GROUND-WATER RESOURCES
of the
CROSBY AREA
DIVIDE COUNTY, NORTH DAKOTA
NORTH DAKOTA GROUND-WATER STUDIES
NUMBER 79

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Appendix
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Bismarck, North Dakota 58505

1983

HYDROLOGIC CYCLE

RAIN CLOUDS

WHILE FALLING

FROM SOIL

FROM STREAMS

FROM VEGETATION

FROM LAKES

INfiltration

SURFACE RUNOFF

PERCOLATION

GROUND WATER
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GROUND-WATER RESOURCES OF THE CROSBY AREA
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INTRODUCTION

Purpose and Scope

In November, 1971, the Crosby City Council approved a motion authorizing the drafting of plans and specifications for a half-million dollar water system improvement project. Proposed for the project was a treatment plant, a 500,000 gallon storage facility, a well and a water transmission line from the well to the plant. Although there was a general consensus that adequate underground water was available to support a municipal supply, the City Council, at the suggestion of their consulting engineer, requested the North Dakota State Water Commission to conduct a ground-water study of the area. The Crosby Ground-Water Survey was approved on December 2, 1971, and field work began immediately.

The purpose of this investigation was to evaluate the quantity and quality of ground water in the Crosby area. The principal objective was to locate the most suitable site for the proposed municipal well.

Field work consisted of drilling test holes and installing observation wells. Water samples were obtained from the wells to determine chemical characteristics of the water. Water level fluctuations were determined by periodic measurements. Actual pumping conditions were observed at the existing municipal well (City Well #3).

A total of 22 test holes were drilled in December before inclement weather forced a shutdown of operations. Drilling was resumed in May 1972; however, extremely wet conditions seriously affected the location of test hole sites. Nineteen additional test holes were drilled in May and June.
ACKNOWLEDGEMENTS

The test drilling was accomplished by Lewis Knutson using the State Water Commission hydraulic-rotary drilling machine and by Tony Mann, Mann Drilling Company of Garrison, North Dakota, using a hydraulic-rotary drilling machine. Field work was under direct supervision of Milton O. Lindvig, Chief of the Hydrology Division, State Water Commission. L. L. Froelich and C. E. Naplin, State Water Commission geologists, logged the test holes. Chemical analyses were performed by G. O. Muri, State Water Commission chemist.

LOCATION AND GENERAL FEATURES

Divide County is in extreme northwestern North Dakota. Crosby, the county seat and largest city (1970 population 1,542), is located in the northeastern part of the county. The Crosby area, as described in this report, includes approximately 92 square miles (all or portions of) in Townships 162, 163, and 164 North, Ranges 96 and 97 West.

The Crosby area, for the most part, lies within the Drift Prairie section of the Central Lowlands physiographic province (fig. 1). It is characterized by a northeastward sloping glacial plain of low relief. The Missouri Escarpment occupies the southeastern corner of the report area. It represents the steep north-facing slope of the Coteau Du Missouri which extends through Divide County in a southeasterly direction across the state into South Dakota. The escarpment is interrupted southwest of Crosby where a large re-entrant into the Coteau marks the buried valley of the Yellowstone River, which flowed north prior to glaciation.

Maximum topographic relief approximates 250 feet. The highest altitude (2,130 feet msl, mean sea level) occurs on the Coteau in the extreme southeast corner of the area. The lowest altitude (1880 feet msl) is in the Long Creek
FIGURE 1 -- MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC PROVINCES AND LOCATION OF THE CROSBY AREA.
channel where it leaves the area. Local relief in the Drift Prairie section rarely exceeds 20 feet.

Drainage from the Missouri Escarpment is toward an unnamed intermittent stream channel at the base of the Coteau which formerly contained Long Creek and which effectively drained a large post-glacial lake that occupied the re-entrant southwest of Crosby. Chains of perennial and intermittent lakes and sloughs in the central part of the Crosby area also represent former ice-marginal courses of Long Creek. Present day Long Creek drains the northern part of the area from west to east. Between the present and former stream channels drainage is nonintegrated and characterized by numerous undrained depressions of various size and shape.

The economy of the Crosby area is based largely on agriculture. The climate is semi-arid. Climatological data recorded at the National Weather Service station at Crosby indicate the average annual precipitation to be 13.36 inches and an average temperature of 38.9°F (National Weather Service, 1971).

Motor transportation to the area is provided by North Dakota State Highways 5 and 42. Crosby is the western terminus of a spur of the Burlington Northern Railroad (formerly Great Northern Railroad). The municipal airport is located one-half mile north of the city at an altitude of 1945 msl.

PREVIOUS INVESTIGATIONS

A study of the geology and ground-water resources of Divide County is included in a series of three reports published as County Ground Water Studies 6 of the North Dakota State Water Commission. The investigation was performed as a cooperative effort of the State Water Commission, North Dakota Geological
Survey, United States Geological Survey and the Divide County Board of Commissioners. In his report, Hansen (1967, p. 2) discusses contributions by authors of publications relating to the geology of Divide County. Armstrong (1967, p. 3) includes prior investigators concerned with the ground water resources of Divide County. Supplemental county-wide ground-water studies include Williams County (County Ground Water Studies 9) and Burke and Mountrail Counties (County Ground Water Studies 14).

The general geology of the Crosby Quadrangle was mapped by Townsend (1954). His report contains a special section in which ground-water resources of the quadrangle are discussed by LaRocque. Naplin (1969) described the ground-water survey of the Columbus area. Columbus is located 25 miles east of Crosby in Burke County.

AREA WATER SUPPLIES

Early settlers of the Crosby area experienced little difficulty in locating shallow ground water to supply hand dug wells. Because surface water supplies were limited and subject to climatic variations, water wells became the major source of public, domestic, and stock requirements. However, the ease with which the shallow waters became polluted, along with the generally high dissolved mineral content of the water, forced many persons to have wells bored to greater depths in search of more suitable supplies. When it was discovered that flowing artesian wells could be obtained throughout much of the area, small diameter drilled wells began replacing the larger diameter dug and bored wells. Armstrong (1965, table 1) lists wells ranging from 16 to 562 feet in depth and 2 to 60 inches in diameter throughout the Crosby area. Water levels are commonly less than 30 feet bsl (below land surface), but range from flowing to a reported 140 feet below land surface.
Simpson (1929, p. 120) described the public supply at Crosby as "furnished by an artesian well 622 feet deep and 5 inches in diameter at the top and 1\frac{1}{4} inches at the bottom." Flow from the well was reported at one gpm (gallon per minute). Simpson also mentioned a shallow (30 feet in depth) well used for public supply near Main Street and the Great Northern Railway, but warned of the danger of pollution. In his report, Simpson discusses a group of wells about one mile west of Crosby and states, "The waters...represented by these wells are unquestionably the best waters in this vicinity, not only for domestic use, but everything considered, for city supply." Apparently Crosby residents followed Simpson's suggestion because Armstrong (1967, p. 49) reports that prior to 1941 the city obtained its water supply from two wells developed in the deposits of the abandoned Long Creek channel to the west of the city. Armstrong estimates 50,000 to 100,000 gpd (gallons per day) were pumped from the wells.

Presumably the drought of the late 1930's caused a serious decline in water levels in the area because in 1941 the city drilled a flowing well, 296 feet in depth, about two miles southeast of Crosby. The well is 12 inches in diameter and reportedly will yield 74 gpm for a few hours (Armstrong, 1967, p. 51). In 1949 city well #2 was drilled a short distance from the 1941 city well #1. The well is six inches in diameter and 390 feet deep. It was used as a standby supply until 1964 when its use was discontinued. The present municipal supply is obtained from city well #3 located in the NW\frac{1}{4} Section 35, Township 163 North, Range 97 West, along the Burlington Northern right-of-way. The 12-inch well was drilled in 1957 to a depth of 310 feet. It originally flowed, but approximately 30 feet of artesian pressure head has been lost since its installation and the present static water level is about 10 feet bsl within the immediate vicinity.
In December, 1971, city well #3 was being pumped at a rate of 260 gpm and had a measured drawdown of 84 feet. Average municipal use approaches 5,000,000 gallons monthly.

WELL NUMBERING SYSTEM

Wells and test holes listed in the tables are numbered according to a system based on the location in the public land classification of the United States Bureau of Land Management. The system is illustrated in figure 2. The first numeral denotes the township north of a base line, the second numeral denotes the range west of the fifth principal meridian, and the third numeral 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). For example, well 163-97-35ADD is in the SE\(\delta\)SE\(\alpha\)NE\(\beta\) Section 35, Township 163 North, Range 97 West. Consecutive terminal numerals are added if more than one well is recorded within a 10 acre tract.

PRINCIPLES OF GROUND-WATER OCCURRENCE

All ground water of economic importance is derived from precipitation. As moisture falls to the earth's surface, part is returned to the atmosphere, part is lost to surface runoff, and the remainder infiltrates into the ground. Most of the infiltrating water is retained temporarily in the soil and gradually returned to the atmosphere by evapotranspiration. The remainder percolates downward to become ground water.

Ground water moves under the influence of gravity from areas of recharge to areas of discharge. The rate of movement is governed by the permeability of the sediments through which the water passes and by the hydraulic gradient.
FIGURE 2   WELL-NUMBERING SYSTEM
Deposits of sorted sand and gravel generally are highly permeable and are called aquifers if they are saturated and of adequate areal extent to yield significant quantities of water to wells. Fine grained materials such as silt, clay, and shale usually have low permeabilities and function as barriers that impede the movement of ground water.

The water level in a well fluctuates in response to recharge to or discharge from the aquifer. When water is pumped from a well, the amount of drawdown is controlled by the transmissivity and storage properties of the aquifer, the physical characteristics of the well, and the rate and duration of pumping. During constant and uniform discharge from a well in an extensive aquifer, the water level will decline rapidly at first and then continue to lower at a decreasing rate as the cone of depression expands. The area influenced by the cone of depression spreads directly with time and inversely with the storage coefficient. Under artesian conditions the storage coefficient is equal to a small fraction of the aquifer's porosity, and the area of influence spreads rapidly. Artesian conditions exist when the water level in a well penetrating a confined aquifer rises above the aquifer due to hydrostatic pressure. Under unconfined or water table conditions the storage coefficient, which is much larger than under artesian conditions, is equal to the specific yield, and the area of influence spreads more slowly.

The theoretical shapes and rates of decline of cones of depression in confined aquifers, such as buried valleys, are distorted by the effects of relatively impermeable barriers, and rates of decline are increased. Water level decline, therefore, is not only a function of transmissivity and storage, but also of the proximity of boundary conditions.
The water level in a pumped well must decline in order that water may flow from the aquifer to the well. However, too great a decline may cause serious problems if (1) it causes water of undesirable quality to move into the aquifer, (2) the yield of the well decreases because of interference from other wells or aquifer boundaries, (3) the pumping lift increases to the point where pumping becomes uneconomical, or (4) the water level declines below the top of the screen. When pumping is stopped, the water level recovers in the vicinity of the well at a decreasing rate until it is at or near the static level.

Under natural conditions, over a period of time, the amount of discharge from an aquifer equals the amount of recharge. Under pumping conditions, however, one or more of the following may eventually occur: (1) a decrease in the rate of natural discharge, (2) an increase in the rate of recharge, or (3) a reduction in volume of groundwater in storage. The maximum rate of ground-water withdrawal that can be maintained indefinitely is related directly to the rate of recharge to the aquifer.

**CHEMICAL QUALITY OF GROUND WATER**

All natural waters contain a certain amount of dissolved minerals. The concentration and nature of dissolved constituents in ground water depends upon the types and solubility of sediments encountered, the duration of contact, temperature, pressure, and gases already in solution. In general, ground water withdrawn near a recharge area will be less mineralized than that which occurs at the discharge area.

The dissolved mineral constituents in water are reported in parts per million (ppm), milligrams per liter (mg/l), or grains per U. S. gallon (gr/gal).
One part per million is a unit weight of a constituent in a million unit weights of water. Milligrams per liter are, for all practical purposes, equivalent to parts per million. Parts per million may be converted to grains per gallon by dividing the ppm by 17.12.

The following summary gives the significance of the various constituents determined by chemical analysis as they apply to a domestic or municipal water supply in North Dakota (Schmid, 1965):

**Silica (SiO₂)**

Silica has no physiological or esthetic significance.

**Iron (Fe)**

Over 0.3 mg/l may cause staining of laundry and fixtures. Over 0.5 mg/l may be tasted by persons unaccustomed to water with a high iron content. Iron removal is economically feasible.

**Manganese (Mn)**

Manganese is similar to iron, producing black stains when present in amounts over 0.05 mg/l.

**Calcium (Ca) and Magnesium (Mg)**

Calcium and magnesium are primary causes of hardness. Over 125 mg/l magnesium may have a laxative effect on persons not accustomed to this type of water.

**Sodium (Na)**

Sodium has no physiological or esthetic significance except for persons on salt-free diets. It eventually affects soils if high-sodium waters are used for irrigation without proper additives.

**Potassium (K)**

Small amounts of potassium are essential to plant and animal nutrition.
Bicarbonate (HCO₃) and Carbonate (CO₃)

These constituents have no definite significance in natural water; there are, however, certain standards to be maintained in water treatment plants. Water with high bicarbonate content tend to have a flat taste.

Sulfate (SO₄)

A North Dakota Department of Health survey indicates a noticed laxative effect when sulfates reach 600 mg/l. Sulfates are classified as follows:

- 0 to 300 mg/l - low
- 300 to 700 mg/l - high
- Over 700 mg/l - very high

Chloride (Cl)

Over 250 mg/l chloride may have a salty taste to persons not accustomed to it. Humans and animals can adapt to higher concentrations.

Fluoride (F)

Fluorides help prevent tooth decay within the limits of 0.9 to 1.5 mg/l in North Dakota. Higher concentrations cause mottled teeth.

Nitrate (NO₃)

Over 45 mg/l nitrate may be toxic to infants. Higher concentrations may be tolerated by adults. In excess of 200 mg/l it may have a deleterious effect on livestock.

Boron (B)

Boron has no physiological or esthetic significance.

Total Dissolved Solids

Persons may become accustomed to water containing 2,000 mg/l or more total dissolved solids. They are classified by the State Department of Health as follows:
0 to 500 mg/l - low
500 to 1,400 - average
1,400 to 2,500 - high
Over 2,500 - very high

**Hardness**

Hardness increases soap consumption but may be removed by a water softening system. The State Department of Health classifies hardness as follows:

0 to 200 mg/l as CaCO₃ - low
200 to 300 mg/l - average
300 to 450 mg/l - high
over 450 mg/l - very high

**pH**

The pH should be between 6.0 and 9.0 for domestic consumption.

**Percent Sodium; Sodium Adsorption Ratio (SAR); Specific Conductance**

These are factors used in determining irrigation feasibility.

**OCCURRENCE OF GROUND WATER**

Ground-water occurrence in any area is directly related to the geology. The interpretation of the geology of the Crosby area is based, for the most part, on the logs of test holes. Additional geohydrologic data have been extrapolated from Hansen (1967) and Armstrong (1965, 1967). Locations of test holes are shown in Plate 1 and individual descriptions are included in table 3 at the conclusion of this report.

The economically recoverable ground-water resources are described in relation to the geologic units in which they occur. There are two major stratigraphic units underlying the Crosby area; (1) bedrock, which consists of Mesozoic rock of Cretaceous age and Cenozoic rock units of Paleocene age; and (2) glacial drift of Quaternary age.
GROUND WATER IN THE BEDROCK

The Crosby area overlies the northern flank of the Williston Basin, a structural basin containing a thick sequence of sedimentary rocks. The rock units that overlie Precambrian rocks were deposited during the Paleozoic, Mesozoic and Cenozoic Eras (Hansen, 1967, p. 11). During the time span which includes Cambrian through Cretaceous age, sediments were deposited chiefly in a marine environment; non-marine rocks were deposited during the late Cretaceous and Early Tertiary. The total thickness of sedimentary rocks at Crosby may be as great as 12,000 feet (Basement Rock Projects Committee, 1967).

Only the Mesozoic and Cenozoic rock units above the Pierre Formation of Late Cretaceous age are considered in this report. Certain formations below the Pierre, notably the sandstone and carbonate rocks, could possibly yield very large supplies of water, however, the water is so highly mineralized that it would not be suitable for most purposes without highly technical and expensive methods of treatment. The Pierre Formation is a thick shale sequence that is too fine grained to transmit significant quantities of water to wells. Depth to the Pierre Formation at Crosby probably is 1,400 to 1,500 feet.

CRETACEOUS ROCKS

The Fox Hills Formation conformably overlies the Pierre Formation. It consists of slightly more than 250 feet of interbedded marine shale and sandstone. The Fox Hills in turn, is overlain by slightly less than 250 feet of non-marine Hell Creek sediments. The contact probably is gradational. The Hell Creek Formation is the youngest Cretaceous formation in the Crosby area and consists chiefly of carbonaceous siltstone and claystone or shale with interbedded fine-grained sandstone.
There are no water wells developed in either the Fox Hills or Hell Creek Formations in the Crosby area. In other parts of the state where development has taken place, the two formations function essentially as a single hydrologic system. Investigations by Croft (1973) have revealed apparent geohydrologic differences between the lower and upper Hell Creek, however.

The sandstone beds in the Fox Hills and Hell Creek Formations may yield small quantities of ground water. The sands are generally poorly sorted which results in low transmissivity and reduces the specific capacity of a well to \( \frac{1}{2} \) to \( \frac{1}{4} \) gallon per minute per foot of drawdown. The water level or potentiometric surface is undetermined at present (1973), but flowing wells are a possibility. The closest sources of recharge are the Brockton and Scobey areas of northeastern Montana where the formations are exposed at the surface. Ground-water discharge is to areas to the north and east of Crosby. The water contained in the sandstone beds can be expected to be a soft sodium bicarbonate type with total dissolved solids in the 1,500 to 2,000 mg/l range.

**PALOCENE ROCKS**

The Ludlow Formation overlies the Hell Creek at a gradational contact. It consists of non-marine carbonaceous shale and bentonitic claystone with thin beds of siltstone, fine-grained sandstone, and lignite. The formation may be 250 to 300 feet thick in the Crosby area. Both Hansen (1967, p. 21) and Armstrong (1967, p. 18) refer to this section as the Ludlow-Cannonball Formations, undifferentiated; however, data are insufficient to suggest the marine sediments of the Cannonball Formation exist in the Crosby area. If the Cannonball is present, a combined thickness of 450 feet is possible for the Ludlow-Cannonball. Hansen (1967, p. 23) indicates the Ludlow subcrops
beneath the glacial drift throughout much of the Crosby area; Armstrong (1967, p. 18) disagrees. In any event, the Ludlow is very difficult to distinguish in the subsurface from the overlying Tongue River Formation.

The Tongue River, the youngest bedrock formation in the Crosby area, is composed of nearly horizontal, but lenticular, non-marine beds of lignite, claystone, siltstone, and sandstone. If Hansen's Ludlow subcrop theory is correct the Tongue River ranges from absent to perhaps 500 feet thick. Test holes drilled in connection with this study usually encountered sandstone deposits at various intervals beneath the glacial drift. Some of these sandstones may be correlative with the basal or "lower Tongue River aquifer" described by Croft (1973, p. 37).

There are no known wells developed in the Ludlow Formation in the Crosby area, although it is possible the municipal artesian well described by Simpson (1929, p. 120) may have recovered water from the Ludlow. The scarcity of wells may suggest only meager water supplies are available from the Ludlow and that the water quality is unsuitable for most purposes. Numerous wells have been developed in the Tongue River Formation and usually yield small but dependable supplies from the sandstone and/or lignite beds. Many of the wells flowed originally; some still do. Discharge results from pumping or flowing wells, upward and lateral seepage to the overlying glacial drift, and natural underflow to the north. The water is generally high in sodium, bicarbonate and total dissolved solids. The water is normally satisfactory for stock water, but not recommended for human consumption if better quality water is available.

GROUND WATER IN THE GLACIAL DRIFT

The bedrock topography, the base of the glacial drift in the Crosby area,
has the approximate configuration shown on Plate 2. This form is an interpretation based on the surface elevations of the bedrock as determined from test drilling and, to some extent, available information on water wells.

Test drilling revealed the thickness of glacial drift in the Crosby area ranges from 45 to over 575 feet (table 3), and is greatest over buried valleys. The largest vertical accumulation of drift overlies the preglacial valley which contained the northeasterly flowing Yellowstone River (Plate 2). More than 450 feet of drift may overlie the Columbus buried valley, created when the Yellowstone River was diverted eastward by continental glaciation. The Crosby buried valley contained a northeasterly flowing stream tributary to the Columbus valley. It probably formed during one of the earlier interglacial periods of the Pleistocene Epoch and is now filled and overlain by about 400 feet of drift. The divides between the former drainage systems consist of buttes and ridges capped by the least thickness of glacial drift. The buried bedrock topography is undoubtedly more complex than indicated on Plate 2 and probably similar in appearance to that now developed on the exposed Tertiary rocks of western North Dakota.

Glacial drift can be separated into three groups of clastic lithologies based on differences in texture and bedding. The groups include: 1) clay and silt, 2) sand and gravel, and 3) till. The stratigraphic relationship of the lithologic groups are illustrated in cross sections A-A', B-B', and C-C' (pl. 3).

Clay and silt occur on the land surface and at depth throughout the Crosby area. They represent the depositional phase of proglacial lakes created by the impoundment of meltwater. These glaciolacustrine sediments occur as thick extensive and generally continuous deposits or as thin narrow lenses. The clays are olive gray to olive black in color and the silts usually light olive gray. Both are commonly laminated and interbedded. Clay and silt do not readily yield water to wells and are, therefore, not considered aquifers.
Extensive stratified glaciofluvial deposits of sand and gravel commonly constitute the fill of the major buried valleys and, in most instances, directly overlie bedrock. Less extensive deposits occur as long narrow interglacial channel fills or as randomly interspersed pockets of indeterminable size and shape associated with glacial till. Surficial sand and gravel deposits are contained in the former and present-day courses of Long Creek. Generally, the sand and gravel varies considerably in grain size, sorting and type of bedding. The ability of these deposits to yield large quantities of ground water depends on their transmissivity, areal extent and the amount of recharge they receive.

The majority of glacial drift is composed of till, a heterogenous mixture of clay, silt and sand with pebbles, cobbles and/or boulders. This debris is a result of 4, or possibly 5, separate glacial advances that overrode the Crosby area. Each ice sheet left deposits of glacial drift and each succeeding one probably removed, redistributed and/or added to the deposits of its predecessor. No attempt is made in this report to correlate the individual drift sheets. Till is relatively impermeable and yields little water to wells.

YELLOWSTONE BURIED VALLEY AQUIFER

The Yellowstone buried valley was eroded in Late Tertiary time by the ancestral Yellowstone River. Originally, the river flowed north from Williston, past Crosby, to its confluence with the preglacial Missouri River near Estevan, Saskatchewan (Armstrong, 1967, p.26). The valley enters the southwest corner of the Crosby area and continues north-northeast into Canada (plate 2).

Two major periods of erosion are believed to exist in the Yellowstone valley. The main valley, approximately 1½ miles wide, formed during an early erosional
sequence. Perhaps as a result of regional uplift an inner valley, approximately 
\(\frac{1}{2}\) mile wide, incised as much as 100 feet below the floor of the main valley. 
This narrow valley-in-valley became filled with gravel, presumably during the 
interglacial period following the initial glacial advance in the area, and was 
subsequently overridden by ice. Any fill which may have been deposited in the 
larger main valley, however, was essentially redistributed and incorporated into 
the debris of the second glacial advance. The fill in the main valley now 
consists primarily of till.

Glaciofluvial gravel, believed to represent the inner valley fill, was 
encountered from 540 to 575 feet in depth in test hole 4445 (163-97-15BCC, 
plate 1). The deposit was not completely penetrated, however. If this gravel, 
which is apparently highly permeable and porous, is continuous with the inner 
valley throughout the Crosby area the potential for development could be 
substantial. Assuming the gravel deposit is present and continuous, it is 
referred to herein as the Yellowstone buried valley aquifer.

Test hole 8289 (163-97-22CCC) and a Missouri Basin test hole (163-97- 
33CCC) are suspected to have been drilled on or near the axis of the Yellow-
stone buried-valley aquifer. However, they were abandoned in the glacial drift 
at depths of 332 and 521 feet, respectively. Other test holes, including 
numbers 3024, 4442, 4443, 4444, 8283, 8286, 8287, and 8288 (plate 1) penetrated 
the fill of the main Yellowstone valley but encountered no recognizable aquifers 
of significance.

A two-inch observation well, screened from 546 to 558 feet, was installed 
in test hole 4445 (163-97-15BCC). Following development, in June 1972, the 
measured water level in the well casing was 36.43 feet bsl (table 2). By 
August, the water level had recovered to 14.48 bsls. In January, 1973, the
water level measured 11.54 feet bsls and stayed fairly consistent. This indicates the Yellowstone buried valley aquifer is under artesian conditions with hydrostatic head about 500 feet above the top of the aquifer.

The chemical analysis of a water sample from the observation well (table 1) indicates the water is low in hardness and a sodium-bicarbonate type. Iron content exceeded the recommended limit. The 90 percent sodium, which is higher than all other analyzed glacial drift waters in the Crosby area, would restrict its use for irrigation.

The chemical quality of the water in the Yellowstone buried valley aquifer suggests the majority of recharge is being transmitted from the underlying Paleocene rocks. Discharge is to the north and laterally within the confines of the buried valley. Some upward leakage to the overlying drift may also occur. Recharge to the aquifer equals discharge over a given period of time.

Development of the aquifer consists of one farm well (163-97-22CDC3, Armstrong, 1965, p. 47) throughout the entire Crosby area. Future development will depend primarily on locating the aquifer by means of test drilling. Difficult drilling conditions can be expected.

COLUMBUS BURIED VALLEY AQUIFER

The Columbus buried valley is a generally west-to-east trending valley formed as a result of the ancestral Yellowstone River being dammed by ice and glacial drift. The damming of the river may have occurred during the second major interglacial period at which time the Yellowstone valley to the south of the Crosby area was filled with runoff water from the melting ice. Apparently the resulting lake was short-lived and eventually the water was diverted to the east, in front of the ice margin, and created the Columbus
valley. The narrowness and depth of the valley indicates a considerable quantity of water was involved and erosion was very rapid. The valley can be traced from the Crosby area to the Columbus area (Naplin, 1969) where it was initially identified by test drilling. From Columbus the valley trends eastward across northern Burke County (Armstrong, 1971, pl. 3).

North of Crosby (plate 2) near the confluence of the Yellowstone and Columbus valleys, another valley, time equivalent to the Columbus valley, is inferred to have entered from the northwest. This valley is believed to have contained water diverted from the ancestral Missouri River. The diversion of the Missouri probably occurred several miles north of Ambrose, North Dakota, in southern Saskatchewan.

Additional subsurface exploration would be required to accurately delineate the boundaries and historical sequence of events concerning the Columbus valley in the Crosby area. However, test hole 4429 (163-97-24BBB) is believed to reasonably represent the aquifer contained in the Columbus buried valley.

As indicated in geologic section C-C' (pl. 3) gravel and cobbles occupy the lower part of the valley fill at a depth of 414 to 440 feet, and presumably directly overlie bedrock. The gravel deposit was not completely penetrated because of lost circulation of the drilling fluid, but extends to at least 457 feet based on the log of a nearby Missouri Basin test hole (163-97-13CCC). In test hole 4429, 38 feet of coarse sand overlies the basal gravel. This sand and gravel, and its extension to the east and west within the confines of the valley, constitutes the Columbus buried valley aquifer. The aquifer is overlain by 37 feet of silty clay, suggesting the valley during its latter stage was blocked at some point downstream and the stream was ponded. The lithologic section above
the lake deposits consists essentially of till.

Test hole 4437 (163-97-24AAA) also encountered the Columbus buried valley aquifer. The position of the test hole along the line of section B-B' (pl. 3) however, creates the illusion the Columbus valley is trending upgradient to the southwest. Actually the sands southwest of test hole 4437 represent the depositional cycles in the Crosby buried valley (plate 2) and will be discussed in the following section dealing with the Crosby buried valley aquifer.

Observation wells were installed in test holes 4429 and 4437. Well 4429 was screened from 420 to 432 feet bgs and well 4437 from 399 to 411 feet bgs. The measured water levels on December 13, 1973 (table 2) were 50.91 and 55.29 respectively, indicating artesian conditions prevail. Converting the water level measurements to elevation above mean sea level, the potentiometric surface at well 4429 was 1864.09 feet and 1863.71 feet at well 4437. Therefore the hydraulic gradient is decreasing to the east at a rate of .38 feet per mile. The Columbus aquifer at wells 4429 and 4437, however, is being influenced by the Crosby buried valley aquifer because of direct hydrologic connection. Therefore, although the slope of the hydraulic gradient may remain fairly constant in the Columbus aquifer as it leaves the Crosby area to the east, an increase in gradient slope could be expected toward the west where the aquifer enters the area.

Test holes 4443, 4444, and 4445 (plate 1) were drilled in the approximate area the Columbus valley was believed to have intersected the Yellowstone valley (plate 2). The Columbus aquifer could not be identified in any of the tests, however. It is assumed, therefore, the aquifer passes just south of test hole 4445. The Columbus valley west of the junction with the Yellowstone valley may
be relatively narrow, possibly in the neighborhood of 1,500 feet wide. It can be identified only by additional test drilling.

Data are insufficient to determine the average depth, width, thickness, and hydrologic properties of the Columbus aquifer within the Crosby area. An estimate of ground-water storage would be conjectural at best. However, based on field sample examination, drilling characteristics, and electric logs from test holes 4429 and 4437, and interpolating results from an aquifer test in the Columbus area (Armstrong, 1971, pp. 31-36), the following estimates seem reasonable. The transmissivity of the aquifer should be about 10,000 ft²/day. The specific capacity of properly constructed wells should approximate 25 gpm per foot of drawdown. Yields of over 500 gpm are possible from individual wells, however, a lesser rate may prove more practical if sustained pumping is to be maintained.

East and west of test holes 4429 and 4437, where the aquifer is assumed to be more confined and influenced less by the Crosby buried valley aquifer, considerable drawdown may result because of the effect of boundary conditions. Drawdown would continue as the cone of depression spreads up and down the buried valley until it nullifies the effects of the lateral boundaries and recharge equals discharge from the aquifer. A 30 to 40 foot loss of head may result if very large withdrawals are introduced. The aquifer would remain saturated but there may be a noticeable decrease of specific capacity under actual pumping conditions.

Water samples from wells 4429 and 4437 indicate the water contained in the Columbus aquifer is a sodium bicarbonate type with sulfate and chloride concentrations within acceptable limits. The water at well 4429 was somewhat softer and contained less total dissolved solids than well 4437, 240, and 1,380 mg/l as compared to 255 and 1,530 mg/l. Well 4437 contained water of exceptionally
high iron concentration as compared to well 4429, 3.3 mg/l to 0.87 mg/l respectively; both exceed recommended limits. Percent sodium (81), SAR (14), and temperature (10°C or 50°F) was consistent at both locations.

Water quality suggests the Columbus aquifer is being recharged principally by underflow from the Paleocene rocks in which the Columbus buried valley is incised. Lateral recharge from the Crosby aquifer and direct infiltration of precipitation through the overlying glacial drift also contribute, but the proportion from each source is unknown. Development of the aquifer would undoubtedly induce more recharge from the glacial drift. Water level measurements indicate the aquifer is essentially in a state of equilibrium (recharge = discharge) at the present time. The Columbus aquifer in the Crosby area is, for all practical purposes, undeveloped.

CROSBY BURIED VALLEY AQUIFER

The Crosby buried valley formed as a major tributary to the Columbus valley. It enters in the south-central part of the Crosby area and joins the Columbus valley near the central part of the area (plate 2). The sequence and distribution of sediments in the valley (plate 3) suggest three cycles of deposition occurred. The first depositional cycle covered the valley floor with glaciofluvial deposits, principally sand and gravel. The second depositional cycle formed as a result of a glacial advance which blocked the drainage of the Columbus valley creating a proglacial lake in both the Columbus and Crosby valleys. Approximately 40 feet of lacustrine clays were deposited in portions of the valleys unoccupied by ice. Till defines the remainder of the area overlain by the glacier prior to recession of the ice. The third depositional cycle was confined to the Crosby valley and that portion of the Columbus valley east
of their confluence and is represented primarily by fluvial sand. The Columbus valley west of the confluence was filled with till during the second depositional cycle. Meltwater which formerly followed the course of the western portion of the Columbus valley apparently was diverted elsewhere during the third cycle.

The Crosby buried valley aquifer is divided into two zones that are separated by clay and/or till. The lower zone, representing the first depositional cycle, is usually encountered from 320 to 390 feet below land surface. It averages 40 feet in thickness, but may be 80 or more feet thick. The upper zone, representing the third depositional cycle, generally is 230 to 310 feet below land surface and averages about 30 feet in thickness. The probable extent of the Crosby aquifer, and its relationship to the Columbus aquifer, are indicated on figure 3. Although thinner the upper zone of the Crosby aquifer appears to be more extensive laterally than the lower zone. The cumulative thickness of both zones is shown on figure 4.

Aquifer characteristics have been determined from the following test holes which penetrated one or both zones of the Crosby aquifer; they are test hole numbers 4423, 4424, 4425, 4428, 4432, 4433, 4438, 4446, 4447, 4450, 8290, 8291, 8292, and 8293 (plate 1). Observation wells were developed in the upper zone in test hole numbers 4423A, 4450, 8292, and 8293 and in the lower zone in numbers 4423, 4428, 4446, and 8291.

Estimates of aquifer constants were interpreted from four pumping tests which include city well #3, two test wells drilled by C. A. Simpson & Son in 1972; and the new, city well #4 drilled in 1973 also developed by the Simpson Drilling firm. All four pumping tests produced water from the upper zone of the Crosby aquifer. Water samples were collected for chemical analyses from all the wells.
FIGURE 3-- PROBABLE EXTENT OF THE COLUMBUS AND CROSBY BURIED VALLEY AQUIFERS
FIGURE 4--CUMMULATIVE THICKNESS OF THE CROSBY BURIED VALLEY AQUIFER
Test drilling establishes the water bearing deposits in the Crosby buried valley as glaciofluvial in origin. Typical of glaciofluvial deposition, the materials are in no way uniform in thickness, grain size, or sorting. A general indication of thickness and grain size may be interpreted from the cross sections (pl. 1). The lower zone commonly consists of nearly equal amounts of sand and gravel. The upper zone is primarily medium to coarse sand with minor amounts of gravel but significant silt and fine sand. The highest degree of sorting appears to be associated with the main part of the valley which conforms essentially with the greater cumulative thickness shown in figure 4. Outward from the main valley the deposits become less sorted with lenticularity increasing proportionately to the distance.

Because of the variable lithology, there is also a variation in lateral permeability within each zone. This variation is more pronounced in the upper zone. The water bearing materials in each zone, nevertheless, are hydrologically connected. There is substantial proof, however, that a definite hydrologic separation exists between the upper and lower aquifer units.

The Crosby well field is located in what is apparently a large meander in the Crosby buried valley. It is near the western limit of the Crosby aquifer but both upper and lower zones are still present. The aquifer is absent within ½ to 1 mile to the north, west, and south of the well field.

In December, 1971, pumping cycles were observed on city well #3 (Schmid, 1972). The well casing is 12 inches in diameter and completed with 6 inch diameter shutter screen from 295 to 310 in depth. It is equipped with a turbine pump. Prior to pumping, the static water level in the well was 9 feet bls (below land surface). The well pumped at a rate of 260 gpm for 110 minutes. Total measured drawdown was 86 feet indicating the specific capacity
of the well is about 3 gpm per foot of drawdown. Based on available and
assumed data, Schmid concluded the well was operating at 20% efficiency. In
1957 Layne-Minnesota Company, after completing and developing city well #3,
obtained a specific capacity of 2.52 gpm/ft dd (F. W. Voedisch, written comm.).
At that time (1957) the static water level was 11½ feet above land surface with
a pumping level of 100 feet bls. The well was pumped at 281 gpm for 19 hours.

In 1972, C. A. Simpson and Son drilled and pumped two 6 inch test wells.
Well 72-1 (163-97-35bdd) was located ½ mile southeast of city well #3 near
the main channel of the Crosby aquifer. Screen was set from 306½ to 324 feet
bgs and after development the static water level was about 10½ feet bgs. After
pumping 80 gpm for 4½ hours this well had a specific capacity of approximately
20 gpm/ft dd. Well 72-2 (163-97-34daa) was drilled slightly more than ½ mile
southwest of city well #3. Screen was set from 287 to 309 feet bgs. Static
water level in the well was 14 feet bgs. Specific capacity of this well was
about 6 gpm/ft dd after 6½ hours of pumping at a rate of 328 gpm.

In July, 1973, C. A. Simpson and Son drilled a 6-inch test well at the
proposed site of the new city well (163-97-34add). The well was screened from
272 to 303 feet bgs and after 5 hours of pumping 30 gpm the calculated specific
capacity was 10 gpm/ft dd. The casing and screen were recovered and the hole
enlarged to accommodate 12 inch casing. Twelve inch nominal screen was then
set from 277 to 307 feet bgs. In September the State Water Commission and
Mr. Fred Simpson performed a pumping test on the production well. Data from
this test are included in a Water Commission open-file report (Schmid, 1974).
The well was pumped at a rate of 450 gpm for 3000 minutes; however, concurrent
with the test, city well #3 was also pumped continuously at 150 gpm. The
specific capacity of the production well was determined to be 7.4 gpm/ft dd.
Schmid concluded that transmissivity of the aquifer in the immediate vicinity of
the Crosby well field was 2,700 ft$^2$/day with a storage coefficient of $5 \times 10^{-5}$.
He also noted that excessive drawdown in observation well 8293 (163-97-35DDD)
as compared to the theoretical drawdown was due to a non-contributing impermeable
boundary to the east. A significant fact illustrated during the pumping test is
that little if any drawdown was observed in observation wells developed in the
lower zone of the Crosby aquifer.

Recharge to both zones of the Crosby aquifer is principally by underflow
from adjacent Paleocene rocks. Direct infiltration of precipitation on the
glacial drift overlying the aquifer also contributes to recharge. The pressure
head or potentiometric surface relates directly to the abrupt increase in
elevation to the south. Discharge is primarily natural underflow toward the
Columbus buried valley aquifer. Water pumped from the upper zone of the Crosby
aquifer during the past 25 years has resulted in a 20 foot lowering of the static
water level in the vicinity of the well field and a cone of depression has
developed. Beyond the area of influence of the city wells, water level measure-
ments (table 2) indicate fluctuations in the potentiometric surface relate to
seasonal variations and suggest the aquifer is essentially in a state of
equilibrium.

An estimate of ground water in storage in the Crosby aquifer has been
made assuming an average thickness of 30 feet for the upper zone and 40 feet
for the lower zone. As delineated on figure 3, the Crosby aquifer underlies
approximately 10 square miles or 6,400 acres. Conservatively assuming an
overall porosity of 30 percent there should be over 130,000 acre-feet of
water in storage within the Crosby area. Approximately 60 percent of this
water could be recovered by wells, however, large scale pumping would in turn induce considerable recharge. It is therefore conceivable that a combination of both zones of the Crosby aquifer could adequately support several properly spaced wells pumping continuously at a rate of 500 gpm.

The lower and upper zones of the Crosby aquifer can be easily differentiated on the basis of water quality as evidenced by Table 1. Water contained in the lower zone is characteristically a sodium-bicarbonate type and closely resembles ground water contained in the Paleocene rocks into which the Crosby buried valley is incised. Noticeably, the total dissolved solids are usually over 1,000 mg/l and the percent sodium, sodium adsorption ratio (SAR) and pH average 82, 15, and 8 respectively. Water in the upper zone is also typically a sodium-bicarbonate type, but approaches or becomes a calcium-bicarbonate type near the central, more permeable part of the valley. Total dissolved solids in the upper zone generally are less than 1,000 mg/l and comparatively, the percent sodium, SAR and pH average about 5.0, 4.5 and 7.6, respectively. Fluoride and chloride concentrations are somewhat higher in the lower zone, however, both constituents are still within acceptable limits for a municipal supply. Sulfates in either unit are variable and apparently relate to the near proximity of glacial till or recharge therefrom. Increased sulfate concentrations are correlative with increased hardness of the water. Iron content for the most part is unpredictable.

UNDIFFERENTIATED GLACIAL-DRIFT AQUIFERS

Associated with the glacial drift, but separate from the aquifers contained in the Yellowstone, Columbus, and Crosby buried valleys, are water bearing deposits of sand and gravel that could or do support the requirements of domestic and stock wells. These deposits occur at the surface and at depth and may range from small isolated pockets or lenses to narrow but relatively lengthy channel
fills. Surficial channel fill deposits occupy the present and former drainage courses of Long Creek and are easily traceable, however, test drilling is the only reliable means of locating the subsurface deposits.

Permeable surficial deposits normally contain very good quality water because of recharge by local precipitation and infiltration. However, water levels are extremely sensitive to climatic variations and there is the danger of contamination. Surficial aquifers in the Crosby area are therefore not highly recommended as a source for municipal supply.

The subsurface deposits, exclusive of the major aquifers, are characterized by generally poor quality water with total dissolved solids ranging from 1,500 to over 3,000 mg/l. These small aquifers contain calcium-sulfate type water when recharged exclusively by the surrounding glacial drift or sodium bicarbonate type water when recharge is derived primarily from the underlying bedrock. Well yields from the minor aquifers in general are limited and not capable of supplying the sustained pumpage required for a municipal water supply system.

**SUMMARY**

The Crosby area, as described in this investigation, includes approximately 92 square miles in northeastern Divide County. The area lies within the Drift Prairie section of the Central Lowlands physiographic province of North Dakota. The average annual precipitation is 13.36 inches and the annual temperature is 38.9°F. Long Creek and an unnamed intermittent stream channel, the ancestral Long Creek, drain the area.

The Crosby area overlies the northern flank of the Williston Basin and is underlain by as much as 12,000 feet of consolidated sedimentary rocks. The test holes in this investigation terminated in bedrock, except where difficult
drilling conditions existed. One test hole penetrated the Fox Hills Formation of Late Cretaceous age, the remainder were completed in the Tongue River Formation of Paleocene age.

Test drilling revealed the thickness of glacial deposits consisting of till and buried outwash ranges from 45 feet to over 575 feet, and is greatest over buried valleys. Extensive stratified glaciofluvial deposits of sand and gravel commonly constitute the fill of the major buried-valley aquifers: the Yellowstone, Columbus, and Crosby. In most instances they directly overlie bedrock.

The Yellowstone buried valley aquifer, approximately 1½ miles wide, enters the southwest corner of the Crosby area and continues north-northeast into Canada. Water-bearing material consists of glaciofluvial gravel in an approximately ¼ mile wide valley-in-valley. The gravel was encountered from 540 to 575 feet, but was not completely penetrated. A chemical analysis indicates the water is low in hardness and a sodium-bicarbonate type. Iron content exceeded the recommended limit. Chemical quality suggests recharge is from the underlying Paleozoic rocks.

The Columbus buried valley aquifer trends west-to-east and resulted from damming of the ancestral Yellowstone River. Water bearing material consists of coarse sand, gravel, and cobbles, and may be as much as 80 feet thick. Data are insufficient to determine the average depth, width, thickness, and hydrologic properties within the Crosby area. Analyses indicate the water is a sodium bicarbonate type and is being recharged by the underlying Paleocene rocks. The Columbus aquifer is practically undeveloped.

The Crosby buried valley aquifer which underlies approximately 10 square miles of the Crosby area is divided into two zones. The lower zone consisting
of glaciofluvial sand and gravel is usually encountered from 320 to 390 feet and averages 40 feet in thickness. The water is a sodium-bicarbonate type similar to ground water in the underlying Paleocene rocks. The upper zone, represented primarily by medium to coarse fluvial sand, is generally encountered 230 to 310 feet below land surface and averages 30 feet in thickness. The water is typically a sodium-bicarbonate type but approaches or becomes a calcium-bicarbonate type near the central, more permeable part of the valley. The Crosby city well #4 was developed in the upper zone.

Ground water in storage in the Crosby aquifer (both zones) is estimated to be over 130,000 acre-feet and should adequately support several properly spaced wells pumping continuously at a rate of 500 gpm.

Associated with the glacial drift, but separate from the Yellowstone, Columbus, and Crosby buried valley aquifers, are water bearing deposits of sand and gravel. These deposits occur at the surface and at depth and range from small isolated pockets or lenses to narrow relatively lengthy channel fills. In general, well yields from minor aquifers are limited for a municipal water supply system.
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*TABLE 1 -- CHEMICAL ANALYSES*

(Analytical results are in milligrams per liter except where indicated)
## TABLE 2 -- WATER-LEVEL RECORDS OF OBSERVATION WELLS
Depth to Water in Feet Below Land Surface

### 162-97-1ccc₁

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TABLE 3 - LOGS OF TEST HOLES

The following test hole logs are a summary of data from driller's logs, geologist's sample descriptions, resistivity, spontaneous potential, and gamma ray logs. Test hole elevations were interpolated from topographic maps published by the U. S. Geological Survey. Color descriptions are of wet samples and are based upon color standards (Goddard and others, 1963). Grain-size classification is C. K. Wentworth's scale from Pettijohn (1957).

Test Holes developed as observation wells are so indicated. Observation wells deeper than 300 feet were completed with 2-inch diameter steel casing; and wells shallower than 300 feet were completed with 1¼-inch diameter plastic pipe. Observation well depths and screened producing intervals (S.I.) are indicated. Water-level records of observation wells are in Table 2 and chemical analyses are in Table 1.

Explanation of Lithologic Symbols

- Clay
- Shale
- Silt
- Siltstone
- Sand
- Sandstone
- Gravel
- Lignite
- Till
LOCATION: 168-97-1ecal
ELEVATION: 1970 feet

DATE DRILLED: 12-1-71
DEPTH: 460 feet

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1
Topsoil, pebbly clay loam, dark brown.

1-13
Clay, silty, sandy, pebbly, dusky reddish yellow, soft to moderately soft, cohesive, moderately plastic, oxidized (Till).

13-28
Clay, silty, slightly sandy, numerous pebbles and occasional cobbles, reddish brown to moderate olive brown, moderately soft, cohesive, slightly plastic, oxidized (Till).

28-39
Clay, silty to slightly sandy, pebbly, occasional cobbles and boulders, olive gray, moderately soft, slightly stiff and brittle (Till).

39-80
Sand, very fine to fine, thin silty to clayey lenses, light olive to olive gray but partially oxidized in upper few feet, loose to slightly cohesive, predominantly quartz laminated with fine lignite particles and carbonaceous material.

80-150
Clay, silty, sandy, pebbly, granite boulders at 130 and 137 feet, olive gray, cohesive, tough (Till).

150-175
Sand, predominantly fine, medium in upper part, very fine in lower part, well-sorted and uniform, quartzose, subrounded, loose, clean.

175-238
Clay, silty, sandy, pebbly, olive gray, moderately soft to slightly hard, tight (Till).

238-283
Sand, coarse to very coarse, some fine gravel, moderately well-sorted, subangular to rounded, loose, clean.

283-308
Clay, silty, sandy, pebbly, occasional cobbles, olive gray, moderately soft, cohesive, fairly stiff (Till).

308-325
Clay, silty, sandy, pebbly, and cobbles, olive to dark olive gray, slightly hard, tightly compacted, stiff and moderately brittle (Till).

325-350
Sand, very fine to fine, slightly clayey, light gray to light olive gray, moderately soft, chunky, crumbly, carbonaceous (Till?); occasional thin layers of marl-like clay.

350-365
Clay, silty, slightly sandy, occasional pebbles, olive gray with green and white, soft, sandy bedrock clays (Till?).

365-390
Clay, variegated greens and grays with black carbonaceous material, occasional sand grains and pebbles, soft to moderately soft (Till?); predominantly reworked bedrock.
LOCATION: 162-97-1 FCC  
ELEVATION: 1970 feet  
(FT, MSL)

DATE DRILLED: 12-1-71

DEPTH: 460 feet  
(FT)

POSSIBILITY (MV)  RESISTANCE (OHMS)

520

560

600

640

680

720

760

800

840

880

920

960

DESCRIPTION OF DEPOSITS

Glacial Drift (Cont.)

390-428 Gravel, medium to very coarse with cobbles, very little sand, generally subrounded, sorted, dark brown, mostly silicates with carbonates and a few granitics; poor sample return, rough drilling.

Tongue River Formation

428-453 Sandstone, very fine, clayey, light green to greenish gray, moderately soft, chunky, slightly friable; interbedded with indurated sandstone and carbonaceous siltstone and shale.

453-460 Shale, dark green and black, hard, smooth, waxy, very tight (bit sample).

2 Observation Wells

Obs. Well 4423 (2-inch steel)
Depth: 411 feet
S. I.: 399 to 411 feet

Obs. Well 4423 A (1½-inch plastic)
Depth: 264 feet
S. I.: 258 to 264 feet
TEST HOLE 4450

LOCATION: 162-97-2bb
ELEVATION: 1975
(FT, MSL)

DATE DRILLED: 6-16-72
DEPTH: 329
(FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1
Topsoil, pebbly silt loam, black.

1-16
Clay, very silty and sandy, occasional pebbles and sand lenses; dark brown; soft, moderately cohesive, sticky (washed till?).

16-26
Clay, silty to sandy, pebbly, yellowish gray with moderate olive brown, moderately soft, cohesive, slightly plastic, oxidized (Till).

26-34
Clay, silty, with coarse sand grains, moderate olive brown with variegated laminations, slightly hard.

34-41
Clay, silty, sandy, pebbly, light olive gray, moderately soft, cohesive, slightly plastic, partially oxidized (Till).

41-44
Cobbles, mostly carbonates and granitics; rough drilling.

44-56
Clay, silty, sandy, pebbly cobbles, olive gray, moderately soft to slightly hard, cohesive, compacted, stiff, slightly brittle (Till).

56-69
Gravel, fine to coarse, sandy, sorted but lenticular, iron-stained, subrounded, mostly carbonates with granitics with black siliceous shale and a little detrital lignite.

69-95
Clay, silty, sandy, occasional pebble or cobbles, olive gray, soft to moderately soft, cohesive to slightly crumbly, laminated, fairly tight.

95-114
Silt, clayey, light olive and olive gray, soft, moderately cohesive, very slightly plastic.

114-154
Clay, silty, sandy, pebbly, occasional cobbles, olive gray, slightly hard, very cohesive, stiff (Till).

154-165
Sand, very fine to medium, light olive gray, lenticular, silty and clayey, loose to slightly cohesive.

165-188
Clay, sandy, pebbly, olive to dark olive gray, soft, moderately cohesive, slightly plastic to slightly crumbly, organic laminae.

188-279
Clay, silty, sandy, pebbly, cobbles and occasional boulders, olive gray, slightly hard, tightly compacted, stiff, tight (Till).

279-305
Gravel, sandy, yellow-brown, clay layer at 253 feet.

305-309
Clay, dark gray, moderately hard, smooth, very stiff, tight.

309-319
Silt, clayey to sandy, interbedded, soft and moderately soft, slightly to moderately cohesive.

319-327
Gravel and cobbles, dark brown, sorted subrounded; mostly dark brown iron-stained silicates with carbonates; rough drilling.
**TEST HOLE 4450 (Cont.)**

<table>
<thead>
<tr>
<th>LOCATION: 162-97-2 bbb</th>
<th>DATE DRILLED: 6-16-72</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEVATION: 1975</td>
<td>DEPTH: 329 FT</td>
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</tbody>
</table>

**ELEVATION:** (FT, MSL)

<table>
<thead>
<tr>
<th>POTENTIAL (MV)</th>
<th>RESISTANCE (OHMS)</th>
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| 520             |                   |
| 560             |                   |
| 600             |                   |
| 640             |                   |
| 680             |                   |
| 720             |                   |
| 760             |                   |
| 800             |                   |
| 840             |                   |
| 880             |                   |
| 920             |                   |
| 960             |                   |

**DESCRIPTION OF DEPOSITS**

**Tongue River Formation**

- **327-329 Shale**, extremely silty with very fine sand, light gray, indurated, chalky.

**Observation Well**

- Depth: 294 feet
- S. I.: 288 to 294 feet
Tongue River Formation

Sandstone, very fine-grained, dark greenish gray, indurated, pyritiferous.
Sandstone, very fine-grained, clayey, light grayish green; slightly hard, slightly friable; interbedded with brownish gray, moderately carbonaceous siltstone and shale.

Glacial Drift

0-2
Topsoil, pebbly loam, dark brownish gray.

2-29
Clay, silty, sandy, pebbly, dark yellowish and reddish brown, moderately soft, cohesive, stiff, oxidized (Till).

29-80
Clay, silty, sandy, pebbly, occasional cobbles, olive gray, moderately soft to slightly hard, very cohesive, tight (Till).

80-112
Till (as above); interbedded with blocks of green shale and sandstone.

112-128
Silt, light olive and olive gray, moderately soft, chunky, friable, laminated; some very fine and fine sand.

128-204
Clay, very silty, sandy, pebbly, occasional cobbles and boulders, olive gray, moderately soft to slightly hard, very cohesive, stiff and tight (Till).

204-234
Till (as above); frequent blocks of soft, green and gray shale and sandstone.

Tongue River Formation

234-235
Sandstone, very fine-grained, dark greenish gray, indurated, pyritiferous.

235-260
Sandstone, very fine-grained, clayey, light grayish green; slightly hard, slightly friable; interbedded with brownish gray, moderately carbonaceous siltstone and shale.
LOCATION: 162-97-56°Cc
ELEVATION: 1960 ft

DATE DRILLED: 12-1-71
DEPTH: 580 ft

POTENTIAL (MV)  RESISTANCE (OHMS)
0-1
1-26
26-38
38-74
74-107
107-204
204-244
244-343
343-547

DESCRIPTION OF DEPOSITS

**Glacial Drift**

0-1 Topsoil, silty clay, brownish black.
1-26 Clay, very silty, slightly sandy, dark yellowish brown; moderately cohesive, slightly plastic, oxidized.
26-38 Sand, fine to medium, subangular to subrounded, moderately well-sorted, slightly lignitic, slightly oxidized.
38-74 Sand (as above); interbedded with gravel and thin lenses of clay or clayey till, lenticular.
74-107 Clay, silty, moderately sandy, gravel lenses and occasional cobbles, moderately soft, cohesive, slightly lignitic (Till).
107-204 Clay, silty, sandy, pebbly, cobbles, olive gray, slightly hard, tightly compacted, stiff (Till).

204-244 Clay, very silty, sandy, sand and gravel lenses, olive gray, moderately soft, cohesive (Till).
244-343 Clay, silty, sandy, pebbly, occasional cobbles, olive gray, slightly hard, very cohesive and compacted, stiff (Till).

343-547 Clay, silty, sandy, pebbly, cobbles, and boulders, occasional gravel lenses, olive gray, very cohesive, stiff and tough (Till).
**TEST HOLE 8286 (Cont.)**

**LOCATION:** 152-97-5000

**ELEVATION:** 1960 feet

(FT, MSL)

**DATE DRILLED:** 12-1-71

**DEPTH:** 580 feet

(FT)

**DESCRIPTION OF DEPOSITS**

**Fox Hills Formation**

547-580 Sandstone, very fine-grained, slightly clayey, medium bluish gray, noncalcareous, micaceous.
TEST HOLE 8283

LOCATION: 162-97-Baaa

ELEVATION: 1980 feet

DATE DRILLED: 11-30-71

DEPTH: 420 feet

(FT, MSL)

DEEPER DESCRIPTION OF DEPOSITS

Glacial Drift

0-1
Topsoil, silty clay; brownish black.

1-30
Clay, silty, sandy, dark yellowish brown, soft, slightly cohesive, oxidized.

30-37
Clay, silty, sandy, pebbly, olive gray, moderate soft, moderately cohesive (Till).

37-110
Clay, silty, sandy, pebbly, cobbles and boulders, numerous interbedded sand and gravel lenses, olive gray, cohesive, moderately stiff (Till).

110-160
Clay, silty, sandy, pebbly, cobbles, olive gray, slightly hard, tightly compacted, stiff (Till).

160-207
Silt, clayey to sandy, interbedded and laminated, olive gray, soft, loose to slightly cohesive; detrital lignite.

207-380
Clay, silty, sandy, pebbly, cobbles and thin gravel lenses, olive gray, cohesive, compacted, stiff (Till).

380-386
Gravel, cobbles, boulders, sorted, subrounded, mostly carbonates; rough drilling.

386-403
Clay, sandy, pebbly, cobbles, olive gray, hard, stiff, brittle, tightly compacted (Till).

403-420
Tongue River Formation

Sandstone, very fine-grained, slightly clayey, medium bluish-gray, moderately soft and friable, micaceous; thinly interbedded with brownish black to medium dark gray, moderately indurated, noncalcareous, carbonaceous shale.
TEST HOLE 8284

LOCATION: 162-97-1

ELEVATION: 1980 feet

DATE DRILLED: 12-1-71

DEPTH: 240 feet

DESCRIPTON OF DEPOSITS

Glacial Drift:

0-1 Topsoil, silty clay, brownish black.

1-16 Clay, very silty to slightly sandy, dark yellowish brown, moderately cohesive, slightly plastic, oxidized.

16-46 Clay, silty, sandy, pebbly, dark yellowish brown, cohesive, slightly plastic, oxidized (Till).

46-213 Clay, silty, sandy, pebbly, cobbles, and occasional gravel lenses, olive gray, moderately soft to slightly hard, cohesive, stiff (Till).

Tongue River Formation

213-240 Sandstone, very fine-grained, slightly clayey, micaceous, noncalcareous; interbedded with thin, medium gray shale beds.
LOCATION: 162-97a
ELEVATION: 1958 feet

DATE DRILLED: 12-1-71
DEPTH: 300 feet (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1
Topsoil, pebbly clay loam, brownish black.

1-27
Clay, silty, sandy, pebbly, dark yellowish brown, moderately cohesive, oxidized (Till).

27-140
Clay, silty, sandy, pebbly, cobbles, gravel lenses, olive gray, moderately soft, cohesive (Till).

140-145
Sand, medium to coarse, slightly clayey, moderately well-sorted, subangular to subrounded.

145-149
Clay, silty, olive gray, moderately soft, smooth, sticky.

149-161
Gravel, fine to coarse, clayey, sorted but lenticular, subangular to rounded; about 50% dark brown silicates, rough drilling.

161-174
Silt, clayey to very sandy, interbedded gravel lenses, moderate yellowish brown, slightly cohesive, oxidized.

174-180
Gravel, fine to coarse, clayey and sandy, poorly sorted.

180-223
Clay, silty, sandy, pebbly, thin gravel lenses, olive gray, moderately soft to slightly hard, cohesive, stiff (Till).

223-272
Clay, very silty, sandy, pebbly, gravel lenses, and sandy detrital lignite, medium-light to light-bluish gray, soft to moderately soft, slightly cohesive, crumbly, very calcareous (Till).

Tongue River Formation

272-300
Shale, light greenish gray, moderately well-indurated, non-calcareous, interbedded with lignite and medium-bluish gray, fine-grained sandstone.

Observation Well

Depth: 153 feet
S. t.: 147 to 153 feet
TEST HOLE 4432

LOCATION: 162-97-12cdd
ELEVATION: 1965

DATE DRILLED: 5-23-72
DEPTH: 300

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, pebbly silt loam, black.
1-5 Clay, very silty, pebbly, dusky yellow, soft, slightly cohesive, oxidized (Till).
5-30 Clay, silty, sandy, pebbly, cobbles, moderate olive brown, moderately soft, moderately cohesive, oxidized (Till).
30-33 Silt, slightly clayey, yellowish gray, soft, crumbly.
33-39 Clay, silty, pebbly, light olive gray, moderately soft, chunky, slightly friable (Till).
39-48 Silt, clayey, sandy, soft, very slightly cohesive.
48-93 Sand, very fine to fine, some medium, light gray, sorted, subrounded, loose.
93-107 Clay, silty, sandy, pebbly, slightly hard, tight (Till); interbedded with layers of clay, silt, and sand; occasional gravel and detrital lignite.
107-158 Clay, very silty, sandy, pebbly, occasional cobbles, olive gray, slightly to moderately hard, very cohesive, compacted (Till).
158-247 Sand, medium to coarse, clayey in upper part, well-sorted.
247-260 Clay, silty, sandy, pebbly, olive gray, slightly hard, slightly brittle, compacted (Till); thin sandy lenses.

Tongue River Formation

269-271 Shale, silty, light gray, hard, brittle.
271-275 Shale (as above); grayish brown; interbedded lignite.
275-283 Lignite, black, hard; possibly fractured.
283-286 Shale, silty, brownish black, hard, smooth, carbonaceous.
286-300 Siltstone, variegated grays and browns to black, hard, porous, carbonaceous.
LOCATION: 162-97-14dd
ELEVATION: 1990 feet

DATE DRILLED: 6-4-59
DEPTH: 378 feet

DESCRIPTION OF DEPOSITS

Glacial Drift

0-4 Topsoil, clayey loam, brownish black.
4-21 Clay, sandy, pebbly, yellowish to brownish orange, mottled, oxidized (Till).
21-95 Clay, silty, sandy, pebbly, lignitic sand and gravel lenses, occasional cobbles, olive gray, moderately soft, cohesive (Till).
95-126 Clay, silty, olive to dark olive gray, moderately soft, cohesive, moderately stiff, laminated.

126-146 Sand, very fine and fine, clayey and lignitic, dark gray, interbedded or lenticular.

146-316 Clay, silty, sandy, pebbly, cobbles and boulders, occasional gravel stringers, olive gray, cohesive, stiff, tough (Till).

316-369 Clay, silty, dark gray, moderately soft to slightly hard, very cohesive, smooth, slight-plastic to stiff and brittle.

Tongue River Formation

369-378 Sandstone, fine-grained, clayey, greenish gray, slightly hard, chunky, friable.
TEST HOLE MB

LOCATION: 163.96-5aa

ELEVATION: 1881 feet

(FT, MSL)

DATE DRILLED: 1947

DEPTH: 200 feet

(FT)

DESCRIPTION OF DEPOSITS

**Glacial Drift**
- 0-3: Topsoil.
- 3-4: Clay, gray.
- 4-14: Gravel.
- 14-45: Clay, silty, gray.

**Tongue River Formation**
- 45-71: Clay, sandy, blue, with fine sand.
- 71-75: Clay, gray, with lignite.
- 75-82: Clay, brown, tight, with strips of light gray clay and lignite.
- 82-86: Clay, blue and gray.
- 86-96: Clay, gray, with strips of lignite.
- 96-99: Lignite, with strips of gray clay.
- 99-121: Clay, gray.
- 121-133: Lignite, hard and soft in strips, some clay.
- 133-157: Clay, gray, strips of lignite.
- 157-159: Lignite.
- 159-169: Clay, gray, tight, strips of lignite.
- 169-181: Lignite, with some clay.
- 181-189: Clay, sandy, gray, strips of lignite.
- 189-192: Sandstone, gray, hard.
- 192-200: Sand, gray, compact.
TEST HOLE 4435

LOCATION: 162-96-8E3S

ELEVATION: 1913

DATE DRILLED: 5-24-72

DEPTH: 300

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, clayey silt loam, black.

1-7 Clay, very silty, sandy, pebbly, dark brown, soft, moderately cohesive, organic (washed till).  

7-17 Sand, fine to coarse, reddish brown, sorted, subrounded, clean, oxidized.

17-32 Clay, silty, sandy, pebbly, moderate olive brown, moderately soft, cohesive, oxidized (Till).

32-39 Clay, very silty, sandy, pebbly, cobbles, olive gray, moderately soft, slightly friable, oxidation stains (Till).

39-79 Clay, very silty, sandy, pebbly, occasional cobbles, dusky yellow to moderate olive brown, moderately soft to slightly hard, cohesive, slightly brittle, oxidized (Till); numerous silt and clayey fine sand lenses.

79-134 Clay, silty, sandy, pebbly, cobbles, moderate olive brown, slightly hard, tightly compacted, oxidized (Till).

134-164 Clay, silty, sandy, pebbly, moderate olive brown and olive gray intermixed (Till).

164-169 Sand, coarse to very coarse with fine and medium gravel, sorted, subrounded, clean.

169-206 Clay, very silty, sandy, pebbly, olive gray, moderately soft to slightly hard, very cohesive, stiff (Till); lenticular sand and gravel.

206-219 Clay, silty, sandy, pebbly, dark olive gray, hard, tightly compacted (Till).

219-243 Silt, clayey with very fine sand, light olive to olive gray, soft, slightly cohesive.

243-256 Gravel, fine to coarse, sandy with possible clay or till layers, poorly sorted.

Tongue River Formation

256-300 Shale, variegated grays and browns, hard, tight; interbedded with greenish gray and dark greenish gray, moderately soft, friable, carbonaceous sandstone.
LOCATION: 163-26-17ada
ELEVATION: 1910

DATE DRILLED: 6-15-72
DEPTH: 320

RESISTANCE (OHMS)

Gamma Log

POTENTIAL (MV)

DESCRIPTION OF DEPOSITS

**Glacial Drift**

Topsoil, sandy silt loam, black.

Clay, very silty, sandy, pebbly, dark brown, soft, sticky (washed till).  

Clay, silty, sandy, pebbly, moderate olive brown, soft, cohesive, moderately plastic, oxidized (Till).

Sand, medium to coarse, light olive gray, well-sorted and uniform, clean, subrounded, lignitic.

Sand (as above); olive gray.

Silt and clayey sand, light olive gray and olive gray, laminated, soft, slightly to moderately cohesive; interbedded sand lenses.

Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive and compacted (Till).

Sandstone, fine-grained, light greenish gray, moderately soft slightly friable, slightly lignitic.

Clay, silty, slightly sandy, pebbly, olive gray, slightly hard, cohesive, stiff (Till); numerous lignitic sand and gravel lenses.

Till (as above); very clayey and sticky, gravel lenses.

**Tongue River Formation**

Lignite, hard, black, fissile.

Shale, silty, variegated, carbonaceous and lignitic.

Shale, sandy, variegated, slightly lignitic with in-durated sandstone or pyritiferous concretions.
LOCATION: 163-26-19daa

ELEVATION: 1922

DATE DRILLED: 5-24-72

DEPTH: 280

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1
Topsoil, clayey silt loam, black.
Clay, very silty, slightly sandy, pebbly, cobbles, moderate to dark olive brown, soft to moderately soft, slightly crumbly to moderately cohesive, oxidized (Till); boulders at 30 and 34 feet.

35-60
Clay, silty, sandy, pebbly, olive gray, moderately soft, stiff (Till); clay layers.

60-67
Sand, medium to coarse, yellowish-brown, loose, sort-ed, subrounded.

67-80
Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft to slightly hard (Till).

80-93
Sand, very fine, silty and moderately clayey, olive gray, soft, slightly cohesive, non-plastic.

93-134
Clay, silty, sandy, pebbly, varigated bedrock boulders containing lignite, slightly hard, compacted, stiff (Till).

134-149
Silt, slightly clayey with very fine sand, light olive gray with brownish tint, chunky, crumbly, nonplastic.

149-202
Sand, very fine to fine, some medium in upper part, becoming siltier with depth, loose to slightly cohesive.

Tongue River Formation

202-208
Siltstone, brownish gray, slightly hard, chunky, slightly friable, carbonaceous.

208-226
Sandstone and siltstone, greenish and brownish gray, slightly hard, moderately friable, slightly carbonaceous and lignitic, thin waxy shales.

226-280
Shale, silty and sandy, varigated greens and grays, hard, brittle, carbonaceous and lignitic.
LOCATION:  163-96-29bbb

ELEVATION:  1325 feet

DATE DRILLED:  12-20-71

DEPTH:  320 feet

DESCRIPTION OF DEPOSITS

Glacial Drift

Topsoil, pebbly clay loam, grayish black.

Clay, moderately silty, slightly sandy, pebbly, moderate yellowish brown, moderately cohesive, oxidized (Till).

Clay, silty, sandy, pebbly, numerous fine to coarse sand lenses, dark yellowish brown, loose to moderately cohesive, oxidized (Till).

Sand, medium to coarse, well-sorted, subrounded, partially oxidized.

Clay, silty, sandy, pebbly, sand and gravel lenses, cobbles, olive gray, moderately soft, cohesive (Till).

Clay, silty, sandy, interbedded, medium gray to medium dark gray with very light gray mottling and laminations, soft to moderately soft, moderately cohesive, slightly plastic.

Clay (as above), dark gray, interbedded with fine and medium, sorted, subrounded sand.

Sand, fine to coarse, thinly interbedded with clay and silty clay lenses, light olive gray, quartzose and lignitic.

Clay, silty, olive gray, moderately soft, very cohesive, slightly plastic to stiff, smooth, laminated.

Silt, slightly clayey to sandy, light olive gray, soft chunky, crumbly, uniform.

Clay, silt, and sand (as above); thinly interbedded or lenticular; sand, fine and medium, light olive gray to slightly grayish-orange, well-sorted, subrounded, mainly quartz and carbonate rocks.

Clay, silty, dark olive gray, slightly hard, smooth, tight.

Sand, medium and coarse, some gravel and detrital lignite, moderately sorted, subrounded to subwrapped, mostly quartz and feldspars.

Tongue River Formation

Sandstone, very fine-grained, slightly clayey, medium bluish gray, micaceous, noncalcareous; thin shaley streaks.
TEST HOLE MB

LOCATION: 161-96-29dd

ELEVATION: 1905 feet (FT, MSL)

DATE DRILLED: 1947

DEPTH: 336 feet (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

0-2 Soil.
2-13 Clay, yellow, gypsiferous.
13-17 Clay, sandy, gray.
17-25 Boulder, limestone.
36-62 Rock.
62-80 Clay, sandy with pebbles, gray (TII).
80-91 Gravel, fine, sandy.
91-204 Clay, sandy with pebbles, cobbles and boulders, gray (TII).

204-209 Sand, fine, lignitic, thinly interbedded with gray clay.
209-266 Clay, sandy with pebbles, boulders and lignite fragments (TII).

266-279 Clay, pebbly, gray (TII).

Tongue River Formation

279-281 Lignite.
281-318 Clay, gray, interbedded with lignite.
318-329 Lignite, soft and hard.

329-336 Clay, sandy, brown, carbonaceous and lignitic.
TEST HOLE 4433

LOCATION: 163-96-31d
ELEVATION: 1928

DATE DRILLED: 5-23-72
DEPTH: 320

Glacial Drift

0-1 Topsoil, silty clay loam, black.
1-35 Clay, silty, sandy, pebbly, yellowish gray to moderate olive brown, soft to moderately soft, moderately cohesive, oxidized (Till); interbedded laminated silt and sandy clay layers.
35-150 Clay, moderately silty, sandy, pebbly, olive gray, moderately soft to slightly hard, cohesive, slightly plastic to stiff and brittle, tightly compacted (Till); granite boulder at 58 feet.
150-255 Clay, silty, slightly sandy, pebbly, cobbles, olive gray, slightly hard, very stiff (Till); thin lignitic sand and carbonate gravel lenses.
255-266 Sand, fine, silty, light olive gray, sorted, subrounded, loose.
266-279 Sand, medium to very coarse, sorted, subangular to subrounded, loose, clean.
279-294 Clay, silty to sandy, dark gray, smooth, tight, sticky; interbedded with fine to coarse, dark brown, heavily iron-stained silicate gravel.

Tongue River Formation

294-296 Lignite, black, hard.
296-304 Sandstone, very fine to fine-grained, greenish gray, moderately soft, friable, micaceous; macerated shell fragments.
304-310 Shale, light gray, hard, fissile, smooth, very tight; possibly bentonitic.
310-320 Sandstone (as above), clayey and lignitic.
TEST HOLE 3023

LOCATION: __161-96-13__

ELEVATION: __1927 feet__

(FT, MSL)

DATE DRILLED: __6-25-63__

DEPTH: __120 feet__

(FT)

DESCRIPTION OF DEPOSITS

**Glacial Drift**

0-2
Clay, silty, pebbly, yellowish gray, moderately soft, cohesive, oxidized (Till).

2-6
Clay, silty, pebbly, thin, fine to coarse, lignitic sand stringers, dark yellowish orange to moderate olive brown, moderately soft, loose to cohesive, oxidized (Till).

6-18
Clay, silty, sandy, pebbly, cobbles, and boulders; interbedded lignitic sand lenses, dark greenish gray to olive gray, moderately soft to slightly hard, cohesive, stiff (Till).

18-41
Clay, silty, sandy, pebbly, abundant lignite fragments, olive gray, moderately hard, chunky, slightly brittle (Till).

41-60
Clay and silt, interbedded, olive gray, laminated, lignitic, soft, slightly to moderately cohesive, non-to slightly plastic.

60-68
Sand, medium to very coarse, some gravel, interbedded, sorted, subangular to subrounded, lignitic; contains 'scoria' and dark brown silicates.

68-80
Silt, clayey, greenish gray, laminated, lignitic and micaceous, soft, calcareous.

80-88
Gravel, fine to coarse, slightly sandy, dark brown, sorted, subrounded.

88-102
Siltstone, varigated very light gray to medium dark gray, lighter material very limey, darker material carbonaceous and non-calcareous, hard, tight.

Tongue River Formation

102-120
Siltstone, varigated very light gray to medium dark gray, lighter material very limey, darker material carbonaceous and non-calcareous, hard, tight.
**TEST HOLE 3024**

**LOCATION:** 163-92-34bb

**ELEVATION:** 1890 feet (FT, MSL)

**DATE DRILLED:** 6-26-63

**DEPTH:** 480 feet (FT)

**DESCRIPTION OF DEPOSITS**

**Glacial Drift**

- **0-6 ft:** Gravel, sandy, assorted, sub-angular to subrounded, highly oxidized.
- **6-14 ft:** Gravel (as above), interbedded with grayish-orange, crumbly, oxidized silt.
- **14-19 ft:** Silt (as above), silty, less oxidized.
- **19-24 ft:** Silt, olive gray, moderately cohesive, calcareous.
- **24-46 ft:** Clay, silty, sandy, pebbly, lignite fragments, olive gray, moderately soft, cohesive (Till).
- **46-74 ft:** Clay, silty, sandy, pebbly, dark yellowish orange to moderate yellowish brown; moderately soft, crumbly to slightly brittle, oxidized (Till); possibly jointed or fractured.
- **74-100 ft:** Clay, silty, sandy, pebbly, occasional cobbles or gravel lenses, dusky yellow to light olive gray, moderately soft, partially oxidized (Till).
- **100-102 ft:** Gravel, granular, sandy, sub-rounded, oxidized.
- **102-143 ft:** Clay, silty, sandy, pebbly, cobbles, boulders, moderate to dark yellowish brown, slightly hard, compacted cohesive, oxidized (Till).
- **143-150 ft:** Clay and silt, moderate yellowish brown, soft, crumbly, laminated, oxidized.
- **150-158 ft:** Gravel, granular, well-sorted, subangular to subrounded, partially oxidized.
- **158-180 ft:** Clay, silty, sandy, pebbly, dark yellowish brown with olive gray blocks, hard tightly compacted, oxidized (Till).
- **180-190 ft:** Silt, moderate yellowish brown, hard, oxidized.
- **190-200 ft:** Clay, silty, sandy, pebbly, cobbles, and gravel lenses, moderate yellowish brown, hard, tightly compacted, oxidized (Till).
- **200-214 ft:** Till (as above), no gravel lenses.
- **214-296 ft:** Clay, silty, sandy, pebbly, cobbles, and boulders, dark greenish gray, hard, cohesive, tightly compacted, stiff (Till).
- **296-365 ft:** Silt, clayey, sandy (very fine and fine), olive gray to black, soft to moderately soft, loose to slightly cohesive, laminated, lignitic.
- **365-394 ft:** Clay, slightly silty, dark greenish gray, hard, smooth, stiff, tight.
- **394-400 ft:** Gravel, granular, sandy, moderately well-sorted, subrounded.
TEST HOLE 3024 (Cont.)

<table>
<thead>
<tr>
<th>POTENTIAL (MV)</th>
<th>RESISTANCE (OHMS)</th>
<th>DESCRIPTION OF DEPOSITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>400-423</td>
<td>-520</td>
<td>Shale, silty, varigated light olive and greenish gray to brownish black, hard, brittle, tight, carbonaceous and lignitic.</td>
</tr>
<tr>
<td>423-430</td>
<td>-560</td>
<td>Sandstone, very fine-grained, light bluish gray, chunky, micaceous, calcareous.</td>
</tr>
<tr>
<td>430-460</td>
<td>-600</td>
<td>Tongue River Formation</td>
</tr>
<tr>
<td>460-490</td>
<td>-640</td>
<td></td>
</tr>
<tr>
<td>490-520</td>
<td>-680</td>
<td></td>
</tr>
<tr>
<td>520-550</td>
<td>-720</td>
<td></td>
</tr>
<tr>
<td>550-580</td>
<td>-760</td>
<td></td>
</tr>
<tr>
<td>580-610</td>
<td>-800</td>
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</tr>
<tr>
<td>610-640</td>
<td>-840</td>
<td></td>
</tr>
<tr>
<td>640-670</td>
<td>-880</td>
<td></td>
</tr>
<tr>
<td>670-700</td>
<td>-920</td>
<td></td>
</tr>
<tr>
<td>700-730</td>
<td>-960</td>
<td></td>
</tr>
</tbody>
</table>

LOCATION: 163°24'22" E
ELEVATION: 1890 feet
DATE DRILLED: 6-25-63
DEPTH: 430 feet

(FT, MSL)

POTENTIAL (W)
RESISTANCE (OHMS)
TEST HOLE 3019

LOCATION: 163-92.4daa
ELEVATION: 1890 feet

DATE DRILLED: 6-16-63
DEPTH: 240 feet

RESISTANCE (OHMS)

0-2
2-7
7-14
14-27
27-48
48-52
52-67
67-72
72-78
78-140
140-145
145-177
177-190
190-204
204-210
210-222
222-240

DESCRIPTION OF DEPOSITS

Glacial Drift

Topsoil, very gravelly.
Clay, very silty, dark yellowish orange, soft, oxidized.
Gravel, fine and medium, angular to rounded, oxidized.
Silt, clayey to very sandy, dusky yellow to light olive gray, soft, loose to slightly cohesive, partially oxidized.
Clay, silty, sandy, pebbly, dark greenish gray, moderately soft, cohesive, slightly plastic (Till).
Sand, very fine and fine, light olive gray, loose, well-sorted, subrounded, quartzose, lignitic, and micaceous.
Clay, silty, slightly sandy, pebbly, dark greenish gray or olive gray with moderate yellowish or greenish brown inclusions, hard, cohesive, tightly compacted (Till).
Gravel, fine, sandy, well-sorted subangular to subrounded, mostly carbonate rocks.
Clay, silty, olive gray, moderately soft, cohesive, slightly plastic, smooth.
Clay, silty, sandy, pebbly, cobbles, and boulders, occasional thin sandy gravel lenses, frequent blocks or boulders of oxidized till, dark greenish gray, moderately hard, cohesive, tight (Till).
Sand, medium to coarse, well-sorted, loose, clean.
Clay, very silty, sandy, pebbly, cobbles and occasional boulders, olive to dark greenish gray, hard, cohesive, compacted (Till).
Gravel, slightly sandy, cobbles, sorted, generally subrounded; very rough drilling.
Clay and silt with thin gravel lenses, olive gray, moderately soft to slightly hard, stiff.
Silt, very sandy (fine), light olive gray, soft, loose to slightly cohesive.

Tongue River Formation

Sandstone, very fine-grained, clayey greenish gray, possibly oxidized in upper few feet, noncalcareous.
Shale and siltstone, sandy and lignitic, hard, brittle, tight, noncalcareous.
TEST HOLE 4441

LOCATION: 163-97-5ccc
ELEVATION: 1929 (FT, MSL)

DATE DRILLED: 6-1-72
DEPTH: 180 (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, silty loam, black.
1-18 Silt, clayey, sandy, pebbly, yellowish gray to moderate olive brown, soft, cohesive, moderately plastic, slightly sticky, oxidized (Till).
18-41 Clay, very silty, sandy, pebbly, moderate olive brown with olive gray, moderately soft, cohesive, slightly plastic, partially oxidized (Till); boulders at 33 and 36 feet.
41-78 Clay, very silty, sandy, pebbly, olive gray, soft, cohesive, plastic, sticky (Till); boulders at 33 and 36 feet.
78-136 Silt, clayey, occasional sand grain or pebble, olive gray, soft, cohesive, plastic, smooth.

Tongue River Formation

136-138 Shale, medium gray, slightly hard, slightly brittle, smooth, tight.
138-145 Lignite, hard, brittle; probably fractured.
145-158 Shale, silty to sandy, variegated browns to black, slightly to moderately hard, oily, carbonaceous and lignite, tight.
158-164 Shale, silty, green with brown stains, moderately soft, smooth.
164-180 Sandstone, very fine-grained, clayey, greenish gray with brown, soft, moderately friable, carbonaceous.

Flowing Test Hole
Plugged
TEST HOLE 4442

LOCATION: 163-97-100th

ELEVATION: 1922

DATE DRILLED: 6-1-72

DEPTH: 380

DESCRIPTIO OF DEPOSITS

Glacial Drift

0-2
Topsoil, clayey silt loam, black

2-18
Clay, silty, sandy, pebbly, moderately olive brown, moderately soft, cohesive, iron-stained, oxidized (Till).

18-27
Till (as above); very gravelly.

27-39
Clay, silty, sandy, pebbly, light olive to olive gray, slightly hard, cohesive, compacted, oxidized (Till).

39-70
Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive, slightly plastic (Till).

70-85
Silt, clayey, sandy, pebbly, dusky yellow, soft, slightly cohesive, oxidized (Till).

85-122
Clay, silty, sandy, pebbly, cobbles, moderate olive brown, moderately soft, cohesive, stiff, oxidized (Till).

122-127
Sand, coarse, sorted, subangular and subrounded, iron-stained.

127-189
Clay, silty, sandy, pebbly, moderate olive brown, slightly hard, stiff, slightly brittle, oxidized (Till); medium to coarse sand and fine gravel lenses.

189-227
Clay, silty, sandy, pebbly, light olive gray, hard, stiff, compacted, partially oxidized (Till).

227-230
Cobbles.

230-308
Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft to slightly hard, cohesive, stiff (Till).

308-323
Gravel, fine and medium, sandy, lenticular, subrounded, loose.

323-327
Clay, dark olive gray, moderately soft, cohesive, stiff, smooth, tight.

327-342
Sand, fine, silty to slightly clayey, laminated grays, soft, crumbly.

342-345
Cobbles.

Tongue River Formation

345-380
Sandstone, very fine, clayey, varigated grays, greens, and browns, moderately soft, friable, micaceous, carbonaceous; interbedded siltstone and sandy shale.
LOCATION: 163-92-10 cac
ELEVATION: 1920 (FT, MSL)
DATE DRILLED: 6-6-72
DEPTH: 540 (FT)

DESCRIPTON OF DEPOSITS

Glacial Drift

Topsoil, pebbly, silty loam, dark brown.
Silt, clayey, very sandy, pebbly, numerous sand and gravel lenses, yellowish gray to reddish brown, soft moderately cohesive, oxidized (washed till).
Clay, very silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive, slightly plastic to stiff (Till).
Clay and silty clay, olive to dark olive gray, moderately soft to slightly hard, moderately stiff and brittle.
Silt, slightly clayey to very sandy, dusky yellow, soft, friable, laminated, oxidized.
Clay and silty clay, olive or dark olive gray, occasional white, green, or brown, moderately soft to slightly hard, cohesive, tight, stiff, brittle, smooth.
Clay, olive gray, soft to moderately soft, cohesive, plastic, sticky; interbedded with silt and silty clay, some fine lignitic sand, frequent coarse sand and gravel lenses, occasional cobbles.
Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft to slightly hard, cohesive, compacted, (Till); sand lenses.
Silt, clayey to very sandy, pebbly, dusky yellow, moderately soft, moderately cohesive, oxidized (Till).
Clay, silty, sandy, pebbly, moderately olive brown, slightly hard, stiff, compacted, oxidized (Till).
Gravel, fine to coarse, sandy, sorted but lenticular, subangular to subrounded; interbedded with oxidized sandy till.
Silt, clayey, very sandy, pebbly dusky yellow, soft, moderately cohesive, oxidized (Till).
Gravel (as above), sandy, "dirty".
**TEST HOLE 4444 (Cont.)**

**LOCATION:** 163-97-10 ca.

**ELEVATION:** 1920

(FT, MSL)

**DATE DRILLED:** 6-5-72

**DEPTH:** 540

(FT)

**DESCRIPTION OF DEPOSITS**

**Glacial Drift (Cont.)**

Clay, extremely silty to moderately sandy, pebbly, cobbles, and frequent sandy gravel lenses, olive gray, cohesive, stiff (Till). Gravel, coarse, many cobbles.

**Tongue River Formation**

Shale, silty, medium dark gray, smooth, hard, brittle.

Sandstone, very fine-grained, light grayish green, moderately soft, slightly friable.

Shale, silty, variegated grays and browns, hard, smooth carbonaceous.

Sandstone, very fine-to fine-grained, grayish green, moderately soft, moderately friable, chunky, micaceous.
LOCATION: 162-97-125cc
ELEVATION: 1925 feet (FT, MSL)

DATE DRILLED: 12-22-71
DEPTH: 220 feet (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, pebbly silt loam, black.
1-26 Clay, silty, sandy, pebbly, moderate olive brown, moderately soft, cohesive, slightly plastic to slightly crumbly, oxidized (Till).
26-30 Sand, coarse, varies from medium sand to fine gravel, generally rounded, heavily iron-stained carbonates with granitics, little shale, no lignite.
30-50 Clay and silt, occasional sand grain or pebble, moderate olive brown, yellowish gray, and light olive gray, soft and moderately soft, plastic to crumbly.
50-104 Clay, very silty and sandy, pebbly, cobbles, numerous lenses of medium to coarse sand and fine to medium gravel, also blocks or boulders of greenish brown oxidized till, moderately soft to slightly hard, very cohesive and tough to crumbly (Till).
104-140 Sand, medium to very coarse, gravelly, interbedded with olive gray clayey till.
140-182 Clay, very silty, sandy, pebbly, olive gray, slightly hard, very cohesive and tough (Till).

Tongue River Formation

182-192 Sandstone, very fine-grained very clayey, light grayish green, moderately soft, slightly friable.
192-195 Lignite, black, hard, brittle; thinly interbedded with carbonaceous shale.
195-206 Shale, very silty, variegated greens, grays, and browns, hard, smooth, tight, carbonaceous.
206-207 Clay, sandy, white, soft, chalky.
207-210 Sandstone, very fine-grained, greenish gray, moderately indurated, CaC03 cement.
210-220 Shale, very silty to sandy, variegated, hard, tight, brittle, carbonaceous and lignitic.
TEST HOLE MB

LOCATION: __ J63-92-13 cc __

ELEVATION: __ 1915 feet __
(FT, MSL)

DATE DRILLED: __ 1947 __

DEPTH: __ 459 feet __
(FT)

DEEPER SARCE OF DEPOSITS

<table>
<thead>
<tr>
<th>POTENTIAL (MV)</th>
<th>RESISTANCE (OHMS)</th>
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<tbody>
<tr>
<td></td>
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<td>440</td>
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<tr>
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<td>480</td>
</tr>
</tbody>
</table>

Glacial Drift

0-1 Soil
1-5 Clay, sandy, gray.
5-7 Sand, fine, some gravel.
7-10 Clay, yellow.
10-33 Clay, blue.
33-45 Clay, yellow and gray.
45-46 Rock.
46-61 Clay, gray, with fine sand.
61-102 Clay, silty, gray.

102-240 Clay, gray with some gravel and lignite fragments (Till).

240-295 Till, as above, interbedded with fine sand.

295-384 Clay, gray.

384-397 Sand, fine, gravel and lignite fragments.
397-428 Gravel and fine sand.

428-448 Sand, fine, with gravel and gray clay.

448-457 Boulders.
457-459 Clay, gray.
DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, clayey silt loam, black.
1-16 Clay, very silty, sandy, pebbly, dark brown, soft, moderately cohesive, slightly sticky (washed till?).
16-28 Clay, silty, sandy, pebbly, moderate olive brown, moderately soft, cohesive, slightly stiff, oxidized (Till).
28-36 Silt, slightly clayey to sandy, dusky yellow, soft, slightly cohesive, nonplastic, oxidized.
36-70 Clay, silty, slightly sandy, pebbly, olive gray, moderately soft, very cohesive (Till).
70-74 Gravel, fine with medium, slightly sandy, well-sorted, subrounded, clean.
74-129 Clay, silty, sandy, pebbly, cobbles, olive gray, slightly hard, very cohesive, stiff, tightly compacted (Till); silt and gravel lenses.
129-131 Clay, dark gray, moderately soft, moderately plastic, smooth.
131-137 Silt, sandy (very fine), light olive to olive gray, soft, slightly cohesive, nonplastic.
137-139 Clay (as above) dark, smooth.
139-164 Silt, slightly clayey to very sandy; olive gray, laminated and interbedded.
164-191 Clay and silty clay, silt, and fine sand, thinly interbedded, variegated grays, soft to moderately soft, loose to cohesive.
191-196 Gravel, fine, sandy, generally subrounded, loose, sorted.
196-202 Clay, dark gray, slightly to moderately hard, brittle, stiff, tight.
202-239 Sand, very fine to medium, loose, laminated; interbedded with silty clay, silt, detrital lignite.
239-266 Silt, clayey to sandy, interbedded and laminated, soft to moderately soft, loose to moderately cohesive, non-to moderately plastic.
266-271 Clay, dark olive gray, slightly hard, stiff, smooth.
271-288 Silt, sandy (fine and medium), sorted but interbedded, generally light olive gray, soft.
288-329 Clay, silty, sandy, variegated grays, soft to hard; blocks of local bedrock, boulder pavement at the base.

Tongue River Formation

329-360 Shale, silty to sandy, variegated grays with green, black and brown, hard, very tight, carbonaceous.
DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, pebbly silt loam, black.

1-30 Clay, silty, sandy, pebbly, cobbles, moderate olive brown to greenish brown, moderately soft to slightly hard, cohesive to slightly crumbly (Till); contains blocks and lenses of clay, silt, and sand, oxidized.

30-42 Silt, slightly clayey, light olive gray, moderately soft, slightly cohesive, laminated; contains sand grains.

42-88 Clay, silty, slightly sandy, pebbly, olive gray, slightly hard, stiff (Till).

88-222 Clay and silty clay, predominantly olive gray but varies from light gray to nearly black, limy to organic, soft to moderately soft, cohesive, slightly crumbly to plastic, smooth.

222-237 Clay, silty, sandy, pebbly, olive to dark olive gray, slightly hard, very cohesive and compacted, stiff and tough (Till).

237-260 Till (as above) interbedded with sandy, fine and medium, carbonate gravel; rough drilling.

260-291 Till (as above) without the gravel.

291-301 Sand, gravelly, assorted, generally subrounded, loose, "dirty"; mostly carbonates with silicates and granitics.

301-317 Clay, silty, sandy, pebbly, olive gray, cohesive, compacted, tough, (Till).

Tongue River Formation

317-340 Sandstone, very fine to fine-grained, clayey, light greenish gray, moderately soft, slightly friable, micaceous, noncalcareous; interbedded with carbonaceous shale and thin indurated sandstone stringers; possibly lignitic near base.
DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, sandy loam, dark brown.
1-10 Sand, medium to very coarse, gravely, assorted, generally subrounded, loose, iron-stained, oxidized.
10-22 Silt, clayey, sandy, pebbly, yellowish gray, soft, slightly cohesive, laminated, oxidized (TIII?).
22-69 Clay, very silty, sandy, pebbly, olive gray, moderately soft to slightly hard, very cohesive, stiff, tightly compacted (TIII).
69-82 Clay, silty, sandy, pebbly, moderate olive brown, moderately soft, slightly crumbly to slightly brittle, partially oxidized (TIII).
82-87 Sand, coarse, reddish brown, sorted, generally subangular, loose, iron-stained.
87-102 Clay, very silty and sandy, pebbly, dusky yellow, soft to moderately soft, slightly crumbly, compacted, oxidized (TIII).
102-135 Clay, silty, sandy, pebbly, cobbles, occasional coarse sand lenses, olive gray, moderately soft, cohesive, moderately stiff (TIII).
135-155 Clay, silty, olive gray, slightly hard, cohesive, stiff, smooth, tight.
155-169 Sand, fine and medium, light brown, sorted, subrounded, loose; thin clay layers.
169-224 Clay, silty, sandy, pebbly, cobbles, variegated but predominantly moderate olive brown, moderately soft, cohesive to slightly crumbly, oxidized to partially oxidized (TIII).
224-239 Clay, silty, sandy, pebbly, olive gray, slightly hard, cohesive, stiff (TIII).
239-266 Sand, medium and coarse, very gravelly, lenticular.
266-289 Clay, silty, sandy, pebbly, olive gray, moderately soft, very cohesive, stiff (TIII); sand and gravel lenses.
289-362 Clay, silty, sandy, pebbly, cobbles and sandy gravel lenses, olive gray, moderately soft, cohesive (TIII).
362-451 Clay, very sandy, pebbly, sand lenses, olive gray, soft to moderately soft, moderately cohesive, compacted (TIII).
451-484 Silt, sandy (very fine and fine) olive gray, laminated, soft, loose to slightly cohesive.
TEST HOLE 4443 (Cont.)

LOCATION: 163-97-15abb
ELEVATION: 1910

DATE DRILLED: 6-2-71
DEPTH: 540

DEPRESSIONS

Glacial Drift (cont.)

484-491 Gravel, fine to coarse, sandy, assorted, subrounded, loose, clean, iron-stained.

491-494 Clay, sandy, white, soft, chalky.

494-502 Cobbles.

Tongue River Formation

502-515 Shale, silty variegated grays, hard, brittle.

515-537 Siltstone, clayey to sandy, buff to tan with light greenish gray laminations, friable.

537-540 Shale, dark gray, hard brittle, possibly bentonitic.

Observation Well

Depth: 244 feet
S. I.: 238 to 244 feet
TEST HOLE 4445

LOCATION: 162-27-15psf
ELEVATION: 1915 (FT, MSL)

DATE DRILLED: 6-7-72
DEPTH: 575 (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

Topsoil, silty loam, black.
Silt, clayey, sandy, dark brown, laminated, soft, sticky, oxidized.
Clay, very silty and sandy, pebbly, sand and gravel lenses, moderate olive brown, soft to moderately soft, moderately cohesive, slightly plastic, oxidized (Till). Gravel with cobbles, iron-stained.
Clay, silty, sandy, pebbly cobbles, moderate olive brown with olive gray, soft to moderately soft, cohesive, slightly stiff (Till); sand and gravel lenses in upper part.
Clay silty, olive to dark olive gray, moderately soft, smooth, slightly crumbly.
Clay, very silty and sandy, pebbly cobbles, dusky yellow to moderate olive brown, slightly hard, tightly compacted, oxidized (Till). Sand, medium to very coarse, yellowish brown, sorted but lenticular, subangular, loose.
Clay, silty, sandy, pebbly, olive gray, slightly hard, very cohesive, partially oxidized (Till).
Clay, silty, sandy, pebbly, moderate olive brown moderately soft, moderately cohesive to slightly crumbly, oxidized (Till); blocks or layers of dark brown, waxy, smooth clay.
Clay, silty, sandy, pebbly, cobbles, olive gray (Till); sand and gravel lenses.
Clay, silty, sandy, pebbly, cobbles, sandy gravel lenses, moderate olive brown, moderately soft, cohesive, oxidized (Till).
Clay, silty, sandy, pebbly, cobbles, moderate olive brown, slightly hard, stiff, compacted, oxidized (Till).
Clay, silty, sandy, pebbly numerous cobbles, yellowish gray, dusky yellow, moderate olive brown, and light olive gray, moderately soft, cohesive, oxidized (Till).
Clay, silty, sandy, pebbly cobbles, boulders, blocks or layers of clay, silt sand, and gravel; poor sample return.
TEST HOLE 4445 (Cont.)

DATE DRILLED: 6-7-72

DEPTH: 575

(FT)

LOCATION: 163-97-1566G

ELEVATION: 1915

(FT, MSL)

DESCRIPTION OF DEPOSITS

Glacial Drift (Cont.)

540-557 Gravel, fine to very coarse, coarse sand and cobbles, moderately sorted, subangular to subrounded, loose, clean.

557-575 Gravel, cobbles, and boulders; very difficult drilling.

Observation Well

Depth: 558 feet
S. I.: 546 to 558 feet
TEST HOLE 4439

LOCATION: 163-97-16ccc
ELEVATION: 1935 (FT, MSL)

DATE DRILLED: 5-31-72
DEPTH: 380 (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1  Topsoil; silty loam, black.
     Sand; fine and medium; yellowish gray, subrounded, sorted, loose; interbedded soft, oxidized clays.

10-17 Clay, silty, sandy, moderate olive brown, moderately soft, cohesive, oxidized (Till).
     Sand, coarse with fine gravel, moderately sorted, subrounded, loose, iron-stained.

20-55 Clay, silty, sandy, pebbly, cobbles, moderate olive brown to light olive gray, slightly hard and brittle, tightly compacted (Till).
     Silt, clayey, sandy, pebbly, dusky yellow, moderately soft, moderately cohesive, oxidized (Till).

55-85 Clay, silty, sandy, pebbly, cobbles, moderate olive brown, moderately soft to slightly hard, cohesive to slightly brittle, compacted, oxidized (Till); iron-stained sand lenses.

85-156 Clay, silty, sandy, pebbly, cobbles, moderate olive brown and light olive gray, slightly hard, very cohesive, stiff, partially oxidized (Till). Clay, olive gray, soft, to moderately soft, cohesive, plastic, smooth, sticky; interbedded silt and sand lenses.
     Sand, very fine to coarse, clayey and silty with gravel stringers, loose to moderately cohesive, thinly interbedded.

Tongue River Formation

Clay, sandy, white, soft, chalky.
Sandstone, fine-grained, dark greenish gray, indurated, CaCO3 cement.
Sandstone, very fine-to fine-grained; predominantly greenish gray but variegated, moderately soft, friable; interbedded with light gray and tan siltstone and light to medium gray shale, occasionally carbonaceous.
LOCATION: 163-97-19aaa
ELEVATION: 1950 (FT, MSL)

DATE DRILLED: 5-31-72
DEPTH: 320 (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil; silty clay loam, black.

1-21 Clay, very silty, sandy, pebbly, moderate olive brown, moderately soft, cohesive, iron-stained, oxidized (Till); interbedded silt and sand lenses.

21-40 Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive, stiff (Till).

40-141 Clay, silty, dark olive gray, moderately soft, cohesive, sticky, tight.

141-223 Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft to slightly hard, very cohesive, stiff (Till); medium to coarse sand lenses.

223-281 Clay, silty, sandy, pebbly, light olive and olive gray, moderately soft, cohesive, slightly plastic to moderately stiff (Till); variegated gray and black clay lenses.

281-288 Gravel, fine and medium, sandy, dark brown, subangular and subrounded, sorted, loose.

Tongue River Formation

288-302 Sandstone, very fine-grained, light greenish gray, moderately soft, slightly cohesive, chalky.

302-310 Lignite, black, hard, brittle; possible carbonaceous shale partings.

310-315 Shale, silty, medium gray, hard, tight, bentonitic.

315-320 Sandstone, very fine-grained, clayey, grayish green, carbonaceous.

Flowing Test Hole
Plugged with cement after obtaining water sample.
**TEST HOLE 8289**

**LOCATION:** 163-97-22ccc  
**ELEVATION:** 1943 feet (FT, MSL)

**DATE DRILLED:** 12-6-71  
**DEPTH:** 332 feet (FT)

### DESCRIPTION OF DEPOSITS

<table>
<thead>
<tr>
<th>POTENTIAL (MV)</th>
<th>RESISTANCE (OHMS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>Topsoil, silty clay, brownish black.</td>
</tr>
<tr>
<td>1-34</td>
<td>Clay, silty, sandy, pebbly, moderate yellowish brown, moderately cohesive, slightly plastic, oxidized (Till).</td>
</tr>
<tr>
<td>34-71</td>
<td>Clay, silty, sandy, pebbly, cobbles, thin sandy gravel stringers, olive gray, slightly hard, cohesive, stiff (Till).</td>
</tr>
<tr>
<td>71-86</td>
<td>Gravel, slightly sandy with cobbles, moderately sorted, angular to subrounded, mostly carbonate rocks; occasional clay or clayey till lenses.</td>
</tr>
<tr>
<td>86-332</td>
<td>Clay, silty, sandy, pebbly, cobbles, and boulders, interlensed with sand and gravel, olive gray, cohesive, compacted, stiff (Till); rough drilling.</td>
</tr>
</tbody>
</table>
LOCATION:  163-97-23 ccg  
ELEVATION:  1947 feet  

DATE DRILLED:  12-4-71  
DEPTH:  280 feet  

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1  Topsoil, pebbly loam, black.
1-30  Clay, silty, sandy, pebbly, dusky yellow to moderate olive brown, moderately soft, cohesive, slightly plastic, oxidized (Till).
30-74  Clay, silty, sandy, pebbly, olive gray, moderately soft, cohesive, slightly plastic to slightly stiff (Till).
74-130  Clay, silty, slightly sandy (very fine), contains coarse sand grains and carbonate pebbles, moderate olive brown, moderately soft, cohesive, compacted, oxidized (Till).
130-132  Sand, medium to very coarse, buff-colored, sorted, sub-rounded, loose.
132-155  Clay, silty, sandy, pebbly, olive gray, moderately soft, cohesive, compacted, moderately stiff (Till).
155-196  Clay, slightly silty, sandy, pebbly, gravel stringers, olive gray, slightly hard, cohesive, very stiff and tough (Till); rounded lignite fragments.
196-232  Till (as above), very gravelly, cobbles and boulders; moderately tough drilling.

Tongue River Formation

232-280  Sandstone, very fine-grained, light grayish green to greenish gray, soft to moderately soft, chunky, friable, carbonaceous, calcareous; interbedded with thin, white, marly or soft limestone layers.
TEST HOLE 4427

LOCATION: 163-97-23ddd
ELEVATION: 1930 feet (FT, MSL)

DATE DRILLED: 12-5-71
DEPTH: 360 feet (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, pebbly silt loam, black.
1-20 Clay, silty, slightly sandy, pebbly, dusky yellow, moderately soft, cohesive, slightly to moderately plastic, oxidized (Till).
20-38 Clay, silty, sandy, pebbly, moderate olive green, slightly hard, slightly brittle to slightly crumbly, partially oxidized (Till).
38-80 Clay, silty, sandy, pebbly, olive gray, moderately soft to slightly hard, very cohesive and tough (Till).
80-263 Clay, very silty, sandy, pebbly, carbonate cobbles and boulders, olive gray, moderately soft to slightly hard, tightly compacted, stiff (Till); interbedded with blocks of clay, silt, sand and fine carbonate gravel.

263-283 Clay, very silty, dark gray, laminated, slightly hard, smooth, tight, waxy, very stiff.
283-306 Sand, very fine to fine with medium, dark gray, sorted, subrounded, loose, highly lignitic.
306-316 Sand, medium to very coarse, moderately well-sorted, subrounded, mostly carbonate rocks.
316-335 Gravel, fine to coarse, sandy, cobbles, assorted or sorted, very lenticular, mostly carbonate rocks.

Tongue River Formation

335-360 Sandstone, very fine-grained, slightly clayey to silty, light grayish green, moderately soft, friable, micaceous, occasionally carbonaceous.

Observation Well

Depth: 327 feet
S. I.: 315 to 327 feet
**TEST HOLE 4437**

**LOCATION:** 163-97-24aaa

**ELEVATION:** 1919 (FT, MSL)

**DATE DRILLED:** 5-25-72

**DEPTH:** 460 (FT)

**DESCRIPTION OF DEPOSITS**

**Glacial Drift**

0-1 Topsoil, silty clay loam, black.

1-4 Clay, silty, sandy, dark brown, soft, slightly cohesive, crumbly (Till).

4-13 Clay, silty, sandy, pebbly, dark brown, soft, moderately cohesive, slightly sticky (Till).

13-21 Clay, silty, sandy, pebbly, yellowish gray to moderate olive brown, moderately soft, cohesive, oxidized (Till).

21-35 Silt, clayey, sandy, dusty yellow, soft, slightly cohesive, oxidized.

35-47 Silt, very clayey to sandy, light olive gray, soft, slightly to moderately cohesive, non-to slightly plastic.

47-53 Clay, olive gray, moderately soft, cohesive, smooth, tight.

53-71 Clay, silty, sandy, pebbly, olive gray, moderately soft to slightly hard, very cohesive, stiff (Till).

71-205 Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive, moderately plastic (Till); occasional layer of clay, silt, sand, and fine gravel.

205-254 Clay and silty clay with fine sand, olive gray, soft to moderately soft, smooth, sticky.

254-265 Sand, medium, lignitic, sorted, loose.

265-285 Clay, very silty, sandy, pebbly, olive gray, stiff, tight (Till).

285-294 Sand, fine and medium, gray, subrounded, sorted, loose, clean.

294-345 Clay, silty, sandy, pebbly, olive gray, moderately soft, cohesive, moderately stiff (Till).

345-363 Clay, dark gray to nearly black, hard smooth, tight, sticky.

363-391 Sand, medium and coarse, light olive gray, subangular and subrounded, sorted, lenticular; fine sand and silt stringers.

391-437 Gravel, fine to coarse, moderately sorted, subrounded, loose.

**Tongue River Formation**

437-460 Sandstone, fine-grained, nearly white to light greenish gray, moderately soft, friable, chalky; interbedded with variegated, noncarbonaceous shales.

**Observation Well**

Depth: 411 feet
S. I.: 399 to 411 feet
DESCRIPTION OF DEPOSITS

Glacial Drift

0-2  Topsoil, clayey loam, black.
2-6  Gravel, fine, sandy, assorted, subangular and subrounded, mostly heavily iron-stained carbonate rocks and granitics.
6-14 Sand, very fine, very silty to clayey, dusky yellow to yellowish gray with limonitic stains, soft, slightly cohesive, laminated, oxidized.
14-76 Clay, silty, sandy, pebbly, olive gray, moderately soft, cohesive, slightly plastic to moderately stiff (Till).
76-89 Silt, clayey to slightly sandy, laminated light and dark grays, soft, crumbly to slightly plastic.
89-101 Sand, very fine and fine, silty to slightly clayey, light olive and olive gray, soft, nonplastic.
101-172 Clay, silty, sandy, carbonate pebbles, olive gray, moderately soft to slightly hard, very cohesive and compacted, tough (Till); occasional blocks of lacustrine clays and silts with thin streaks of medium and coarse sand.
172-180 Sand, medium and coarse, moderately well-sorted, subrounded, loose, mostly carbonates and quartz.
180-268 Clay, silty, sandy, pebbly, cobbles, olive gray, (slightly lighter than till above), highly calcareous, tough (Till).
268-276 Sand, medium to very coarse with some fine gravel, well-sorted, subrounded with subangular, loose, mostly carbonate rocks.
276-339 Clay, very silty, sandy, pebbles, and interbedded medium to very coarse sand and gravel stringers, generally olive gray, stiff (Till).
339-376 Clay, silty, olive and dark olive gray, soft and moderately soft, moderately cohesive, smooth.
376-414 Sand, medium to very coarse with gravel, sorted but lenticular, subrounded, loose, clean, mainly granitics and carbonates.
414-440 Gravel, sandy with cobbles and boulders; lost circulation, 15 bags of bentonite.

Observation Well

Depth: 432 feet
S. l.: 420 to 432 feet
TEST HOLE 4428

LOCATION: 163-92-25aa...

ELEVATION: 1926 feet

DATE DRILLED: 12-6-71

DEPTH: 440 feet

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1
Topsoil, pebbly silt loam, black.

1-34
Clay, silty, sandy, pebbly, dusky yellow to moderate olive brown, moderately soft to cohesive, slightly plastic to slightly stiff, oxidized (Till).

34-50
Clay, silty, sandy, pebbly, moderate olive green, moderately soft, cohesive, slightly stiff to slightly crumbly, partially oxidized (Till).

50-70
Clay, silty, sandy, pebbly, olive gray, moderately soft to slightly hard, very cohesive, slightly stiff to slightly crumbly, tightly compacted (Till).

70-195
Clay, silty, sandy, numerous carbonate pebbles and cobbles, boulders and thin sandy gravel lenses, olive gray, slightly hard, cohesive, very stiff, tight and tough (Till).

195-231
Silt, very sandy (very fine) to clayey, generally olive gray, laminated with light gray, carbonate silty clay and black detrital lignite streaks, soft to moderately soft, slightly cohesive to crumbly.

231-267
Sand, very fine to fine, silty and lignitic, soft, crumbly, laminated.

267-304
Sand, medium, some fines, lignitic, well-sorted and uniform, subrounded, streaks of fine to medium gravel.

304-332
Clay, silty, sandy, pebbly, cobbles, and boulders, interbedded with carbonate gravels, olive gray, cohesive (Till).

332-370
Sand, very fine to medium, occasionally coarse, well-sorted but lenticular, laminated, quartzose and lignitic.

370-418
Sand, medium to very coarse with interbedded gravel, sorted, subrounded, sand mainly quartz and carbonates, gravel mostly dark brown silicates and carbonates.

Tongue River Formation

418-420
Clay, sandy, white, soft, crumbly highly calcareous.

420-422
Sandstone, very fine-grained, indurated, CaCO3 cement.

422-440
Sandstone, very fine and fine, silty to slightly clayey, light grayish green, moderately soft, chunky, friable; interbedded with dark green and black waxy shales.

Observation Well

Depth: 390 feet
S.I.: 378 to 390 feet
LOCATION: 163-97-25dd

ELEVATION: 1925 (FT, MSL)

TEST HOLE 4438

DATE DRILLED: 5-30-72

DEPTH: 440 (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

Topsoil, pebbly very fine sandy loam dark brown.

Clay, silty, sandy, pebbly, yellowish brown, soft, moderately cohesive, oxidized (Till).

Sand, coarse, fine gravel, reddish brown, sorted, generally subangular, heavily iron-stained, oxidized.

Clay, extremely silty, sandy, moderate olive brown, moderately soft, moderately cohesive, oxidized.

Sand, fine to medium, dusky yellow, well-sorted, subrounded, loose, oxidized.

Silt, clayey, dusky yellow, soft, slightly cohesive, oxidized.

Sand, fine, dusky yellow, oxidized.

Clay, very silty to slightly sandy, pebbly, cobbles, dark olive gray, slightly hard, very cohesive, stiff, compacted (Till).

Clay, silty to very silty with very fine sand, olive gray, thinly interbedded, soft to moderately soft, slightly to moderately cohesive.

Gravel, fine and medium, sandy, sorted, interbedded, subrounded, loose.

Sand, fine to coarse; interbedded with clay, silt, gravel and detrital lignite.

Silt, clayey to sandy (very fine and fine), olive gray, soft, slightly to moderately cohesive, lenticular.

Clay, very silty, sandy, pebbly, olive gray, soft, cohesive, slightly plastic (Till); blocks or layers of clay, silt, sand, and gravel.

Gravel, fine to coarse; clayey streaks.

Till, as above; silty and sandy clay lenses.

Silt, very sandy, light olive gray, soft, slightly cohesive.

Clay, silty to sandy (fine to coarse); very lenticular.

Sand, very fine and fine, silty, olive gray, sorted, loose.

Clay, silty to sandy, olive gray, laminated, soft to moderately soft, slightly to moderately cohesive.

Gravel, fine to coarse; cobbles and boulders.

Tongue River Formation

Sandstone, very fine, clayey, light greenish gray to grayish green, moderately soft, slightly friable, marly; thin bentonitic clay layers.

Observation Well

Depth: 134 feet
S.I.: 128 to 134 feet
LOCATION: 161-97-26add
ELEVATION: 1936 (FT, MSL)

DATE DRILLED: 6-16-72
DEPTH: 373 (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

0-2
Topsoil, silty loam, black.

2-22
Clay, very silty, sandy, pebbly, dark olive brown, soft, cohesive, sticky, oxidized (Till).

22-40
Clay, silty, sandy, pebbly, moderate olive brown, soft to moderately soft, cohesive, slightly plastic, oxidized (Till).

40-225
Clay, very silty, sandy, pebbly, cobbles, olive gray, moderately soft to slightly hard, cohesive, slightly plastic to stiff (Till).

225-285
Clay, silty, sandy, pebbly, olive gray, slightly hard, cohesive, stiff, brittle, tightly compacted (Till); occasional gravel lenses.

Tongue River Formation

285-299
Shale, silty and sandy, variegated, smooth, tight; thin indurated layers.

299-372
Shale and sandstone, interbedded, variegated, moderately soft to indurated.

Sandstone, very fine-grained, dark green, indurated.
TEST HOLE MB

LOCATION: 163-97-26bbb
ELEVATION: 1944 feet (FT, MSL)
DATE DRILLED: 1947
DEPTH: 438 feet (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

0-4 Soil
4-18 Clay, pebbly, yellow (Till).
18-69 Clay, sandy with pebbles, gray (Till).
69-85 Clay, sandy with pebbles, yellow (Till).
85-194 Clay, sandy with pebbles and cobbles, brown (Till).

194-230 Clay, sandy with pebbles, blue (Till).
230-233 Gravel, sandy, lignitic.
233-300 Clay, sandy with pebbles and cobbles, gray (Till).
300-306 Gravel, mostly carbonate rocks.
306-337 Clay, sandy with pebbles and cobbles, lignitic, gray (Till).

Tongue River Formation

337-375 Clay, sandy, lignitic, gray.
375-415 Clay, sandy, gray.

415-416 Rock.
416-430 Clay, sandy, gray.
430-438 Sand, fine.
LOCATION: 163-97-26ddd
ELEVATION: 1940

DATE DRILLED: 6-14-72
DEPTH: 380

DESCRIPTION OF DEPOSITS

Glacial Drift

Topsoil, pebbly silty loam, black.
Clay, silty, sandy, pebbly, dark brown, moderately soft, very cohesive, slightly plastic, oxidized (Till).
Clay, silty, sandy, pebbly, moderate olive brown to light reddish brown, soft to moderately soft, moderately cohesive, oxidized (Till); lenses of loose, medium grained sand.
Clay, silty to sandy, dark olive gray, moderately soft, slightly friable, laminated.
Clay, silty, sandy, pebbly, cobbles, olive gray, slightly hard, stiff, brittle, compacted (Till).
Silt, clayey, sandy, light olive gray, moderately soft, slightly cohesive to friable, laminated, partially oxidized.
Silt, clayey to very sandy, gravel lenses, light olive and olive gray to light brown, laminated, soft and slightly cohesive to loose.
Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive, stiff (Till); gravel lenses.

Tonque River Formation

Sandstone, very fine-grained, dark greenish gray, indurated.
Sandstone, very fine-grained, clayey, greenish gray, moderately soft, slightly friable, chalky.

Observation Well

Depth: 369 feet
S. I.: 357 to 369 feet
TEST HOLE 8288

LOCATION: 163-97-22sc

ELEVATION: 1962 feet

DATE DRILLED: 12-3-21

DEPTH: 500 feet

DEPTH: (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

Topsoil, silty clay, brownish-black.

0-1

Clay, moderately silty, sandy, pebbly, dark yellowish brown, moderately cohesive, oxidized (Till).

1-39

Clay, very silty, sandy, pebbly, cobbles, olive gray, cohesive, slightly plastic (Till).

39-80

Clay, very silty, sandy, medium dark gray, slightly plastic to crumbly.

80-100

Clay, very sandy, pebbly, much interbedded fine sand and occasional gravel lenses, moderate yellowish brown, soft, crumbly oxidized (Till).

100-144

Clay, silty, light olive gray, cohesive, moderately plastic.

144-148

Clay, silty, sandy, pebbly, cobbles, numerous blocks or lenses of clay, silt, and sand, occasional gravel stringer, moderate yellowish brown with olive gray motting, moderately soft and cohesive, partially oxidized (Till).

148-220

Clay, very silty, sandy, pebbly, olive gray, moderately soft, compacted, stiff to slightly friable (Till).

220-245

Gravel, fine to coarse, sandy, moderately sorted, angular to subrounded, mostly carbonates, some dark brown silicates.

245-273

Clay, silty, sandy, pebbly, cobbles, occasional boulders, frequent sand and gravel lenses, olive gray, slightly hard, cohesive and compacted, stiff and slightly brittle (Till).

273-459

Gravel, fine to coarse, slightly sandy, clay bed at 466 feet, cobbles near base, angular to subrounded, mostly carbonates and silicates.

459-476
LOCATION: 163-97-27688
ELEVATION: 1962 feet

DATE DRILLED: 12-3-71
DEPTH: 500 feet

DESCRIPTION OF DEPOSITS

Tongue River Formation

476-500 Sandstone, fine-grained, slightly clayey, medium bluish gray, friable, noncalcareous; interbedded with medium gray shale.

Observation Well
Depth: 264 feet
S.I.: 258-264 feet
LOCATION: 163-97-27d6d

ELEVATION: 1953 feet
(FT, MSL)

DATE DRILLED: 12-2-71

DEPTH: 420 feet
(FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1
Topsoil, pebbly silty loam, black.

1-28
Clay, silty, sandy, pebbly, yellowish brown, moderately soft, cohesive, slightly plastic, oxidized (Till).

28-33
Sand, fine, dusty yellow, loose, well-sorted, subrounded, oxidized.

33-64
Clay, silty, slightly sandy, numerous carbonate pebbles, moderate olive brown to moderate olive green, moderately soft, cohesive, slightly plastic to slightly stiff, partially oxidized (Till).

64-91
Clay, silty, sandy, pebbly, olive gray, moderately soft to slightly hard, very cohesive and compacted (Till).

91-185
Clay, olive to dark olive gray, soft to slightly hard, smooth, tight, waxy, stiff, laminated, sticky.

185-213
Clay, dark to very dark gray, slightly hard, very tightly compacted, smooth, tight.

213-255
Sand, very fine and fine, slightly silty and clayey, light olive and olive gray, laminated, fairly uniform.

255-270
Sand, coarse and very coarse, some gravel, moderately sorted, generally subrounded, loose, clean, mostly carbonates with granitics and silicates.

270-310
Clay, silty, olive and olive gray, laminated, smooth, slightly hard and brittle, tightly compacted.

310-322
Sand, medium to very coarse with thin lenses of silt, sandy clay, sorted, lenticular, subrounded; wood fragments.

322-330
Clay, silty, olive gray, slightly hard, very cohesive, tight, stiff, smooth.

330-339
Sand, coarse, well-sorted, subrounded, loose, clean.

339-342
Clay, sandy (very fine), light olive gray, soft, slightly cohesive.

342-364
Sand, medium to very coarse with some gravel, moderately sorted, subangular and subrounded, yellowish-brown, loose, mostly carbonates and silicates.

364-379
Gravel, fine to coarse with sand lenses, sorted, lenticular, subangular and subrounded, brown.

379-384
Gravel, coarse, very little sand, numerous cobbles, generally subrounded, dark brown, mostly silicates.

Tongue River Formation

384-420
Siltstone and silty shale, variegated but primarily yellowish-brown or light gray, some greens, occasionally carbonaceous, very tight, slightly to moderately hard, chunky to slightly fissile; indurated laminated siltstone at 403 feet.
TEST HOLE 8287

LOCATION: 163-97-286
ELEVATION: 1950 feet (FT, MSL)

DATE DRILLED: 12-2-71
DEPTH: 500 feet (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1  Topsoil, very silty clay, brownish black.

1-21 Clay, very silty, moderately sandy, pebbly, dark yellowish brown, moderately cohesive, oxidized (Till).

21-43 Clay, silty, sandy, pebbly, sand and gravel lenses, cobbles, olive gray, loose to moderately cohesive (Till).

43-84 Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive (Till).

84-120 Silt, clayey with very fine sand, olive gray, soft, slightly cohesive, laminated.

120-241 Clay, silty, slightly sandy, medium gray with light gray laminae and dark greenish gray mottling, very cohesive, stiff to slightly brittle, smooth, tight.

241-266 Clay, very silty, olive gray, soft, chunky, moderately plastic, smooth.

266-276 Clay, silty, sandy, pebbly, gravel stringers, yellowish brown, slightly cohesive, crumbly, oxidized (Till).

276-409 Clay, silty, sandy, pebbly, cobbles, sandy gravel lenses, olive gray, slightly hard, cohesive, stiff (Till).

409-463 Clay, sandy, numerous pebbles, cobbles, and boulders, dark olive gray, hard, very tightly compacted, brittle (Till).
TEST HOLE 8287 (Cont.)

LOCATION: 163-27-28c#4
ELEVATION: 1950 feet

DATE DRILLED: 12-2-71
DEPTH: 500 feet

(FT, MSL)

RESISTANCE (OMHMS)

POTENTIAL (MV)

DESCRIPTION OF DEPOSITS

Tongue River Formation

- 463-470 Siltstone, clayey, light bluish gray, moderately indurated, noncalcereous.
- 470-484 Sandstone, fine-grained, medium bluish gray, moderately soft, micaceous.
- 484-500 Siltstone, as above, moderately to highly indurated.
Glacial Drift

0-10
Gravel, sandy, assorted, subangular and subrounded, oxidized.

10-28
Clay, very silty, sandy, shale and carbonate pebbles, moderate yellowish brown to dark greenish gray (Till); numerous sand and gravel lenses.

28-119
Clay, silty, sandy, pebbly, cobbles, boulders, olive gray to dark greenish gray, slightly hard, very cohesive (Till); blocks of bedrock shale and clayey sandstone.

119-140
Clay, silty, slightly sandy, dark greenish gray, smooth, tight.

140-158
Sand with gravel and silty layers, sorted, lenticular.

158-161
Clay, very silty, olive gray, moderately soft, smooth.

161-181
Silt, extremely sandy (very fine and fine), olive gray to black, laminated, soft, loose to very slightly cohesive, lignitic.

181-200
Clay, silty, sandy, pebbly, cobbles, boulders, light olive to olive gray, slightly hard, tightly compacted (Till).
LOCATION: 163-97-33 ccs
ELEVATION: 1977 feet

DATE DRILLED: 1947
DEPTH: 521 feet

DESCRIPTION OF DEPOSITS

Glacial Drift

0-13 Clay, sandy with pebbles, yellow (T111).
13-24 Clay, dark yellow.
24-41 Clay, sandy with pebbles, gray (T111).
41-46 Gravel.
46-48 Clay, gray.
48-52 Gravel.
52-56 Clay, sandy, gray.
56-64 Sand, interbedded gray clay, gravel, and detrital lignite.
64-71 Gravel, fine, lignitic.
71-76 Gravel, interbedded gray clay and boulders.
76-84 Clay, sandy with pebbles, gray (T111).
84-165 Clay, sandy, gray.

165-167 Gravel.
167-326 Clay, sandy with pebbles and cobbles, gray (T111); interbedded sandy gravel lenses.

326-366 Clay, sandy with pebbles and cobbles, gray (T111).

366-428 Clay, sandy with pebbles, gray, lignitic (T111).

428-444 Gravel, interbedded clay and detrital lignite.

445-496 Clay, sandy with pebbles and lignite fragments, gray (T111).
TEST HOLE MB (Cont.)

LOCATION:  163-97-3356C

ELEVATION:  1977 feet

DATE DRILLED:  1947

DEPTH:  521 feet

RESISTANCE (OHMS)

DESCRIPTION OF DEPOSITS

Glacial Drift (Cont.)

496-497  Rock.
497-521  Clay, sandy, gray.
TEST HOLE 8291

LOCATION: 163-57-34abb
ELEVATION: 1952 feet

DATE DRILLED: 12-20-71
DEPTH: 400 feet

DESCRIPTION OF DEPOSITS

Glacial drift

0-1 Topsoil, silty clay, brownish black.

1-27 Clay, silty, sandy, pebbly, dark yellowish brown, slightly cohesive to crumbly, oxidized (Till).

27-78 Clay, silty, sandy, pebbly cobbles, olive gray, moderately soft, cohesive (Till).

78-117 Silt and silty clay, slightly sandy (very fine to fine), medium dark gray with light gray laminae and mottling, thinly interbedded, moderately cohesive, slightly plastic; thin layers of fine gravel.

117-165 Clay, silty, sandy, pebbly, occasional cobble or boulder, olive gray, moderately soft to slightly hard, cohesive, stiff (Till).

165-243 Clay, silt, medium dark gray with very light gray mottling, cohesive, slightly plastic to slightly brittle, smooth, tight, laminated.

243-261 Clay, silty, moderately sandy, pebbly, cobbles, sandy gravel lenses, olive gray, moderately soft to slightly hard, chunky, crumbly (Till).

261-273 Gravel, medium to coarse, slightly sandy, cobbles, clay layers, sorted, highly lenticular, subrounded, loose, mostly carbonate rocks.

273-291 Clay, silty, sandy, pebbly, cobbles, olive gray, slightly hard, cohesive and compacted, stiff (Till).

291-298 Sand, medium to coarse, moderately well-sorted, subrounded, loose, clean, mostly quartz and carbonate rocks.

298-325 Clay, very silty, sandy, pebbly, slightly hard, chunky, brittle, compacted (Till).

325-342 Sand, fine and medium, slightly silty, thinly interbedded, fairly uniform, loose to very slightly cohesive.

342-363 Clay, very silty and sandy, pebbly, sandy gravel lenses, olive to dark olive gray, slightly hard, cohesive and compacted, stiff and brittle (Till).

363-385 Gravel, fine to coarse, slightly sandy, cobbles, poorly sorted angular to subrounded, mostly brown silicates and carbonates, some granitics and lignite; rough drilling.
**TEST HOLE 8291 (Cont.)**

**LOCATION:** 163-97-3&ab

**ELEVATION:** 1952 feet

**DATE DRILLED:** 12-20-71

**DEPTH:** 400 feet

**DESCRIPTION OF DEPOSITS**

**Tongue River Formation**

- 385-400 Siltstone, clayey, medium light gray, moderately well-indurated, bedded, soapy, slightly calcareous.

**Observation Well**

- Depth: 378 feet
- S.I.: 366 to 378 feet

<table>
<thead>
<tr>
<th>POTENTIAL (MV)</th>
<th>RESISTANCE (OHMS)</th>
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CITY WELL #4 (T.H. 73-1)
(Log from C. A. Simpson & Son)

LOCATION: 163-97-34add1
ELEVATION: 1563
(FT, HSL)

DATE DRILLED: (#4) 7-5-73
(73-1) 4-6-72
DEPTH: 325 feet

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<th>Lithology</th>
<th>Thickness</th>
<th>Depth</th>
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<td>Glacial drift:</td>
<td>Topsoil</td>
<td>1</td>
<td>1</td>
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<tr>
<td></td>
<td>Clay, slightly sandy, yellow</td>
<td>15</td>
<td>16</td>
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<td></td>
<td>Clay, yellow, rock at 31 feet</td>
<td>29</td>
<td>45</td>
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<td></td>
<td>Clay, blue, some rocks</td>
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<tr>
<td></td>
<td>Gravel</td>
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<tr>
<td></td>
<td>Clay, sandy, blue</td>
<td>39</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>Clay, some sand, blue</td>
<td>120</td>
<td>235</td>
</tr>
<tr>
<td></td>
<td>Clay, very sandy, blue</td>
<td>5</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>Clay, sandy, gray</td>
<td>34</td>
<td>274</td>
</tr>
<tr>
<td></td>
<td>Sand, medium</td>
<td>33</td>
<td>307</td>
</tr>
<tr>
<td></td>
<td>Clay, pebbly, blue</td>
<td>18</td>
<td>325</td>
</tr>
</tbody>
</table>

City Well #4 (12-inch steel casing)
Depth: 307 feet
S. I.: 277-307 feet (12-inch nominal screen)
Test Hole 72-2
(Log from C. A. Simpson & Son)

LOCATION: 103-97-34dau
DATE DRILLED: 10-24-72
ELEVATION: 1904 feet
(FT. HSL)

DEPTH: 322 feet

<table>
<thead>
<tr>
<th>Formation</th>
<th>Lithology</th>
<th>Thickness (feet)</th>
<th>Depth (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glacial drift:</td>
<td>Topsoil----------------------------------------</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Clay, yellow, rock at 32----------------------</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Clay, sandy, pebbly, gray----------------------</td>
<td>79</td>
<td>111</td>
</tr>
<tr>
<td></td>
<td>Sand, clayey------------------------------------</td>
<td>3</td>
<td>114</td>
</tr>
<tr>
<td></td>
<td>Clay, sandy, light-gray------------------------</td>
<td>17</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>Clay, very little sand, blue--------------------</td>
<td>15</td>
<td>146</td>
</tr>
<tr>
<td></td>
<td>Clay, very sandy, gray-------------------------</td>
<td>11</td>
<td>157</td>
</tr>
<tr>
<td></td>
<td>Clay, some gravel, blue------------------------</td>
<td>32</td>
<td>189</td>
</tr>
<tr>
<td></td>
<td>Gravelly hardpan, rock-------------------------</td>
<td>2</td>
<td>191</td>
</tr>
<tr>
<td></td>
<td>Gravel and clay---------------------------------</td>
<td>5</td>
<td>196</td>
</tr>
<tr>
<td></td>
<td>Rock--------------------------------------------</td>
<td>2</td>
<td>198</td>
</tr>
<tr>
<td></td>
<td>Clay, gravelly, blue---------------------------</td>
<td>11</td>
<td>209</td>
</tr>
<tr>
<td></td>
<td>Rock--------------------------------------------</td>
<td>1</td>
<td>210</td>
</tr>
<tr>
<td></td>
<td>Clay, gravelly, blue---------------------------</td>
<td>2</td>
<td>212</td>
</tr>
<tr>
<td></td>
<td>Rock--------------------------------------------</td>
<td>1</td>
<td>213</td>
</tr>
<tr>
<td></td>
<td>Clay, very sandy, blue-------------------------</td>
<td>12</td>
<td>225</td>
</tr>
<tr>
<td></td>
<td>Clay, slightly sandy, gray----------------------</td>
<td>25</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>Clay, gravelly, pebbly, gray--------------------</td>
<td>30</td>
<td>260</td>
</tr>
<tr>
<td></td>
<td>Clay, sandy, gray-------------------------------</td>
<td>12</td>
<td>292</td>
</tr>
<tr>
<td></td>
<td>Sand, fine to coarse, clayey--------------------</td>
<td>17</td>
<td>309</td>
</tr>
<tr>
<td></td>
<td>Clay, gravelly, detrital lignite, gray-----------</td>
<td>13</td>
<td>322</td>
</tr>
</tbody>
</table>
LOCATION: 163-37-35add
ELEVATION: 1950 feet

DATE DRILLED: 12-4-71
DEPTH: 460 feet

DESCRIPTON OF DEPOSITS

Glacial Drift

0-1 Topsoil pebbly clay loam, black.
1-20 Clay, silty, sandy, pebbly, moderate olive brown, slightly hard, very cohesive, slightly brittle, tight, oxidized (Till).
20-67 Clay, silty, sandy (very fine), numerous carbonate pebbles, moderate olive green, moderately soft to slightly hard, cohesive, slightly plastic to slightly brittle, partially oxidized (Till).
67-165 Clay, silty, sandy (very fine), pebbly, olive gray, moderately soft to slightly hard, very cohesive, slightly plastic to slightly brittle (Till); thin layers of carbonate sand and fine gravel, blocks of clay and silty clay.
165-202 Clay, silt, and sandy clay, predominantly olive gray, laminated with light and dark grays to black, thinly interbedded, soft to moderately soft, slightly to moderately cohesive, non- to slightly plastic to very crumbly; usually dry and powdery.
202-275 Clay, silty, sandy, pebbly, olive gray, moderately soft, cohesive, slightly plastic (Till).
275-305 Sand, fine to coarse, clean and uniform, well-sorted, subrounded, loose, mostly carbonate rocks.
305-338 Clay, silty, olive and dark olive gray with black lignite flakes, laminated, moderately soft to slightly hard, compacted; rounded lignite pebbles. Sand, very fine to very coarse, thinly interbedded with clay, silt, and gravel; erratic drilling.
338-407 Gravel, fine to very coarse with cobbles, subangular to rounded, assorted, "dirty", clay layers, mostly carbonate rocks with brown silicates and granitics.
407-416 Boulders.

Tongue River Formation

416-418 Clay, very sandy, white soft, crumbly, highly calcareous.
418-421 Sandstone, very fine-grained. Indurated, CaCO3 cement.
421-426 Sandstone, very fine-grained, grayish green, moderately soft, friable.
TEST HOLE 4425 (Cont.)

LOCATION: 163-97-35add
ELEVATION: 1550 feet (FT, MSL)

DATE DRILLED: 12-5-71
DEPTH: 460 feet (FT)

RESISTANCE (OHMS)

<table>
<thead>
<tr>
<th>POTENTIAL (MV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>520</td>
</tr>
<tr>
<td>560</td>
</tr>
<tr>
<td>600</td>
</tr>
<tr>
<td>640</td>
</tr>
<tr>
<td>680</td>
</tr>
<tr>
<td>720</td>
</tr>
<tr>
<td>760</td>
</tr>
<tr>
<td>800</td>
</tr>
<tr>
<td>840</td>
</tr>
<tr>
<td>880</td>
</tr>
<tr>
<td>920</td>
</tr>
<tr>
<td>960</td>
</tr>
</tbody>
</table>

DESCRIPTION OF DEPOSITS

Tongue River Formation (Cont.)

443-448 Shale, very light gray, hard, moderately brittle, smooth, tight, possible bentonitic.
448-460 Siltstone, clayey to sandy, light gray with brown carbonaceous stains, moderately hard, tight.

Observation Well

Depth: 283 feet
S. I.: 277 to 283 feet
Plugged: 12-22-71
DESCRIPTION OF DEPOSITS

**Glacial drift**

<table>
<thead>
<tr>
<th>Depth</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>Topsoil, silty clay, brownish black.</td>
</tr>
<tr>
<td>1-38</td>
<td>Clay, silty, moderately sandy, pebbly, dark yellowish brown, slightly cohesive, slightly plastic, oxidized (Till).</td>
</tr>
<tr>
<td>38-69</td>
<td>Clay, very silty, sandy, pebbly, sand and gravel lenses, occasional cobbles, loose to slightly cohesive, iron-stained, oxidized (Till).</td>
</tr>
<tr>
<td>69-94</td>
<td>Clay, very silty, sandy, pebbly, sand and gravel lenses, olive gray, moderately soft, cohesive, moderately stiff (Till).</td>
</tr>
<tr>
<td>94-112</td>
<td>Silt, light olive gray, soft, chunky, crumbly.</td>
</tr>
<tr>
<td>112-121</td>
<td>Clay and silty clay, light olive to olive gray, laminated, soft to moderately soft, cohesive, slightly plastic.</td>
</tr>
<tr>
<td>121-124</td>
<td>Clay, dark gray to black, slightly hard, cohesive, smooth, stiff, very tight, organic.</td>
</tr>
<tr>
<td>124-138</td>
<td>Clay and silty clay, slightly sandy, interbedded, light and medium gray to brownish gray, soft, cohesive; mostly reworked bedrock shales.</td>
</tr>
<tr>
<td>138-153</td>
<td>Clay to silty clay, dark greenish gray to medium dark gray, slightly hard to moderately soft, brittle to slightly plastic, smooth, tight.</td>
</tr>
<tr>
<td>153-160</td>
<td>Sand, very fine and fine, silty, gray, loose, subrounded, soft, lignitic.</td>
</tr>
<tr>
<td>160-166</td>
<td>Silt, clayey to slightly sandy, light olive gray, soft, friable, laminated.</td>
</tr>
<tr>
<td>166-195</td>
<td>Clay, very sandy, pebbly, cobbles, boulders, thin gravel stringers, olive gray, cohesive, stiff (Till).</td>
</tr>
<tr>
<td>195-214</td>
<td>Gravel, fine to coarse, sorted, thinly interbedded with sandy clay till as above, cobbles and boulders.</td>
</tr>
<tr>
<td>214-237</td>
<td>Clay, silty, moderately sandy, pebbly, cobbles, boulders, blocks of bedrock shale and clayey sandstone, greenish, brownish, and medium grays, slightly to moderately hard, cohesive, stiff and tough (Till).</td>
</tr>
<tr>
<td>237-274</td>
<td>Clay, silty, sandy, carbonate pebbles, cobbles, slightly hard, very cohesive and compacted, stiff (Till).</td>
</tr>
<tr>
<td>274-305</td>
<td>Sand, medium and coarse, interbedded clayey and gravelly lenses, sorted, lenticular, subangular to subrounded, slightly lignitic.</td>
</tr>
</tbody>
</table>
LOCATION:  163-97-35bce  
ELEVATION:  1965 feet  
(FT, MSL)  

DATE DRILLED:  12-22-71  
DEPTH:  420 feet  
(FT)  

<table>
<thead>
<tr>
<th>POTENTIAL (MV)</th>
<th>RESISTANCE (OHMS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>305-312</td>
<td>520</td>
</tr>
<tr>
<td>312-320</td>
<td>560</td>
</tr>
<tr>
<td>320-362</td>
<td>600</td>
</tr>
<tr>
<td>362-380</td>
<td>640</td>
</tr>
<tr>
<td>380-385</td>
<td>720</td>
</tr>
<tr>
<td>385-395</td>
<td>680</td>
</tr>
<tr>
<td>395-420</td>
<td>760</td>
</tr>
<tr>
<td>420-440</td>
<td>800</td>
</tr>
<tr>
<td>440-460</td>
<td>840</td>
</tr>
<tr>
<td>460-480</td>
<td>880</td>
</tr>
<tr>
<td>480-500</td>
<td>920</td>
</tr>
<tr>
<td>500-520</td>
<td>960</td>
</tr>
</tbody>
</table>

**DESCRIPTION OF DEPOSITS**

**Glacial Drift (Cont.)**

305-312 Clay, silty, very sandy, pebbly, sand lenses, moderate yellowish brown with olivaceous mottling, moderately cohesive, oxidized (Till).

312-320 Clay, silty, light olive to dark olive gray, slightly hard, smooth, stiff, tight.

320-362 Sand, fine to coarse, sorted, thinly interbedded silty clay or clayey till lenses, loose, subangular and subrounded.

362-380 Sand, medium, moderately well-sorted and uniform, loose, clean, subrounded, quartzose, slightly lignitic.

380-385 Gravel, fine to coarse, slightly sandy, cobbles, assorted, angular to subrounded, mostly carbonate rocks, small amount of brown silicates and lignite.

**Tongue River Formation**

385-395 Sandstone, clayey, moderately soft to indurated, medium bluish gray.

395-420 Siltstone, clayey, medium light gray, moderately indurated, tight.

**Observation Well**

Depth:  300 feet  
S. I.:  294 to 300 feet
Test Hole 72-1
(Log from C. A. Simpson & Son)

LOCATION: 103-97-35odd
ELEVATION: 1560 feet

DATE DRILLED: 8-30-72
DEPTH: 330 feet

<table>
<thead>
<tr>
<th>Formation</th>
<th>Lithology</th>
<th>Thickness (feet)</th>
<th>Depth (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glacial Drift:</td>
<td>Topsoil</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Clay, yellow</td>
<td>34</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Clay, sandy, blue, some rocks</td>
<td>266</td>
<td>301</td>
</tr>
<tr>
<td></td>
<td>Clay, sandy</td>
<td>0</td>
<td>307</td>
</tr>
<tr>
<td></td>
<td>Sand, medium, slightly clayey</td>
<td>3</td>
<td>310</td>
</tr>
<tr>
<td></td>
<td>Sand, medium to coarse, gravelly</td>
<td>15</td>
<td>325</td>
</tr>
<tr>
<td></td>
<td>Clay, blue</td>
<td>5</td>
<td>330</td>
</tr>
</tbody>
</table>
DESCRIPTION OF DEPOSITS

**Glacial drift**

0-1  Topsoil, silty clay, brownish black.
1-18 Clay, silty, slightly sandy, pebbly, moderate yellowish brown, slightly cohesive, slightly plastic, oxidized (Till).
18-29 Clay, silty, sandy, pebbly, cobbles, dark yellowish brown to light olive gray, moderately soft, cohesive, partially oxidized (Till).
29-272 Clay, silty, sandy, pebbly, cobbles, occasional boulder, lenses or blocks of clay, silt, sand, and gravel, generally olive gray, moderately soft to slightly hard, cohesive and compacted, slightly plastic to very stiff and tough, calcareous (Till).

272-306 Sand, medium and coarse, well-sorted and uniform, subangular to subrounded, loose, clean, mostly quartz and feldspar with carbonates and some lignite.
306-322 Silt, slightly clayey to very sandy, some fine gravel, lenticular and laminated, soft, loose to very slightly cohesive.
322-362 Clay, very silty to slightly sandy, interbedded sand lenses, lenticular and laminated, soft, loose to slightly cohesive, crumbly, calcareous.
362-390 Gravel, fine to coarse, sandy, cobbles, interbedded clayey streaks, angular to subrounded, poorly sorted, mostly carbonate rocks.

**Tongue River Formation**

390-420 Siltstone, clayey, medium gray to light greenish gray, moderately indurated, brittle, tight, noncalcareous; some interbedded bluish green sandstone.

**Observation Well**

Depth: 283 feet
S. L.: 277 to 283 feet
TEST HOLE 4447

LOCATION: 163-97-36d

ELEVATION: 1940 (FT, MSL)

DATE DRILLED: 6-15-72

DEPTH: 271 (FT)

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1
Topsoil, silty loam, black.

1-13
Clay, very silty, sandy, pebbly, yellowish gray with dark brown, soft, cohesive, plastic, sticky.

13-27
Clay, silty, sandy, pebbly, dusky yellow with moderate olive brown, soft, cohesive, moderately plastic to slightly stiff, oxidized (Till).

27-36
Clay, very silty, sandy, pebbly, olive gray, moderately soft, cohesive (Till).

36-52
Clay, silty, olive gray with light gray laminations, moderately soft, very cohesive, smooth, slightly sticky, tight.

52-91
Clay, very silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive, slightly plastic to stiff (Till).

91-111
Till, as above, interbedded with layers of sandy gravel.

111-122
Gravel, fine and medium, sandy, assorted, subrounded, loose.

122-235
Clay, silt, sandy, pebbly, cobbles, olive gray, moderately soft to slightly hard, cohesive, tightly compacted (Till); blocks or layers of clay and sandy clay, sand and gravel lenses.

235-242
Sand, very fine and fine, light olive gray, sorted, lenticular, loose; detrital lignite.

Tongue River Formation

242-245
Shale, very silty, light gray, moderately soft, smooth, bentonitic.

245-250
Lignite, black, hard, fissile.

250-270
Shale and lignite; interbedded with varigated siltstone and sandstone.

270-271
Sandstone, very fine-grained dark greenish gray, indurated, calcareous.
TEST HOLE 3018

LOCATION: 164-97-31 d.a.  
ELEVATION: 1890 feet  

DATE DRILLED: 6-15-63  
DEPTH: 160 feet  

DEPTH:  
-POTENTIAL (MV)-  
-RESISTANCE (OMMS)-  

0-6  Fill  

Glacial Drift  

6-10  Gravel, fine, sandy, rounded, iron-stained, oxidized.  

10-13  Clay, silty, sandy, pebbly, dark yellowish orange, cohesive, oxidized (Till).  

13-30  Clay, silty, sandy, pebbly, dark greenish gray, moderately soft, cohesive (Till).  

30-60  Sand, very fine to coarse, sorted, interbedded, silty clay or clayey till lenses, subangular to subrounded, quartzose and lignitic.  

60-90  Clay, silty to sandy, pebbly, dark greenish gray, moderately soft, cohesive, sticky (Till); poor sample return.  

90-94  Sand, medium, gray, sorted, subrounded, quartzose.  

94-107  Silt, light olive gray, soft, chunky, friable.  

107-135  Clay, silty, sandy, pebbly, olive gray, moderately hard, compacted, stiff (Till).  

Tongue River Formation  

135-142  Sandstone, fine, clayey, dusky yellow, soft, friable, oxidized.  

142-160  Sandstone, fine, clayey, bluish gray, noncalcareous.
REFERENCES


APPENDIX

The report preceding this appendix was written in 1973 by L. L. Froelich. The appendix was written in 1982 by Alan Wanek, State Water Commission hydrologist.

MUNICIPAL WATER SUPPLY

In July 1973 a 12-inch diameter, 307 feet deep municipal well was installed by C. A. Simpson and Son Drilling. The well is located in the SE\(\frac{1}{4}\), NW\(\frac{1}{4}\) Section 34, Township 163 North, Range 97 West. The well provides part of the present water supply for the city of Crosby. A log of the well is included in Table 3 and is labeled "city well #4."

WATER LEVEL FLUCTUATIONS: 1972-1980

Since the original manuscript was written in 1973 water levels in nine observation wells in the Crosby area have been monitored by the U. S. Geological Survey. Hydrographs illustrating these data are included in Table 2. Note that the vertical scale varies between hydrographs depending on the magnitude of the water level fluctuations.

Well 163-97-35BCC is located 72 feet east of the Crosby municipal well. The water level in this well fluctuates in direct response to the pumping of the municipal well. The general water level in this observation well declined approximately ten feet from 1972 through 1980. In addition to the general decline, the well fluctuates 15-20 feet in response to the municipal well pumping schedule. The low water levels measured during summer months reflect more pumping of the municipal well during this time.

The influence of the municipal well on the water level in the upper zone of the Crosby aquifer can be seen in the hydrographs of well 162-97-028BB.
This observation well is located 3000 feet south of the municipal well. The water level in the observation well fluctuates five to ten feet through the year with the lowest water levels occurring in the summer. The water level in this observation well has declined approximately two feet from 1973 to 1980.

Another observation well of interest is well 163-97-34ABB, located 3000 feet northwest of the municipal well. This well is screened in the lower zone of the Crosby aquifer. Twenty-one feet of glacial till separate the upper and lower zones of the Crosby aquifer at this location. The water level in this observation well has declined approximately eight feet from 1972 to 1980. The water level in this well declines in summer then partially recovers in winter. These fluctuations suggest that a limited hydraulic connection exists in places between the upper and lower zones of the Crosby aquifer.

The normal ground-water fluctuations over time are apparent from the hydrographs for other observation wells. These wells are screened in the lower zone of the Crosby aquifer, the Columbus aquifer, the Yellowstone aquifer and isolated sand and gravel lenses. The water levels in these wells fluctuate as much as five feet, generally having the lowest water levels in the summer, but do not show the overall decline in water level which is experienced in wells within one mile of the Crosby municipal well.
WELL NO. 162-097-02BBB  COUNTY: DIVIDE  STATE: NORTH DAKOTA
AQUIFER:  DEPTH: 294 FT  LSD: 1972 FT

HIGHEST WATER LEVEL 25.19  LOWEST 40.79
WELL NO. 163-097-15BCC  COUNTY: DIVIDE  STATE: NORTH DAKOTA
AQUIFER:
DEPTH: 558 FT  LSD: 1915 FT

HIGHEST WATER LEVEL 10.31, LOWEST 14.48
WELL NO. 163-097-23DDD  COUNTY: DIVIDE  STATE: NORTH DAKOTA
AQUIFER:  DEPTH: 327 FT  LSD: 1931 FT

HIGHEST WATER LEVEL 18.02, LOWEST 22.62
WELL NO. 163-097-24AAA  COUNTY: DIVIDE  STATE: NORTH DAKOTA
AQUIFER:  DEPTH: 411 FT  LSD: 1919 FT

HIGHEST WATER LEVEL 52.66, LOWEST 56.35
WELL NO. 163-097-25AAA
COUNTY: DIVIDE
AQUIFER:
DEPTH: 390 FT
STATE: NORTH DAKOTA
LSD: 1926 FT

HIGHEST WATER LEVEL 45.33, LOWEST 48.13
WELL NO. 163-097-25DD
AQUIFER:
COUNTY: DIVIDE
STATE: NORTH DAKOTA
DEPTH: 126 FT
LSD: 1925 FT

HIGHEST WATER LEVEL 7.71, LOWEST 11.49
WELL NO. 163-097-27CCC  COUNTY: DIVIDE  STATE: NORTH DAKOTA
AQUIFER:               DEPTH: 263 FT  LSD: 1962 FT

HIGHEST WATER LEVEL 4.18  LOWEST 7.78
WELL NO. 163-097-34ABB  
COUNTY: DIVIDE  
AQUIFER:  
DEPTH: 378 FT  
STATE: NORTH DAKOTA  
LSD: 1952 FT

HIGHEST WATER LEVEL 2.10  LOWEST 11.53