Ground-Water Resources of the New Salem Area

Morton County, North Dakota

NORTH DAKOTA GROUND-WATER STUDIES
No. 84

By
CHARLES E. NAPLIN AND ROBERT B. SHAVER
NORTH DAKOTA STATE WATER COMMISSION

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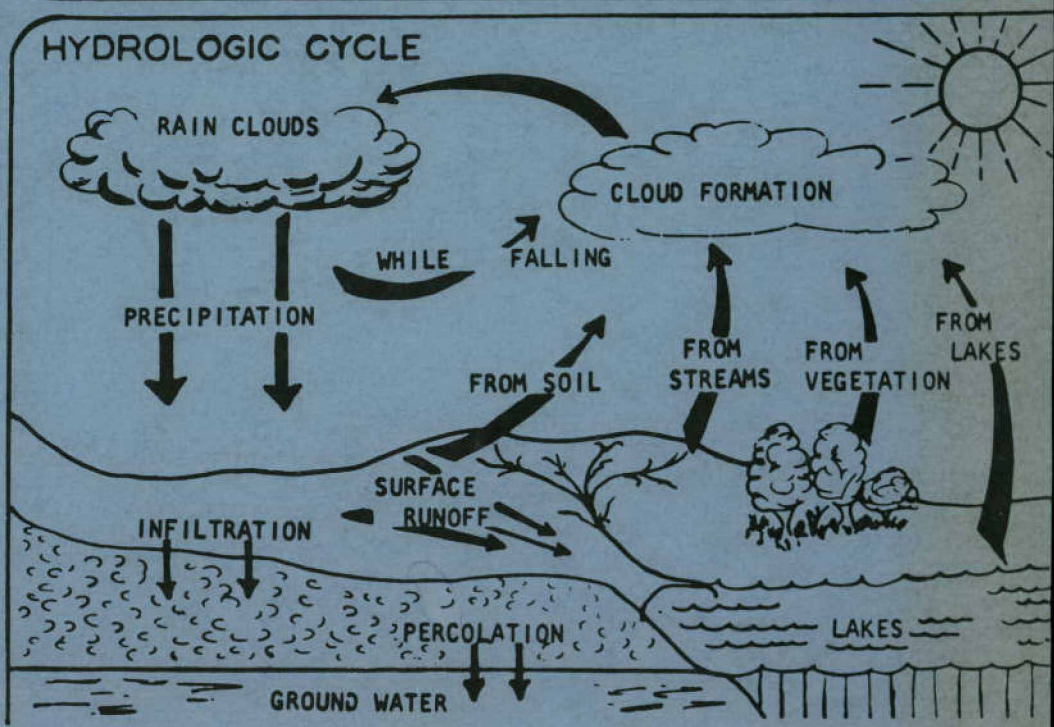

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GROUND-WATER RESOURCES OF THE NEW SALEM AREA MORTON COUNTY, NORTH DAKOTA

By:
Charles E. Naplin and Robert B. Shaver
Ground-Water Geologists

INTRODUCTION

PURPOSE AND SCOPE

On December 8, 1972, the New Salem City Council passed a resolution requesting that the North Dakota State Water Commission conduct a ground-water survey for the city. The Commission approved this resolution on December 18, 1972, and the study was conducted during May and June of 1974 (Nov.-Dec. 1975, Mar.-Apr.-May 1976).

The geohydrology of the area was determined by test drilling, installing observation wells, collecting water samples for chemical analysis, and water-level measurements. An aquifer test was conducted to determine the hydraulic properties of the aquifer. Data compiled during the field work and from additional sources contributed to the compilation of this report.

ACKNOWLEDGEMENTS

Well inventory data was furnished by Daniel Ackerman of the U. S. Geological Survey. The test drilling was carried out under contract by H. and H. Service Company of Bowman, North Dakota, and Mann Drilling Company of Garrison, North Dakota under direct supervision of the authors. The chemical analyses were performed by Garvin Muri, State Water Commission chemist, at the North Dakota State Laboratories Department in Bismarck. Special acknowledgement is extended to Mayor Melvin Clendenen for his cooperation and assistance during this investigation.

LOCATION AND GENERAL FEATURES

The study area is located in north-central Morton County and is within the Missouri Slope division of the Missouri Plateau physiographic province of North Dakota (fig. 1). Geohydrologic data collected for this study describes a 69 square mile area in portions of Township 138 and 139 North, Range 86 West, Township 140 North, Range 85 West and all of Township 139 North, Range 85 West (fig. 2).

Climatological data based on a 68-year period of record at the National Weather Service Station located six miles west-northwest of New Salem, show the mean annual temperature to be 41.9°F. The mean annual precipitation based on the same period of record is 15.33 inches (National Weather Service, 1971).

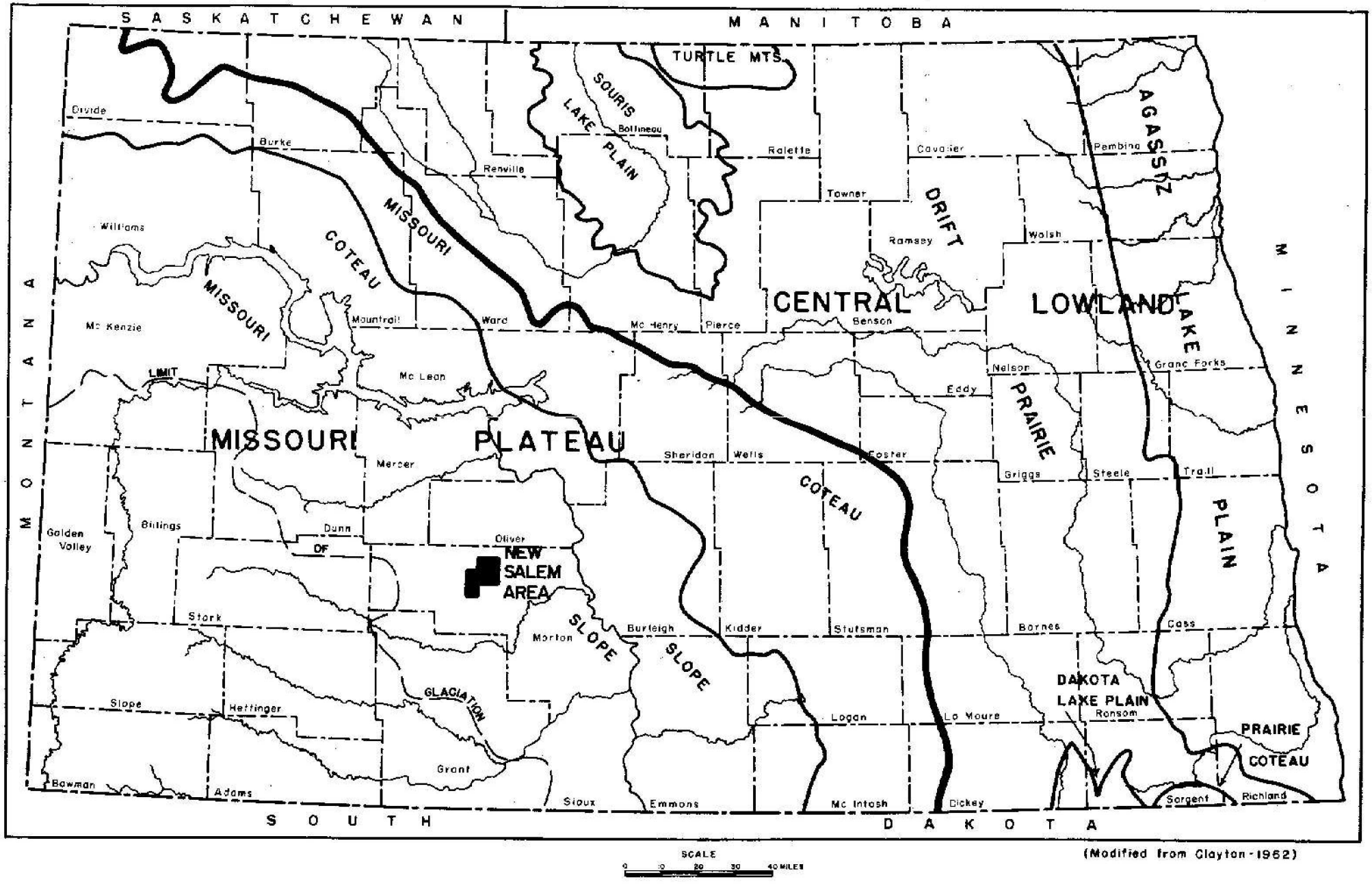
The topography is typical of western North Dakota where erosion of the relatively soft bedrock has produced numerous steep-sided valleys, flat-topped buttes and conical-shaped hills. Surface elevations range from less than 1,950 feet south of Sims to more than 2,350 feet on top of School Hill northwest of New Salem.

Hailstone, Muskrat, Sweetbriar, and Sims Creeks and their numerous tributaries, form a well established drainage system. The deep, narrow valleys occupied by these streams were entranched primarily by glacial meltwaters that flowed southeastward through Morton County and emptied into the preglacial Missouri drainage system.

New Salem (1970 population 943) is an agricultural community. It is served by U. S. Interstate Highway 94, State Highway 31, and is on the mainline of the Burlington Northern railroad.

WELL-NUMBERING SYSTEM

The wells and test holes listed in Table 3 are numbered according to a system based on the location in the public land classification of the United



SCALE 0 10 20 30 40 MILES

(Modified from Clayton-1962)

FIGURE I -- MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC PROVINCES AND LOCATION OF THE NEW SALEM AREA

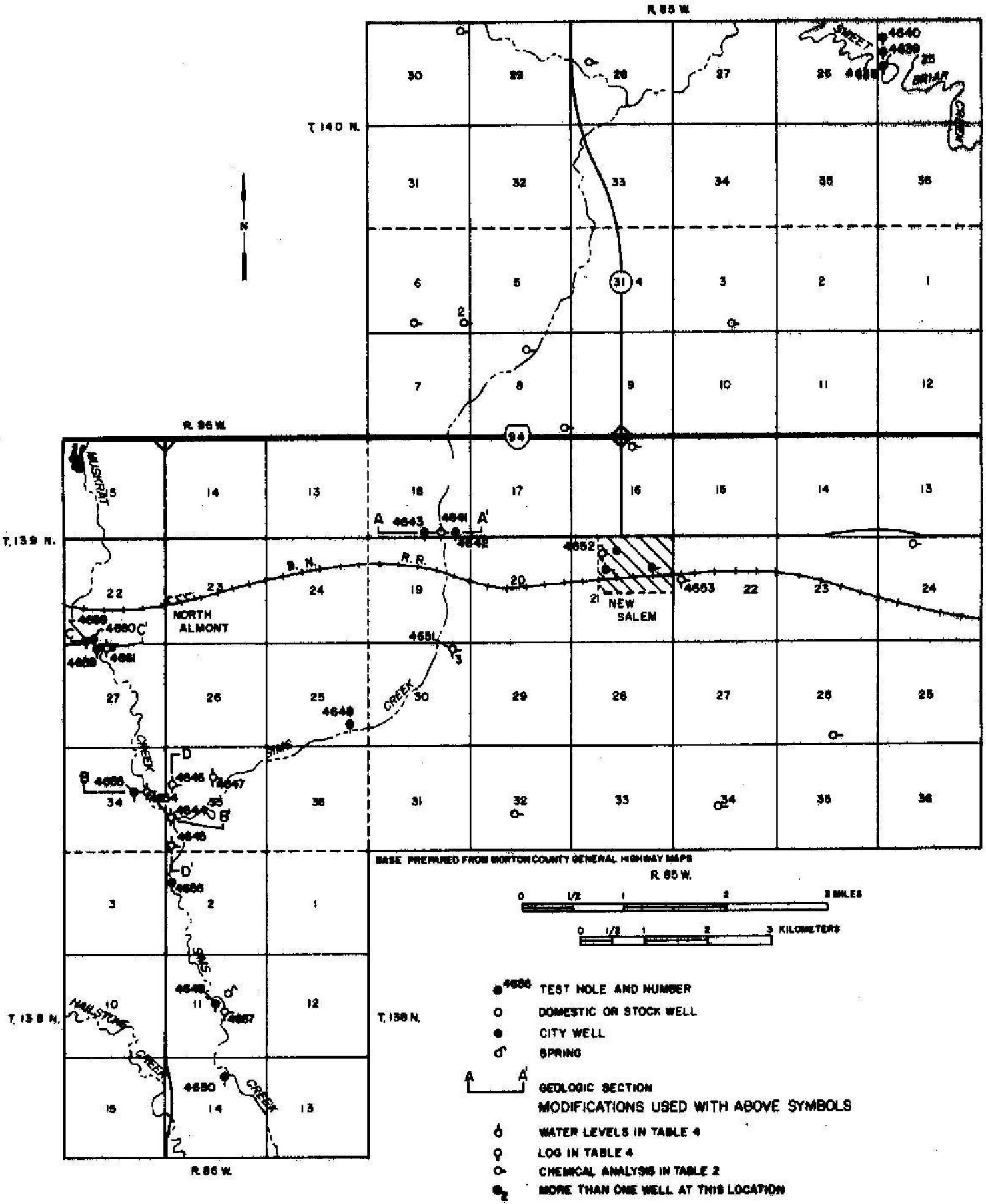


FIGURE 2--LOCATION OF WELLS, TEST HOLES, GEOLOGIC SECTIONS, AND RELATED FEATURES IN THE NEW SALEM AREA

States Bureau of Land Management (fig. 3). The first numeral denotes the township north of a baseline, 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 139-85-15DAA is in the NE¼NE¼SE¼ Section 15, Township 139 North, Range 85 West. Consecutive terminal numerals are added if more than one well is located in a 10-acre tract.

PREVIOUS INVESTIGATIONS

A general reconnaissance of Morton County was made by Simpson (1929) to assess the ground-water resources of this area. His report lists an inventory of private and municipal wells, chemical analyses, and briefly discusses the topographic and geologic characteristics of the county. Simpson describes wells in the city of New Salem as ranging in depth from 30 to 420 feet. Chemical analyses of water from wells at New Salem are not listed in his report, but he describes the shallow water as hard and the deep water as soft.

A ground-water survey of Morton County was initiated in 1972. This investigation is a cooperative program between the U. S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and the Morton County Water Management District. Data obtained during this three year study will describe the county's ground-water resources.

PRESENT WATER SUPPLY

The city of New Salem obtains its water supply from three wells located within the city limits. These wells are completed in the basal sandstone of the Tongue River Formation of tertiary age at depths ranging from 300 to 312 feet. Well yields range from 26 to 55 gpm (gallons per minute).

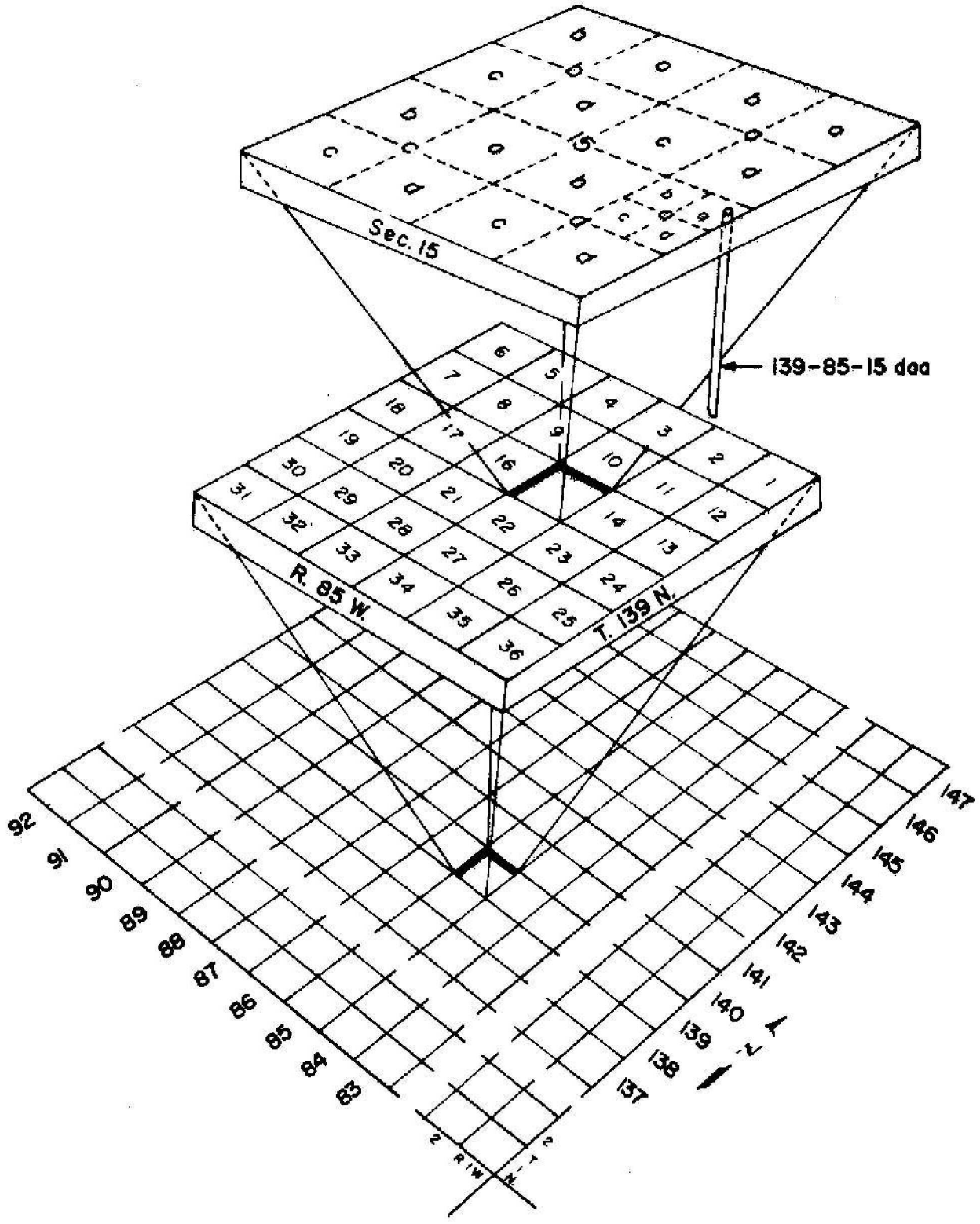


FIGURE 3 --SYSTEM OF NUMBERING WELLS AND TEST HOLES.

It has been indicated by the New Salem City Council that water quantity and quality problems exist. The quality of their water supply is of primary concern. Water from the basal Tongue River sandstone is characteristically high in sodium and other dissolved solids. It is very soft, has a flat taste, and can have adverse effects on soils.

DEFINITION OF SELECTED TERMS

Aquifer -- A permeable deposit that contains sufficient saturated material that will yield significant quantities of water to wells.

Artesian aquifer -- A confined aquifer in which water is under sufficient pressure to rise above the top of the aquifer.

Bedrock -- Semiconsolidated rock underlying glacial and alluvial deposits of Pleistocene and/or Holocene age.

Discharge -- The removal or loss of water from an aquifer or the flow of water into a stream.

Evapotranspiration -- The process by which water is returned to the atmosphere through direct evaporation from water or land surfaces and by transpiration of vegetation.

Ground-water -- Water in the zone of saturation.

Ground-water movement -- The movement of ground water in the zone of saturation.

Hydraulic gradient -- Slope of the water table or potentiometric surface in either feet per foot or in feet per mile.

Infiltration -- The movement of water from the surface towards the zone of saturation.

Observation well -- A well from which hydrologic data are measured and recorded.

Outwash -- Glacial material deposited by meltwater streams beyond active glacial ice.

Permeable rock -- A rock that has a texture permitting water to move through it under ordinary pressure differentials.

Potentiometric surface -- The imaginary horizon formed by the head in an artesian aquifer.

Recharge -- The addition of water to the zone of saturation.

Storage -- The quantity of water contained in openings in the zone of saturation.

Water table -- The upper surface of the zone of saturation where the hydrostatic pressure is equal to atmospheric pressure. The configuration of the water table commonly is a subdued expression of the land surface.

Zone of saturation -- The zone below the water table.

WATER QUALITY

All natural water occurring on the earth's surface or underground contains dissolved minerals. As it falls to the surface and infiltrates into the ground, precipitation dissolves mineral matter. Dissolved minerals in groundwater vary in type and concentration depending primarily upon the composition and solubility of rocks encountered, the length of time the water is in contact with the rocks, and the amount of carbon dioxide and soil acids in the water. Water which has been underground for a long time, or which has travelled a long distance from the recharge area, usually contains more dissolved mineral matter than water which has been underground for only a short time and is withdrawn close to a recharge area.

Dissolved mineral constituents are reported in milligrams per liter (mg/l). A milligram per liter is one thousandth (0.001) of a gram of dissolved material per liter of solution. Hardness is usually reported in milligrams per liter, but may be converted to grains per U. S. gallon (gr./gal.) by dividing milligrams per liter by 17.12.

Table 1 lists the various constituents of water for a domestic or municipal

Table 1 -- Dissolved chemical constituents in water -- their effects upon usability and recommended concentration limits for domestic and municipal water supplies in North Dakota.

Constituent or Parameter	Effects of dissolved constituents on water use	Suggested limits for drinking water in North Dakota[1]	U.S. Public Health Service recommended limits for drinking water[2]
Silica (SiO_2)	No physiological significance		
Iron (Fe)	Concentrations over 0.1 mg/l will cause staining of fixtures. Over 0.5 mg/l may impart taste and colors to food and drink.		0.3 mg/l
Manganese (Mn)	Produces black staining when present in amounts exceeding 0.05 mg/l		0.05 mg/l
Calcium(Ca) and Magnesium (Mg)	Calcium and magnesium are the primary causes of hardness. High concentrations may have a laxative effect on persons not accustomed to this type of water.		
Sodium (Na)	No physiological significance except for people on salt-free diets. Does have an effect on the irrigation usage of water.		
Potassium (K)	Small amounts of potassium are essential to plant and animal nutrition.		
Bicarbonate (HCO_3) and Carbonate (CO_3)	No definite significance, but high bicarbonate content will impart a flat taste to water.		
Sulfate (SO_4)	Combines with Calcium to form scale. More than 500 mg/l tastes bitter and may be a laxative	0-300 mg/l - low 300-700 mg/l - high over-700 mg/l - very high	250 mg/l
Percent Sodium and Sodium Adsorption Ratio (SAR)	Indicate the sodium hazard of irrigation water.		
Chloride (Cl)	Over 250 mg/l may impart a salty taste, greatly excessive concentrations may be physiologically harmful. Humans and animals may adapt to higher concentrations.		250 mg/l
Flouride (F)	Flouride helps prevent tooth decay within specified limits. Higher concentrations cause mottled teeth.	Limits of 0.9 mg/l to 1.5 mg/l	Recommended limits depend on average of daily temperatures. Limits range from 0.6 mg/l at 32°C. to 1.7 mg/l at 10°C.
Nitrate (NO_3)	Over 45 mg/l can be toxic to infants. Larger Concentrations can be tolerated by adults. More than 200 mg/l may have a deleterious effect on livestock health		45 mg/l
Boron (B)	No physiological significance. Greater than 2.0 mg/l may be detrimental to many plants		
Total dissolved solids	Persons may become accustomed to water containing 2,000 mg/l or more dissolved solids.	0-500 mg/l - low 500-1400 mg/l average 1400-2500 mg/l high over 2500 mg/l very high	500 mg/l
Hardness (as $CaCo_3$)	Increases soap consumption, but can be removed by a water-softening system.	0-200 mg/l - low 200-300 mg/l average 300-450 mg/l high over 450 mg/l very high	
pH	Should be between 6.0 and 9.0 for domestic consumption		
Specific Conductance	An electrical indication of total dissolved solids measured in micromhos per Centimeter at 25°C. Used primarily for irrigation analyses.		

1. Schmid, R. W., 1965, Water Quality Explanation: North Dakota State Water Commission, unpublished report, File No. 989.
2. U.S. Public Health Service, 1962, Public Health Service Drinking Water Standards: U.S. Public Health Service, Pub. No. 956, 61 p.

water supply in North Dakota. Results of chemical analyses for wells in the study area are listed in Table 2.

BASIC HYDROLOGIC CONCEPTS

All ground water of economic importance is derived from precipitation. After the precipitation falls on the earth's surface, part is returned to the atmosphere by evaporation, some runs into streams, and the remainder percolates into the ground. Much of the water that sinks into the ground is held temporarily in the soil and is returned to the atmosphere either by evaporation or by transpiration. The remainder infiltrates downward to the zone of saturation and becomes ground water.

Ground water moves under the influence of gravity from areas of recharge to areas of discharge. The movement of ground water is generally very slow and may be only a few feet per year. The rate of movement is governed by the permeability of the deposits through which the water moves and by the hydraulic gradient. Gravel and well-sorted medium to coarse sand are very permeable. Fine-grained materials such as silt, clay, and shale have low permeability. These act as confining barriers that restrict the free movement of ground water into or out of more permeable rocks.

The water level in a well fluctuates in response to recharge to and discharge from the aquifer. Land surface loadings and atmospheric pressure changes cause minor water level fluctuations in confined aquifers. Pumping a well causes its water level to be lowered. The water level surface surrounding the well resembles a cone and is referred to as the cone of depression. Water level drawdown is the difference between static and pumping levels. The degree of drawdown is controlled by the hydraulic properties of the aquifer, the physical characteristics of the well, and the rate and duration of pumping. Continuous withdrawal of water from an aqulfer by pumping will cause

TABLE 2 -- CHEMICAL ANALYSES

(Analytical results are in milligrams per liter except where indicated)

AQUIFERS Owner or Designation	Location	Depth of Well (feet)	Temp (°F)	Date of Collection	(SiO_2)	(Fe)	(Mn)	(Co)	(Mg)	(Na)	(K)	(HCO_3)	(CO_3)	(SO_4)	(Cl)	(F)	(NO_3)	(B)	Total Dissolved Solids	Total Hardness as $CaCO_3$	Total Hardness Noncarbonate	Percent Sodium	SAR	Specific Conductance	pH
FOX HILLS FM.																									
Test Hole 4651	139-85-30aab$_1$	962	48	6-11-74	9	1.9	0.16	6.6	2.3	800	4.8	1090	40	4.9	590	2.7		3.6	1960	26	0	98	68	3450	8.5
CANNONBALL - LUDLOW FMS.																									
Test Hole 4651-A	139-85-30aab$_2$	474	48	6-5-74	11	3.8	0	3.2	1.5	640	2.1	1440	23	110	54	1.2	1.0	1.9	1560	14	0	99	74	2460	8.4
William Tellmann	140-85-28bcd	528	54	6-27-73	11	0.04	0	2.2	2.3	644	3.5	1550	19	32	71	1.1	2.3	0.75	1550	15	0	99	72	2440	8.4
Elmer Holle	140-85-30aaa	595	50	6-27-73	12	0.04	0.01	2.4	2.7	663	3.4	1620	14	7.0	66	1.0	0.8	0.82	1580	17	0	99	70	2470	8.3
TONGUE RIVER FM.																									
A. Goetz	139-85-3dcc	320	48	4-17-73	8	1.6	0.02	1.9	1.8	566	1.9	1180	21	230	5.4	3.8	1.0	0.30	1460	12	0	99	71	2190	8.4
M. Hoherz	139-85-6cdd	120	45	4-17-73	6.2	0.14	0.06	11	7.2	634	3.3	1450	0	223	13	1.3	4.6	0.09	1610	57	0	96	37	2480	8.1
Robert Goebe	139-85-6ddd	56	48	4-17-73	10	0.26	0.60	70	48	258	5.8	555	0	435	19	0.2	4.7	0	1160	374	0	60	5.8	1650	8.0
Robert Goebe	139-85-6ddd$_2$	60	40	4-17-73	9.5	0.10	0.20	88	28	92	5.3	370	0	185	18	0.2	45.0	0	676	336	33	37	2.2	1020	8.0
Howard Neas	139-85-8abc	60	45	4-17-73	12	0.06	0.02	118	79	502	8.5	754	0	654	108	0.2	358	0	2240	619	1	63	8.6	3040	7.5
Steve Doll	139-85-8ddd	80	45	4-17-73	11	0.08	0.03	30	1.6	242	1.7	510	0	122	7.2	0.4	2.1	0.21	633	14	0	97	28	1020	8.0
Skyron's Texaco	139-85-16abb	350	52	4-18-73	10	0.28	0.02	1.8	1.6	602	2.0	1140	26	345	5.0	1.7	1.0	0.73	1560	11	0	99	79	2390	8.5
New Salem City Well	139-85-21adc	300	50	4-18-73	7.5	0.40	0.01	2.6	1.3	573	2.6	1160	23	285	6.3	1.4	0.4	0.56	1450	12	0	99	72	2240	8.5
Test Hole 4652	139-85-21bac	324	48	6-12-74	8.4	3.7	0.08	5.2	3.2	700	3.4	1320	69	380	5.9	2.5	1.0	0.17	1850	26	0	98	60	2800	
New Salem City Well	139-85-21bdb	312	48	4-18-73	5.3	0.26	0.04	2.1	1.2	398	3.7	385	28	191	11	0.6	0.2	0.56	993	10	0	98	55	1670	8.7
Test Hole 4653	139-85-22bcb	344	47	6-11-74	9.3	4.1	0.10	4.0	2.7	700	2.6	1320	20	410	4.6	2.9	1.0	1.1	1800	21	0	98	66	2740	8.5
Julius Brandt	139-85-24bab	306	39	4-18-73	12	0.59	0.02	2.4	1.4	569	2.6	1140	22	258	7.1	2.5	0.5	0.82	1380	12	0	99	71	2190	8.5
Dallas Norton	139-85-26dcc	365	48	4-18-73	9.7	0.22	0.01	3.9	5.2	580	2.6	1180	20	290	6.5	2.7	2.5	0.73	1450	31	0	97	45	2280	8.4
Test Hole 4651-B	139-85-30aab$_3$	270	47	6-3-74	21	0.04	0.22	82	33	300	5.9	889	0	270	2.3	0.3	1.0	0.78	1160	340	0	65	7.1	1730	8.2
Clarence Burman	139-85-32cad	180	45	4-18-73	8.1	0.32	0.03	31	25	427	3.8	906	0	309	19	1.1	10.0	0.43	1260	180	0	83	14	1930	8.1
Myron Norton	139-85-34caa	390	52	4-18-73	10	0.69	0.05	2.5	1.9	556	2.3	1190	22	201	8.5	2.7	2.5	0.86	1340	14	0	99	65	2110	8.4
GLACIAL DIVERSION CHANNELS																									
Test Hole 4657	138-86-11dbb	70	47	6-10-74	25	2.1	0.08	9.9	4.5	350	1.6	740	9	180	2.3	2.3	1.0	0.13	990	43	0	94	23	1460	
Test Hole 4641	139-85-18dcd	159	47	5-29-74	25	0.22	0.16	89	26	290	5.0	778	0	300	2.3	0.4	1.0	0.99	1130	330	0	65	6.9	1640	8.2
Test Hole 4661	138-86-27baa	60	48	6-11-74	18	6.1	0.52	50	18	280	3.5	644	0	290	3.0	1.3	1.0	0.86	983	200	0	75	8.6	1500	8.1
Test Hole 4654	139-86-34adc	90	47	6-10-74	25	1.9	0.12	84	24	130	3.1	541	0	140	3.2	0.3	1.0	0.56	675	310	0	47	3.2	1040	7.9
Test Hole 4646	139-86-35bcc	63	45	5-29-74	26	0.74	0.05	24	9.0	300	3.1	652	0	200	1.2	0.7	1.0	0.73	886	97	0	87	13	1360	8.2
Test Hole 4647	139-86-35bda	79	48	6-5-74	23	3.2	0.70	144	29	170	3.8	576	0	370	13	0.3	1.0	0.65	1050	480	8	43	3.4	1500	8.0
Test Hole 4644	139-86-35cbc	103	46	5-23-74	25	0.31	0.40	78	18	200	3.2	595	5	200	7.9	0.2	1.0	0.47	830	270	0	61	5.3	1250	8.3
Test Hole 4645	139-86-35ccc	133	45	5-31-74	17	1.3	0.05	18	4.9	380	2.4	843	0	160	2.6	1.1	1.0	0.13	1000	65	0	92	20	1540	8.2

TABLE 2--CHEMICAL ANALYSES (CONT)
(Analytical results are in milligrams per liter except where indicated)

AQUIFERS Owner or Designation	Location	Depth of Well (feet)	Temp (°F)	Date of Collection	(SiO_2)	(Fe)	(Mn)	(Ca)	(Mg)	(Na)	(K)	(HCO_3)	(CO_3)	(SO_4)	(Cl)	(F)	(NO_3)	(B)	Total Dissolved Solids	Total Hardness as $CaCO_3$	Total Hardness Noncarbonate	Percent Sodium	SAR	Specific Conductance	pH
GLACIAL DIVERSION CHANNELS																									
New Salem 4897A	139-86-34daa$_4$	82		11-20-75	13	.40	.06	64	34	350	2.6	797	0	130	3.4	9	2.0	.92	980	30	0	96	28	1460	8.1
Test Hole 4899	139-86-34daa$_3$	88		3-18-76	15	9.6	.08	50	18	190	3.0	593	0	130	3.7	.4	1.0	.44	704	200	0	67	5.8	1250	8.0
Test Hole 4900	139-86-34daa$_4$	95		3-19-76	18	.58	.06	28	12	290	2.8	661	0	180	1.6	.5	2.5	.48	867	120	0	84	12.0	1280	8.1
New Salem 4898	139-86-34dab$_1$	75		11-21-75	13	1.3	.40	76	29	140	3.6	528	0	190	5.9	.4	2.5	.32	749	310	0	49	3.5	1110	7.6
Test Hole 4901	139-86-34dab$_2$	87		3-18-76	18	.94	.28	84	24	130	3.3	512	0	170	5.0	.2	2.5	.08	695	310	0	47	3.2	1050	8.0
Test Hole 4903	139-86-35cbc$_2$	110		3-18-76	20	.90	.04	23	8.2	290	2.6	718	0	140	2.9	.6	1.0	.80	871	91	0	87	13	1280	8.1
Test Hole 4903	139-86-35cbc$_3$	120		5-14-76	29	1.3	.05	32	7.3	280	2.9	722	0	130	2.6	.6	1.0	.84	795	110	0	84	12	1300	7.9
Test Hole 4903	139-86-35cbc$_4$	100		5-14-76	31	.12	.06	42	16	270	2.8	685	0	170	5.7	.6	1.0	.32	896	170	0	77	9	1320	8.0
Test Hole 4902	139-86-35ccc$_2$	121		3-18-76	20	1.0	.05	16	5.6	330	2.4	806	0	140	3.5	.8	2.0	.80	942	63	0	92	18	1410	8.2
Aquifer Test 13hr.	139-86-34daa$_1$	90		3-23-76	14	4.0	.20	92	24	110	3.3	527	0	130	4.3	.3	1.5	.20	634	330	0	42	2.6	983	7.5
Aquifer Test 24hr.	139-86-34daa$_1$	90		3-24-76	20	3.4	.20	92	24	110	3.0	526	0	130	4.6	.2	1.0	.20	631	330	0	42	2.6	991	7.4
Aquifer Test 48hr.	139-86-34daa$_1$	90		3-25-76	19	4.0	18	92	24	110	2.9	530	0	130	4.7	.2	1.0	.28	650	330	0	42	2.6	1010	7.4
Aquifer Test 72hr.	139-86-34daa$_1$	90		3-26-76	19	3.9	.17	93	26	110	2.9	533	0	130	4.7	.2	2.0	.12	653	340	0	41	2.6	1010	7.6
Aquifer Test 100hr.	139-86-34daa$_1$	90		3-27-76	19	3.8	.16	93	26	110	3.0	535	0	130	4.6	2	1.0	.04	659	340	0	41	2.6	1020	7.4

a decrease in the rate of natural discharge, an increase in the rate of recharge, and a reduction in the volume of water in storage.

GROUND WATER IN PREGLACIAL ROCKS

Greater than 8,000 feet of consolidated sediments consisting of interbedded claystones, siltstones, sandstones, shales, limestones, and evaporites overlie Precambrian crystalline rocks in the New Salem area. The bedrock formations range from Cambrian to Tertiary in age, dip to the west-northwest and thicken in that direction. The New Salem area is situated on the southeastern flank of the Williston Basin, a saucer-shaped structural depression containing sediments that were deposited millions of years ago in seas of both continental and marine origin. This investigation is concerned only with the Upper Cretaceous and Tertiary rocks that underlie the study area, and are of importance as potential sources of municipal water supply.

Sedimentary rocks in the study area can be divided into the following units for descriptive purposes: (1) Fox Hills and Hell Creek Formations of Cretaceous age, (2) Cannonball-Ludlow, (3) Tongue River, and (4) Sentinel Butte Formations of Tertiary age. These formations consist primarily of compacted clays and silts that have very low permeabilities and do not readily yield water to wells. However, test drilling indicates that about 20 percent of the bedrock material in the study area consists of permeable sandstones that are saturated and may be a potential source of groundwater. Therefore, the sandstone units, and to a lesser extent certain lignite beds, are the principal bedrock aquifers in this vicinity. Plate 1 is a cross-sectional view of upper Cretaceous and Tertiary rocks and illustrates the depositional sequence, relative continuity of the sandstone units, and the regional structural dip into the Williston Basin.

CRETACEOUS SYSTEM

Sandstone beds in the Fox Hills and Hell Creek Formations are the most important bedrock aquifers in most of western North Dakota and in the New Salem area. One of the objectives of this investigation was to assess the geohydrologic properties of the Fox Hills and Hell Creek Formations by using the methods of subsurface exploration and available well inventory data. However, a well inventory of selected domestic and stock wells in the New Salem vicinity indicates the local stock, domestic and municipal wells tap aquifers only in the Tongue River and Cannonball-Ludlow Formations.

Fox Hills Formation

Thickness and Lithology - Test hole 4651 (139-85-30AAB), located about one and a half miles west of New Salem, penetrated sandstone from depths of 915 to 965 feet and from 1030 to 1065 feet (pl. 1). Drill cuttings indicated both sandstone intervals are very fine-to-fine-grained, generally subangular, semi-consolidated, glauconitic, micaceous, and light bluish-gray in color. The sandstones are slightly clayey and the upper bed contains numerous fossil shell fragments which may be oysters of the genus Crassostrea (Feldman, 1972. p 21).

The total thickness of the Fox Hills in test hole 4651 was 195 feet. Correlation of test hole data from adjacent areas in Morton County suggest that the upper and lower sandstones penetrated in test hole 4651 are respectively, the Colgate and Timber Lake members of the Fox Hills.

Hydraulic Properties

Test hole 4651 was completed as an observation well at a depth of 962 feet in the upper Fox Hills sandstone. The well has a static water level of about 249 feet lsd. (land surface datum) which is equivalent to a mean sea level elevation of 1,817 feet for the potentiometric surface. Interpolation of data from test hole 4651 (elev. 2,065) suggests that a well completed in the upper

Fox Hills at New Salem (elev. 2,155) would have a static water level exceeding 330 feet lsd and would be about 1,050 feet in depth.

Hydrologic data from Fox Hills wells at 139-83-12DBA and 139-88-34BCC in Morton County show that water levels in the upper Fox Hills are at a higher static level than those of wells completed in the lower Hell Creek. This indicates that water is moving upward from the Fox Hills into the Hell Creek at a slow rate.

Well yields from the Fox Hills are generally low. The fine-grained lithology, small amounts of intergranular clay and silt, and low permeability of the sandstone do not permit the rapid movement of water into a well bore. A study made by Croft (1973) in Mercer and Oliver Counties showed that specific capacities of wells tapping the Fox Hills Formation range from 0.1 to 0.6 gpm per foot of drawdown. More recent hydrologic data collected on the Fox Hills in western North Dakota suggests that an average specific capacity for the upper sandstone would be about 0.3 gpm per foot. Using 0.3 gpm per foot as the average specific capacity for a 100 gpm. Fox Hills well at New Salem, the pumping water level or degree of drawdown would be about 300 feet.

Water Quality - A water sample from the well at 139-85-30AAB, indicates the water is a very soft, sodium bicarbonate type and contained 1,960 mg/l dissolved solids (Table 2). Sodium accounts for 98 percent of the total cations making this water undesirable for watering lawns and gardens. Flouride concentration of 2.7 mg/l exceeds the recommended limits set by the U. S. Public Health Service (Table 1).

Hell Creek Formation

Thickness and Lithology - Test hole 4651 (139-85-30AAB) penetrated a very clayey, silty, fine-grained, medium light gray sandstone from a depth of 805 to 858 feet.

A total of 335 feet of Hell Creek was encountered and the formation generally consists of silty to sandy, brownish-gray siltstone and dark brown, waxy carbonaceous shale. The sandstone bed near the base of the formation is probably equivalent to the Breien member of the Hell Creek that was deposited in a marine or brackish-water environment as discussed by Frye (1969, p. 35).

Hydraulic Properties - Water level data for the Hell Creek sandstone is not available in the study area. However, the interpretation of water levels from test holes at 139-83-12DBA and 139-88-34BCC in Morton County show that the static water levels in the Hell Creek may be more than 30 feet lower than water levels in the underlying Fox Hills. This suggests that water from the Fox Hills is moving upward into the Hell Creek due to the difference in head. This upward migration of water into the Hell Creek sandstone may account for the similarity in water quality between the Fox Hills and Hell Creek sandstones. Therefore, it is possible to assume that a well tapping the Hell Creek sandstone at New Salem could have a static water level exceeding 350 feet.

Anticipated well yields from the Hell Creek may be very similar to those of the Fox Hills. The Hell Creek sandstone section penetrated in test hole 4651 was very fine-to fine-grained, very silty and clayey, and was interbedded with claystone. The combination of these lithologic criteria effectively lower permeability and adversely effect well yields. Domestic wells tapping the Hell Creek commonly yield only a few gallons per minute. No observation wells were completed in the Hell Creek sandstone in the study area.

Water Quality - Chemical anlayses of water from the Hell Creek are typically very similar to those of the Fox Hills. The water is very high in sodium and is of the sodium bicarbonate type. Fluoride concentrations are usually above recommended levels.

TERTIARY SYSTEM

Cannonball-Ludlow Formations

Thickness and Lithology - The Cannonball-Ludlow stratigraphic interval in the study area consists mostly of medium to dark gray, sandy siltstone that is occasionally interbedded with greenish-gray, glauconitic sandstone. Test hole 4651 (139-85-30AAB) penetrated 300 feet of Cannonball-Ludlow sediments. Four sandstone beds ranging from 10 to 15 feet in thickness occur throughout the complete stratigraphic section. Drill cuttings and electric logs indicate the sandstones are very fine-to fine-grained, clayey, silty, and limey. They are often well cemented. Hard, sandy limestone concretions occur throughout the Cannonball-Ludlow interval. Test drilling has shown that the Cannonball-Ludlow sandstones are quite lenticular, discontinuous, and often pinch out locally.

Hydraulic Properties - An observation well (139-85-30AAB2) completed at a depth of 474 feet in the Cannonball-Ludlow west of New Salem has a static water level of 192 feet lsd. By comparing altitudes of water levels of wells in the Cannonball-Ludlow with those of the Hell Creek it is apparent that there is a downward migration of water into the underlying Hell Creek sediments. The regional slope of the Cannonball-Ludlow potentiometric surface is toward the east.

A ground-water study of Mercer and Oliver Counties states that well yields of 5 to 100 gpm are possible from efficient, fully penetrating, and properly designed wells (Croft, 1973). Sandstones that are interbedded with siltstone or that are locally cemented will have lower permeabilities than clean well-sorted beds and will produce lower well yields.

Three wells in the study area are completed in the Cannonball-Ludlow. They range in depth from 474 to 595 feet and may tap one or more of the

Cannonball-Ludlow sandstones. Well yields are usually low.

Water Quality

Chemical analyses of three water samples show the water is a sodium bicarbonate type. It is typically high in sodium, may contain moderate amounts of sulfate. Total dissolved solids average more than 1,500 mg/l and fluoride ranges from 1.0 to 1.2 mg/l. The water is soft and generally suitable for domestic and livestock purposes. It should be used with caution for irrigation purposes because of very high sodium-absorption ratios.

Tongue River Formation

Thickness and Lithology

Sandstones and lignites in the Tongue River Formation provide water to most domestic, stock, commercial, and municipal wells in the New Salem area. Test holes 4651 (139-85-30AAB), and 4653 (139-85-22BCB) completely penetrated the formation (fig. 2). A total of 313 feet of interbedded siltstone, claystone, sandstone, carbonaceous shale, and lignite was encountered in test hole 4653. A very fine-to fine-grained, slightly clayey, subangular, medium bluish-gray sandstone was encountered from a depth of 296 to 356 feet. This basal sandstone unit is an important aquifer in the New Salem area, and more than 60 percent of the Tongue River wells inventoried in this study are completed in this stratigraphic interval. Drilling data from adjacent areas in central and western Morton County, indicate the basal Tongue River sandstone is a good marker bed and generally present in the subsurface (pl. 1).

Lignite beds ranging in thickness from 2 to 12 feet occur throughout the Tongue River Formation in the Study area. Nearly 40 percent of the domestic and stock wells tap lignites in the Tongue River.

Hydraulic Properties - Wells completed in the basal Tongue River sandstone

range in depth from 270 to 390 feet. Shallow wells ranging in depth from 56 to 180 feet are most likely completed in lignites of the Upper Tongue River. The static water level in a well at 139-85-22BCB and in the water tower well (139-85-21ADC) is about 210 feet lsd which is equivalent to an elevation of approximately 1950 feet for the potentiometric surface. Hydrologic data indicates that water levels in the basal sandstone are higher than those of wells in the underlying Cannonball-Ludlow. Thus, the movement of groundwater is downward into the underlying Cannonball-Ludlow sediments.

Interstitial clay and silt and the sandstone's fine-grained lithology generally restrict well yields to a few gallons per minute for domestic and stock wells. Well yields for the three city wells at New Salem range from 26 to 55 gpm (Clendenen, personal communication, 1974). It is reported that the 10-inch diameter water tower well (139-85-21ADC) has an average yield of about 50 gpm with 32 feet of drawdown. Therefore, the specific capacity of this well is about 1.6 gpm per foot.

Water Quality - Sixteen water samples collected from wells completed in the Tongue River Formation indicated the water is a sodium bicarbonate type. Total dissolved solids ranged from 633 to 2,240 mg/l and sulfate content ranged from 122 to 654 mg/l. The water in general contained 0.04 to 4.1 mg/l iron and 0.2 to 3.8 mg/l fluoride. The water is suitable for domestic and stock use but is not recommended for irrigation due to high sodium adsorption ratios.

Sentinel Butte Formation

Well inventory and test drilling did not encounter any significant aquifer within the Sentinel Butte in the New Salem area. This formation directly overlies the Tongue River in only the northwestern portion of the area and has been removed by erosion elsewhere. It consists of interbedded siltstone, claystone, sandstone, and thin lignite stringers. A resistant, cemented sandstone caps

many of the conical-shaped buttes that remain in the topographically higher area. Generally the Sentinel Butte sequence is unsaturated in this vicinity.

GROUND WATER IN THE GLACIAL DRIFT

Several thousand years ago during Pleistocene time glacial ice advanced southward over the New Salem area depositing glacial drift ranging from 0 to 188 feet in thickness. The thickest section of drift occurs west of New Salem in Sims Creek. With the exception of numerous small valleys, a very thin mantle of ground moraine overlies most of the area. Ground moraine consists of till which is an unsorted mixture of clay, silt, sand, pebbles, cobbles and boulders. Numerous boulders of glacial derivation directly overlie bedrock and most are exposed at land surface. Most till in the area is very sandy and silty, and has been oxidized by chemical weathering to a yellowish-brown color. Deposits of till encountered in glacial diversion channels are commonly olive gray in color. These deposits are within the zone of saturation.

Meltwater streams coursed southeastward through Morton County as the wasting ice front receded, entrenching numerous glacial diversion channels and depositing outwash. Hailstone, Muskrat, Sims, and Sweetbriar Creeks are former meltwater channels which contain varying amounts of outwash consisting primarily of sand and gravel, with some interbedded clay and silt. Test drilling during this investigation indicates that Sims and Muskrat Creeks are underlain by significant amounts of saturated sand and gravel and are of importance as a potential ground-water supply.

QUATERNARY SYSTEM

Glacial Diversion Channels

Thickness and Lithology - Buried outwash deposits along Sims and Muskrat Creeks consist of sand and gravel interbedded with clay, silt, and till (pl. 2). The

cumulative saturated thickness of sand and gravel ranges from 10 feet in test hole 4650 (138-86-14ABC) to 134 feet in test hole 4645 (139-86-35CCC). The permeable materials range in size from fine sand to coarse gravel with cobbles and are moderately well-sorted. Permeabilities are high in much of the clastic material as evidenced by the rapid loss of drilling fluid at several locations. Thin lenses of clay and silt occur as interstitial material within the aquifer and locally may lower the permeability and reduce well yields.

Geologic sections A-A', B-B', and C-C' show cross-sectional views of the outwash drawn at right angles to the aquifer (pl. 2). Geologic section D-D' shows a cross-sectional view of the outwash drawn longitudinal to the aquifer. Test drilling indicates that the width of the outwash varies from less than one eighth mile to about one quarter mile (fig. 4). Outwash underlying Sims and Muskrat Creeks is thickest near the confluence of these diversion channels. A city well completed in this vicinity would require about 5½ miles of pipeline in order to tie into the municipal water system (fig. 2).

Hydraulic Properties - Nineteen observation wells ranging from 60 to 159 feet in depth were completed in the outwash deposits along Sims and Muskrat Creeks (fig. 2). Static water levels range from about 8 to 80 feet lsd. The aquifer material may be under either confined or water-table conditions. The hydraulic gradient is southeast toward Big Muddy Creek south of the study area.

The outwash deposits underlying Sims and Muskrat Creeks are recharged by the direct infiltration of precipitation through the overlying alluvium. Moderate concentrations of sodium and brown coloration in water from these outwash deposits suggest that additional recharge occurs as underflow from the Tongue River Formation.

Subsurface data obtained in the course of this investigation indicate the outwash deposits underlying Sims and Muskrat Creeks are extremely narrow and

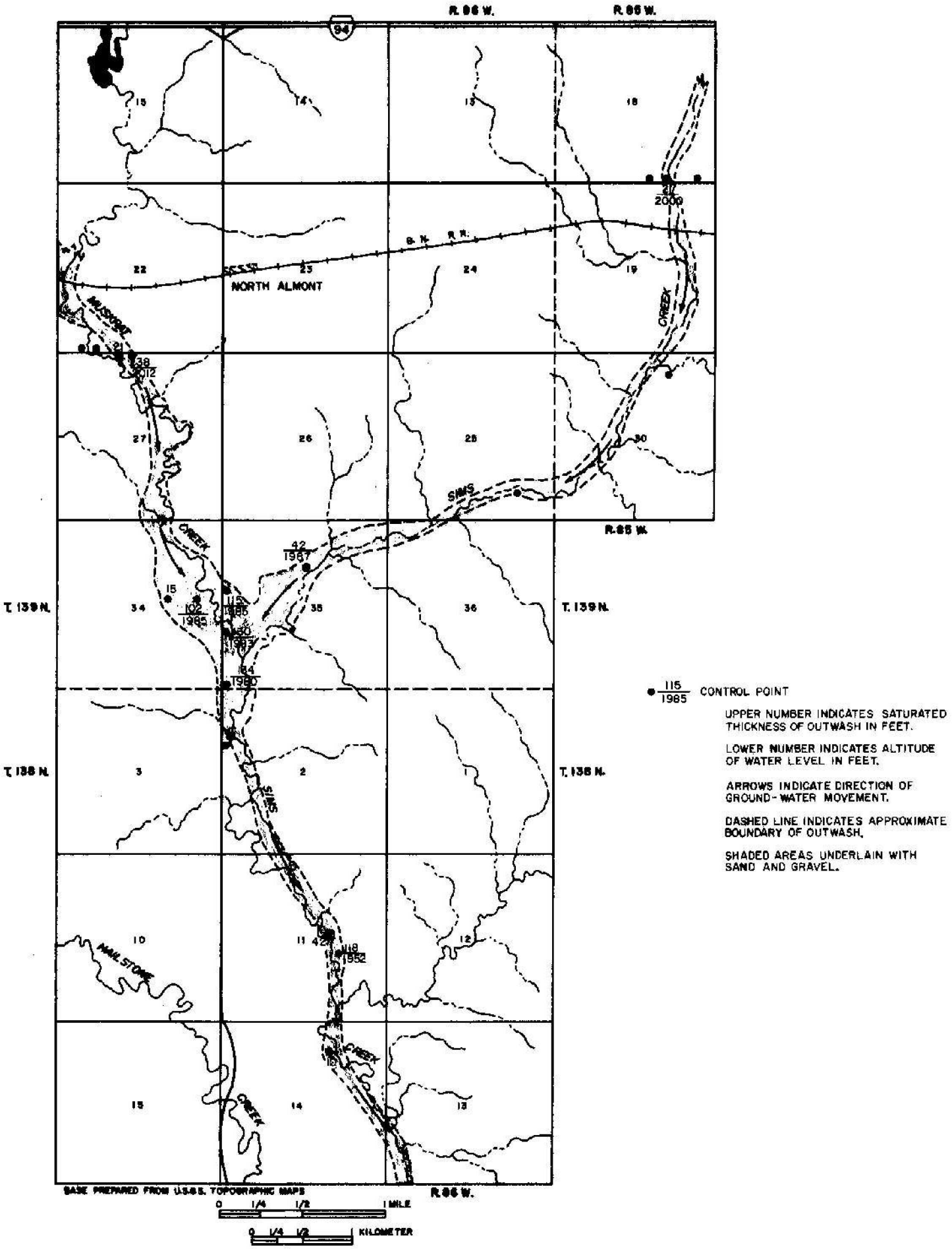


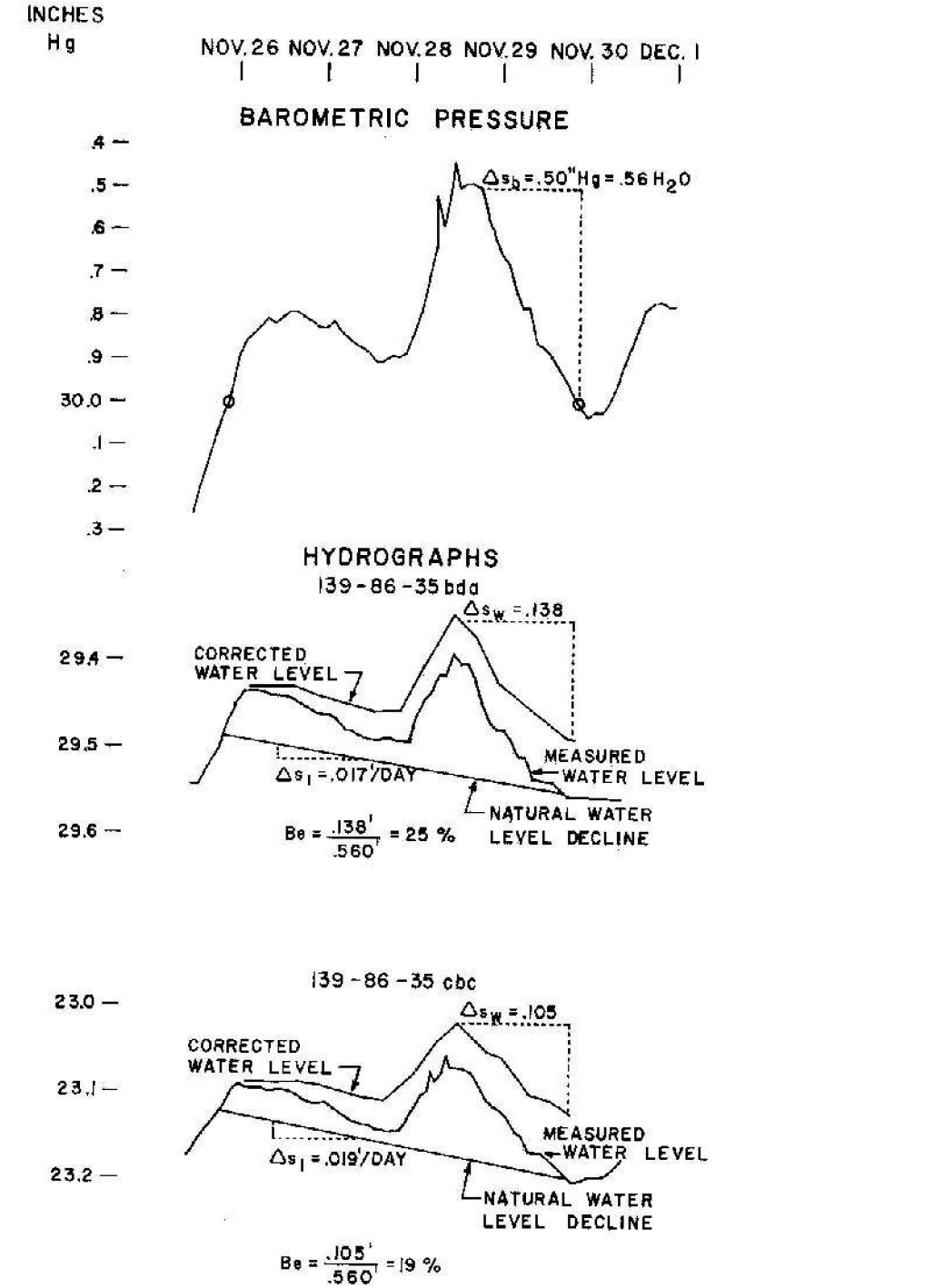
FIGURE 4--LOCATION, THICKNESS, AND CONFIGURATION OF BURIED OUTWASH DEPOSITS UNDERLYING MUSKRAT AND SIMS CREEK

have a wide variation in thickness. However, the greatest potential for groundwater development exists in the area of the confluence of the two diversion channels in Sections 34 and 35, Township 139 North, Range 86 West (fig. 4). Properly constructed, large diameter wells may yield in excess of 200 gpm at selected locations in this area.

Aquifer Test - An aquifer test was conducted in the buried outwash deposits near the confluence of Muskrat and Sims Creek. This test site was chosen because the buried outwash deposits in this area are more extensive with respect to both width and thickness. The production well is located in Township 139 North, Range 86 West, Section $34DAA_1$.

The water bearing sand and gravel is overlain by a silty, sandy, clay horizon of variable thickness in the vicinity of the production well. Water levels in the observation wells monitored (except Township 134 North, Range 86 West, Section $34DAB_1$) are close to the interface of the surficial silty, sandy, clay zone and the lower sand and gravel zone. Water levels in the aquifer change with barometric fluctuations which indicates that the aquifer is confined. Water levels in many of the observation wells were measured using Keck and Stevens devices during the months of November, December and February. With this water level data and corresponding barometric data, barometric efficiency was calculated. Values range between 19 and 25 percent (fig. 5).

The production well was drilled to a depth of 90 feet. It was 12 inches in diameter and was steel cased to a depth of 70 feet. Twenty feet of 8-inch nominal, 25 slot (0.024 inch) screen with a 12-inch lead packer top was installed between 70 and 90 feet. The turbine pump was powered by a Ford six cylinder, propane combustion engine.



Δs_l NATURAL WATER LEVEL RATE OF DECLINE

Δs_w NET CHANGE IN WATER LEVEL (CORRECTED FOR NATURAL W.L. DECLINE) (FT.)

Δs_b NET CHANGE IN ATMOSPHERIC PRESSURE (FT. OF H_2O)

ΔB_e BAROMETRIC EFFICIENCY = $\frac{\Delta s_w}{\Delta s_b}$

FIGURE NO. 5 CALCULATIONS OF BAROMETRIC EFFICIENCY

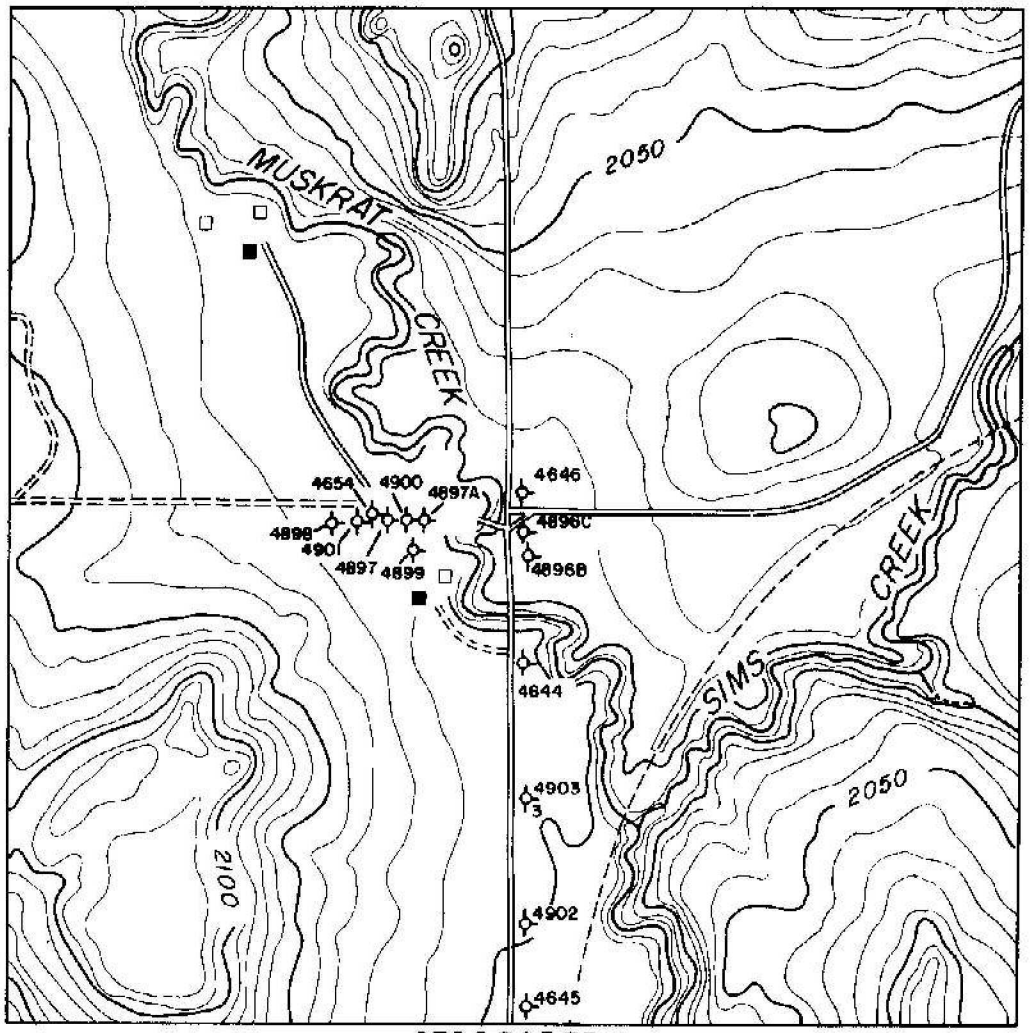
Brown water occurs in this aquifer with depth. Data has defined this horizon between 1900 and 1925 feet above mean sea level in the vicinity of the test site. Therefore, the production well was screened above the upper elevation of this interval.

A preliminary test was conducted on March 22, 1976, to set both the discharge rate and the Keck-Stevens water level recording devices.

The aquifer test was started at 0900 hours on March 23 and was shut off at 1300 hours on March 27. The total pumping time was 6000 minutes (100 hours). The following list shows the observation well network monitored during this test (see fig. 6).

LOCATION	RADIUS FROM WELL	MEASURING DEVICE	TOTAL DRAWDOWN AFTER 6000 MINUTES OF PUMPING
T139-R86-34 DAA_1	r= .5'	Steel Tape	28.10'
T139-R86-34 DAA_4	r= 50'	Keck & Stevens	3.07'
T139-R86-34 ADC	r= 100'	Keck & Stevens	3.39'
T139-R86-34DAB_2	r= 150'	Keck & Stevens	3.19'
T139-R86-34 DAA_2	r= 175'	Keck & Stevens	3.48'
T139-R86-34 DAA_3	r= 190'	Keck & Stevens	2.97'
T139-R86-34 DAB_1	r= 300'	Keck & Stevens	1.37'
T139-R86-35 BCC	r= 700'	Keck & Stevens	.24'
T139-86-35 CBC_1	r= 1060'	Keck & Stevens	.20'

The discharge water was disposed of approximately 250 feet to the east into Muskrat Creek. The direction of flow in Muskrat Creek is to the south, away from the test site. This, coupled with frozen ground, minimized the return of water to the aquifer in the vicinity of the test site. A constant discharge rate of 74 gpm was maintained by a gate valve. This rate was continuously monitored by a Cox Pitot tube coupled with a Barton flowmeter.



MODIFICATIONS USED WITH ABOVE SYMBOLS

- WATER LEVEL IN TABLE 4
- LOG IN TABLE 4
- CHEMICAL ANALYSIS IN TABLE 2
- O_3 MORE THAN ONE WELL AT THIS LOCATION

FIGURE 6 -- LOCATION OF OBSERVATION WELL NETWORK IN THE VICINITY OF THE AQUIFER TEST SITE

Personnel helping during this test included Dave Ripley, Gary Sunderland, Hydrologists and Mike Hove, Technician, all from the State Water Commission. Elevations of the wells used for the test and others in this glacial diversion channel aquifer were measured by a State Water Commission survey crew.

The following techniques were used to analyze the data obtained from this aquifer test:

1) Theis log-log (time-drawdown)

2) Jacob semi-log (time-drawdown)

3) Chow semi-log (time-drawdown)

4) Theis recovery (time-residual drawdown)

Table 3 presents the calculated aquifer coefficients derived from each analytical technique. The values of transmissibility range from approximately 1200 to 4900 Ft^2/day. Five of the six observation wells yield T values in the 1200-1800 Ft^2/day range. These are quite consistent. Storage coefficient values range from 0.001 to 0.0004. The larger values are from the two closest observation wells.

Because of the following, certain assumptions built into the analytical techniques used are not valid with respect to this aquifer test. Test drilling indicates that the aquifer is both non-homogeneous and anisotropic. Thin clay partings in the upper sand cause permeability to be greater in the horizontal as compared to the vertical direction. The pumping well does not penetrate the full thickness of the aquifer. Finally, as pumping continues, the aquifer converts from confined to unconfined conditions.

Aquifer coefficients are determined from the first 100 minutes of the data plots. The potentiometric surface drops below the upper confining layer almost immediately in all observation wells except 139-86-DAB_1. The fine grained nature of the aquifer material is such that delayed yield from gravity drainage does not become significant until after approximately 100 minutes of

OBSERVATION WELLS		ANALYTICAL TECHNIQUE						
LOCATION	DISTANCE FROM PRODUCTION WELL	THEIS LOG-LOG (< 100 MINUTES)		JACOB SEMI-LOG (< 100 MINUTES)		CHOW SEMI-LOG (< 100 MINUTES)		THEIS SEMI-LOG (RECOVERY)
		T (FT²/DAY)	S	T (FT²/DAY)	S	T (FT²/DAY)	S	T (FT²/DAY)
139-86-34 DAA_1	PRODUCTION WELL r = .5'	—	—	1630	—	—	—	1450
139-86-34 DAA_4	r = 50'	1720	.005	1760	.004	1590	.005	1680
139-86-34 ADC	r = 100'	1320	.002	1370*	.001*	1240	.002	1410
139-86-34 DAB_2	r = 150'	1530	.0007	1630*	.0005*	1490	.0006	1860
139-86-34 DAA_2	r = 175'	1290	.0005	1450*	.0004*	1370	.0004	1450
139-86-34 DAA_3	r = 190'	1550	.0005	1630*	.0004*	1320	.0005	1800
139-86-34 DAB_1	r = 300'	4730	.0009	5220*	.0006*	4860	.0008	4740

* NOT VALID (U < .01)

TABLE 3- CALCULATED AQUIFER COEFFICIENTS

pumping (see fig. 7-8). At this time, the rate of change of drawdown decreases. In observation well 139-86-43DAB$_1$ where confining conditions exist, the rate of change of drawdown also decreases after 100 minutes of pumping. Delayed yield from gravity drainage in the immediate vicinity of the pumping well imposes less stress with respect to drawdown at all points in the observation well network. Delayed yield continued until the aquifer test was terminated after 6000 minutes of pumping. The specific capacity at 6000 minutes was 2.63 gpm/ft.

Recovery was monitored in all observation wells and the production well. Semi-log plots of residual drawdown yield tranmissibilities which are consistent with those calculated utilizing time-drawdown data (fig. 9).

All data is presented in complete form in a State Water Commission open file report entitled, "The New Salem Aquifer Test, Morton County".

Water Quality

Water samples were collected from seventeen observation wells in this aquifer. During the aquifer test, five additional water samples were also collected from the production well. All samples were sent to the State Lab for chemical analysis. The results of the chemical analyses are presented in Table - 2.

Chemical analyses show that the water is a sodium bicarbonate type and contains dissolved solids ranging from 631 to 1,130 mg/l. Dissolved iron and manganese range in concentration from 0.12 to 6.1 mg/l and 0.04 to 0.70 mg/l respectively. The water is suitable for domestic and stock use. It has a moderate salinity hazard and should be used only on well drained soils.

Immediately upon collection, it was noted that some samples displayed a brown coloration while others appeared clear. Data indicates that the top of the brown water horizon occurs between 1900 and 1925 feet above mean sea level

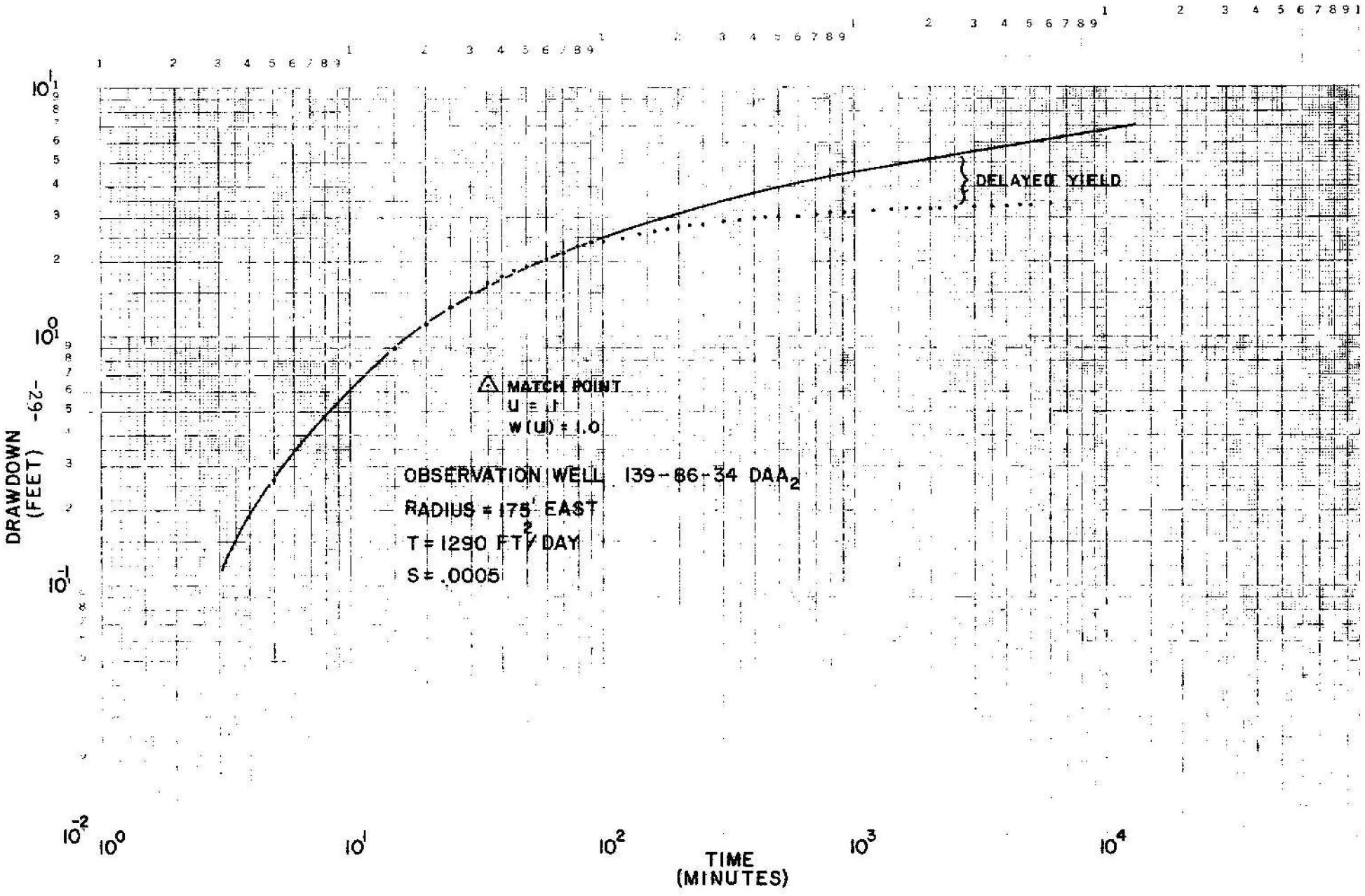


FIGURE 7- THEIS LOG-LOG METHOD

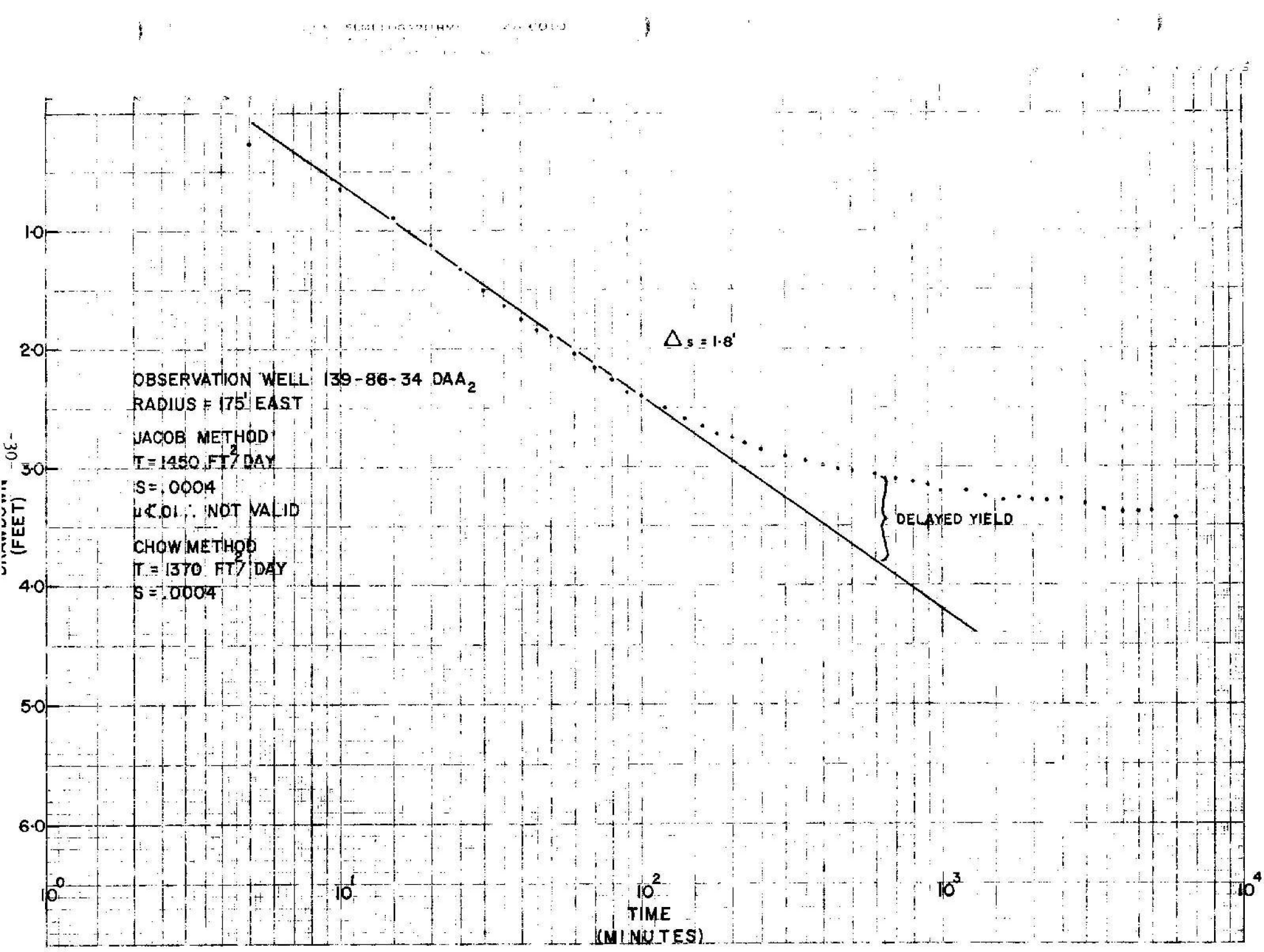


FIGURE 8- JACOB, CHOW SEMI-LOG METHOD

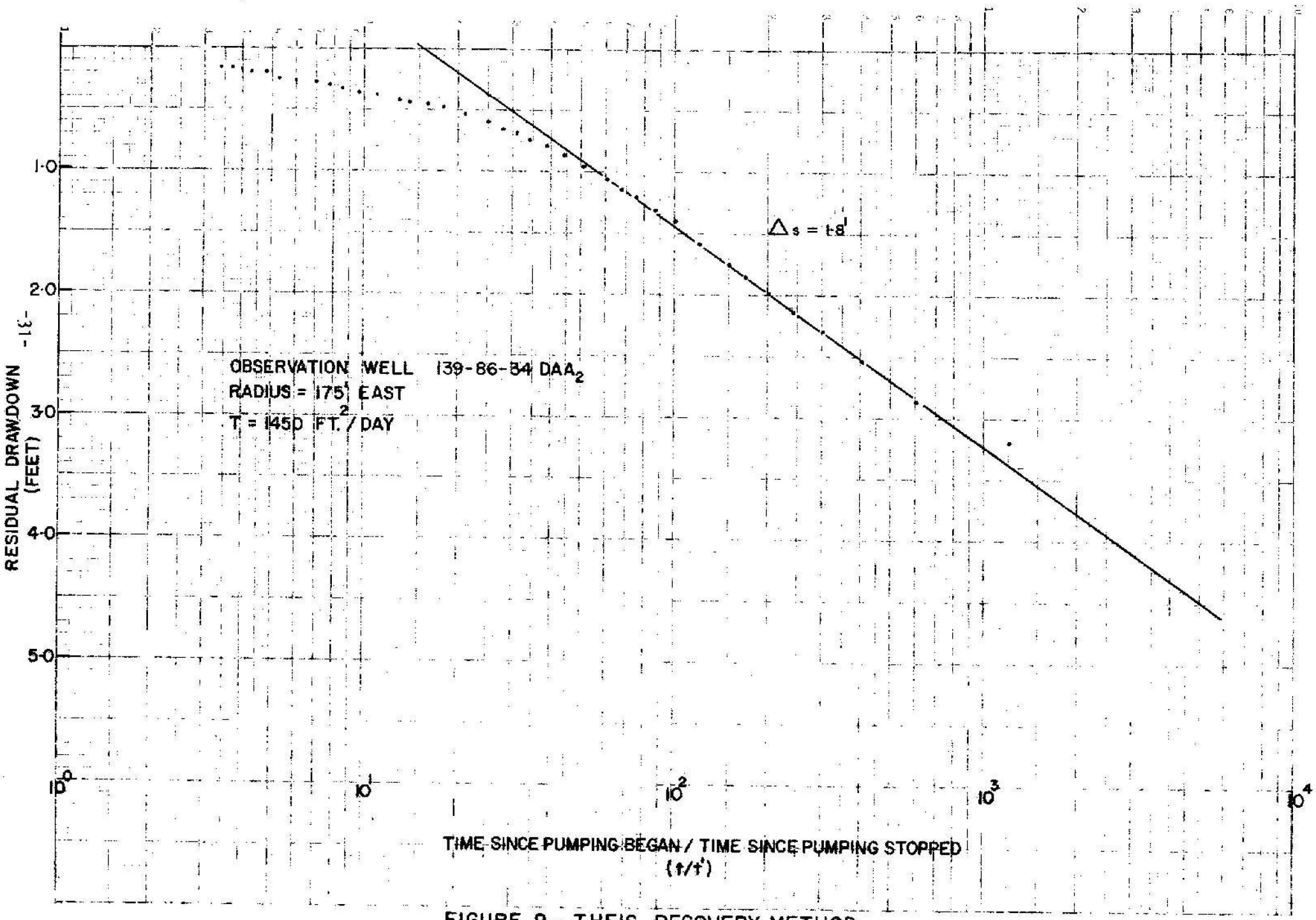


FIGURE 9- THEIS RECOVERY METHOD

in the vicinity of the test site. Many inorganic constituents within the upper clear water zone differ, with respect to concentration, from those within the lower brown water zone. Iron, magnesium and calcium are consistently higher in association with the clear water. Sodium, bicarbonate and total dissolved solids are consistently higher in association with the brown water. Water quality of the Tongue River Formation which flanks the glacial aquifer compares quite favorably to that of the lower brown water zone. This suggests that the glacial aquifer receives inflow from the surrounding bedrock aquifers.

The brown coloration presents a problem with respect to a potable water supply. Therefore, a better understanding of the source and chemical composition of the brown water is desirable. This will provide better insight into the possible treatment processes involved in removing the brown coloration.

A stock well was drilled for Mr. Joel Johnson in August of 1972. It is located approximately 2000 feet due west of the production well used for the aquifer test. The log indicates bedrock lithologies from surface down to the total depth of 151 feet. This is therefore a representative section of the bedrock that flanks the glacial channel aquifer. The first water bearing material encountered at this site was a coal aquifer between 1900 and 1932 feet above mean sea level. The water obtained from this coal aquifer is brown in color. The elevation of this coal aquifer compares quite favorably with the elevation of the brown water horizon in the glacial aquifer in the vicinity of the test site. This indicates that the brown water is associated with and probably originates within the coal aquifer.

Water samples were collected from observation well 139-86-35CCC$_1$ and sent to a U.S.G.S., organic geochemistry laboratory, in Lakewood, Colorado. Analytical results indicate that the coloration is essentially due to organic solutes consisting of primarily hydrophobic acids. The total dissolved organic carbon was 11.5 mg/l.

The colored constituents were removed by passing the water through a column packed with a Rohm and Hass XAD-8 macroreticulate resin. It was suggested by the project chief of this research group, that a filtration bed filled with this type of resin could successfully remove the brown coloration. A problem with this technique is that the pH must be lowered substantially prior to filtration. Thus after filtration the pH must be raised to an acceptable level. Further research is required to determine the economic feasibility of this treatment process.

SUMMARY AND CONCLUSIONS

Geohydrologic data collected during this investigation describe a 69 square mile area in the vicinity of New Salem in Morton County. The area is situated within the Missouri Slope division of the Missouri Plateau physiographic province of North Dakota. The average annual temperature is 41.9°F and the mean annual precipitation is 15.33 inches.

The New Salem area is underlain by more than 8,000 feet of sedimentary rocks and is situated on the southeastern flank of the Williston Basin. This study was concerned only with upper Cretaceous and Tertiary rocks that are potential aquifers in this area. The important bedrock aquifers consist of the (1) Fox Hills, (2) Hell Creek, (3) Cannonball-Ludlow, and (4) Tongue River Formations. These formations consist of alternating beds of claystone, siltstone, sandstone, shale, and lignite that were deposited in ancient seas.

The Fox Hills section contained sandstone from depths of 915 to 965 feet and from depths of 1030 to 1065 feet at a test hole (139-85-30AAB) located one and a half miles west of town. A city well tapping the upper sandstone unit would be about 1,050 feet in depth and would yield water of the sodium bicarbonate type containing in excess of 1,900 mg/l dissolved solids. Well yields of 100 gpm with greater than 300 feet of drawdown are possible from properly constructed wells.

A test hole at 139-85-30AAB penetrated clayey and silty sandstone from a depth of 805 to 858 feet in the Hell Creek Formation. This was the only significant sandstone section encountered in the Hell Creek in the study area. Water from this formation is typically of the sodium bicarbonate type and not suitable for irrigation purposes. Anticipated well yields are similar to those of the Fox Hills.

The Cannonball-Ludlow stratigraphic interval contains four sandstone beds, each of which range in thickness from 10 to 15 feet. Wells ranging from 454 to 595 feet in depth tap one or more of the Cannonball-Ludlow sands. Sodium bicarbonate water is also common to the Cannonball-Ludlow and dissolved solids may exceed 1,500 mg/l.

The majority of domestic and stock wells in this area are either completed in lignites or the basal sandstone bed of the Tongue River Formation. Test drilling indicates the lignites range from 2 to 12 feet in thickness and the basal sandstone may be as much as 60 feet thick. The basal sandstone underlies all of the study area and is tapped by the city wells as a source of municipal water supply. Water contained in the formation ranges from 633 to 2,240 mg/l dissolved solids, is of the sodium bicarbonate type, and is not suitable for irrigation because of high sodium adsorption ratios. Wells range in depth from 56 to 390 feet and yields exceeding 50 gpm are possible from properly constructed wells.

Glacial deposits consisting of till, silty clay, and outwash occur in this area but they are thin and discontinuous. Significant deposits of buried outwash were encountered in the glacial diversion channels now occupied by Sims and Muskrat Creeks. The outwash ranges in saturated thickness from 10 to 134 feet and is thickest near the confluence of the two creeks. Nineteen observation wells ranging from 60 to 159 feet in depth were completed in the outwash. Static water levels are usually less than 80 feet lsd and the hydraulic gradient

is southeast.

The occurrence of brown, organic enriched water in the lower zone of saturation necessitates the construction of a capture system in the upper portion of the aquifer. Here the water is not only clear but is lower in sodium and total dissolved solids. This water would require treatment for the removal of iron and manganese. The capture system should probably consist of two or three wells that penetrate the upper portion of the aquifer. They should be designed with spacings and discharge rates that would minimize the drawdown at each well site. Data indicates that a substantial supply of good quality water is available in this upper zone. This supply is adequate to meet the needs of the city of New Salem.

TABLE 4 - LOGS OF TEST HOLES

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

Grain-size classification is C. K. Wentworth's scale from Pettijohn (1957). Color descriptions are of wet samples and are based upon color standards of the National Research Council (Goddard and others, 1948).

Test holes are called observation wells when they have been completed with 1-¼ inch diameter plastic casing or 2-inch diameter steel pipe and screened at the bottom. Well depths, screened producing intervals (S.I.) and water levels, with date of measurement, are so designated. Water levels are in feet below land surface.

Elevations, based on mean sea level datum, were interpreted from the Judson, New Salem, New Salem N.E., and North Almont Quadrangles, published by the U.S. Geological Survey.

Explanation of Lithologic Symbols

Sand and Gravel

Till

Siltstone and Claystone

Shale

Silty and Sandy Clay

Sandstone

Lignite

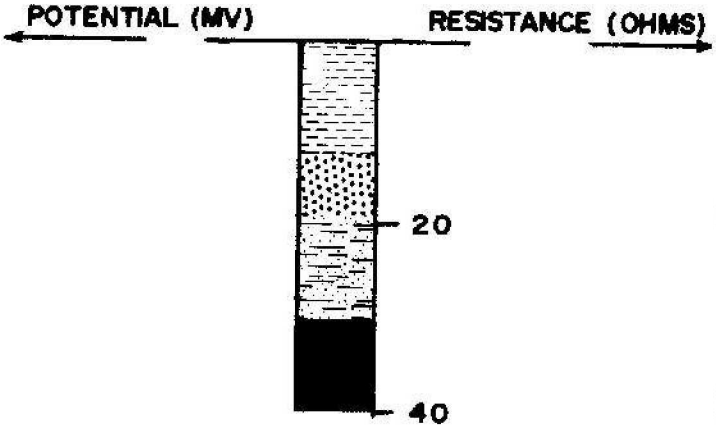
TEST HOLE 4656

LOCATION: 138-86-2bcb

DATE DRILLED: 6-4-74

ELEVATION: 2015
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-12	Clay, silty, sandy, dusky yellow, oxidized.
12-19	Gravel, clayey, very sandy, fine to coarse, angular to subrounded, oxidized.

Tongue River Formation

19-30	Siltstone, clayey, light-gray, limey.
30-40	Lignite, black, brittle,hard.

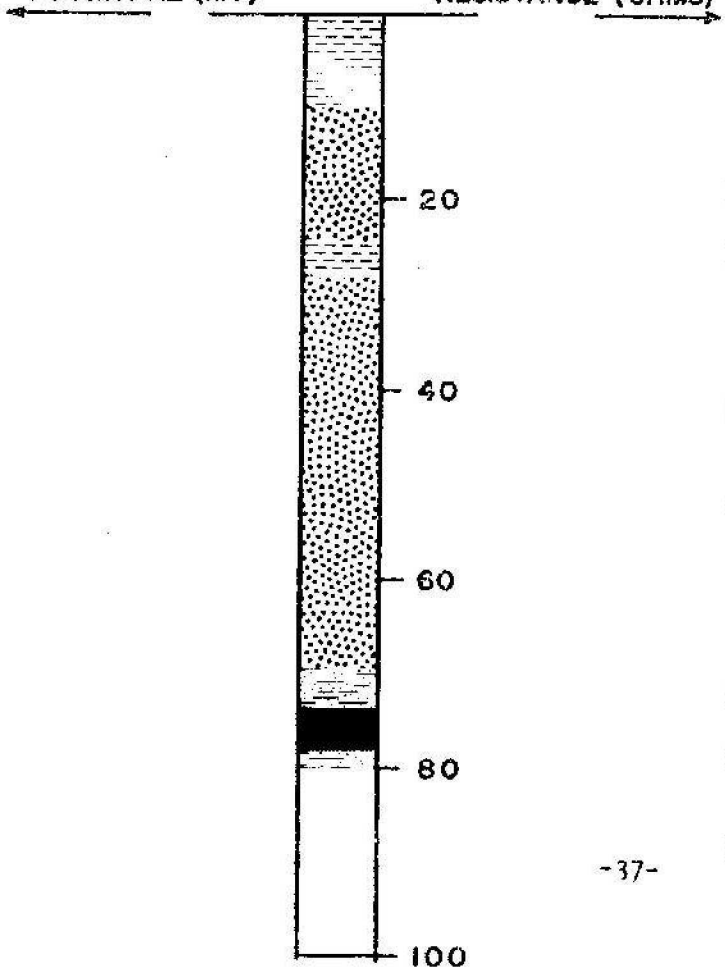
TEST HOLE 4649

LOCATION: 138-86-11acc

DATE DRILLED: 5-24-74

ELEVATION: 1965
(FT, MSL)

DEPTH: 80
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-10	Clay, silty, sandy, yellowish brown, oxidized.
10-17	Sand, gravelly, clayey, fine to very coarse, subangular, oxidized.
17-24	Gravel, sandy, medium to coarse, angular to well-rounded, about 60% brownish silicates, 30% local sandstone and shale, 10% granite and carbonate rocks.
24-28	Clay, sandy, silty, medium-gray to brownish-gray, lignite chips, calcareous.
28-70	Sand, occasional clay layers, very fine to medium-grained, medium gray subangular, lignitic.

Tongue River Formation

70-74	Claystone, hard, brittle, medium-gray, non-calcareous.
74-79	Lignite, hard, black, brittle, dark brown carbonaceous shale partings.
79-80	Siltstone, medium light-gray, calcareous.

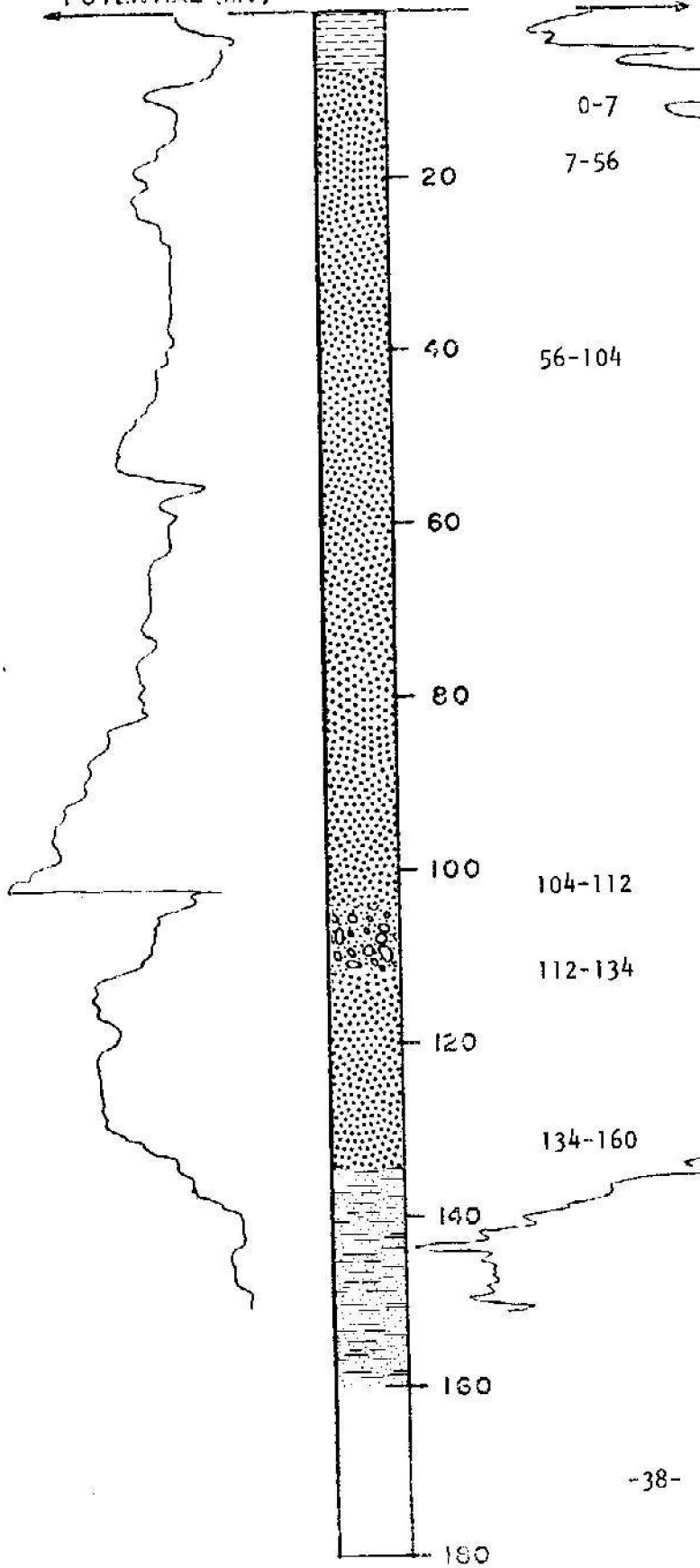
TEST HOLE 4657

LOCATION: 138-86-11dbb

DATE DRILLED: 6-4-74

ELEVATION: 1960
(FT, MSL.)

DEPTH: 160
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-7 Clay, silty, sandy, moderate yellow-brown, oxidized.

7-56 Gravel, about 40% sand, some clay, fine to coarse, some cobbles, about 60% brownish western silicates, 30% local sandstone and siltstone, 10% granitics and carbonates taking water.

56-104 Sand, gravel stringers, fine to very coarse, subrounded, lignitic.

104-112 Clay, sandy, silty, pebbly, olive-gray, lignite fragments (Till).

112-134 Sand, slightly gravelly, fine to very coarse, subangular to rounded, detrital lignite.

Tongue River Formation

134-160 Claystone, sandy, dark greenish-gray.

Observation Well

Depth: 70 feet
S. I.: 67-70 feet
Water level: 7.87 feet
Measured: 6-12-74

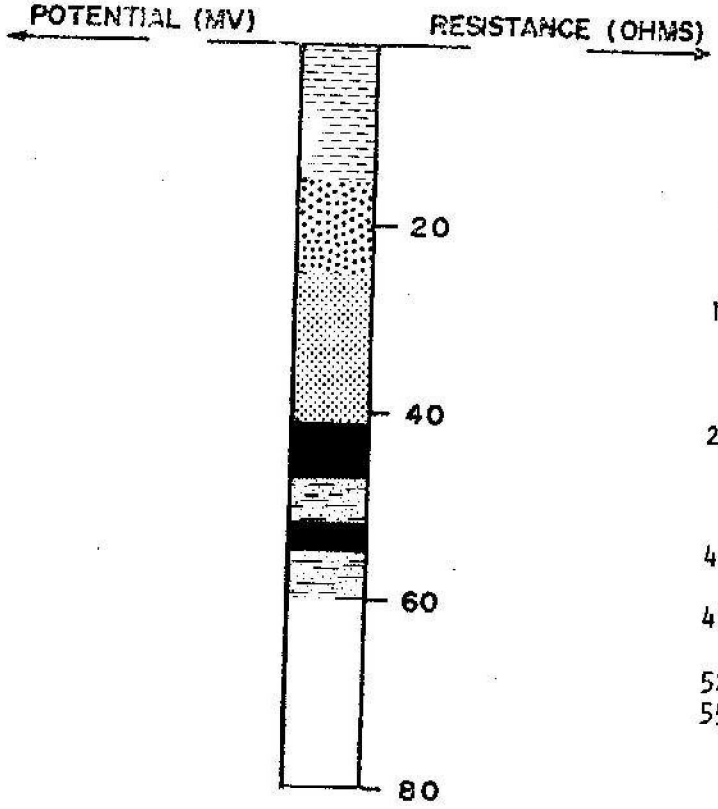
TEST HOLE 4650

LOCATION: 138-86-14abc

DATE DRILLED: 5-24-74

ELEVATION: 1950
(FT, MSL)

DEPTH: 60
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0- 5 Clay, silty, sandy, dark yellowish brown, oxidized.

5-15 Clay, silty, olive-gray, highly calcareous, wood fragments, sand layers.

15-25 Sand, gravelly.

Tongue River Formation

25-41 Sandstone, some thin claystone bedding, very fine to fine-grained, bluish-gray, subangular to subrounded, micaceous.

41-47 Lignite, hard, black, some shale parting.

47-52 Claystone, brownish-gray, moderately indurated.

52-55 Lignite, hard, brownish-black.

55-60 Claystone, brownish-gray to medium gray.

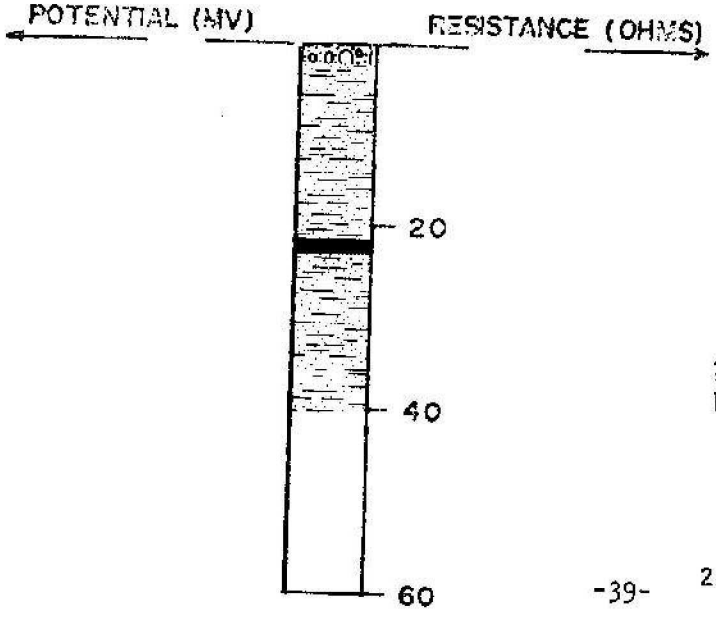
TEST HOLE 4643

LOCATION: 139-85-18dcc

DATE DRILLED: 5-23-74

ELEVATION: 2015
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0- 2 Clay, silty, sandy, pebbly, yellowish brown, oxidized (Till).

Sentinel Butte Formation

2-14 Siltstone, slightly clayey, dusky yellow, oxidized.

14-15 Limestone, light-gray, hard.

15-21 Siltstone, clayey, dark yellowish brown, medium-gray mottling, oxidized.

Tongue River Formation

-39- 21-22½ Lignite, brownish-black, shale partings, oily.

22½-40 Claystone, silty, medium to greenish-gray, bentonitic.

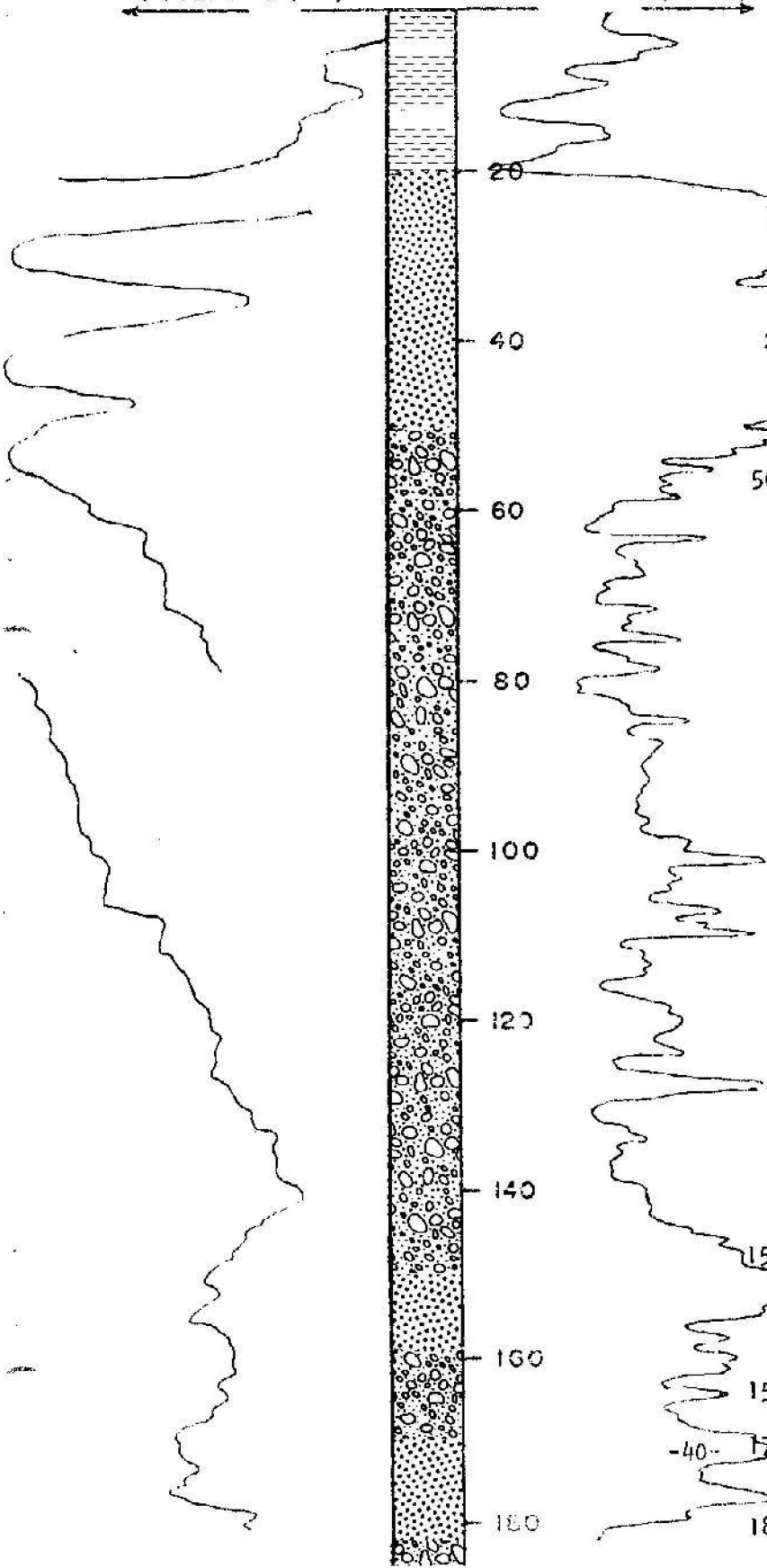
TEST HOLE 4641

LOCATION: 139-85-18dcd

DATE DRILLED: 5-23-74

ELEVATION: 2080
(FT, MSL)

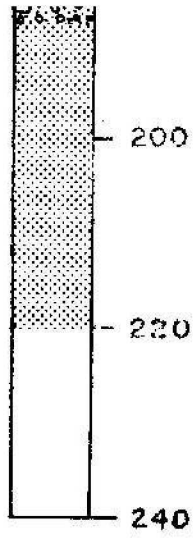
DEPTH: 220
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0- 4	Clay, silty, sandy, brownish-black.
4-16	Clay, silty, dark yellowish-brown, oxidized.
16-20	Clay, silty, dusky yellow to yellowish brown, oxidized.
20-50	Sand, about 5% gravel, fine to very coarse, angular to subrounded, lignitic, occasional silty clay layers, oxidized.
50-150	Clay, sandy, silty, few pebbles, lignite chips, dark yellow-brown grading to olive-gray, occasional sand layers (Till).
150-159	Gravel, about 30% sand, fine to very coarse, some clay, angular to subrounded, some granitic carbonate and siliceous rocks, much detrital lignite.
159-170	Clay, sandy, silty, olive-gray, pebbly (Till).
170-182	Gravel, fine to coarse, angular, about 80% detrital lignite, 20% granitic and carbonate rocks.
182-188	Clay, pebbly, silty, olive-gray (Till).



188-220

Tongue River Formation

Sandstone, very slightly clayey, very fine to fine-grained, sub-angular, consolidated, medium bluish-gray, few brownish-gray carbonaceous shale partings.

Observation Well

Depth: 159 feet
S. I.: 153-159 feet
Water Level: 79.92 feet
Measured: 6-12-74

31

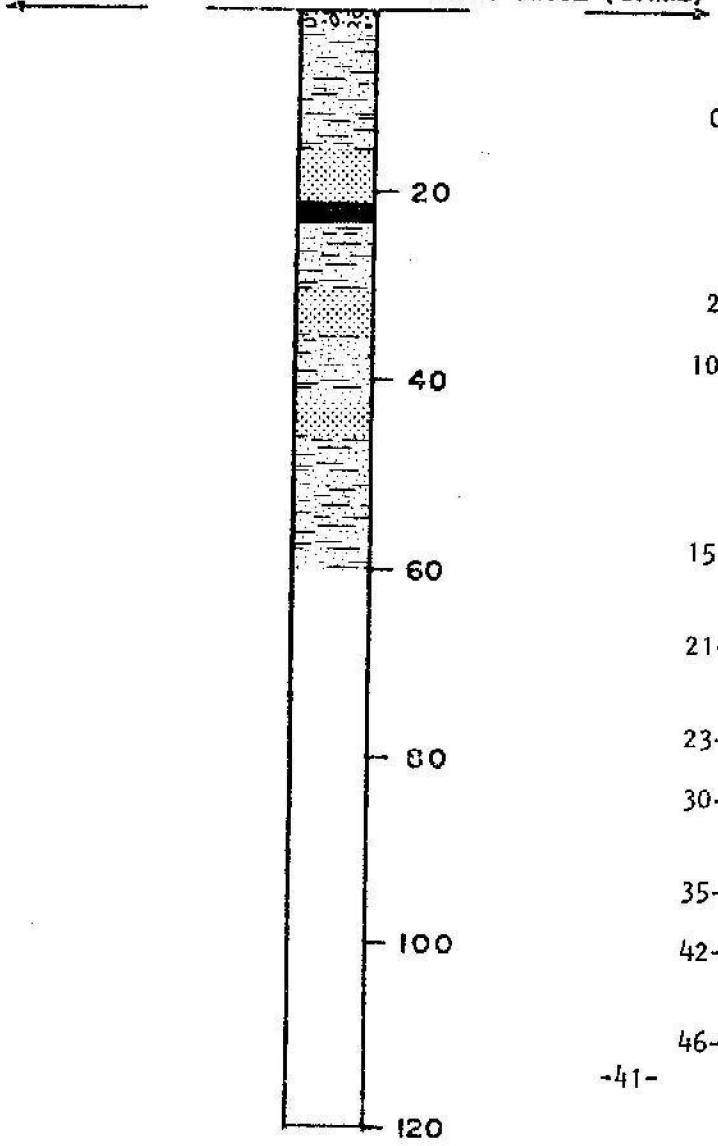
TEST HOLE 4642

LOCATION: 139-85-18ddc

DATE DRILLED: 5-23-74

ELEVATION: (FT, MSL) 2125

DEPTH: (FT) 60



DESCRIPTION OF DEPOSITS

Glacial Drift

0- 2 Clay, silty, sandy, dusky-yellow to yellowish-brown, oxidized (Till).

Sentinel Butte Formation

2-10 Siltstone, clayey, dusky-yellow. oxidized.

10-15 Siltstone, clayey, medium-gray, yellowish-brown mottling, lime-stone concretion.

Tongue River Formation

15-21 Sandstone, very clayey and silty, very fine to fine-grained, medium-gray, consolidated.

21-23 Lignite, black, brittle, dark-brown carbonaceous shale partings, some oily leonardite.

23-30 Claystone, silty, bluish-gray to greenish-gray, bentonitic.

30-35 Sandstone, dark yellowish brown, very fine to fine-grained, sub-angular, well oxidized.

35-42 Claystone, silty, greenish-gray, calcareous, slightly bentonitic.

42-46 Sandstone, slightly clayey, bluish-gray, very fine to fine-grained, subangular, fossiliferous.

46-60 Claystone, sandy medium-gray, brownish-gray mottling.

139-85-21adc

City of New Salem (No. 1)

(Water Tower Well)

Elevation: 2160 feet Depth: 300 feet

Description of Deposits

Sentinel Butte Formation

1- 8	Sandy clay
8- 40	Clay
40- 41	Hard sand rock

Tongue River Formation

41- 43	Coal
43- 95	Clay
95- 97	Rock
97-136	Clay
136-138	Coal
138-170	Clay
170-172	Hard rock
172-180	Sand, dry
180-190	Clay
190-193	Shale
193-203	Coal
203-209	Clay
209-219	Shale
219-240	Coal
240-284	Shale
284-286	Rock
286-304	Sandy clay
304-347	Sand

Well completed with 10-inch diameter steel casing and screened on bottom.

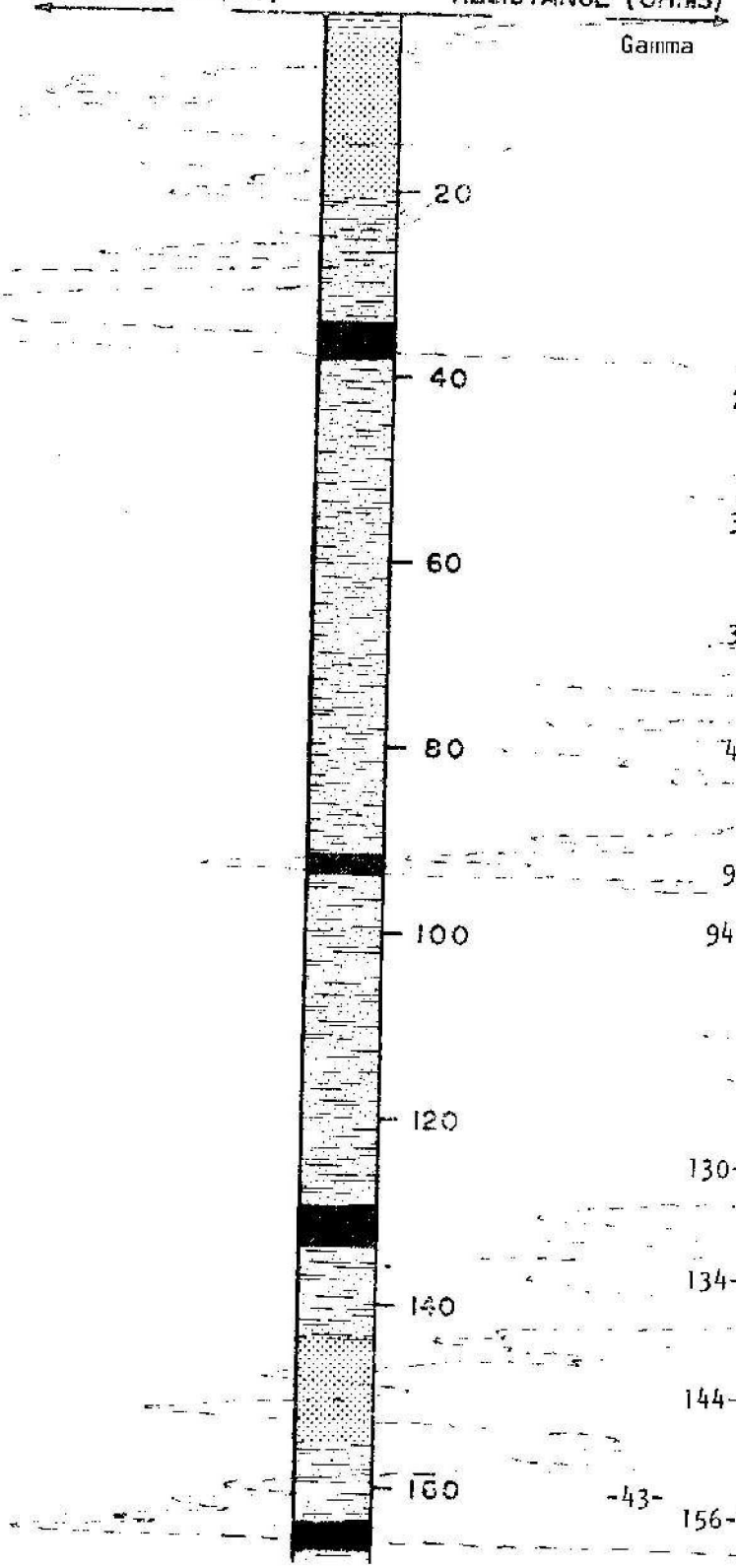
TEST HOLE 4652

LOCATION: 139-85-21bac

DATE DRILLED: 6-3-74

ELEVATION (FT, MSL): 2160

DEPTH (FT): 340



DESCRIPTION OF DEPOSITS

Glacial Drift

0- 2 Clay, sandy, silty, dark yellow-brown, oxidized.

Sentinel Butte Formation

2-20 Sandstone, fine-grained, subangular to subrounded, yellow-brown, semi-consolidated, quartzose, oxidized.

20-34 Claystone, sandy, silty, yellow-brown, oxidized.

Tongue River Formation

34-38 Lignite, brittle, black, hard.

38-46 Siltstone, siliceous, greenish-gray, non-calcareous.

46-92 Siltstone, clayey, sandy, medium light-gray to medium-gray, few brownish-gray shale layers, non-calcareous.

92-94 Lignite, hard, brittle, black, carbonaceous shale partings.

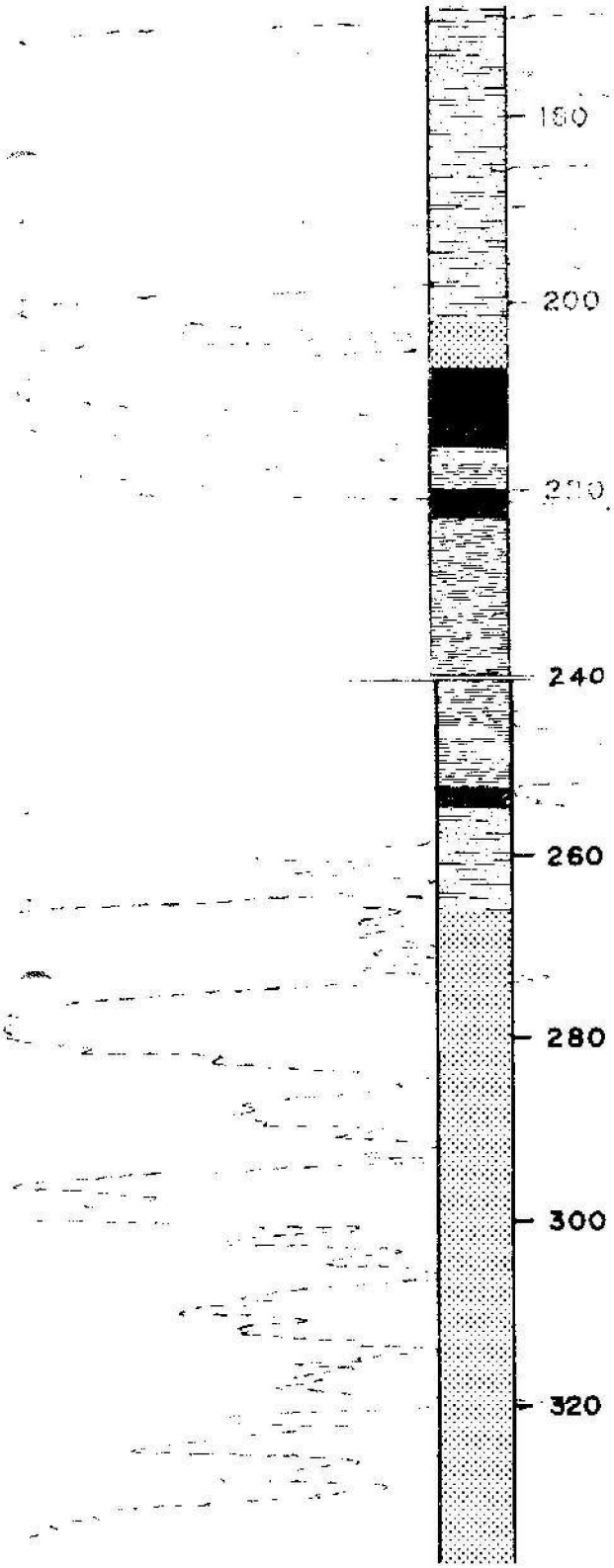
94-130 Claystone, sandy, silty, medium-gray, few yellowish-gray limestone concretions.

130-134 Lignite, brownish-black to black, brittle, shaley.

134-144 Claystone, silty, sandy layers, medium-gray, few carbonaceous shale partings and lignite stringers.

144-156 Sandstone, silty, very fine to fine-grained, consolidated to well-cemented, medium light-gray, limey micaceous.

156-164 Siltstone, clayey, light-gray, calcareous, limey.



164-167	Lignite, hard, black, brittle, shale partings.
167-202	Claystone, silty, brownish-gray, limestone and sandstone concretions.
202-207	Sandstone, clayey, very fine to fine-grained, light bluish-gray, slightly cemented.
207-216	Lignite, brittle, black to brownish-black, shale partings.
216-220	Shale, silty, dark-brown to brownish-gray, carbonaceous.
220-223	Lignite, black, brittle, taking water.
223-253	Shale, sandy, brownish-gray, carbonaceous.
253-255	Lignite, brownish-black to black, soft, oily, leonardite.
255-266	Claystone, silty, greenish-gray, non-calcareous, bentonitic.
266-340	Sandstone, very fine to medium-grained, subangular to subrounded, light bluish-gray, lignitic, micaceous, few thin claystone interbeds, lost circulation.

34

Observation Well

Depth: 324 feet
S. I.: 318-324 feet
Water Level: 225.40 feet
Measured: 6-12-74

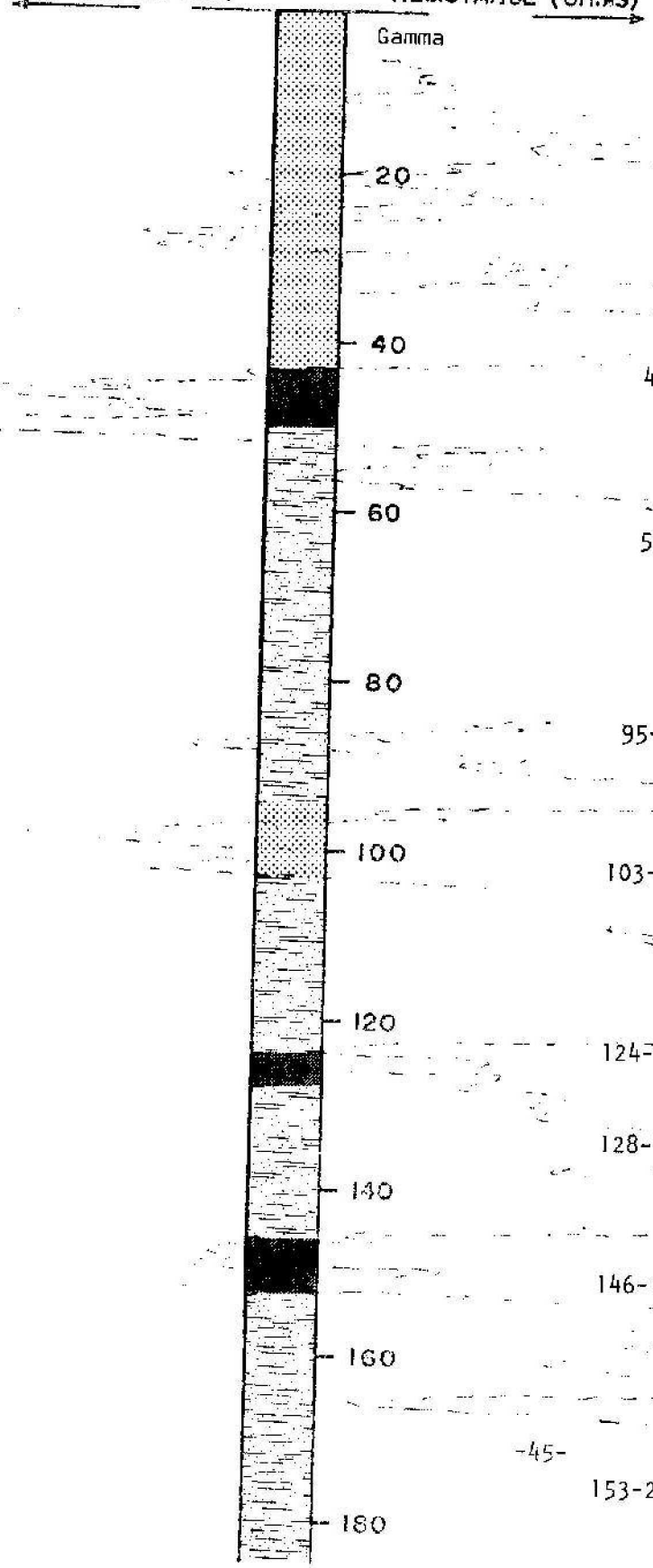
TEST HOLE 4653

LOCATION: 139-85-22bcb

DATE DRILLED: 6-3-74

ELEVATION: (FT, MSL) 2162

DEPTH: 360 (FT)



DESCRIPTION OF DEPOSITS

Sentinel Butte Formation

1-43 Sandstone, silty, clayey, very fine to fine-grained, subangular, yellowish brown, oxidized.

Tongue River Formation

43-50 Lignite, brownish-black to black, brittle, carbonaceous shale partings.

50-95 Siltstone, siliceous, greenish-gray to medium-gray, bentonite, thin sandstone concretions and lignite stringers.

95-103 Sandstone, clayey, silty, very fine-grained, bluish-gray, well consolidated, micaceous.

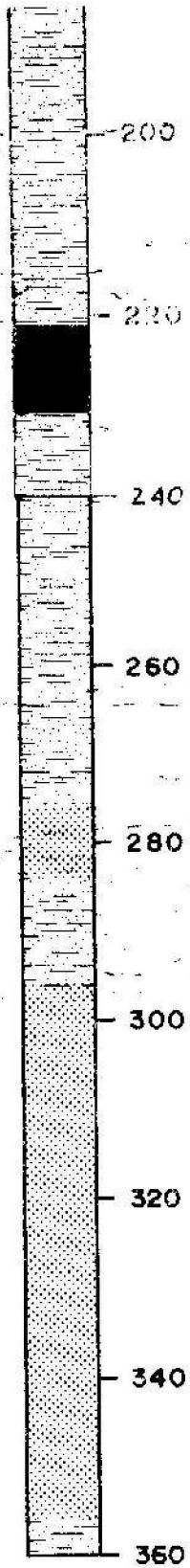
103-124 Claystone, silty, medium-gray with light brownish-gray bedding.

124-128 Lignite, black to dark-brown, medium gray sandy siltstone, interbedding.

128-146 Claystone, sandy, silty, medium light-gray to light brownish-gray, few limey siltstone concretions and lignite stringers.

146-153 Lignite, black, brittle, shale partings.

153-221 Claystone, sandy, light brownish-gray, carbonaceous.



	221-231	Lignite, black to brownish-black, siltstone and carbonaceous shale interbeds.
36	231-260	Claystone, silty, brownish-gray, carbonaceous.
	260-276	Claystone, sandy, medium-gray to greenish-gray.
	276-284	Sandstone, clayey, very fine to fine-grained, subangular to subrounded, light greenish-gray mecaceous.
	284-296	Claystone, silty, brownish-gray to medium-gray.
	296-356	Sandstone, slightly clayey, medium bluish-gray, very fine to fine-grained, subangular to subrounded, cemented 248-256.
		Cannonball-Ludlow Formations
	356-360	Siltstone, medium light-gray, siliceous, limey.

Observation Well

Depth: 344 feet
S. I.: 338-344 feet
Water Level: 210.17 feet
Measured: 6-12-74

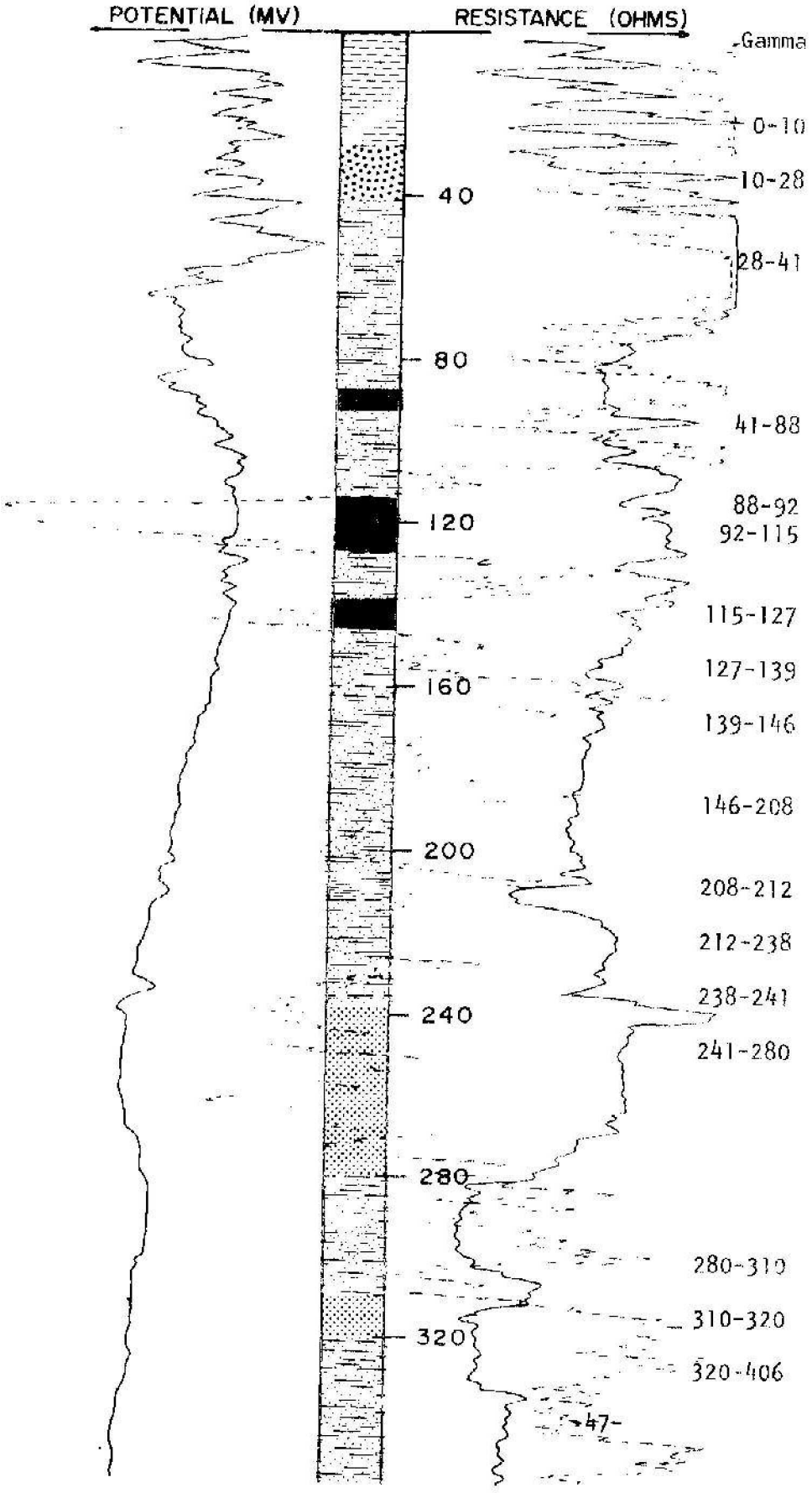
TEST HOLE 4651

LOCATION: ~~139-85-30aab~~

ELEVATION: 2065
(FT, MSL)

DATE DRILLED: 5-24 to 30-74

DEPTH: 1140
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

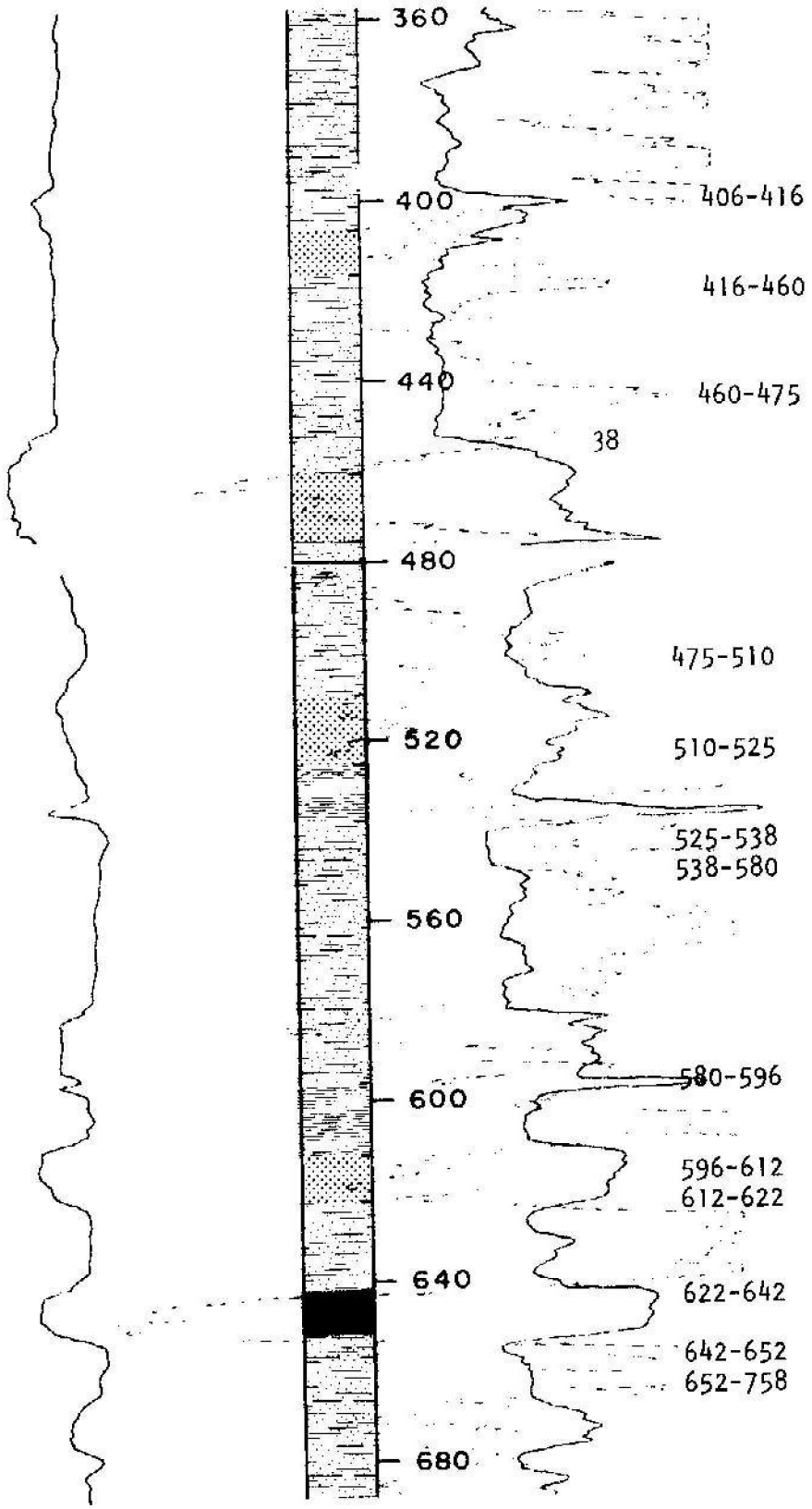
Clay, sandy, yellowish-brown, oxidized.
Clay, sandy, silty, few gravelly sand layers, dark yellowish brown to dusky-yellow, oxidized.
Sand, gravelly, clayey, fine to very coarse-grained, angular to subrounded, oxidized.

Tongue River Formation

Claystone, silty to sandy, medium-gray to greenish-gray, bentonitic, calcareous.
Lignite, hard, black, brittle.
Claystone, sandy, light brownish-gray, thin dark-brown carbonaceous shale partings.
Lignite, hard, black to dark brownish-black.
Siltstone, sandy, light greenish-gray, bentonitic.
Shale, dark brownish-black to black, dark brown carbonaceous shale partings.
Claystone, about 30% sand, brownish-gray to medium bluish-gray, light yellowish-gray mottling.
Shale, silty, brownish-gray, carbonaceous.
Claystone, about 40% sand, medium-gray.
Sandstone, fine-grained, bluish-gray, cemented, very hard.
Sandstone, very fine to medium-grained, subangular to subrounded, quartzose, angular limestone grains medium bluish-gray, lignitic, [illegible] coal seams.

Cannonball-Ludlow Formations

Siltstone, clayey, medium-gray, yellowish-gray mottling.
Sandstone, silty, very fine-grained, light-gray, calcareous.
Siltstone, clayey, locally sandy, medium dark-gray, local greenish-gray sandstone layering, silt inclusions, few yellowish-gray limestone concretions, calcareous.



406-416 Sandstone, clayey, very fine to fine-grained, subangular, dark greenish-gray, glauconitic.

416-460 Siltstone, sandy, clayey, medium-gray, calcareous.

460-475 Sandstone, slightly clayey, silty, very fine to fine-grained, dark greenish-gray, consolidated, locally limey, mecaceous, glauconite, cemented and hard 473'-475'.

475-510 Claystone, sandy, silty, medium dark-gray, some limestone concretions, non-calcareous.

510-525 Sandstone, clayey, cemented, dark greenish-gray, glauconitic, micaceous.

525-538 Shale, grayish-brown, carbonaceous.

538-580 Siltstone, sandy, light-gray, limey and calcareous, occasional thin dark greenish-gray sandstone bedding.

Hell Creek Formation

580-596 Claystone, sandy, silty, brownish-gray, sandstone concretions from 594-596

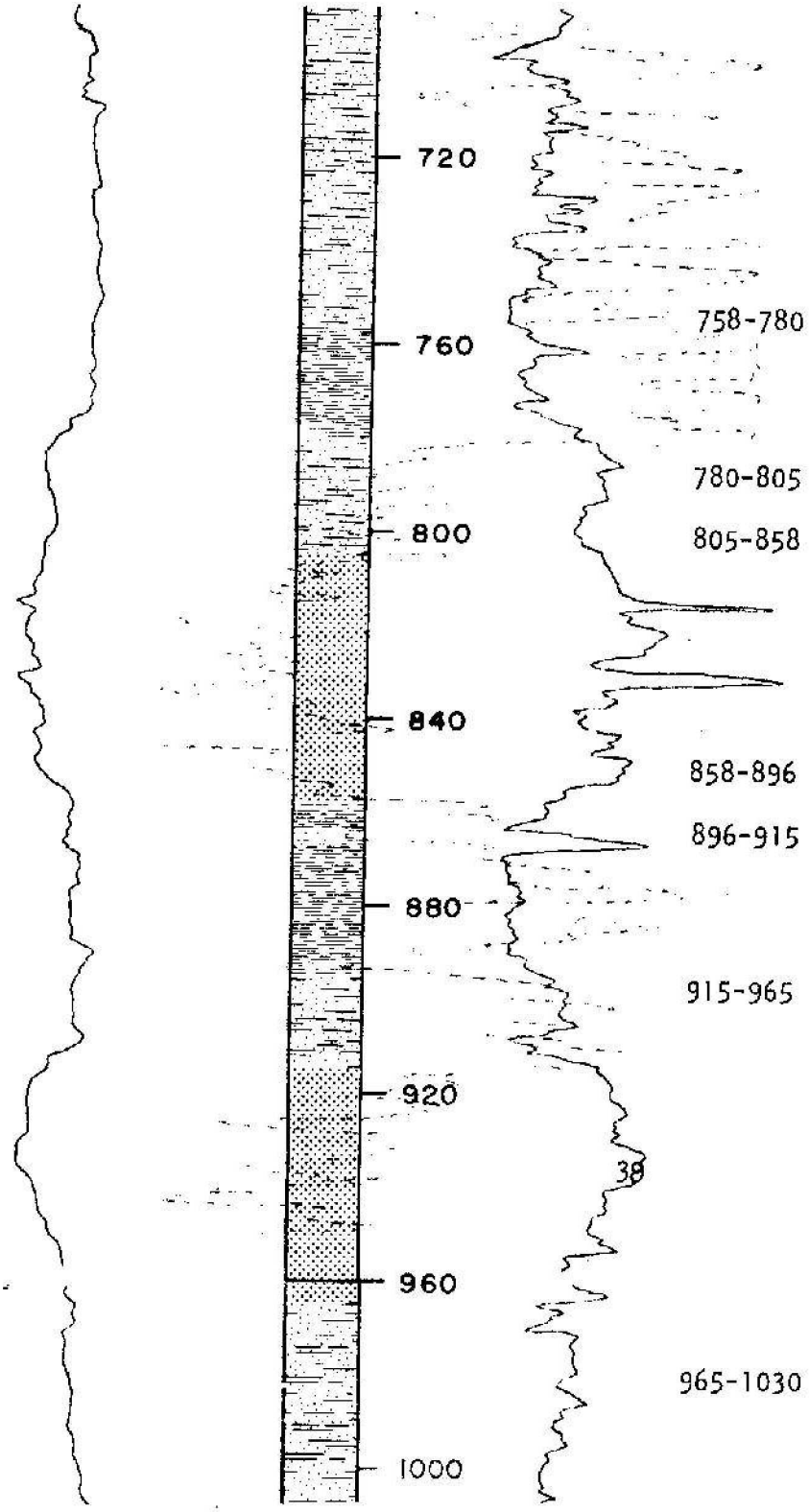
596-612 Shale, dark brown, carbonaceous.

612-622 Sandstone, very fine-grained, dark greenish-gray, micaceous, consolidated.

622-642 Claystone, sandy, silty, light brownish-gray, noncalcareous.

642-652 Lignite, black, brittle to soft.

652-758 Claystone, silty, brownish-gray to grayish-brown, slightly carbonaceous, some thin siltstone bedding, few lignite partings.



758-780 Shale, dark-brown, waxy, carbonaceous.

780-805 Claystone, sandy, light brownish-gray, slightly carbonaceous.

805-858 Sandstone, very clayey, silty, very fine to fine-grained, subangular to subrounded, claystone interbeds, medium light-gray, consolidated, locally cemented beds.

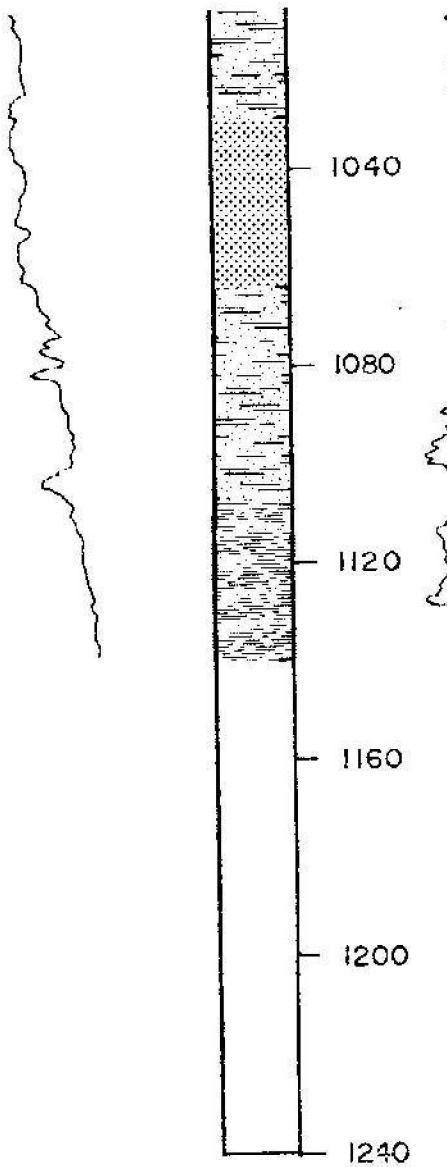
858-896 Shale, silty, dark-brown to brownish-gray, slightly carbonaceous.

896-915 Siltstone, sandy, light greenish-gray.

Fox Hills Formation

915-965 Sandstone, some clay, very fine to fine-grained, light bluish-gray, subangular to subrounded, semiconsolidated, micaceous, few glauconite grains, fossiliferous.

965-1030 Siltstone, sandy, siliceous, medium light-gray to light grayish-brown, non-calcareous.



1030-1065 Sandstone, clayey, silty, light bluish-gray, consolidated, siltstone and claystone interbedding, very fine to fine-grained, micaceous, few glauconite grains.

1065-1110 Siltstone, clayey, siliceous, medium dark-gray, local cemented sandstone concretions.

Pierre Formation

1110-1140 Shale, medium dark-gray to grayish black, brittle, fissile, non-calcareous.

Observation Wells

Depth West Well: 962 feet
S. I.: 950-962 feet
Water Level: 248.39 feet
Measured: 6-12-74

Depth Center Well: 474 feet
S. I.: 462-474 feet
Water Level: 191.87 feet
Measured: 6-12-74

Depth East Well: 270 feet
S. I.: 258-270 feet
Water Level: 76.69 feet
Measured: 6-12-74

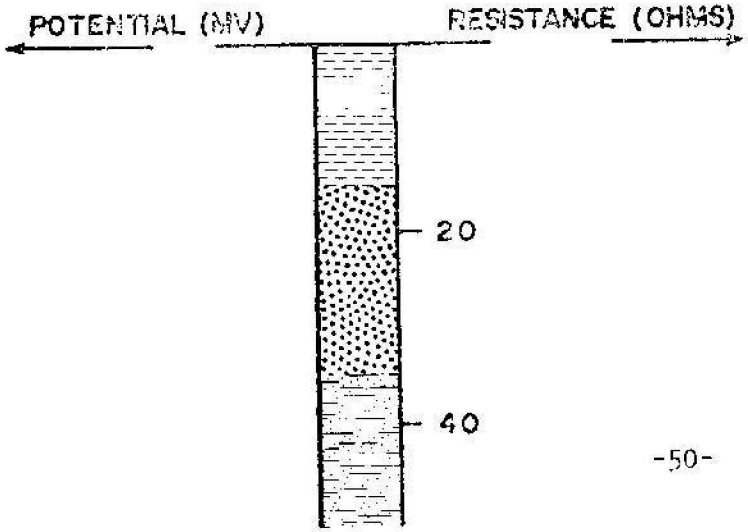
TEST HOLE 4659

LOCATION: 139-86-22ccd1

ELEVATION: 2035
(FT, MSL)

DATE DRILLED: 6-5-74

DEPTH: 60
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-15 Clay, silty, sandy, dusky yellow to dark yellowish brown, oxidized.

15-19 Gravel, sandy, clayey, fine to coarse, angular, oxidized.

19-35 Sand, about 30% fine gravel, mediu to very coarse, angular to sub-rounded.

Tongue River Formation

35-60 Siltstone, sandy, medium light-gray, calcareous.

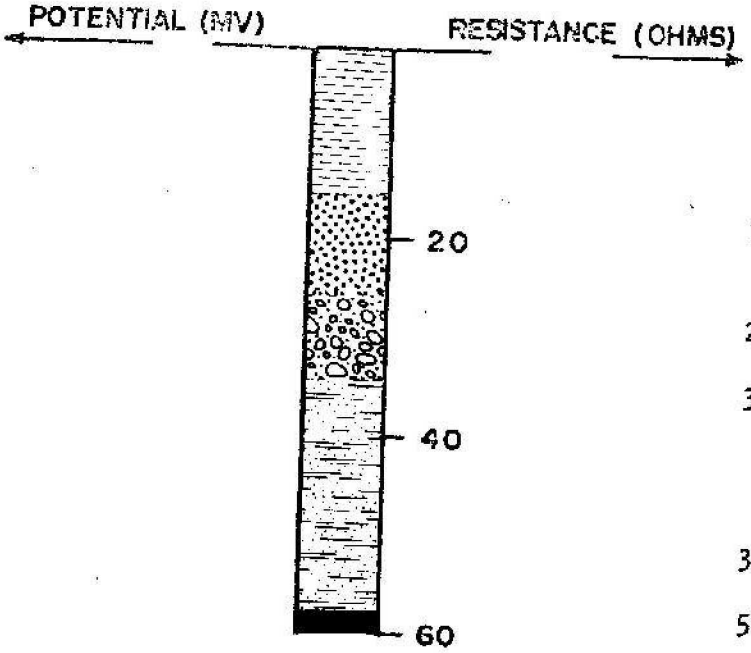
TEST HOLE 4660

LOCATION: 139-86-22ccd$_2$

DATE DRILLED: 6-5-74

ELEVATION: (FT, MSL) 2040

DEPTH: (FT) 60



DESCRIPTION OF DEPOSITS

Glacial Drift

0-15	Clay, silty, sandy, yellowish brown to dusky yellow, oxidized.
15-25	Gravel, sandy, fine to very coarse, angular to subrounded, oxidized.
25-30	Clay, silty, sandy, pebbly, dark yellowish-brown, oxidized (Till).
30-34	Clay, pebbly, sandy, olive-gray, angular lignite fragments (Till).

Tongue River Formation

34-58	Siltstone, sandy, medium light-gray, few lignite stringers.
58-60	Lignite, black, brittle, hard.

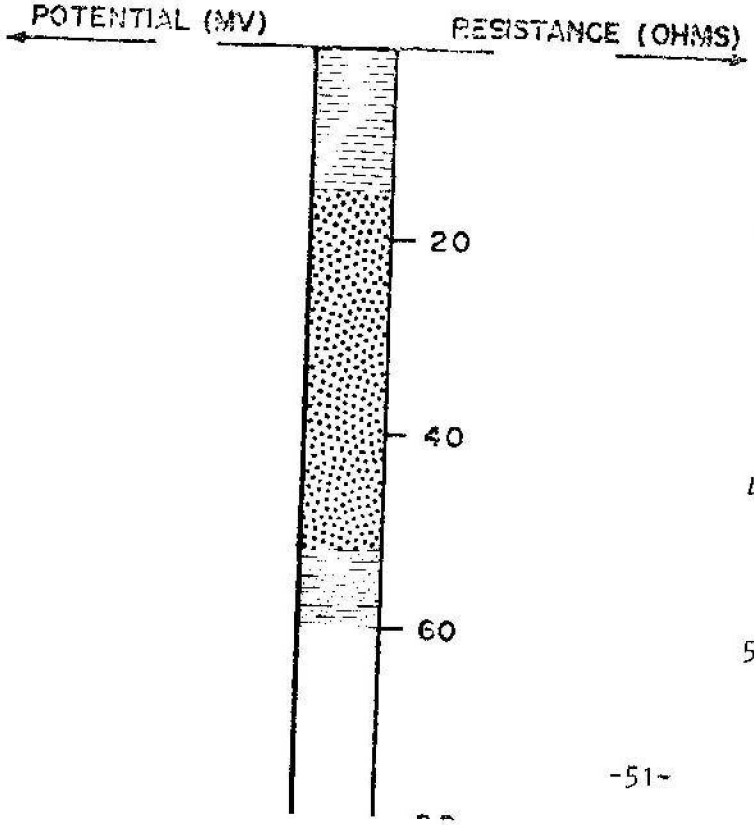
TEST HOLE 4648

LOCATION: 139-86-25ddb

DATE DRILLED: 5-24-74

ELEVATION: (FT, MSL) 2045

DEPTH: (FT) 60



DESCRIPTION OF DEPOSITS

Glacial Drift

0-15	Clay, silty, sandy, yellowish brown, oxidized.
15-48	Sand, about 25% gravel, fine to very coarse, subangular to sub-rounded, lignitic, occasional clay layers, oxidized.
48-52	Gravel, sand, fine to coarse, angular to subrounded, oxidized.

Tongue River Formation

52-60	Claystone, silty, medium-gray, calcareous.

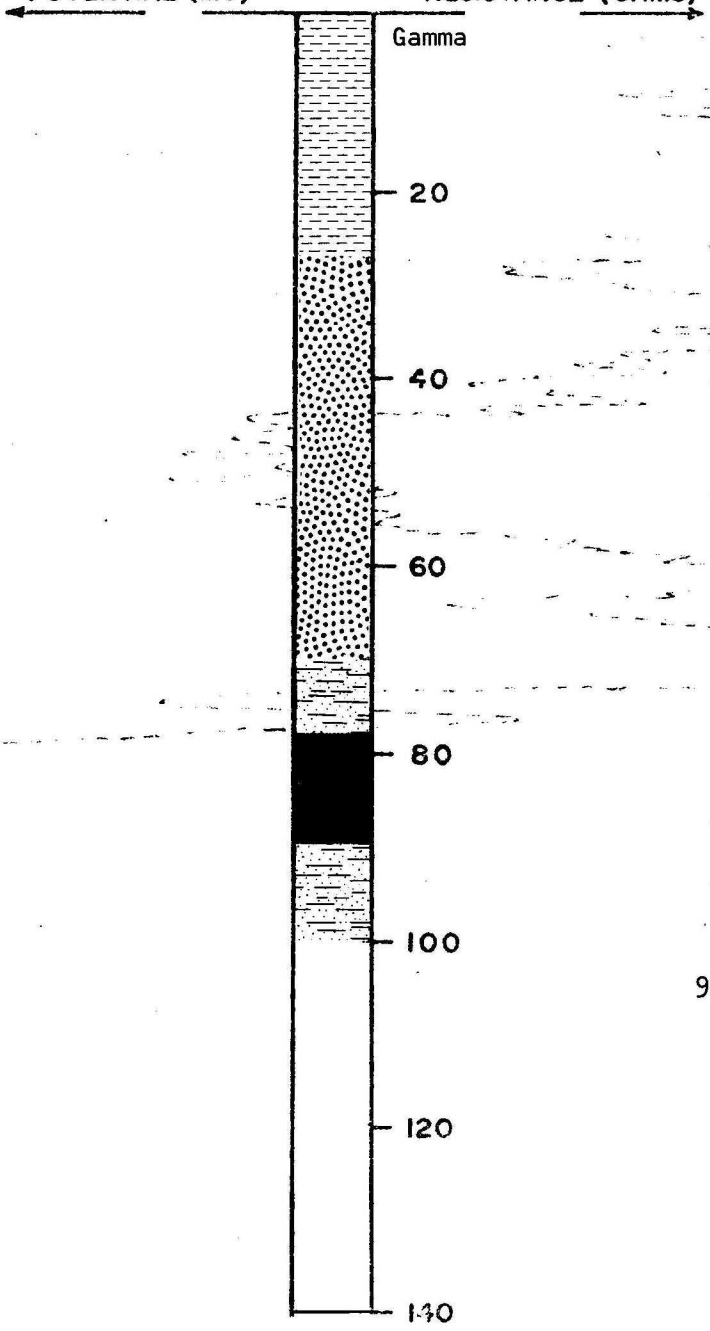
TEST HOLE 4661

LOCATION: 139-86-27baa

DATE DRILLED: 6-5-74

ELEVATION: 2045
(FT, MSL)

DEPTH: 100
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-27	Clay, silty, sandy, dusky yellow to yellowish brown, oxidized.
27-32	Gravel, about 30% sand, clayey, fine to coarse, oxidized.
32-44	Sand, gravelly, clay layers, fine to very coarse, dark yellow-brown staining, angular to subrounded, oxidized.
44-70	Gravel, about 40% sand, some thin clay stringers, fine to coarse, cobbles, angular to well rounded, about 60% brownish western silicates, 30% local sandstone and siltstone, 10% granitic and metamorphic rocks and detrital lignite.

Tongue River Formation

70-78	Siltstone, clayey, medium light-gray, calcareous.
78-90	Lignite, black to brownish-black, brittle, hard, few carbonaceous shale partings.
90-100	Claystone, silty, brownish-gray.

Observation Well

Depth: 60 feet
S. I.: 57-60 feet
Water Level: 32.48 feet
Measured: 6-12-74

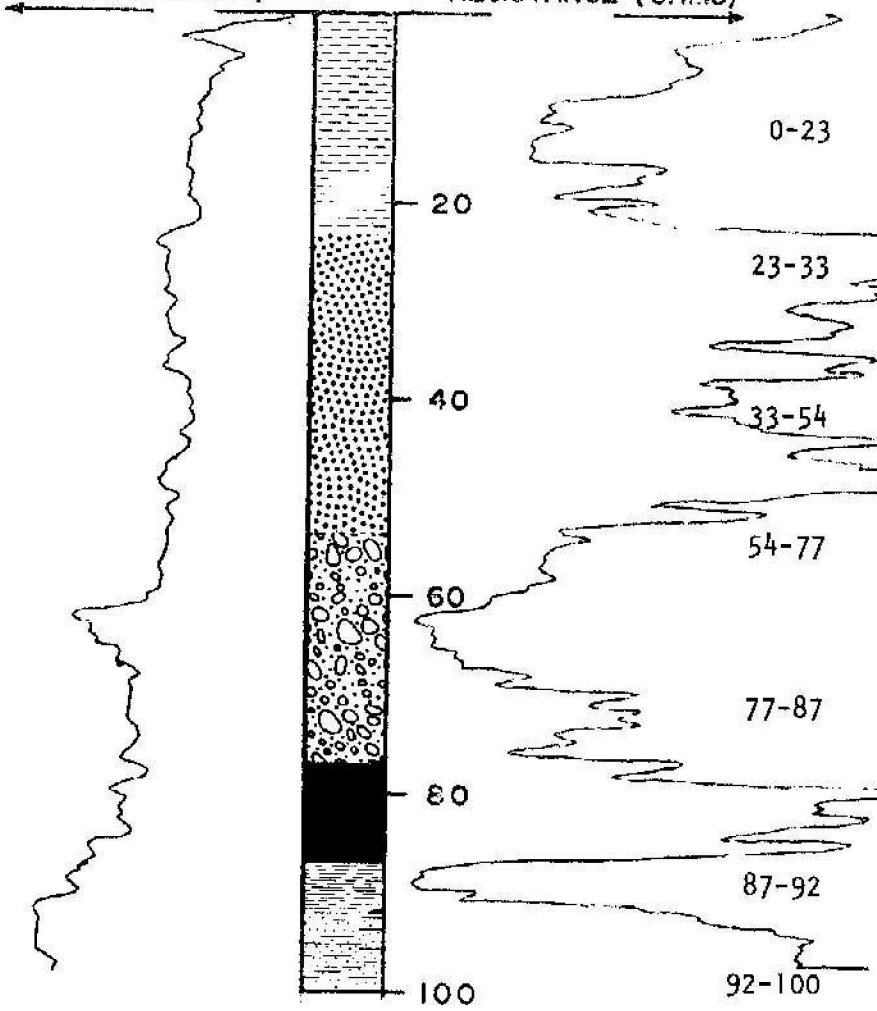
TEST HOLE 4658

LOCATION: 139-86-27bab

DATE DRILLED: 6-5-74

ELEVATION: 2040
(FT, MSL)

DEPTH: 100
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-23 Clay, silty, sandy, dusky yellow, oxidized.

23-33 Gravel, about 30% sand, fine to coarse, angular to rounded, oxidized.

33-54 Sand, about 25% gravel, fine to very coarse, subrounded, lignitic.

54-77 Clay, silty, sandy, pebbly, olive-gray (Till).

Tongue River Formation

77-87 Lignite, brownish-black to black, brittle, carbonaceous shale partings.

87-92 Shale, sandy, dark brown, carbonaceous.

92-100 Siltstone and sandstone, medium light-gray, interbedded.

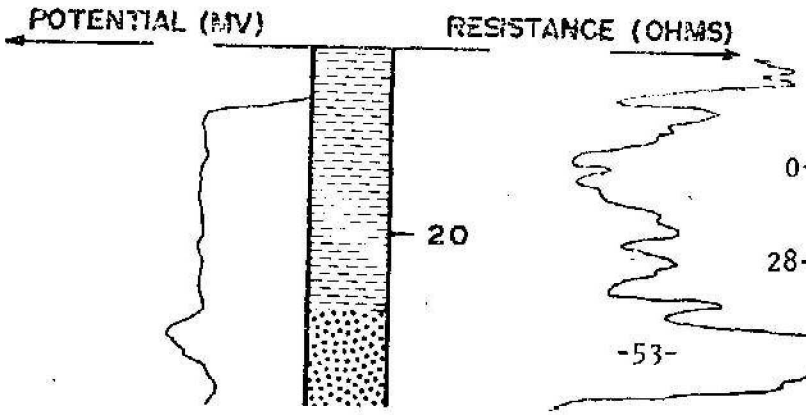
TEST HOLE 4655

LOCATION: 139-86-34acd

DATE DRILLED: 6-4-74

ELEVATION: 2030'
(FT, MSL)

DEPTH: 140'
(FT)



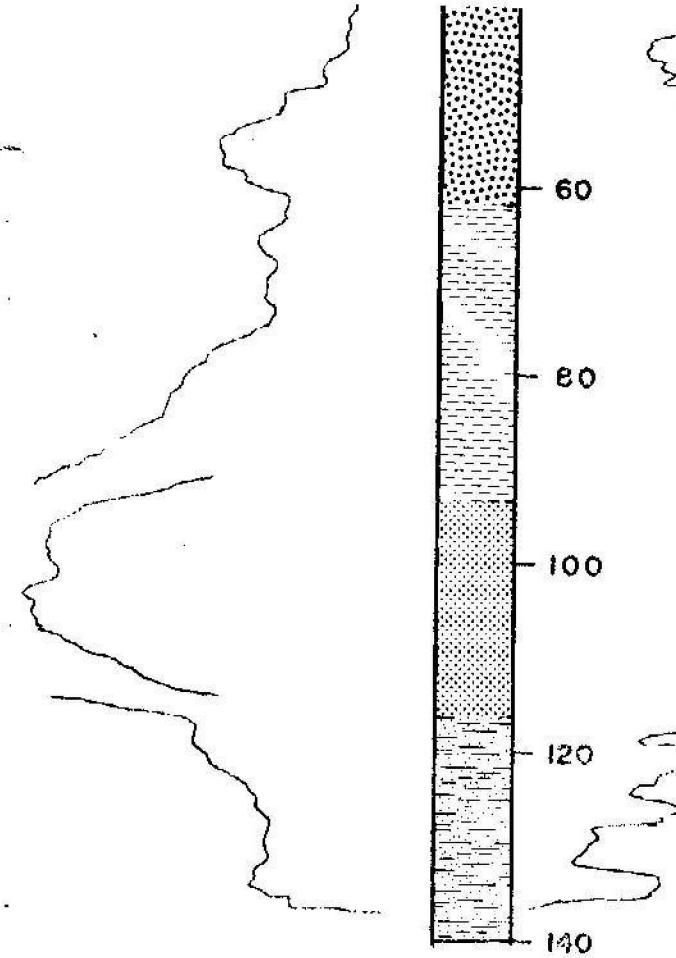
DESCRIPTION OF DEPOSITS

Glacial Drift

0-28 Clay, silty, sand, dusky-yellow, oxidized.

28-36 Gravel, sandy, some clay, fine to coarse, mostly angular, yellowish-brown to reddish-brown, well oxidized, mostly local sandstone and siltstone,

-53-



36-62 Gravel, very sandy, very clayey, fine to coarse, angular to subrounded, detrital lignite.

62-94 Clay, very silty to sandy, gravelly, few pebbles and angular lignite fragments, some reworked till.

Tongue River Formation

94-116 Sandstone, very fine to medium, subangular to subrounded, medium bluish-gray, micaceous.

116-140 Claystone, silty, brownish-gray to medium-gray, few carbonaceous shale layers.

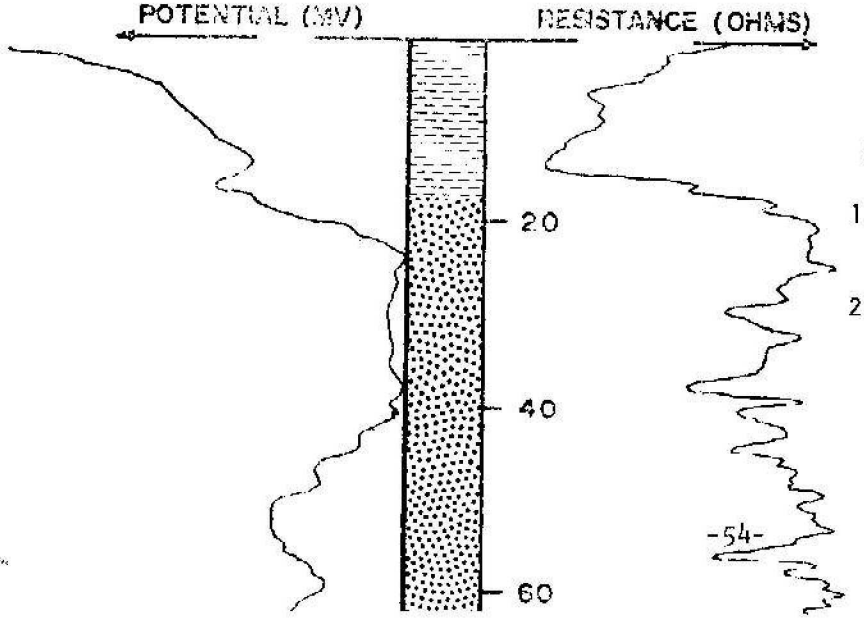
TEST HOLE 4654

LOCATION: 139-86-34adc

DATE DRILLED: 6-4-74

ELEVATION: 2010'
(FT, MSL)

DEPTH: 180'
(FT)



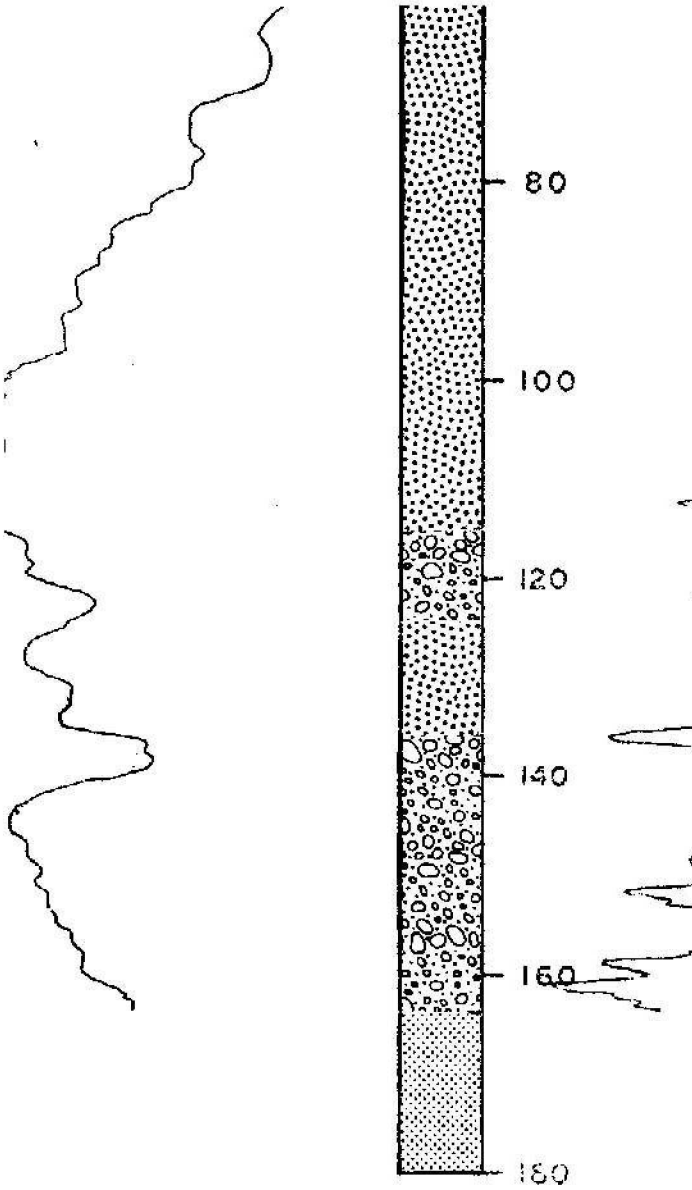
DESCRIPTION OF DEPOSITS

Glacial Drift

0-17 Clay, silty, dusky yellow, oxidized.

17-27 Gravel, about 30% sand, fine to coarse, angular to subrounded, partially oxidized.

27-97 Sand, slightly gravelly, fine to very coarse, subangular to rounded, detrital lignite, few clayey silt lenses.



97-115	Gravel, about 30% sand, fine to coarse, some cobbles, angular to rounded, about 40% brownish western silicates, 30% local sandstone, 10% shale, 20% granitic, metamorphic and carbonate rocks, some detrital lignite.
115-124	Clay, sandy, pebbly, gravelly, olive-gray, lignite fragments (till).
124-136	Gravel, sandy, medium to coarse, angular to rounded, caving in.
136-164	Clay, silty, very sandy, pebbly, olive-gray, light brownish-gray mottling, lignite and sandstone fragments (till).
	Tongue River Formation
164-180	Sandstone, clayey, medium bluish-gray, semi-consolidated, sub-angular, micaceous.

Observation Well

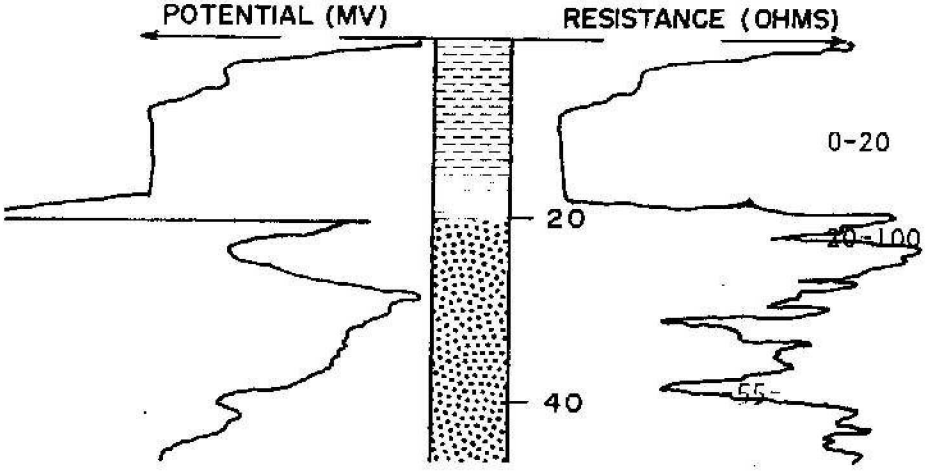
Depth: 90 feet
S. I. 87-90 feet
Water level: 25.22 feet
Measured: 6-12-74

TEST HOLE

LOCATION: 139-86-34 DAA1
(Production Well)
ELEVATION: 2007.2
(FT, MSL)

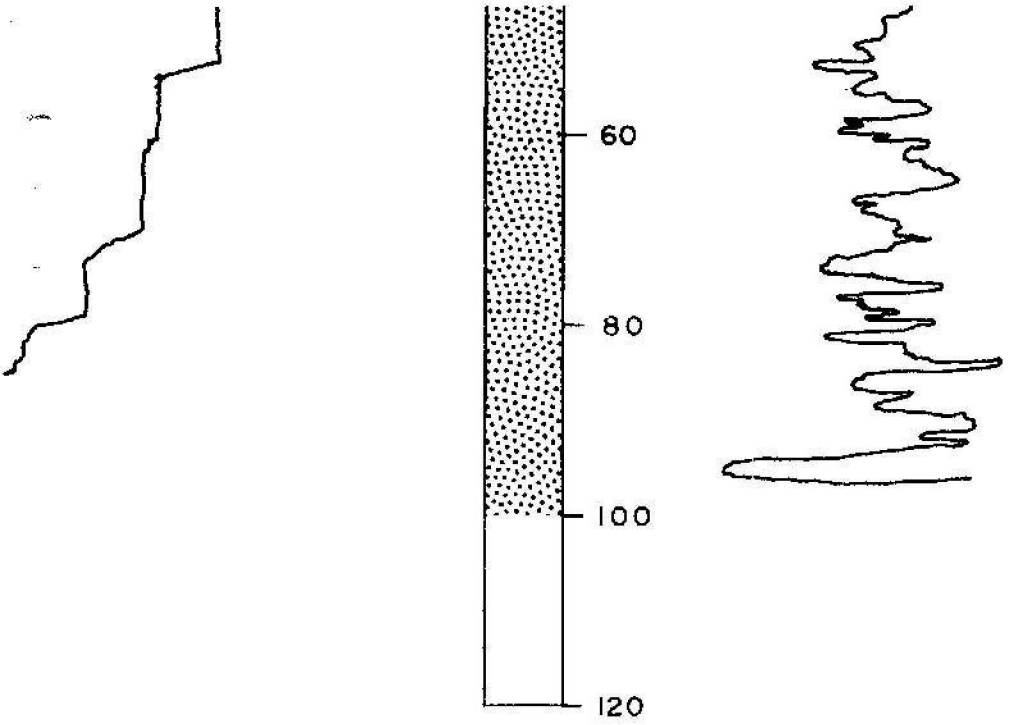
DATE DRILLED: 11-19-75

DEPTH: 100
(FT)



DESCRIPTION OF DEPOSITS

0-20	Clay, silty, dark yellow brown, soft.
20-100	Sand, fine to medium, medium dark gary, lignitic, thin clay partings.



Production Well

Depth: 90 feet
S.I.: 70-90 feet
Water Level: 23.78 feet
Measured: 5-14-76

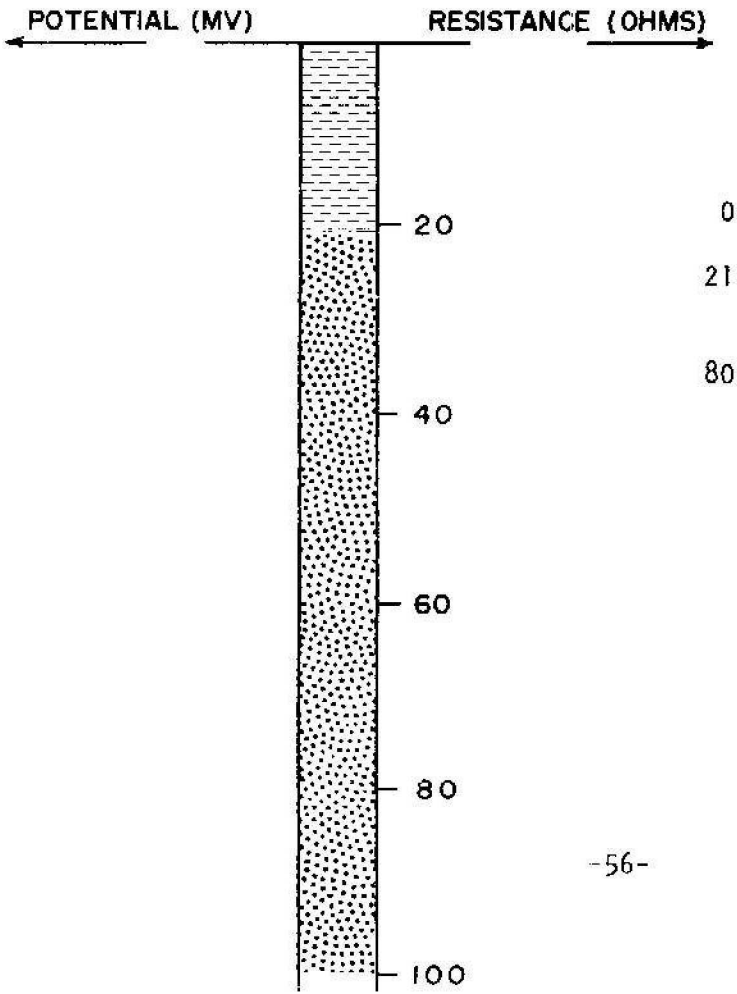
TEST HOLE 4897_A

LOCATION: $139\text{-}86\text{-}34DAA_2$

DATE DRILLED: 11-19-75

ELEVATION: 2002.65
(FT, MSL)

DEPTH: 100
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-21	Clay, silty, dark yellow brown, soft, sticky, oxidized.
21-80	Sand, fine to medium, medium dark gray, very lignitic, thin clay partings.
80-100	Gravel, fine to coarse, sandy, mostly carbonates, lignitic, clean, thinly bedded with sand.

Observation Well

Depth: 82 feet
S. I.: 79-82 feet
Water Level: 19.74 feet
Measured: 5-14-76

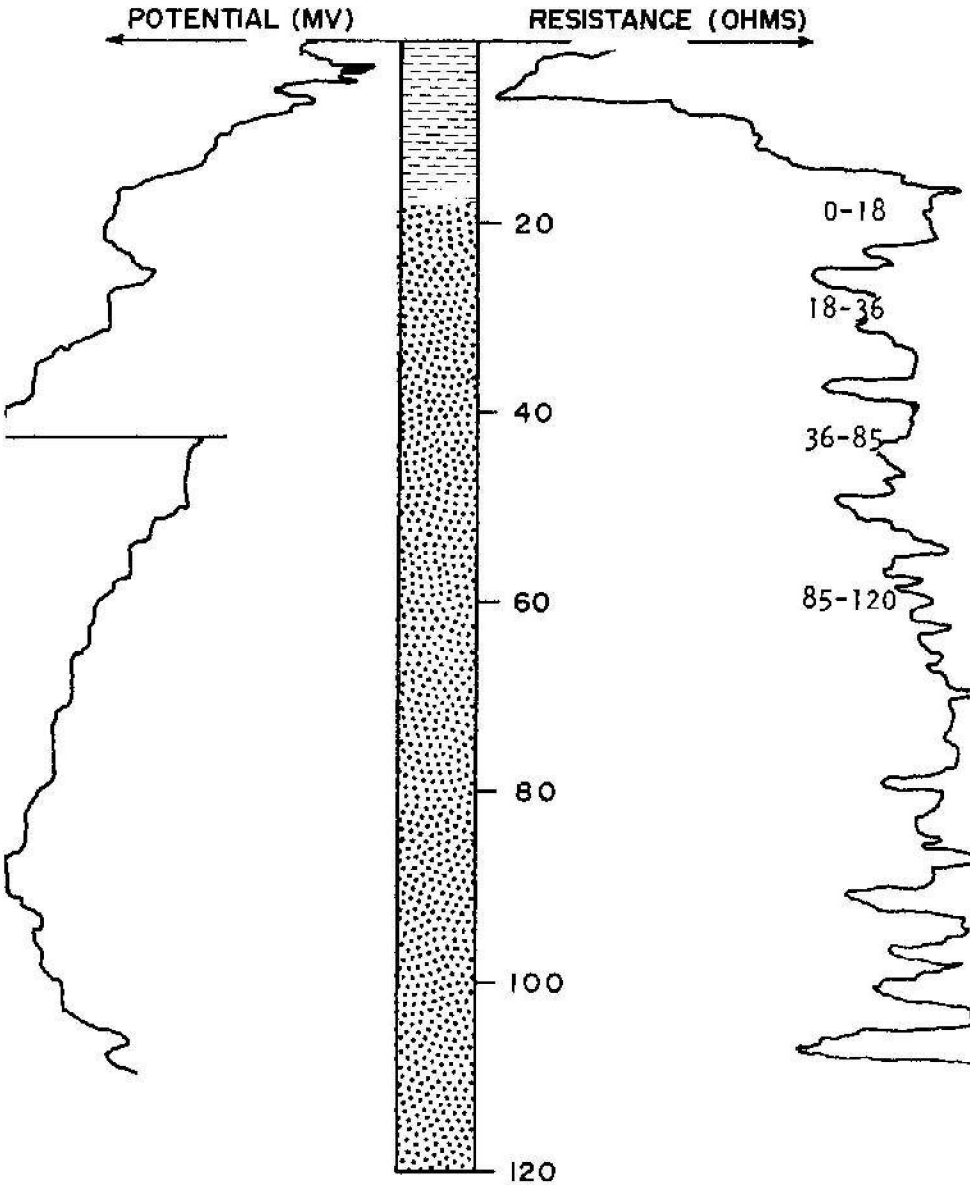
TEST HOLE 4899

LOCATION: 139-86-34DAA$_3$

DATE DRILLED: 2-26-76

ELEVATION: (FT, MSL) 2004.58

DEPTH: (FT) 120



DESCRIPTION OF DEPOSITS

Glacial Drift

0-18 Clay, sandy, silty, moderate yellowish brown, cohesive, very slightly plastic, oxidized.

18-36 Gravel, fine to coarse, angular to subrounded, predominately carbonates, some quartz and igneous poorly sorted, oxidized.

36-85 Sand, fine to coarse, subangular to rounded, medium gray, mostly quartz, some carbonates and igneous, very lignitic, clean, taking water.

85-120 Gravel, fine to coarse, angular to subrounded, predominantely carbonates, some quartz, slightly lignitic, taking water.

Observation Well

Depth: 88 feet
S. I.: 85-88 feet
Water Level: 20.96 feet
Measured: 5-14-76

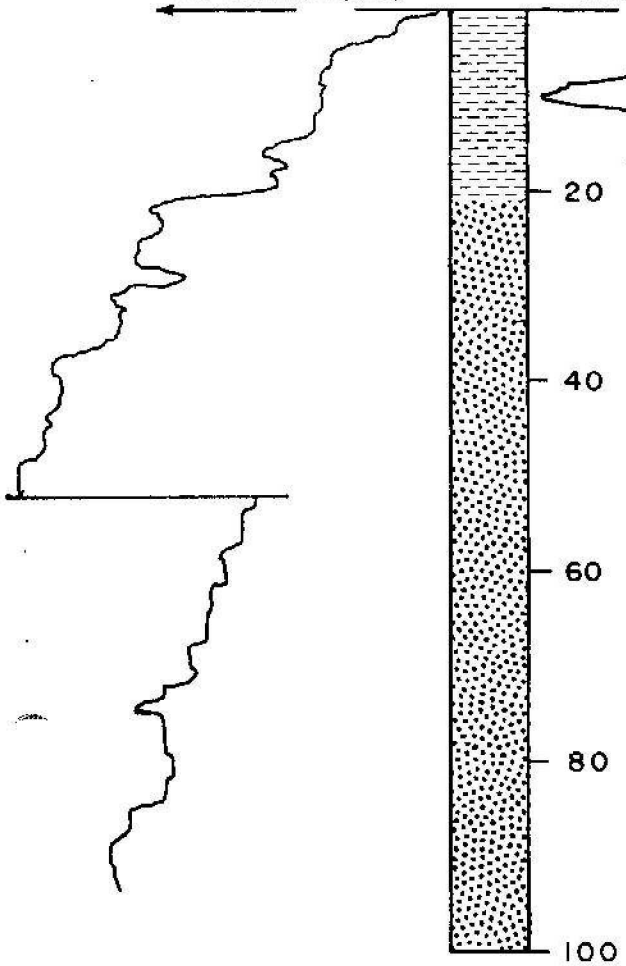
TEST HOLE 4900

LOCATION: 139-86-34DAA$_4$

DATE DRILLED: 2-27-76

ELEVATION: 2005.3 (FT, MSL)

DEPTH: 120 (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-21 Clay, silty, moderately sandy, moderately yellowish brown, soft, slightly plastic, cohesive, oxidized.

21-33 Sand (60%), gravel (40%), sand, fine to coarse, angular to rounded, mostly quartz; gravel, fine to coarse, angular to sub-rounded, mostly carbonates, lignitic, oxidized, taking water.

33-100 Sand, as above, very lignitic, clay partings, slightly gravelly, shaly, becoming more gravelly after 80 feet.

Observation Well

Depth: 95 feet
S. I.: 92-95 feet
Water Level: 22.49 feet
Measured: 5-14-76

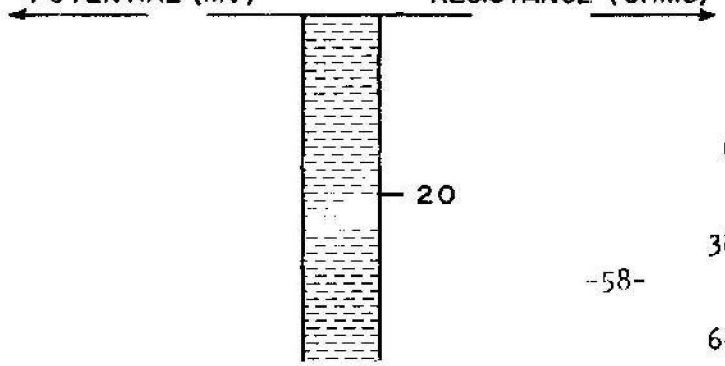
TEST HOLE 4898

LOCATION: 139-86-34DAB$_1$

DATE DRILLED: 11-19-75

ELEVATION: 2010.77 (FT, MSL)

DEPTH: 85 (FT)



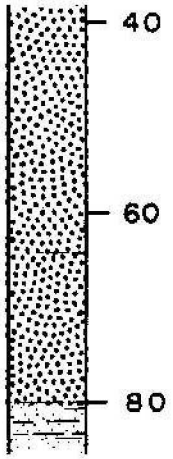
DESCRIPTION OF DEPOSITS

Glacial Drift

0-38 Clay, silty, sandy, gravelly, dark yellow brown, soft, plastic, oxidized.

38-64 Sand, fine to medium slightly gravelly, lignitic, with silt lenses.

64-80 Gravel, sandy, lignitic.



Tongue River Formation

80-85 Claystone, dark gray, plastic

Observation Well

Depth: 75 feet
S. I.: 72-75 feet
Water Level: 26.50 feet
Measured: 5-14-76

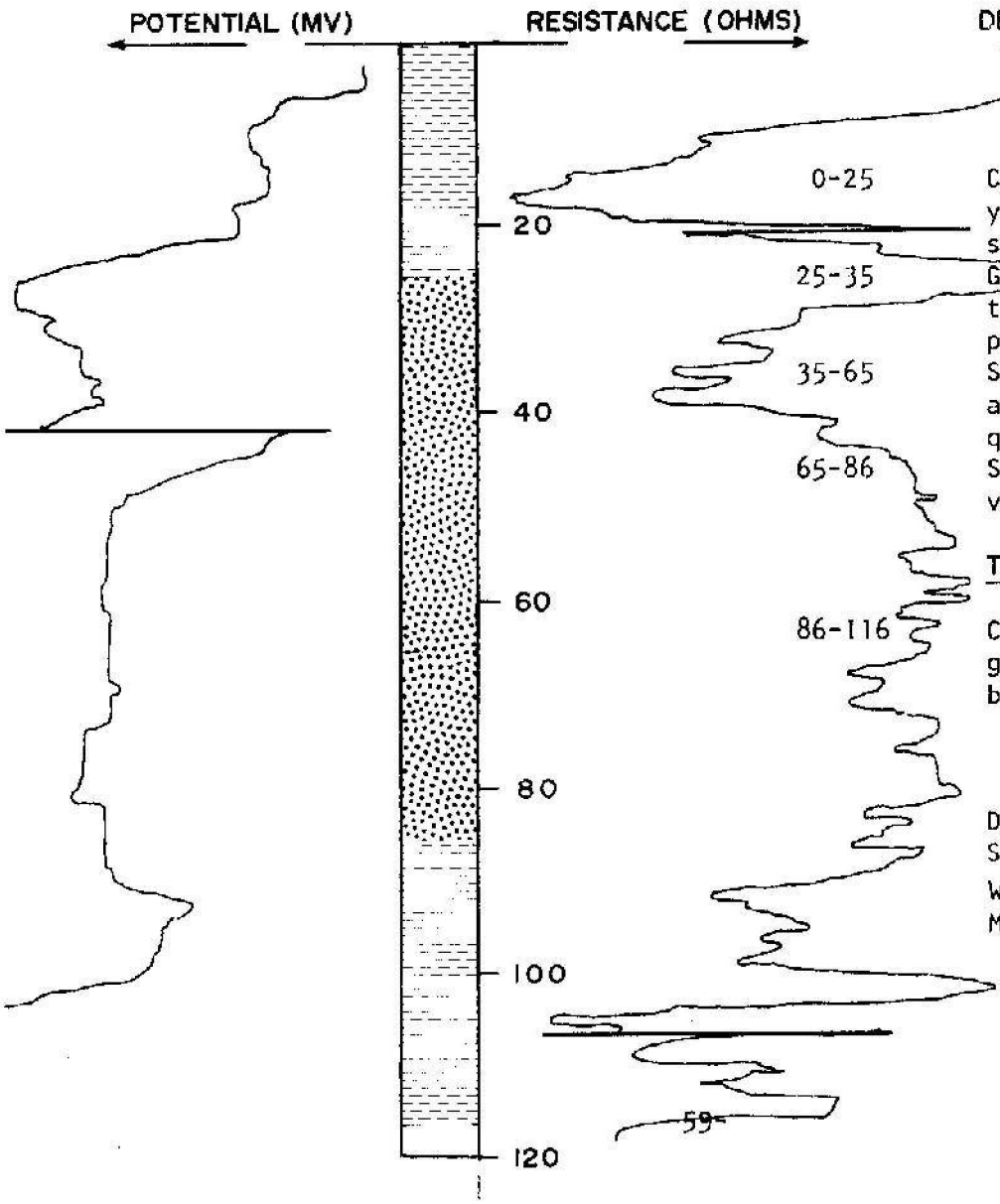
TEST HOLE 4901

LOCATION: 139-86-34DAB$_2$

DATE DRILLED: 3-8-76

ELEVATION: (FT, MSL) 2010.10

DEPTH: (FT) 116



DESCRIPTION OF DEPOSITS

Glacial Drift

0-25 Clay, very silty, sandy, moderate yellowish brown, cohesive, very slightly plastic, oxidized.

25-35 Gravel, fine to coarse, angular to subrounded, mostly carbonates, poorly sorted, oxidized.

35-65 Sand, fine to very coarse, gray, angular to subrounded, mostly quartz, 20% gravel as above,

65-86 Sand, as above, 50% gravel, very lignitic, shaly.

Tongue River Formation

86-116 Clay, sandy, silty, medium dark gray to brownish gray, tight, brittle.

Observation Well

Depth: 87 feet
S. I.: 84-87 feet
Water Level: 25.48 feet
Measured: 5-14-76

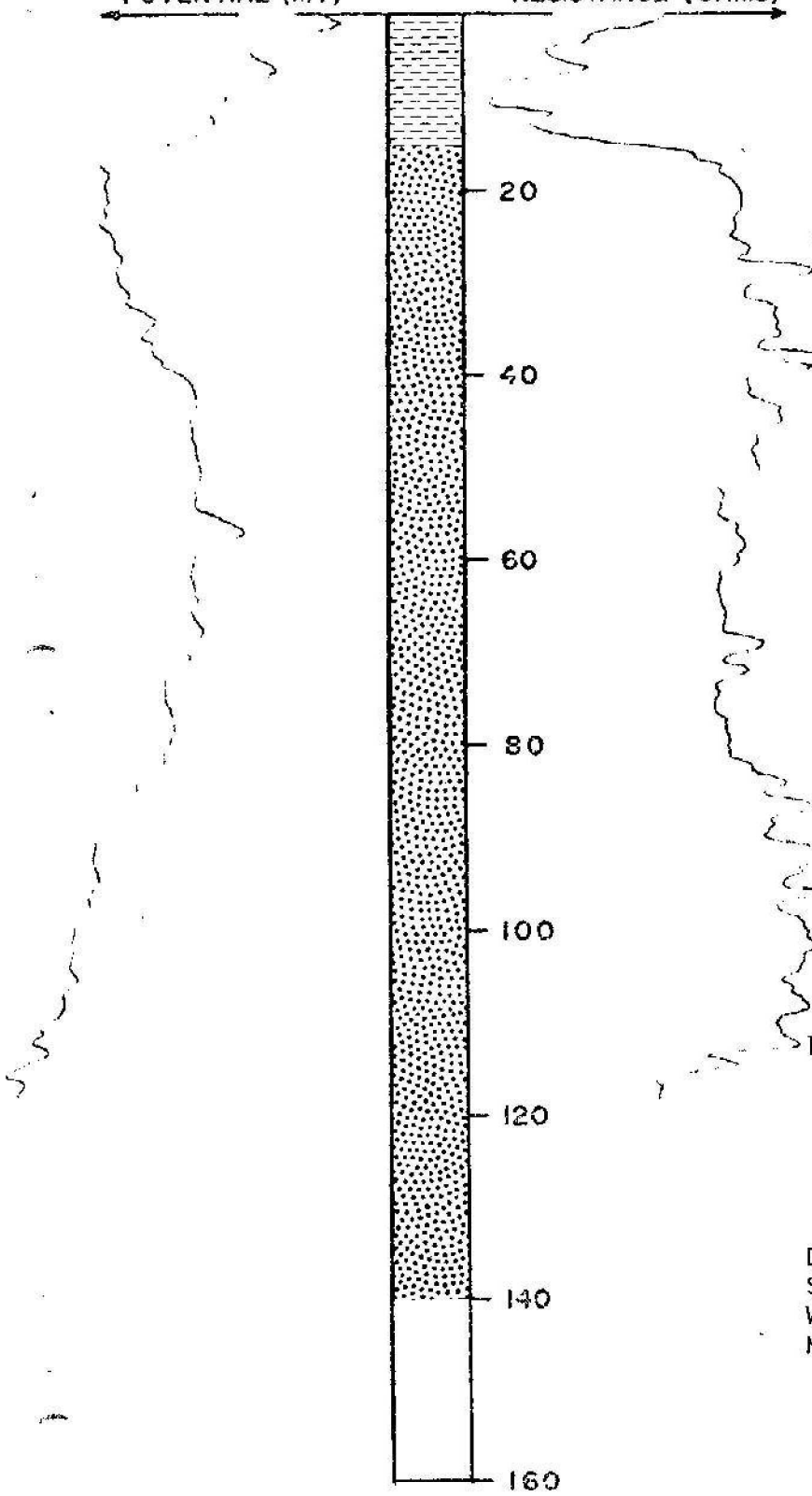
TEST HOLE 4646

LOCATION: 139-86-35 bcc

DATE DRILLED: 5-23-74

ELEVATION: 2010'
(FT, MSL)

DEPTH: 140'
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-15	Clay, silty, sandy, dark yellowish brown, oxidized.
15-25	Gravel, sandy, fine to coarse, angular to subrounded, oxidized.
25-117	Sand, few clay layers, fine to very coarse, subrounded, lignitic.
117-140	Gravel, about 30% sand, fine to coarse, angular to well-rounded, mostly brownish silicates and local sandstone and shale.

Observation Well

Depth: 63 feet
S. I. 57-63 feet
Water level: 24.88 feet
Measured: 6-12-74

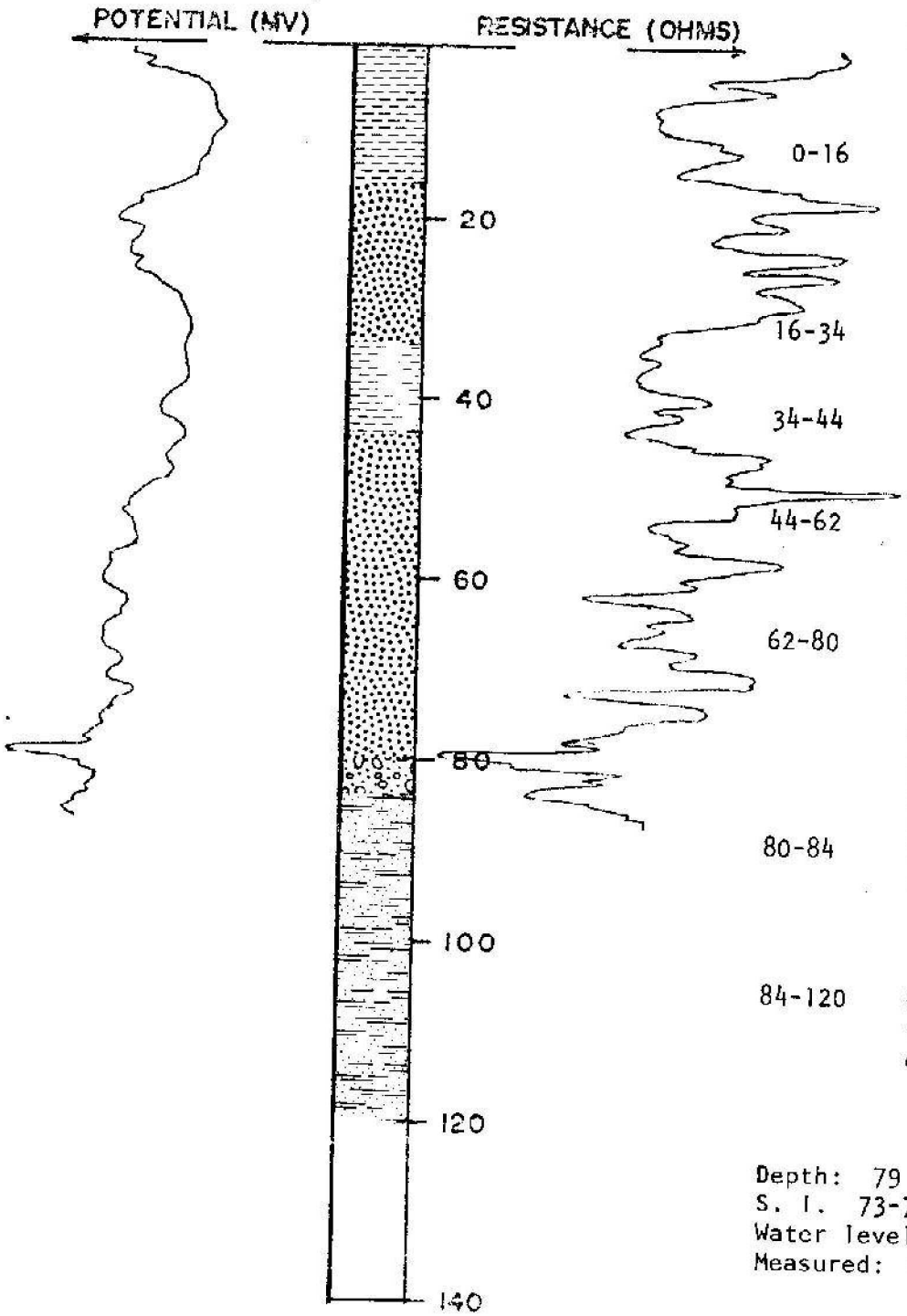
TEST HOLE 4647

LOCATION: 139-86-35bda

DATE DRILLED: 5-24-74

ELEVATION: 2015'
(FT, MSL)

DEPTH: 120'
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-16 Clay, silty, dark yellowish brown, oxidized.

16-34 Sand, gravelly, clayey, fine to coarse, angular to subrounded, oxidized.

34-44 Silt, sandy, occasional gravelly sand and clay layers, dark yellowish brown, oxidized.

44-62 Sand, about 20% gravel, fine to very coarse, subangular, dark yellowish brown staining, oxidized.

62-80 Gravel, about 20% sand, fine to coarse, angular to well-rounded, about 40% local sandstone and shale, 20% carbonates, 10% granitics and metamorphics, 30% brownish silicates, detrital lignite.

80-84 Clay, silty, pebbly, olive-gray, detrital lignite chips (till).

Tongue River Formation

84-120 Claystone, sandy, brownish-gray to medium gray, brownish-black carbonaceous shale layers.

Observation Well

Depth: 79 feet
S. I. 73-79 feet
Water level: 27.87 feet
Measured: 6-12-74

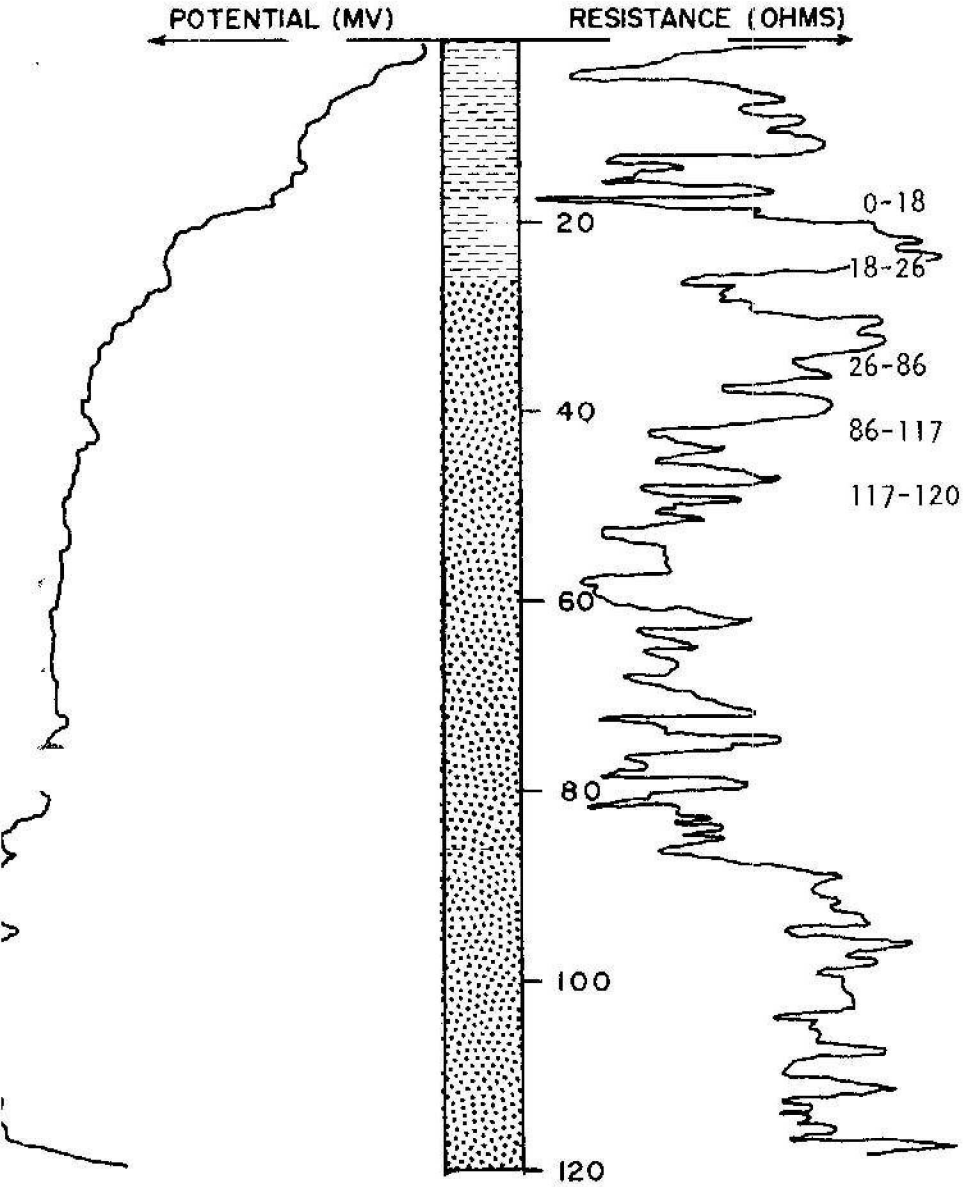
TEST HOLE 4896A

LOCATION: 139-86-35CBB$_1$

DATE DRILLED: 11-17-75

ELEVATION: 2005
(FT, MSL)

DEPTH: 120
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-18 Clay, silty, sandy, brownish-gray, cohesive oxidized.

18-26 Sand, very silty, clay stringers, dark yellow brown, iron stained, oxidized, lignitic.

26-86 Sand slightly silty, very fine to fine, lignitic, taking water.

86-117 Sand, fine to medium, cleaner than above.

117-120 Sand, as above, 20% very coarse, predominately carbonates.

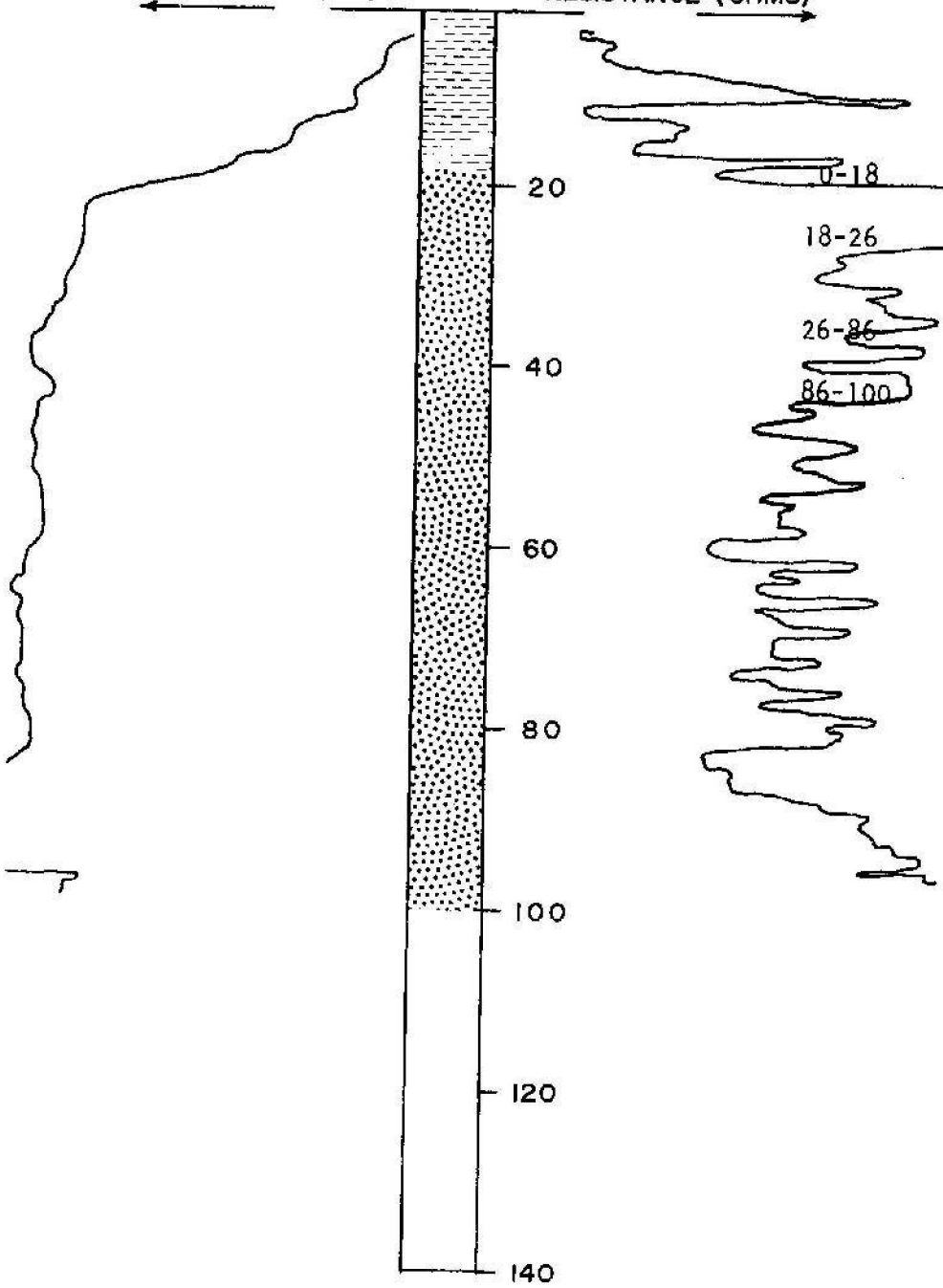
TEST HOLE 4896B

LOCATION: 139-86-35CBB$_2$

DATE DRILLED: 11-17-75

ELEVATION: 2004.93
(FT, MSL)

DEPTH: 100
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-18 Clay, Silty, sandy, brownish gray, cohesive, oxidized.

18-26 Sand, very silty, clay stringers, dark yellow brown, iron stained, oxidized, lignitic.

26-86 Sand, slightly silty, very fine to fine, lignitic, taking water.

86-100 Sand, fine to medium, cleaner than above.

Observation Well

Depth: 93 feet
S. I.: 90-93 feet
Water Level: 24.45 feet
Measured: 5-14-76

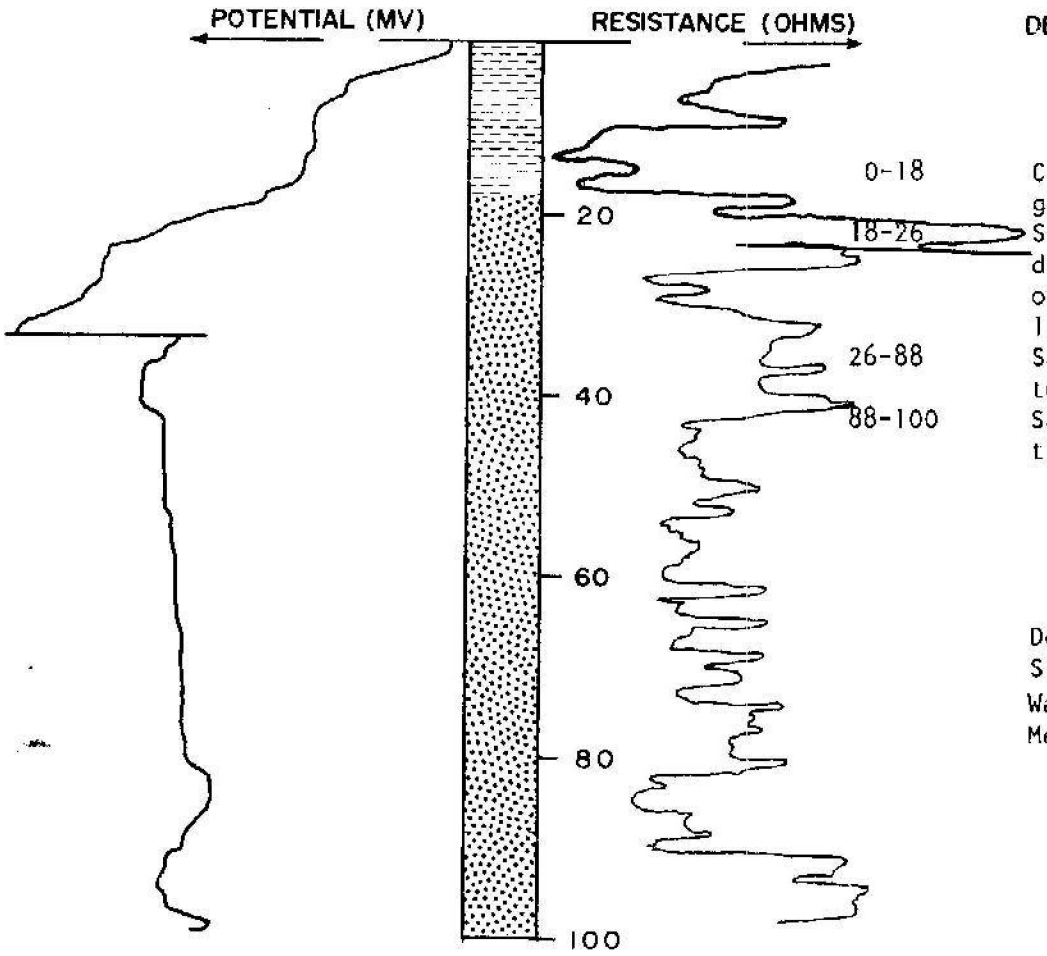
TEST HOLE 4896C

LOCATION: 139-86-35CBB3

DATE DRILLED: 11-17-75

ELEVATION: 2005.17
(FT, MSL)

DEPTH: 100
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

Clay, silty, sandy, brownish gray, cohesive, oxidized.
Sand, very silty, clay stringers, dark yellow brown, iron stained, oxidized, lignitic, few gravel lenses.
Sand, slightly silty, very fine to fine, lignitic, taking water.
Sand, fine to medium, cleaner than above.

Observation Well

Depth: 91 feet
S. I.: 88-91 feet
Water Level: 24.46 feet
Measured: 5-14-76

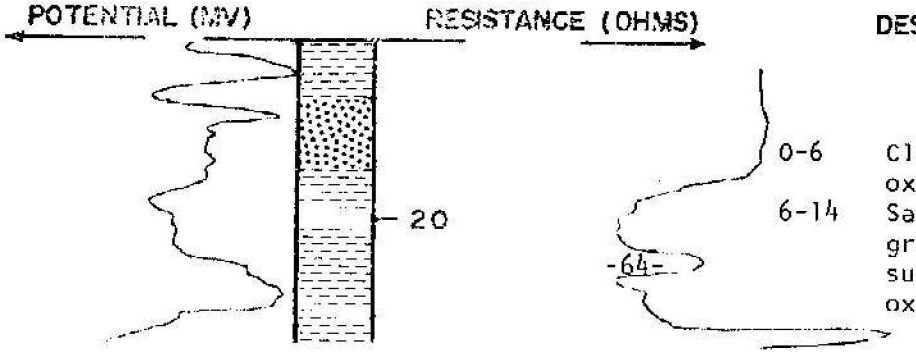
TEST HOLE 4644

LOCATION: 139-86-35cbc

DATE DRILLED: 5-23-74

ELEVATION: 2005'
(FT, MSL)

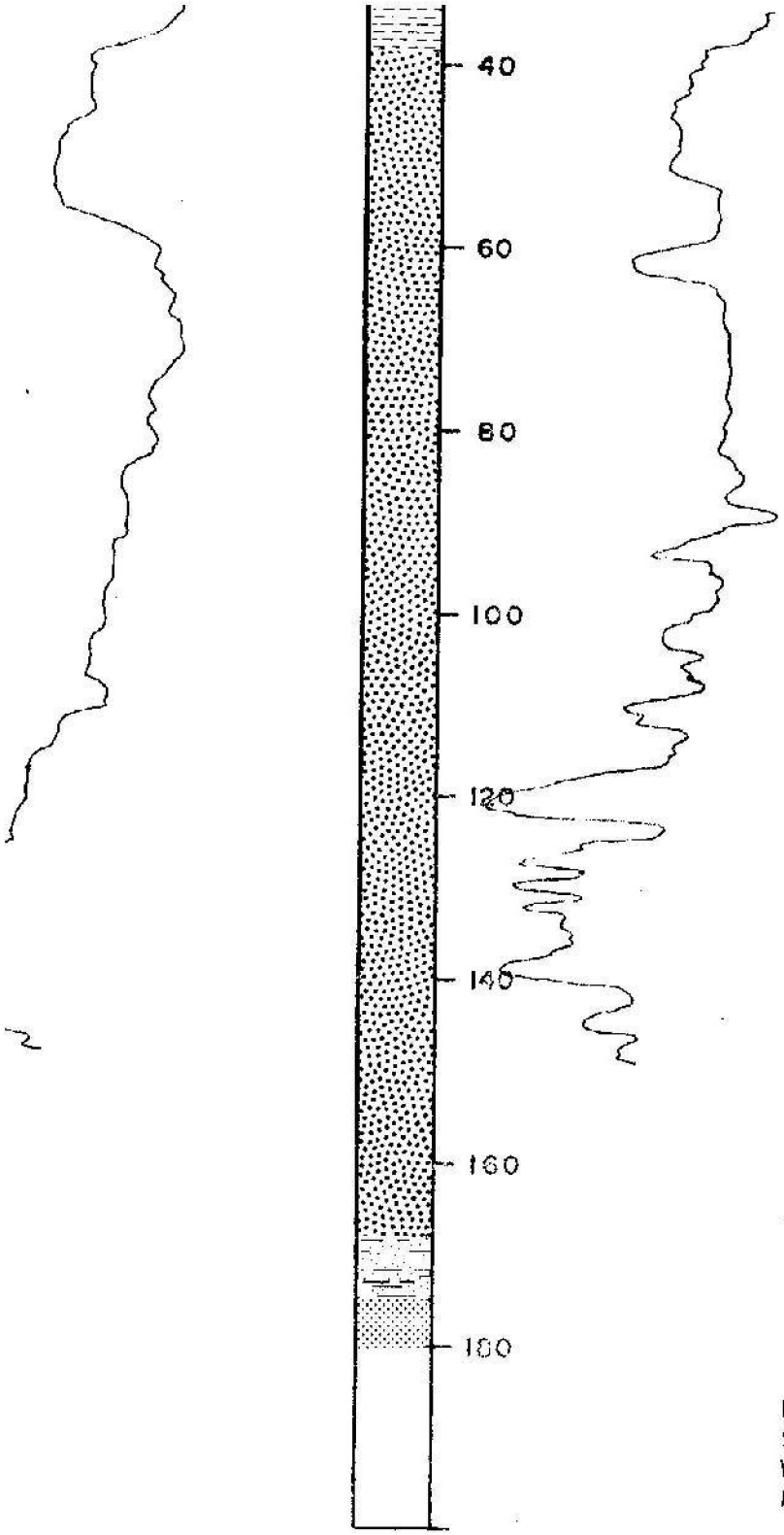
DEPTH: 180'
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

Clay, silty, yellowish-brown, oxidized.
Sand, about 40% fine to medium gravel, fine to very coarse, subangular to subrounded, oxidized.



14-38 Clay, silty, olive-gray, occasional sand layers, lignite fragments.

38-118 Sand, few clay layers, very fine to coarse, subrounded, detrital lignite.

118-140 Gravel, about 30% sand, fine to coarse, subangular to well-rounded, about 20% carbonates, 40% brownish silicates, 30% local sandstone and shale, 10% granitic, some detrital lignite.

140-168 Cobbles, boulders, gravel, clay, mostly brownish silicates and local sandstone and shale, some granitics, detrital lignite.

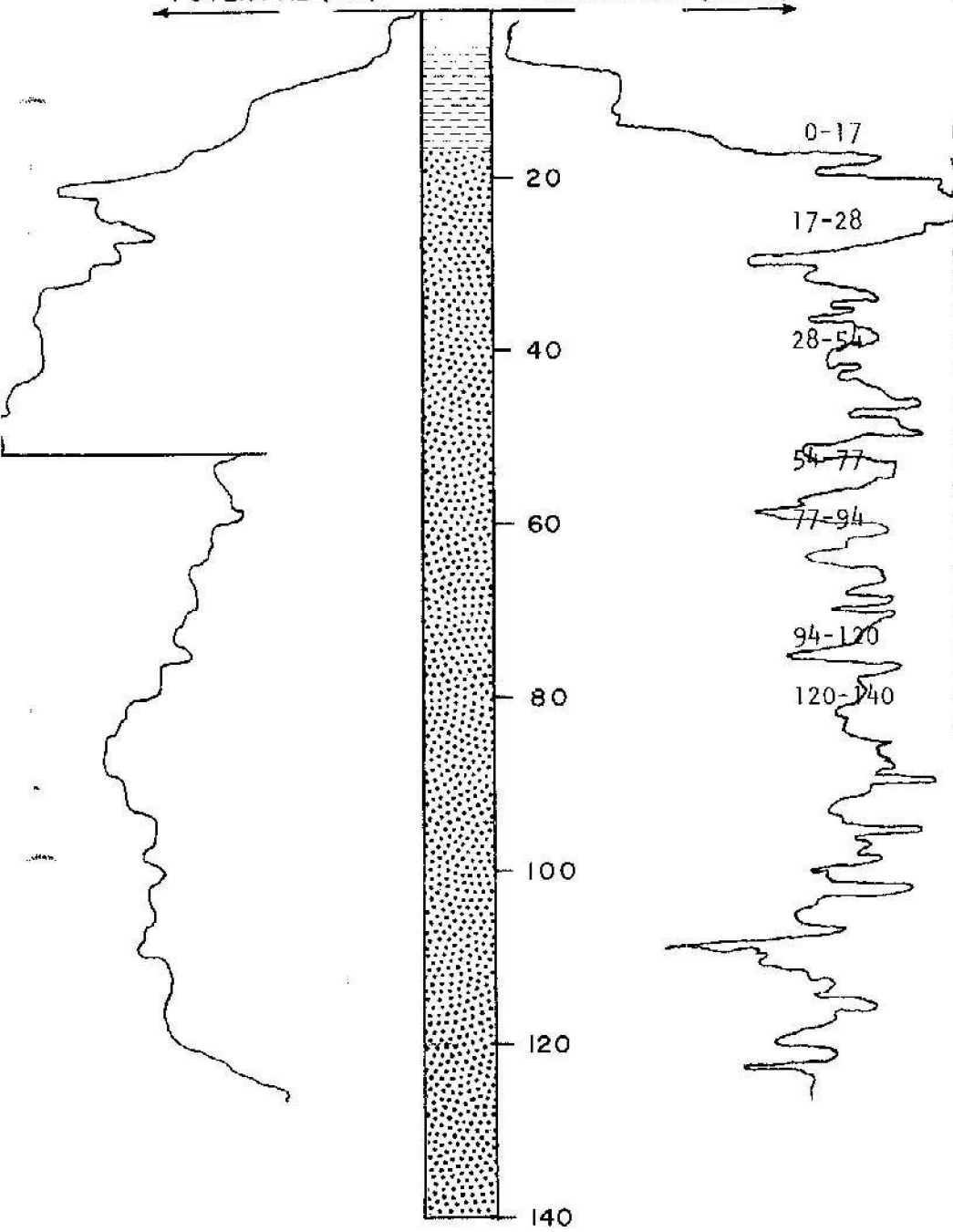
Tongue River Formation

168-175 Claystone, silty, greenish-gray, brown concretions.

175-180 Sandstone, clayey, bluish-gray, fine-grained, subangular, consolidated, friable.

Observation Well

Depth: 103 feet
S.I. 97-103 feet
Water level: 21.68 feet
Measured: 6-12-74



DESCRIPTION OF DEPOSITS

Glacial Drift

0-17	Clay, silty, dark olive gray, with yellow brown streaks, oxidized, plastic.
17-28	Sand, gravelly, fine to coarse, dark yellow brown, with red brown iron stains, angular to rounded, poorly sorted, oxidized.
28-54	Sand, very slightly gravelly, fine to medium, dark gray, fair sorting, lignitic, few clay partings.
54-77	Sand, as above, predominately medium to coarse.
77-94	Sand, as above, detrital lignite increasing, becoming coarser, interbedded with fine carbonate gravel.
94-120	Gravel, fine to coarse, sandy, lignitic.
120-140	Gravel, coarse to very coarse, with thin dark gray clay partings.

Observation Well

Depth: 110 feet
S. I.: 107-110 feet

Water Level: 21.57 feet
Measured: 5-14-76

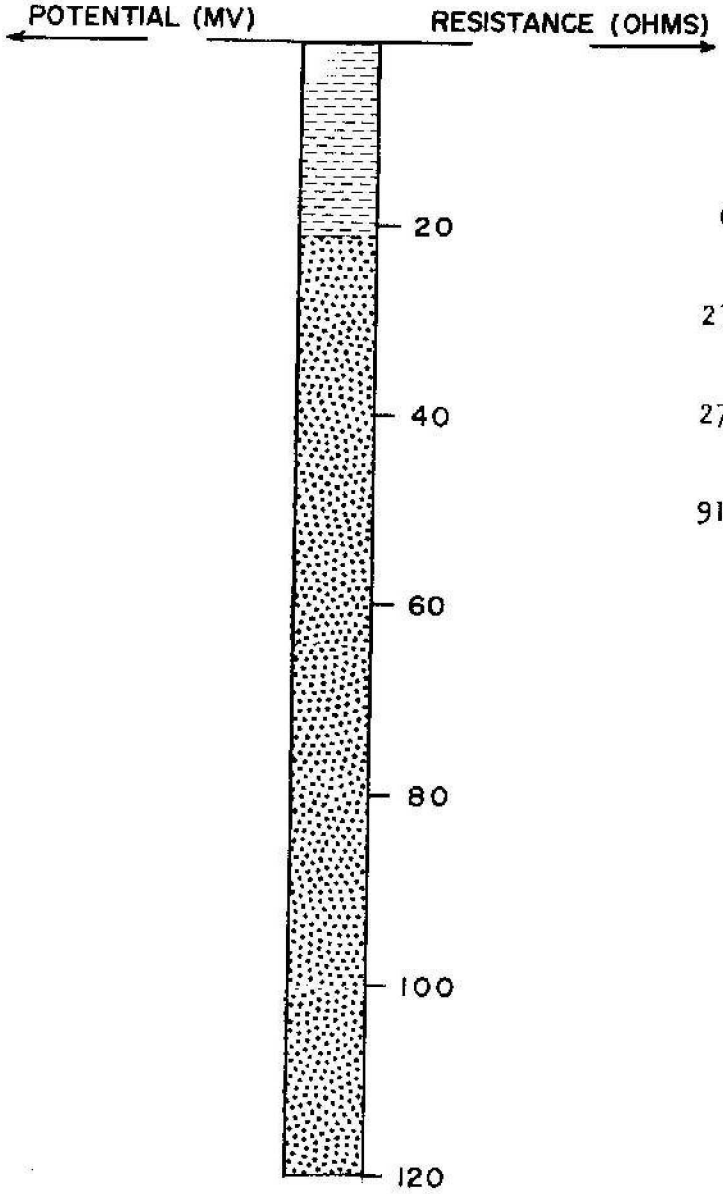
TEST HOLE 4903_B

LOCATION: $139\text{-}86\text{-}35CBC_3$

DATE DRILLED: 5-13-76

ELEVATION: 1999
(FT, MSL)

DEPTH: 120
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-21	Clay, silty, medium brown with pale yellow stringers, cohesive, moderately plastic.
21-27	Gravel, sandy, angular to rounded 90% shale and carbonates, 10% silicates.
27-91	Sand, fine to medium predominately fine, lignitic, after 35 feet becomes coarser.
91-120	Sand, as above, gravelly, 90% shale and carbonates, 10% silicates very lignitic.

Observation Well

Depth: 103 feet
S. I.: 100-103 feet

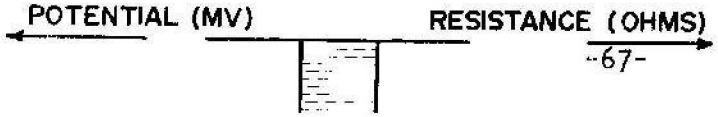
TEST HOLE 4903C

LOCATION: $139\text{-}86\text{-}35CBC_4$

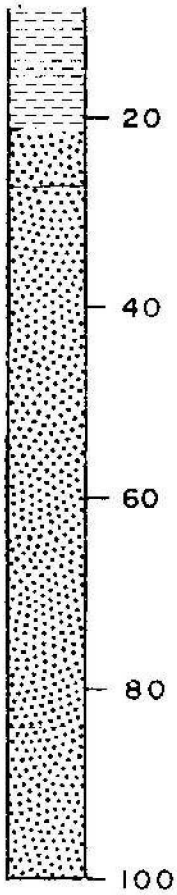
DATE DRILLED: 5-13-76

ELEVATION: 1999
(FT, MSL)

DEPTH: 100
(FT)



DESCRIPTION OF DEPOSITS



Glacial Drift

0-21	Clay, silty, medium brown with pale yellow stringers, cohesive, moderately plastic.
21-27	Gravel, sandy, fine to coarse, angular to rounded, 90% shale and carbonates, 10% silicates.
27-84	Sand, fine to medium, predominately fine, well sorted, lignitic.
84-100	Sand, as above, becoming gravelly.

Observation Well

Depth: 90 feet
S. I.: 87-90 feet

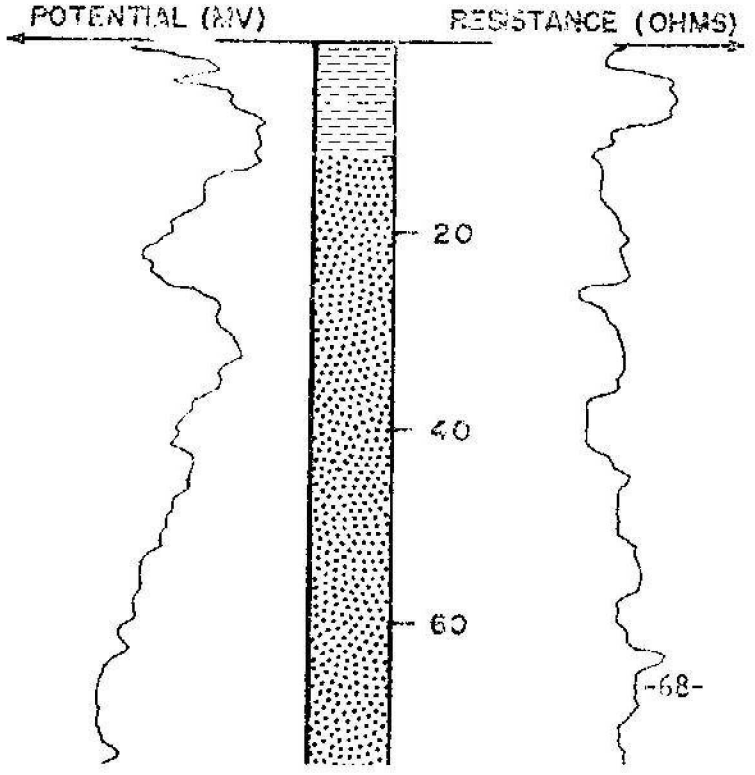
TEST HOLE 4645

LOCATION: 139-86-35ccc

DATE DRILLED: 5-23-74

ELEVATION: 1995'
(FT, MSL)

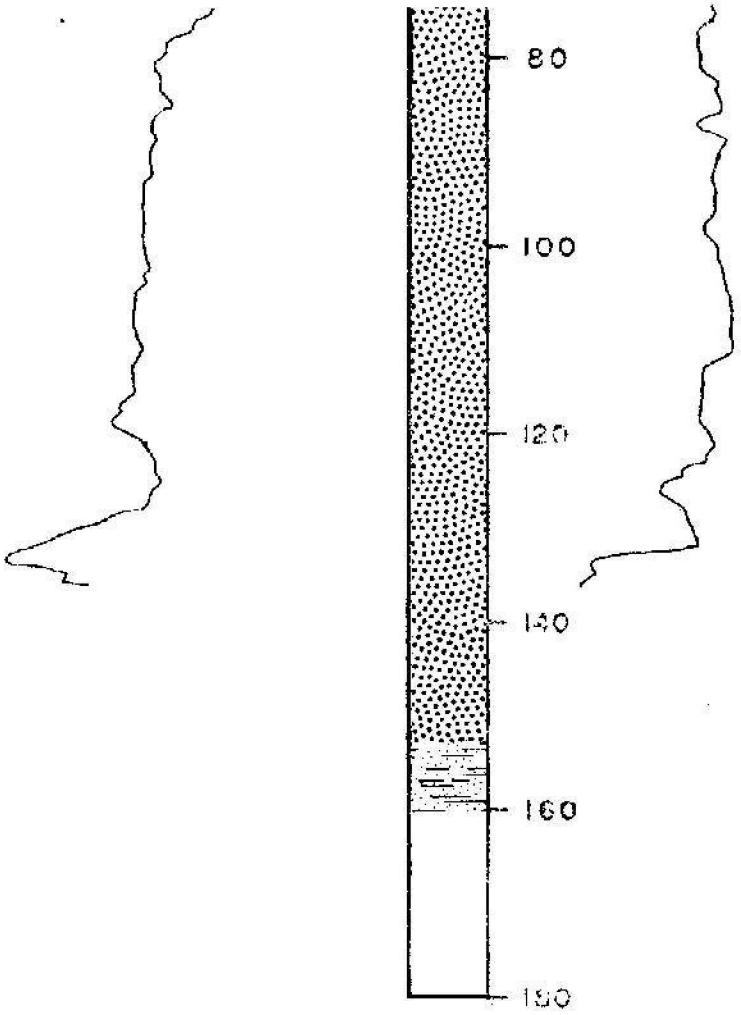
DEPTH: 160'
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-12	Clay, silty, sandy, yellowish-brown, oxidized.
12-25	Gravel, about 40% sand, fine to coarse, subangular, oxidized, reddish-brown staining.
25-128	Sand, fine to coarse-grained, subangular to rounded, lignitic, thin clay layers.



128-153 Gravel, about 30% sand, fine to coarse, subangular to rounded, 30% brownish silicates, 20% carbonates, 30% local sandstone and shale, 20% granitics and metamorphics.

Tongue River Formation

153-160 Claystone, silty, medium to greenish-gray, bentonitic.

Observation Well

Depth: 133 feet
S.I. 127-133 feet
Water level: 18.86 feet
Measured: 6-12-74

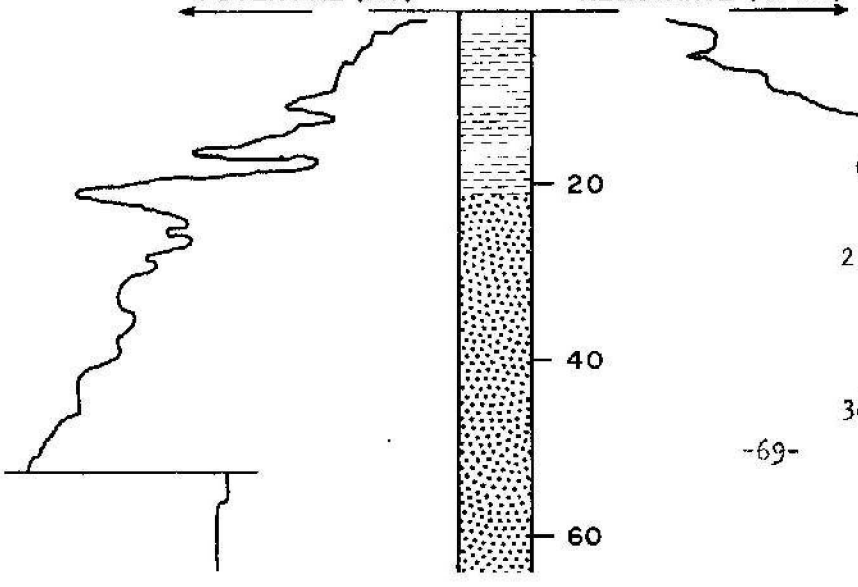
TEST HOLE 4902

LOCATION: 139-86-35CCC$_2$

DATE DRILLED: 3-8-76

ELEVATION: 1997.43 (FT, MSL)

DEPTH: 140 (FT)



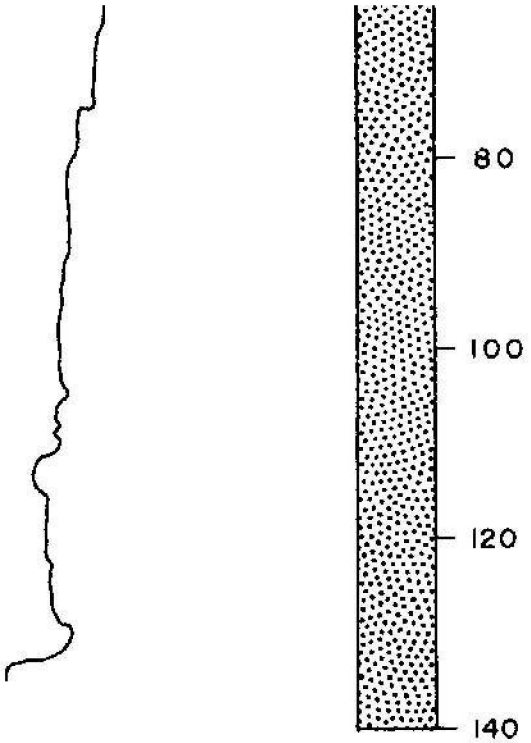
DESCRIPTION OF DEPOSITS

Glacial Drift

0-21 Clay, silty, slightly sandy, moderate yellowish brown, cohesive oxidized.

21-38 Gravel, fine to coarse, angular to subrounded, predominately carbonates and shale, some quartz, about 30 % fine to coarse sand, oxidized to about 26 feet.

38-85 Sand, very fine to coarse, subangular to rounded, predominately quartz, some carbonates, very lignitic, moderate to well sorted, taking water.



85-133 Sand, as above, 30-40% gravel, fine to medium, predominately carbonates and shale, very lignitic.

133-140 Gravel, fine to coarse, angular to subrounded, predominately carbonates and shale, very lignitic.

Observation Well

Depth: 121 feet
S. I.: 118-121 feet
Water Level: 20.20 feet
Measured: 5-14-76

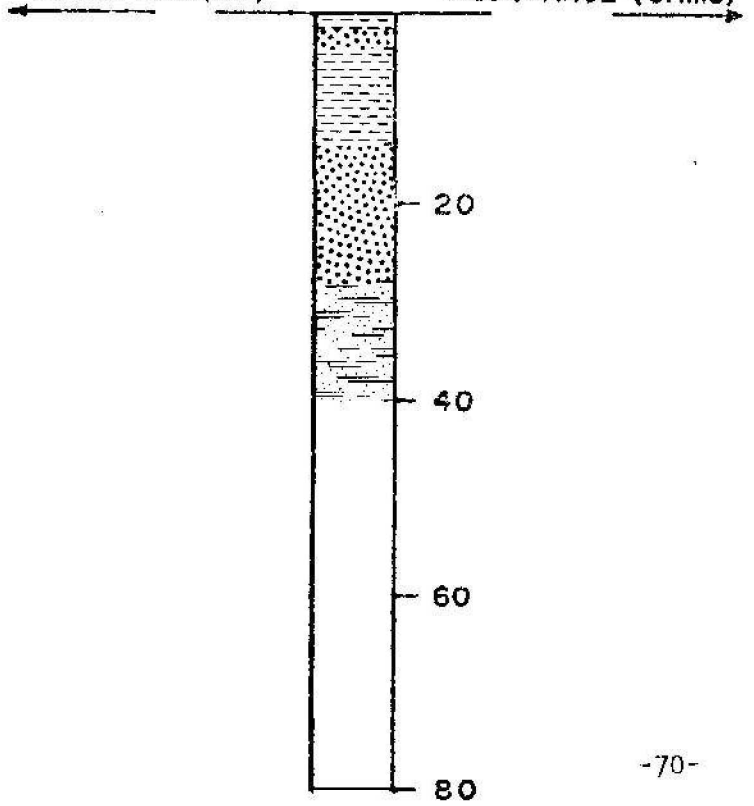
TEST HOLE 4640

LOCATION: 140-85-25bbc

DATE DRILLED: 5-22-74

ELEVATION: 2012' (FT, MSL)

DEPTH: 40' (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-2 Clay, very silty, light-brownish-gray, cohesive, oxidized.

2-4 Sand, gravelly, fine to very coarse, angular, oxidized.

4-10 Clay, silty, yellowish-brown, oxidized.

10-14 Clay (as above) only olive-gray.

14-19 Gravel, about 40% sand, fine to coarse, angular to subrounded, mostly local bedrock material, some granitic and carbonate rocks, slightly oxidized.

19-28 Gravel, sandy, fine to coarse, caving, mostly local sandstone, some granitic, metamorphic and carbonate rocks.

Tongue River Formation

28-40 Siltstone, clayey, light to medium-gray, highly calcareous.

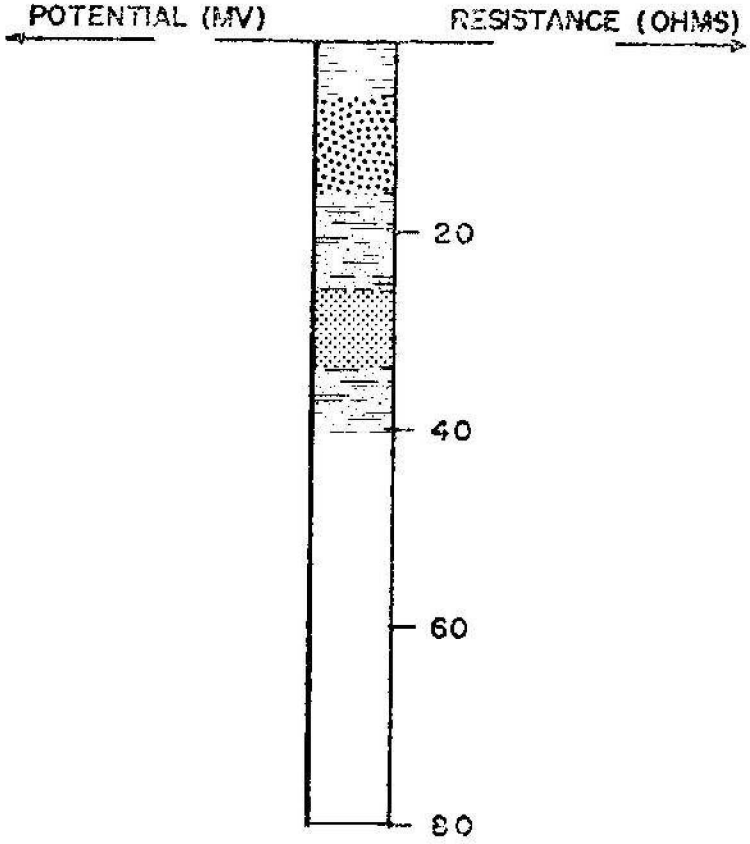
TEST HOLE 4639

LOCATION: 140-85-25bcb

DATE DRILLED: 5-22-74

ELEVATION: 2010'
(FT, MSL)

DEPTH: 40'
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-6	Clay, very silty, light brownish-gray, oxidized.
6-14	Sand, gravelly, fine to very coarse-grained, angular, brown, oxidized.
14-16	Gravel, fine to medium, angular to subrounded, brown, oxidized.

Tongue River Formation

16-26	Claystone, silty, medium gray, lignite stringers, calcareous.
26-34	Sandstone, medium light-gray, very fine to fine, lignitic, micaceous.
34-40	Siltstone, light-gray, moderately indurated, highly calcareous.

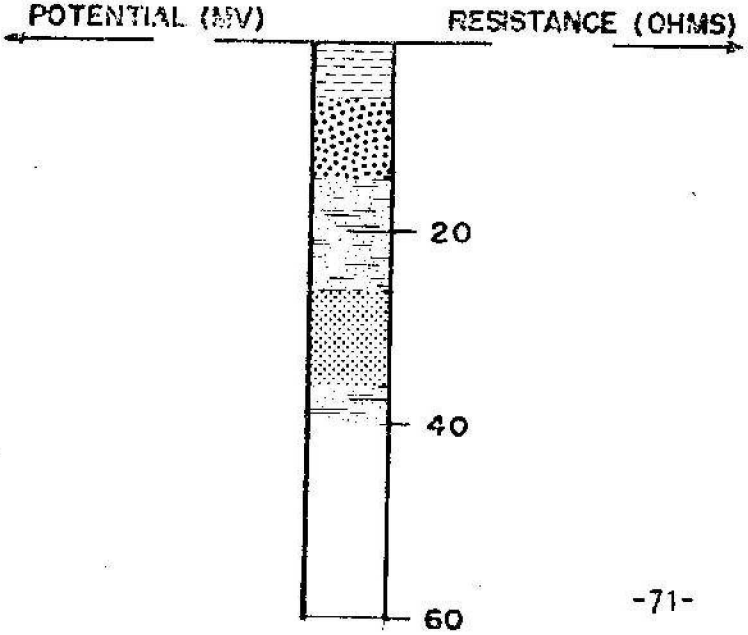
TEST HOLE 4638

LOCATION: 140-85-25bcc

DATE DRILLED: 5-22-74

ELEVATION: 2005'
(FT, MSL)

DEPTH: 40'
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-6	Clay, silty, light brownish-gray.
6-14	Sand, gravelly, fine to very coarse, subangular, oxidized, lignitic, clay stringers.

Tongue River Formation

14-26	Claystone, brownish-gray to medium-gray, thin lignite stringers.
26-36	Sandstone, silty, very fine-grained, semi-consolidated, light-gray, highly calcareous.
36-40	Siltstone, sandy, medium light-gray, highly calcareous.

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