-46			
163-94-22bbc	Test hole 3599	240	4 3/4	Dr.	1968			T		See log
163-94-22cbb$_1$	Test hole 3596	100	1 1/4	Dr.	1968	26.02	7-14-68	T	Gravel	See log, C. A.
163-94-22cbb$_2$	Test hole 3600	190	4 3/4	Dr.	1968			T	Gravel	See log
163-94-22cc	Lars Horntvedt	198	2 1/2	Dr.	1911	48.00	5-21-46	D,S	Sandstone	
163-94-22db		98	3	Dr.	1912	55.09	5-21-46	S		
163-94-23ab	E. O. Brenell	110	18	Bo.	1927	67.60	5-22-46	S		
163-94-23ba	Henry Gurerhan	86	18	Bo.	1923	65.08	5-21-46	S	Gravel	
163-94-23cd	U.S. Geological Survey	231	4 3/4	Dr.	1918	32.80	8-25-67	T		
163-94-23db$_1$	Julian O. Shefstad	28	36-24	Du.	1918	17.75	5-22-46	S	Sand	
163-94-23db$_2$	Julian O. Shefstad	26	18	Du.	1908	17.40	5-22-46	D		
163-94-24aa	Anton Brenno Estate	200	4	Dr.	1917	94.08	5-22-46	S		
163-94-25aab	Test hole 4	293	1 1/4	Dr.	1968	46.16	9-11-68	T	Gravel	See log, C. A.
163-94-25ba	Leroy Iverson	22	36	Du.	1919	11.50	5-22-46	D,S	Sand	
163-94-26ba$_1$	Harold Gunlock	20	36	Du.	1916	7.33	5-22-46	S		
163-94-26ba$_2$	Harold Gunlock	29	18	Bo.	1918	7.10	5-22-46	S		
163-94-26cb	Jacob Kleppen	90	5	Dr.	1917	52.08	5-21-46	S		

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

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
163-94-26dd$_1$	John Iverson	30	18	Bo.	1918	12.09	5-22-46	D	Sand	
163-94-26dd$_2$	John Iverson	14	36	Du.	1919	12.82	5-22-46	U	Sand	
163-94-27cbb	Test hole 3594	120	4 3/4	Dr.	1968			T		See log
163-94-27ccc	Test hole 3595	40	4 3/4	Dr.	1968			T		See log
163-94-28ad	Martin Tandberg	25		Du.		10.95	9-10-45	D,S	Sand	
163-94-28cd$_1$	W. Kleinert	22	14	Bo.		14.08	5-17-46	D	Sand	
163-94-28cd$_2$	W. Kleinert	12	48	Du.		5.25	5-17-46	U	Sand	
163-94-29aaa	Test hole 3601	40	4 3/4	Dr.	1968			T		See log
163-94-30ad	C. Darras	309	4	Dr.		47.01	5-16-46	D,S	Sandstone	
163-94-31dcc	A. F. Shefstad	25	24	Bo.		14.09	9-11-45	S		C. A.
163-94-32bd	Hans Rolie	80	18-3	Bo.		1.00	5-17-46	S		
163-94-32dd	Lincoln Fire Ins. Co.	47	12	Bo.		14.66	5-17-46	U		
163-94-33aa$_1$	Hans Nordum	270	2 1/2	Dr.		40.00	9-10-45	S		
163-94-33aa$_1$	Hans Nordum	15	12	Bo.		7.08	5-17-46	D		
163-94-34aa^2	Otto Pasche	74	24	Bo.	1926	63.67	5-21-46	S	Gravel	
163-94-34cd$_1$	Frank Myers	48	2	Dr.		20.00	5-24-46	S	Sand	
163-94-34cd$_2$	Frank Myers	52	10	Bo.		11.57	5-24-46	U		
163-94-34cd$^2_3$	Frank Myers	12	36	Du.		6.05	5-24-46	D		
163-94-34dd^3	Westly Brenno	51	18	Bo.	1927	39.58	5-23-46	S		
163-94-36abb	Test hole 2890	100	4 3/4	Dr.	1967			T		See log

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 Pettijohn (1957).

Elevations are based on mean sea level datum as represented on the Atcoal, Columbus and Stampede, N. Dak., U. S. Geological Survey, topographic maps.

163-93-17ddd
Test hole 3467
Elevation 1,918 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial drift:				
	Topsoil, silty, sandy, clayey, yellowish-brown	1	0	1
	Clay, silty, yellowish-brown to medium dark gray, calcareous, moderately cohesive, oxidized	22	1	23
	Sand, silty, pebbly, coarse to very coarse, angular to subangular, poorly sorted, mostly shale and limestone with some light-colored granitic fragments, oxidized	15	23	38
	Clay, silty, pebbly, moderate olive brown, slightly cohesive, calcareous, (till)	10	38	48
	Gravel, silty, sandy, medium to coarse, angular to subangular, poorly sorted, mostly limestone and dolostone with some shale and light-colored granitic rocks	9	48	57
	Clay, silty, pebbly, olive gray, cohesive, calcareous, (till)	5	57	62
	Gravel, very sandy, fine to medium, angular to subrounded, sorting is fair, mostly shale and limestone with some granitics	11	62	73
	Clay, silty, pebbly, olive gray, moderately cohesive, calcareous, limestone and dolostone grains, granules and pebbles present, (till)	7	73	80

Observation well

163-93-18aaa
Test hole 2894
Elevation 1,917 feet

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 with a few moderate reddish-brown laminations, slightly to moderately cohesive, slightly to moderately plastic, calcareous, oxidized (till) ----------	23	1	24
	Clay, silty, sandy, olive gray, moderately cohesive to cohesive, moderately plastic, calcareous, numerous limestone, lignite, and shale grains, granules, and a few pebbles, (till) ----------	65	24	89
Tongue River Formation:				
	Lignite, black, slightly indurated ------	1	89	90
	Shale, siliceous, light gray to light bluish-gray, moderately indurated, non-calcareous ----------	30	90	120

163-93-19aaa
Test hole 2893
Elevation 1,916 feet

Glacial drift:				
	Topsoil, silty, sandy, brownish-black ---	1	0	1
	Clay, silty, sandy, moderate yellowish-brown with a few moderate reddish-brown laminations, moderately cohesive, plastic, oxidized, (till) ----------	11	1	12
	Clay, silty, sandy, olive gray, moderately cohesive, moderately plastic, calcareous, numerous limestone, dolostone and shale grains and granules (till) ----------	93	12	105
	Sand, fine to coarse-grained, angular to subrounded, fair sorting, mostly quartz and limestone with some granitic fragments, poor samples ----------	2	105	107
	Clay, silty, sandy, gravelly, olive gray, moderately cohesive to cohesive, slightly to moderately plastic, calcareous, numerous limestone, shale, and lignite grain, granules, and pebbles, (till) ----------	27	107	134
	Clay, very silty, sandy, olive gray with a few light gray laminations, slightly cohesive, non-plastic, very calcareous, (fluvial sediment) ----------	116	134	250

163-93-19aaa
Test hole 2893 (Cont.)
Elevation 1,916 feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Clay, very sandy, very silty, olive gray to dark greenish-gray, slightly cohesive, non-plastic, very calcareous, interbedded with sand (mostly limestone, quartz, and lignite), (fluvial sediment) ----------	65	250	315
	Clay, silty, olive gray, moderately cohesive to cohesive, moderately plastic, calcareous, numerous limestone, dolostone, shale, and lignite grains, granules, and pebbles (till) ----------	36	315	351
	Gravel, fine to coarse, angular to sub-rounded, fair sorting, approximately 30-40 percent limestone and dolostone; remainder being shale, chalcedony and granitic rocks ----------	5	351	356
	Clay, silty, sandy, gravelly, olive gray to moderate brown, slightly to moderately cohesive, slightly plastic, calcareous, (till) ----------	24	356	380
	Clay, silty, sandy, gravelly, olive gray to moderate brown, slightly to moderately cohesive, moderately plastic, calcareous (till) ----------	68	380	448
Tongue River Formation:				
	Shale, siliceous, light bluish-gray, indurated, non-calcareous ----------	12	448	460

163-93-19add
Test hole 2895
Elevation 1,919 feet

Glacial drift:				
	Topsoil, silty, sandy, brownish-black -----	1	0	1
	Clay, sandy, silty, moderate yellowish-brown with a few moderate reddish-brown layers, slightly to moderately cohesive, moderately plastic, calcareous, oxidized (till) ----------	19	1	20
	Clay, silty, sandy, olive gray, slightly cohesive, slightly plastic, very calcareous, numerous limestone, shale, and lignite grains and granules, (till) -----	18	20	38

163-93-19add
Test hole 2895 (cont.)
Elevation 1,919 feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Clay, very sandy, silty, olive gray with light gray laminations, slightly cohesive, very slightly plastic, calcareous, (fluvial sediment)	50	38	88
	Clay, sandy, silty, gravelly, olive gray, moderately cohesive to cohesive, slightly plastic, calcareous, numerous limestone, dolostone, shale, and lignite grains, granules, and a few pebbles (till)	109	88	197
	Clay, very sandy with a few light gray laminations, silty, olive gray, slightly cohesive, slightly plastic, very calcareous (fluvial sediment)	10	197	207
	Clay, silty, sandy, gravelly, olive gray, moderately cohesive to cohesive, non-plastic to slightly plastic, calcareous, numerous limestone, dolostone, shale, and lignite grains, granules, and a few pebbles (till)	43	207	250
	Clay, very silty, sandy, olive gray to dark greenish-gray with a few brownish-black laminations, cohesive, slightly plastic, very calcareous, (fluvial sediment)	25	250	275
	Gravel, fine to coarse, angular to rounded, fair sorting, approximately 40-50 percent yellowish-gray limestone, and grayish-orange dolostone; remainder being granitic rocks, quartz, dark yellowish-brown to grayish-black shale, light brownish-gray to light gray, calcareous, sandstone	10	275	285
	Clay, sandy, silty, gravelly, olive gray, moderately cohesive to cohesive, moderately plastic, calcareous, numerous limestone, dolostone, quartz, shale and granite grains, granules, pebbles, and a few cobbles (till)	15	285	300
	Gravel, fine to coarse, angular to rounded, fair sorting, approximately 10-20 percent moderate brown, translucent, chalcedony, 10-15 percent dark gray to grayish-black, non-calcareous, shale, 20-30 percent yellowish-gray to light gray limestone and grayish-orange dolostone; remainder being granitic rocks, milky quartz, grayish-red, cemented sandstone	7	300	307
	Clay, very sandy, silty, olive gray to light gray, very calcareous, moderately cohesive, plastic, (fluvial sediment)	3	307	310
	Gravel, fine to coarse, angular to rounded, fair sorting, mostly limestone, dolostone, shale, with some granitic rocks, quartz, and sandstone	17	310	327

163-93-19add
Test hole 2895 (cont.)
Elevation 1,919 feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Clay, sandy, silty, gravelly, olive gray, cohesive, slightly plastic to non-plastic, very calcareous, (till) -----	23	327	350
	Clay, very sandy, silty, olive gray, slightly to moderately cohesive, slightly plastic to non-plastic, very calcareous (fluvial sediment) ----------	25	350	375
	Clay, silty, olive gray, cohesive, slightly plastic, calcareous, numerous limestone, dolostone, shale, and quartz grains and granules (till) ----------	5	375	380
	Sand, gravelly (approximately 25-35 percent fine to medium, angular to subrounded gravel), fine to medium-grained, angular to subrounded, moderately well-sorted, approximately 75-85 percent quartz; remainder being limestone, granitics, lignite, and shale ----------	15	380	395
	Clay, sandy, silty, olive gray, cohesive, non-plastic to slightly plastic, calcareous, (till) ----------	1	395	396
	Sand, gravelly (approximately 35-45 percent fine to medium, angular to subrounded gravel), medium to very coarse, angular to subrounded, moderately well-sorted ---	24	396	420
	Gravel, sandy (approximately 20-30 percent coarse to very coarse, angular to rounded sand, with the sand content decreasing towards bottom of section), fine to coarse with cobble and boulder size material lower 5-6 feet of section, angular to rounded, fairly well-sorted, approximately 45-55 percent siliceous rocks including: grayish-orange to light brown, translucent chalcedony, reddish and greenish granitics, porphyritic volcanics (basalt), dark reddish-brown quartzite; remainder being grayish-black to moderate olive brown shale, dark yellowish-brown, calcareous sandstone, yellowish-gray limestone and grayish-orange dolostone, lost circulation ----------	56	420	476
Tongue River Formation:				
	Sandstone, clayey, light bluish-gray to greenish-gray, fine to medium-grained, consolidated, non-calcareous, not cemented ----------	4	476	480

Observation well

163-93-19bcc
Test hole 2897
Elevation 1,925 feet

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, moderately cohesive, plastic, calcareous, numerous limestone, dolostone, shale, and lignite grains, granules, and a few pebbles, oxidized (till) ---------	24	1	25
	Clay, very sandy (approximately 40-50 percent medium to coarse grained, angular to subrounded sand), silty, olive gray to dark greenish-gray, slightly cohesive, very slightly plastic, calcareous, (till) ----------	49	25	74
	Clay, silty, sandy to very sandy, olive gray, slightly to moderately cohesive, slightly plastic, calcareous, numerous limestone, dolostone, shale, and lignite grains, granules, and a few pebbles (till) ----------	66	74	140
	Clay, very silty, sandy, olive gray with a few light gray laminations, cohesive, moderately plastic to plastic, calcareous, (fluvial sediment) ----------	72	140	212
	Clay, silty, sandy, olive gray, slightly to moderately cohesive, moderately plastic, calcareous, numerous limestone, dolostone, shale, and lignite grains and granules (till) ----------	24	212	236
	Clay, very silty, sandy, olive gray with a few light gray laminations, cohesive, plastic, calcareous, (fluvial sediment)--	6	236	242
Tongue River Formation:				
	Sandstone, clayey, medium bluish-gray, fine to medium-grained, consolidated, not cemented, slightly calcareous, lignitic --	15	242	257
	Shale, siliceous, medium dark gray, indurated, slightly calcareous ----------	8	257	265

Electric log

163-93-19ccc
Test hole 2896
Elevation 1,916 feet

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 dark yellowish-brown with a few moderate reddish-brown laminations, slightly to moderately cohesive, oxidized (till) ---	24	1	25
	Clay, silty, sandy, gravelly, olive gray, very cohesive, slightly to moderately plastic, calcareous, numerous angular to subrounded, limestone, dolostone, granitic and lignite grains, granules and a few cobbles (till) ----------	75	25	100
	Clay, silty, sandy, gravelly, olive gray to dark gray, cohesive to moderately cohesive, slightly to moderately plastic, calcareous, numerous limestone, dolostone, granitic, shale, lignite grains and granules with a few pebbles and cobbles (till) ---------	50	100	150
	Clay, very silty, sandy, olive gray with a few light olive gray laminations, moderately cohesive, plastic, very calcareous, (fluvial sediment) ----------	30	150	180
	Clay, sandy, silty, gravelly, olive gray, cohesive, slightly plastic to plastic, calcareous, (till) ----------	33	180	213
	Sand, clayey, medium to coarse, angular to subrounded, moderately well-sorted, mostly limestone, quartz and granitics, poor samples ----------	4	213	217
	Clay, sandy, silty, gravelly, olive gray to dark greenish-gray, cohesive, slightly plastic, calcareous, numerous limestone, dolostone, shale, and lignite grains, granules, and pebbles (till) ----------	51	217	268
	Gravel, sandy (approximately 20-30 percent coarse to very coarse, angular to subrounded sand), fine to coarse, angular to rounded, fairly well-sorted, approximately 25-35 percent yellowish-gray limestone and very pale orange to grayish-orange dolostone, 20-30 percent grayish-black to brownish-black shale, 5-10 percent biotitic granitics; remainder being light brown to moderate yellowish-brown, translucent to opaque chalcedony, light olive gray to medium dark gray, calcareous siltstone, grayish-red to greenish-gray, calcareous sandstone, gneiss (micaceous), lost circulation ----------	30	268	298

163-93-19ccc$_1$
Test hole 2896 (cont.)
Elevation 1,916 feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Gravel, clayey, sandy, medium to coarse, angular to rounded, fair sorting, mostly limestone and dolostone with some shale, granitics, sandstone, siltstone, cobble and boulder size material toward bottom of section, lost circulation ----------	32	298	330

Observation well
Electric log

163-93-19ccc$_2$
Test hole 1
Elevation 1,918 feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial drift:	Topsoil, silty, clayey, sandy, black----------	1	0	1
	Clay, silty, sandy, pebbly, moderate yellowish-brown, oxidized (till) ----------	19	1	20
	Clay, silty, sandy, pebbly, occasional cobbles and boulders, olive gray (till) ----	154	20	174
	Gravel, sandy ----------	29	174	203
	Clay, silty, sandy, pebbly, olive gray (till)-	22	203	225
	Gravel, sandy, numerous cobbles ----------	5	225	230
	Clay, silty, sandy, pebbly, olive gray (till)-	32	230	262
	Gravel, sandy ----------	28	262	290

Observation well
Electric log

163-93-19dda
Test hole 2900
Elevation 1,923 feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial drift:				
	Topsoil, sandy, silty, brownish-black --------	1	0	1
	Clay, sandy, silty, moderate yellowish-brown, moderately cohesive, moderately plastic, oxidized (till) ----------	11	1	12
	Clay, silty, sandy, gravelly, olive gray, cohesive, slightly plastic, calcareous, numerous limestone, dolostone, granitic, and lignite grains, granules, and pebbles (till) ----------	48	12	60
	Clay, very silty, sandy, olive gray with light olive gray laminations, cohesive, plastic, very calcareous, (fluvial sediment) ----------	13	60	73

163-93-19dda
Test hole 2900 (cont.)
Elevation 1,923 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
	Gravel, clayey, sandy (approximately 25-35 percent coarse to very coarse, angular to subrounded sand), fine to medium, angular to subrounded, poorly sorted, mostly limestone, dolostone and shale ----------	1	73	74
	Clay, silty, sandy, gravelly, olive gray with a few grayish-brown to grayish-green laminations, slightly to moderately cohesive, moderately plastic, very calcareous, (till)----------	59	74	133
	Gravel, sandy (approximately 25-35 percent angular to subrounded, fine to coarse sand), fine to coarse, angular to subrounded, moderately well-sorted, approximately 60-70 percent yellowish-gray limestone and grayish-yellow dolostone; remainder being shale and granitics ----------	11	133	144
	Clay, silty, sandy, gravelly, olive gray, moderately cohesive, slightly plastic, calcareous (till) ----------	40	144	184
	Gravel, sandy (approximately 20-30 percent medium to very coarse, angular to subrounded sand), fine grading to coarse, angular to rounded, moderately well-sorted, approximately 45-55 percent siliceous rocks: moderate olive brown to moderate red, translucent chalcedony, moderate red jasper; remainder being grayish-olive green, calcareous, cemented sandstone, yellowish-gray limestone, a few granitic rocks and scoria ----------	33	184	217
Tongue River Formation:				
	Shale, light gray to medium light gray, moderately indurated, very calcareous, lignitic ----------	43	217	260

Observation well
Electric log

163-93-20aaa
Test hole 3466
Elevation 1,918 feet

Glacial drift:				
	Topsoil, silty, sandy, brownish-black -----	1	0	1
	Clay, silty, sandy, yellowish-brown, moderately cohesive, calcareous, oxidized (till) ---	32	1	33

163-93-20aaa
Test hole 3466 (cont.)
Elevation 1,918 feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Gravel, coarse, angular to subangular, moderately well-sorted, approximately 35-40 percent shale with some limestone, quartz, and light-colored granitic rocks--	10	33	43
	Clay, very silty, sandy, moderate olive brown with some light olive brown laminations, lignitic, (till) ----------	8	43	51
	Gravel, sandy, medium to coarse, angular to subrounded, moderately well-sorted, approximately 50 percent limestone, 20 percent shale, with some light-colored granitic rocks, a few large (18-22 mm) dolostone pebbles -------	18	51	69
	Clay, silty, medium dark gray to dark gray, cohesive, calcareous, (till) ----------	31	69	100
	Clay, silty gravelly, medium dark gray to dark gray, cohesive, calcareous, (till)---	20	100	120
	Silt, clayey, light gray, slightly cohesive, calcareous (fluvial sediment) ----------	16	120	136
	Gravel, coarse, angular to subrounded, moderately well-sorted, predominantly limestone and shale, with some granitic rocks ----------	5	136	141
	Silt, extremely sandy, light gray, slightly cohesive, very calcareous, sand is very fine-grained (fluvial sediment) ----------	6	141	147
	Sand, silty, very fine to fine-grained, subangular to subrounded, well-sorted, > 50 percent quartz with some limestone, shale and light-colored granitic fragments -----	16	147	163
	Clay, extremely silty, light gray to medium light gray, slightly cohesive, calcareous, (till) ----------	37	163	200
	Gravel, sandy, medium to coarse, angular to subangular, poorly-sorted, the sand is coarse-grained ----------	3	200	203
	Clay, medium dark gray, very cohesive, calcareous, a few sand grains present, (till) ----------	26	203	229
	Gravel, sandy, coarse, angular to subangular, moderately well-sorted, the sand is coarse-grained ----------	4	229	233
	Clay, sandy, medium dark gray, cohesive, calcareous, the sand is medium to coarse and occurs as lenses, limestone and dolostone boulders at 233 and 237 feet, (till) ----------	7	233	240

163-93-20aaa
Test hole 3466 (cont.)
Elevation 1,918 feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Boulder (or boulders?), reddish-pink granite--	7	240	247
	Gravel, sandy, medium to coarse, subangular to rounded, moderately well-sorted, the sand is medium to coarse-grained ----------	9	247	256
	Clay, dark gray, very cohesive, calcareous, a few quartz grains present, (till) --------	24	256	280
	Clay, silty, medium gray to medium dark gray cohesive, calcareous, some detrital lignite, frequent black, viscous, very soft organic material (Leonardite?), a few light-colored granitic boulders, (till) ----------	18	280	298
	Clay, silty, grayish-black to brownish-black, very soft, calcareous, a few thin light gray laminations (fluvial sediment) ----------	55	298	353
	Sand, coarse to very coarse-grained, sub-angular to subrounded, well-sorted, approximately 25-30 percent shale, 30-35 percent limestone and dolomite, some light to dark-colored granitic fragments and sandstone----------	26	353	379
	Clay, silty, sandy, light gray, moderately cohesive, calcareous (till) ----------	4	379	383
	Gravel, coarse to very coarse, subrounded to rounded, well-sorted from 392-420 feet and 434-483 feet, numerous cobbles and boulders throughout the entire section, some very coarse sand from 420-430 feet, composition - red, calcareous sandstone, light green, calcareous sandstone, pale yellowish-brown, non-calcareous sandstone, light gray, pyritiferous, calcareous, sandstone, yellowish-gray limestone, pinkish-gray dolostone, light to dark-colored granitics, chert, chalcedony, agate, black shale, rapidly taking water ----------	100	383	483
Tongue River Formation:				
	Shale, sandy, very pale blue to light blue, moderately indurated, calcareous ----------	7	483	490

Observation well
Electric log

163-93-20ccc
Test hole 2892
Elevation 1,924 feet

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, with a few moderate reddish-brown laminations, slightly to moderately cohesive, moderately plastic, calcareous, oxidized, (till) ----------	19	1	20
	Clay, silty, olive gray, moderately cohesive, moderately plastic, calcareous, numerous limestone, dolostone, and shale grains and granules (till) ----------	12	20	32
	Gravel, fine to coarse, angular to sub-rounded, poorly sorted, mostly limestone and dolostone, with some shale and ganitic rocks ----------	4	32	36
	Clay, very silty, olive gray with numerous light gray laminations, calcareous, very cohesive, plastic, (fluvial sediment) ----	40	36	76
	Clay, silty, sandy, gravelly, olive gray, moderately cohesive to cohesive, slightly to moderately plastic, calcareous (till)--	14	76	90
	Clay, silty, sandy, olive gray, cohesive, slightly plastic, calcareous, numerous angular lignite grains and granules, some limestone, dolostone and shale grains (till) ----------	58	90	148
	Sand, clayey, silty, very fine to fine-grained, angular to rounded, poorly sorted, >70 percent quartz with some limestone, dolostone and lignite ----------	12	148	160
	Clay, very silty, sandy, olive gray, moderately cohesive, plastic, calcareous, (fluvial sediment) ----------	7	160	167
	Gravel, sandy (approximately 20-30 percent medium to very coarse, angular to subrounded sand), fine to coarse, angular to rounded, moderately well-sorted, approximately 20-30 percent yellowish-gray to dark gray limestone, 25-35 percent grayish-brown to pale yellowish-brown chalcedony, 15-25 percent grayish-black to greenish-black shale, some grayish-red, non-calcareous and yellowish-brown calcareous sandstone, greenish granite, dark reddish-brown quartzite ----------	8	167	175
Tongue River Formation:				
	Sandstone, fine to medium-grained, light bluish-gray, consolidated, not cemented, slightly calcareous to calcareous --------	25	175	200

Electric log

163-93-21cbb
Test hole 2898
Elevation 1,916 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial Drift:				
	Topsoil, silty, sandy, clayey, brownish-black	1	0	1
	Clay, silty, sandy, moderate yellowish-brown, moderately cohesive, plastic, calcareous, numerous limestone, dolostone, granitic, and shale grains and granules, oxidized (till)	21	1	22
	Clay, sandy, silty, olive gray, cohesive, moderately plastic,calcareous, numerous limestone, dolostone, granitic, shale, and lignite grains and granules (till)	66	22	88
	Gravel, clayey, sandy (approximately 20-30 percent medium to coarse, subangular sand), fine, subrounded to subangular, poorly sorted, mostly limestone, dolostone, and granitics	4	88	92
	Clay, silty, sandy, gravelly towards bottom of section, olive gray, moderately cohesive, slightly plastic, calcareous, numerous limestone, dolostone, granitic, and lignite grains, granules, and a few pebbles (till)	62	92	154
	Gravel, clayey, sandy (approximately 25-35 percent coarse to very coarse, subangular to subrounded sand), fine to coarse, subangular to rounded, fair sorting approximately 30-40 percent siliceous rocks: dark reddish-brown jasper, moderate brown to dark yellowish-brown, translucent chalcedony, grayish-red to dusky red quartzite; 15-20 percent siliceous, non-calcareous, grayish-black to grayish-brown shale; remainder being non-calcareous, cemented (silica), moderate brown to dark greenish-gray sandstone, light olive gray to grayish-blue-green limestone, granitics, quartz, and lignite	46	154	200
Tongue River Formation:				
	Sandstone, clayey, medium bluish-gray, fine to medium-grained, consolidated, not cemented, slightly calcareous, lignitic	40	200	240

Observation well
Electric log

163-93-22cdd
Test hole 2899
Elevation 1,920 feet

Formation	Material	Thickness (feet)	Depth (feet)	
Glacial drift:				
	Topsoil, silty, sandy, brownish-black -----	1	0	1
	Clay, silty, sandy, gravelly, moderate yellowish-brown, slightly to moderately cohesive, moderately plastic, calcareous, oxidized (till) ----------	13	1	14
	Boulder, limestone ----------	2	14	16
	Clay, silty, sandy, gravelly, moderate yellowish-brown, moderately cohesive, moderately plastic, calcareous, numerous limestone, dolostone, shale, and granitic grains, granules, and pebbles, oxidized, (till) ----------	20	16	36
	Clay, very silty, sandy, gravelly, olive gray, moderately cohesive, moderately plastic, calcareous (till) ----------	92	36	128
	Clay, very silty, sandy, olive gray with light olive gray laminations, moderately cohesive, slightly to moderately plastic, calcareous, (fluvial sediment) ----------	34	128	162
	Clay, sandy, silty, gravelly, olive gray to dark greenish-gray, moderately cohesive, slightly plastic, calcareous, numerous limestone, dolostone, shale, and lignite grains, granules, pebbles and a few cobbles (till) ----------	12	162	174
	Gravel, clayey, sandy (approximately 30-40 percent medium to very coarse, angular to subrounded sand), fine to medium, angular to subrounded, moderately well-sorted, approximately 50-60 percent medium gray to dark gray, non-calcareous mudstone; remainder being yellowish-gray limestone, grayish-yellow dolostone, granitics, chalcedony, interbedded throughout section with clay-	20	174	194
	Clay, very silty, lignitic, sandy, medium gray to medium dark gray, cohesive, plastic, calcareous, (fluvial sediment) ----------	4	194	198
	Sand, fine to coarse, angular to subrounded, poorly sorted, poor samples ----------	2	198	200
	Clay, sandy, silty, olive gray, moderately cohesive, slightly plastic, calcareous, numerous limestone, granitic, shale, and lignite grains, granules, and a few pebbles (till) ----------	14	200	214

163-93-22cdd
Test hole 2899 (cont.)
Elevation 1,920 feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Tongue River Formation:				
	Sandstone, clayey, medium bluish-gray, fine to medium-grained, consolidated, not cemented, slightly calcareous ----------	26	214	240

Electric log

163-93-29ddd
Test hole 3391
Elevation 1,927 feet

Fill:	Road fill	3	0	3
Glacial drift:				
	Clay, silty, moderate olive brown, soft, cohesive, plastic, occasional sand grains and pebbles ----------	21	3	24
	Clay, silty, sandy, pebbly, moderate olive brown, moderately soft, cohesive, oxidized, (till) ----------	10	24	34
	Clay, silty, sandy, pebbly, olive gray, moderately soft, cohesive, occasional sand stringers and rocks (till) ---------	49	34	83
	Clay, silty, sandy, gravelly, olivegray, cohesive, moderately soft, (till) -------	18	83	101
	Clay, very silty, occasional sand grains and pebbles, olive gray, moderately soft, very cohesive, (till) ----------	15	101	116
Tongue River Formation:				
	Shale, light olive gray, slightly indurated, smooth ----------	8	116	124
	Sandstone, clayey, very fine-grained, light, greenish-gray, carbonaceous, slightly friable, moderately soft, micaceous and glauconitic? ----------	16	124	140

Electric log

163-93-30bbb$_2$
Test hole 2
Elevation 1917 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial drift:				
	Topsoil, silty, slightly sandy, clayey, black	1	0	1
	Clay, silty, sandy, pebbly, moderate yellowish-brown, oxidized (till)	16	1	17
	Clay, silty, sandy, pebbly, olive gray (till)	108	17	125
	Gravel, sandy	8	125	133
	Clay, silty, sandy, pebbly, olive gray (till)	75	133	208
	Gravel, sandy	14	208	222
	Clay, silty, slightly sandy, pebbly, olive gray (till)	29	222	251
	Gravel, very sandy	14	251	265
	Clay, silty, sandy, pebbly, olive gray (till)	13	265	278
	Gravel, sandy	25	278	303
	Clay, silty, sandy, occasional gravel lenses, olive gray (till)	12	303	315
	Gravel, sandy, numerous cobbles	32	315	347
	Clay, silty, sandy, occasional gravel lenses, olive gray (till)	22	347	369
	Clay, silty, sandy, pebbly, olive gray (till)	67	369	436
	Gravel, sandy, numerous cobbles	30	436	466
Tongue River Formation:				
	Shale	4	466	470
	Lignite	4	470	474
	Shale	26	474	500

Observation well
Electric log, caliper log, gamma ray log

163-93-30bbb$_3$
Test hole 3
Elevation 1918 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial drift:				
	Topsoil, silty, sandy, clayey, black	1	0	1
	Clay, silty, slightly sandy, pebbly, moderate yellowish-brown, oxidized (till)	8	1	9
	Clay, silty, sandy, pebbly, occasional gravel lenses, a few cobbles and boulders, olive gray (till)	126	9	135

163-93-30bbb$_3$
Test hole 3 (cont.)
Elevation 1,918 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
	Gravel, sandy	13	135	148
	Clay, silty, sandy, pebbly, olive gray (till)	50	148	198
	Gravel, sandy	10	198	208
	Clay, silty, sandy, pebbly, olive gray (till)	34	208	242
	Clay, silty, sandy, pebbly, occasional gravel lenses, olive gray (till)	35	242	277
	Gravel, sandy	23	277	300

Observation well
Electric log

163-93-30dcc
Test hole 2889
Elevation 1,924 feet

Glacial drift:				
	Topsoil, silty, sandy, brownish-black	1	0	1
	Clay, silty, sandy, moderate yellowish-brown, a few moderate reddish-brown laminations, slightly to moderately cohesive, moderately plastic, calcareous, oxidized (till)	19	1	20
	Clay, silty, sandy, dark greenish-gray, cohesive, slightly to moderately plastic, calcareous (till)	9	20	29
	Clay, silty, olive gray, cohesive, moderately plastic, calcareous, numerous limestone, shale, quartz and lignite grains and granules (till)	37	29	66
Tongue River Formation:				
	Shale, siliceous, medium bluish-gray to grayish-brown lower 5-6 feet, moderately indurated, non-calcareous	20	66	86
	Sandstone, clayey, light bluish-gray, consolidated, calcareous, becomes increasingly sandy with depth	14	86	100

Electic log

163-93-30ddd
Test hole 2891
Elevation 1927 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial drift:				
	Topsoil, silty, sandy, brownish-black --------	1	0	1
	Clay, silty, sandy, moderate yellowish-brown with a few moderate reddish-orange laminations, slightly to moderately cohesive, moderately plastic, calcareous, oxidized (till) ----------	39	1	40
	Clay, silty, sandy, olive gray, moderately to slightly plastic, moderately cohesive to cohesive, calcareous, numerous limestone, quartz, lignite, and granitic grains, granules, and a few pebbles, (till) ----------	15	40	55
	Sand, fine to coarse, angular to subrounded, poorly sorted, mostly limestone, granitic, and quartz fragments ----------	1	55	56
	Clay, silty, sandy, olive gray, cohesive, moderately plastic, calcareous, numerous limestone, shale, granitic, and lignite grains, granules, and a few pebbles, (till) ----------	11	56	67
	Sand, fine to coarse, angular to subrounded, poorly sorted, poor samples ----------	2	67	69
	Clay, silty, sandy, gravelly, olive gray, cohesive, slightly plastic, calcareous, (till) ----------	5	69	74
	Sand, no samples ----------	1	74	75
	Clay, sandy, silty, gravelly, olive gray, cohesive, slightly plastic calcareous (till) ----------	43	75	118
Tongue River Formation:				
	Shale, siliceous, light olive gray to medium dark gray, moderately indurated, non-calcareous ----------	24	118	142
	Sandstone, fine to medium grained, light bluish-gray, consolidated, not cemented ----	18	142	160

163-94-16daa
Test hole 3597
Elevation 1,910 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial drift:				
	Clay, silty, pebbly, yellowish-gray, slightly cohesive, fractured, oxidized (till) -------	5	0	5
	Clay, silty, sandy, pebbly, moderate olive brown, moderately plastic, cohesive, oxidized (till) ----------	33	5	38
	Clay, silty, sandy, pebbly, occasional cobbles and medium to coarse-grained sand lenses, olive gray, moderately cohesive, moderately plastic (till) --------	18	38	56
	Sand, medium to coarse-grained, subrounded, moderately well-sorted, very lignitic, not much water loss ----------	87	56	143
	Gravel, coarse, sandstone and granite boulders ----------	8	143	151
	Silt, light gray, slightly to moderately cohesive, very thin carbonaceous laminae, plastic, interbedded with very fine-grained quartzose sand ----------	29	151	180

Electric log

163-94-19daa
Test hole 3603
Elevation 1,914 feet

Glacial drift:				
	Topsoil, pebbly loam, dark brown ----------	1	0	1
	Clay, silty, sandy, pebbly, yellowish-gray, plastic, slightly cohesive, oxidized (till) ----------	6	1	7
	Clay, silty, sandy, pebbly, slightly gravelly, moderate olive brown, moderately plastic, cohesive, oxidized (till) ----------	26	7	33
Tongue River Formation;				
	Shale, light gray, slightly indurated, cohesive ----------	15	33	48
	Limestone, dark gray, indurated, calcareous --	1	48	49
	Shale, medium gray, slightly indurated, cohesive ----------	6	49	55
	Shale, silty, light greenish-gray to light olive-gray, interbedded lignite layers -----	5	55	60

163-94-20bbb
Test hole 3604
Elevation 1,908 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial drift:				
	Clay, silty, sandy, gravelly, yellowish-gray, plastic, slightly cohesive, fractured, oxidized (till)	5	0	5
	Clay, silty, sandy, pebbly, occasional cobbles, moderate olive brown, moderately plastic, cohesive, oxidized (till)	12	5	17
	Sand, medium-grained, subangular to subrounded, well-sorted, much detrital lignite, oxidized	14	17	31
	Sand, medium to coarse-grained, occasional gravel layers, lignitic, lost circulation	40	31	71
	Clay, silty, sandy, pebbly, olive gray, moderately plastic, cohesive (till)	20	71	91
	Sand, medium to coarse-grained, lignitic, poor samples	14	91	105
	Clay, silty, sandy, pebbly, occasional thin gravel lenses, olive gray, moderately plastic, cohesive (till)	22	105	127
	Gravel, sandy, fine to coarse, subrounded, oxidized, mostly brownish siliceous pebbles with some limestone, dolostone and granite fragments	11	127	138
Tongue River Formation:				
	Shale, very silty, light gray, indurated	3	138	141
	Lignite, black	3	141	144
	Shale, medium gray, slightly indurated	4	144	148
	Sandstone, clayey, very fine-grained, light greenish-gray	5	148	153
	Shale, silty, light greenish-gray indurated	7	153	160
	Siltstone, light brownish-gray, indurated		160	+

Electric log

163-94-21cbb
Test hole 3602
Elevation 1,910 feet

Glacial drift:				
	Clay, silty, sandy, pebbly, yellowish-gray, moderately plastic, fractured oxidized (till)	8	0	8
	Clay, very silty, slightly sandy, pebbly, light olive gray, slightly plastic, cohesive (till)	15	8	23

163-94-21cbb
Test hole 3602 (cont.)
Elevation 1,910 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
	Sand, medium to coarse-grained, moderately well sorted, subrounded, oxidized	18	23	41
	Clay, very silty, dusky yellow, plastic, cohesive, oxidized	4	41	45
	Sand, clayey, silty, fine-grained	7	45	52
	Clay, silty, sandy, pebbly, olive gray, moderately plastic, slightly cohesive (till)	11	52	63
	Sand, medium to coarse-grained, moderately well-sorted, subrounded, mostly quartz, lignitic	23	63	86
	Silt, clayey, slightly plastic, cohesive	16	86	102
	Gravel, sandy, fine	6	102	108
	Clay, silty, olive gray, moderately plastic, moderately cohesive	7	108	115
	Sand, medium-grained, lignitic	7	115	122
	Clay, silty, interbedded with very fine-grained sand, olive gray, plastic, moderately cohesive	75	122	197
	Silt, clayey, sandy, olive gray, plastic, slightly to moderately cohesive, much detrital lignite	107	197	304
	Clay, silty, olive gray, plastic, cohesive	15	304	319
	Clay, silty, sandy, pebbly, occasional cobbles, olive gray, moderately cohesive, moderately plastic, a few thin lenses of gravelly sand (till)	34	319	353
Tongue River Formation:				
	Sandstone, very fine to fine-grained, greenish-gray, interbedded with light gray silty shale, carbonaceous shale	47	353	400

Electric log

163-94-22bbc
Test hole 3599
Elevation 1,905 feet

Glacial drift:				
	Clay, silty, sandy, yellowish-gray, plastic, slightly to moderately cohesive, fractured, oxidized (till)	5	0	5

163-94-22bbc
Test hole 3599 (cont.)
Elevation 1,905 feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Clay, silty, sandy, pebbly, moderate olive brown, moderately plastic, cohesive, oxidized (till)	33	5	38
	Clay, silty, sandy, pebbly, olive gray, moderately plastic, cohesive (till)	31	38	69
	Gravel, sandy, fine to medium-grained, moderately well-sorted, subangular to subrounded, mostly limestone, dolostone, and granitics	10	69	79
	Clay, silty, sandy, pebbly, olive gray, cohesive (till)	46	79	125
	Gravel, sandy coarse, subrounded, mostly limestone, dolostone, and granitics, some lignite, taking water	10	125	135
	Sand, medium to coarse-grained, light brown well-sorted, subrounded, lignitic, mostly quartz, taking water	68	135	203
Tongue River Formation:				
	Shale, very silty, light gray, slightly indurated	9	203	212
	Sandstone, very fine-grained, dark greenish-gray carbonaceous	6	212	218
	Lignite, black	3	218	221
	Siltstone, light gray, interbedded with fine-grained sandstone, indurated	19	221	240

Electric log

163-94-22cbb1
Test hole 3596
Elevation 1,900 feet

Glacial drift:				
	Gravel, sandy, fine to medium, poorly sorted, oxidized	7	0	7
	Silt, clayey, dusky yellow, slightly cohesive plastic, oxidized	14	7	21
	Silt, moderate olive brown, interbedded with fine to medium-grained sand, cohesive, plastic	16	21	37
	Sand, medium to coarse-grained, very lignitic, well-sorted	44	37	81
	Gravel, sandy, fine to medium, subangular to subrounded, mostly limestone and dolostone, some granitics and lignite, lost circulation	79	81	160

Observation well

163-94-22cbb$_2$
Test hole 3600
Elevation 1,901 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial drift:				
	Gravel, sandy, fine to medium, subangular subrounded, oxidized	5	0	5
	Silt, clayey, sandy, dusky yellow, plastic, slightly cohesive, oxidized	14	5	19
	Sand, fine-grained, interbedded with silty clay, moderate olive brown, partially oxidized	35	19	54
	Sand, medium to coarse-grained, well sorted, subrounded, much detrital lignite	41	54	95
	Gravel, sandy, fine to coarse, subangular to subrounded, mostly limestone, dolostone and granitics, some chert, jasper, metamorphics, lost circulation, caving in	95	95	190

Electric log

163-94-25aab
Test hole 4
Elevation 1,917 feet

Glacial drift:				
	Topsoil, silty, sandy, clayey, black	1	0	1
	Clay, silty, slightly sandy, pebbly, moderate yellowish-brown, moderately cohesive, plastic, oxidized (till)	19	1	20
	Sand, very silty, slightly gravelly, clayey, oxidized	11	20	31
	Clay, silty, occasional sand and gravel stringers, olive gray (till)	129	31	160
	Gravel	10	160	170
	Clay, silty, sandy, gravelly, olive gray (till)	29	170	199
	Gravel, sandy, mostly limestone and dolostone pebbles	43	199	242
	Clay, silty, sandy, pebbly, olive gray (till)	18	242	260
	Gravel, sandy, mostly limestone and dolomite	40	260	300

Observation well

Electric log

163-94-27cbb
Test hole 3594
Elevation 1,915 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial drift:				
	Clay, silty, sandy, pebbly, yellowish-gray, plastic, slightly cohesive, oxidized (till)-	5	0	5
	Clay, silty, sandy, pebbly, moderate olive brown, moderately plastic, cohesive, oxidized (till) ----------	32	5	37
	Sand, very coarse-grained, well-sorted, subrounded, oxidized ----------	2	37	39
	Clay, silty, sandy, pebbly, olive gray, moderately plastic, cohesive (till) --------	58	39	97
Tongue River Formation:				
	Shale, medium gray, slightly indurated -------	5	97	102
	Shale, very silty, light gray, moderately cohesive ----------	7	102	109
	Sandstone, slightly clayey, very fine-grained, dark greenish-gray, slightly cohesive, lignitic ----------	11	109	120

Electric log

163-94-27ccc
Test hole 3595
Elevation 1,917 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Glacial drift:				
	Clay, silty, sandy, pebbly, yellowish-gray, slightly cohesive, plastic oxidized (till) ----------	4	0	4
	Clay, silty, sandy, pebbly, moderate olive brown, cohesive, moderately plastic, oxidized (till) ----------	24	4	28
Tongue River Formation				
	Shale, silty, sandy, moderate yellowish-brown to yellowish-green and dusky yellow, moderately cohesive, slightly indurated, oxidized ----------	8	28	36
	Lignite, black ----------	4	36	40

163-94-29aaa
Test hole 3601
Elevation 1,900 feet

Formation	Material	Thickness (feet)	Depth (feet) From	To
Gracial drift:				
	Topsoil, sandy loam, yellowish-gray ----------	1	0	1
	Sand, slightly gravelly, medium to coarse-grained, subangular to subrounded, moderately well-sorted, mostly quartz and granitics with some limestone ----------	15	1	16
	Clay, very silty, sandy, pebbly, moderate olive brown, plastic, moderately cohesive, oxidized (till) ----------	7	16	23
Tongue River Formation:				
	Sandstone, clayey, very fine to fine-grained, yellowish-green, plastic, slightly indurated, oxidized ----------	12	23	35
	Sandstone, very fine-grained, light bluish-gray, indurated, calcareous cementation ----	1	35	36
	Shale, very sandy, medium bluish-gray, moderately indurated ----------	4	36	40

163-94-36abb
Test hole 2890
Elevation 1,930 feet

Glacial drift:				
	Topsoil, sandy, silty, brownish-black --------	1	0	1
	Clay, silty, sandy, moderate yellowish-brown with a few moderate reddish-brown laminations, slightly to moderately cohesive, slightly to moderately plastic, calcareous, oxidized (till) ----------	27	1	28
	Boulder, reddish and blackish specular granite, weathered ----------	1	28	29
	Clay, sandy, silty, gravelly, olive gray, moderately cohesive, plastic, calcareous (till) ----------	4	29	33
	Clay, silty, sandy, olive gray to brownish-gray, cohesive, semi-plastic, calcareous (till) ----------	15	33	48
	Clay, very sandy, silty, olive gray, slightly cohesive, slightly plastic to non-plastic, calcareous, (fluvial sediment) ----------	14	48	62

163-94-36abb
Test hole 2890 (cont.)
Elevation 1,930 feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Gravel, fine to coarse, angular to sub-rounded, poorly sorted, mostly limestone, dolostone, and granite, with some shale and lignite	4	62	66
	Clay, silty, sandy, olive gray, moderately cohesive, semi-plastic, calcareous, numerous limestone, shale, and lignite grains and granules, (till)	12	66	78
Tongue River Formation:				
	Shale, siliceous, light bluish-gray to medium bluish-gray, non-calcareous, moderately indurated	11	78	89
	Sandstone, fine to medium grained, light bluish-gray, consolidated, cemented from 89-95 feet, calcareous to slightly calcareous	11	89	100

Electric log

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