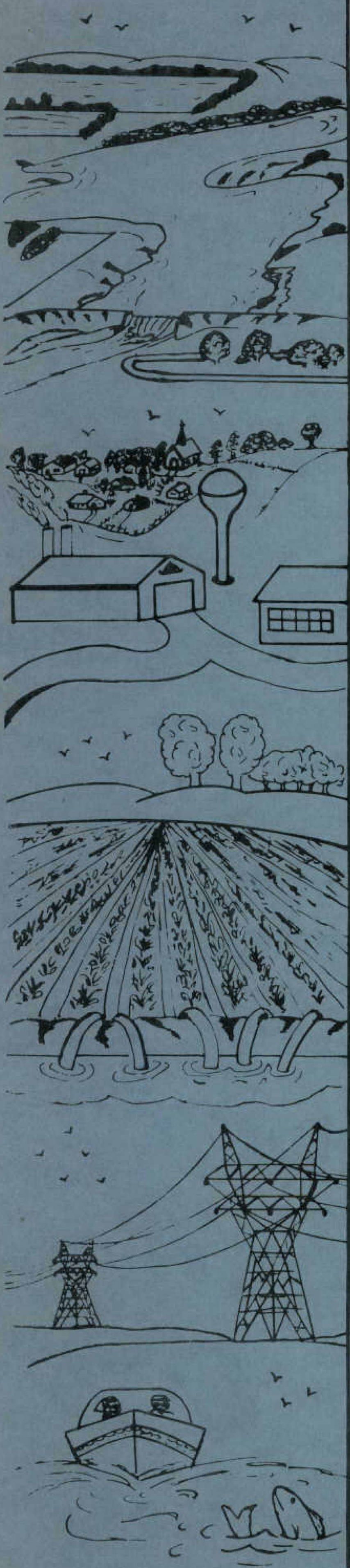
GROUND WATER IN THE ELLENDALE AREA
DICKEY COUNTY, NORTH DAKOTA
N.D.S.W.C.C. PROJECT NO. 750



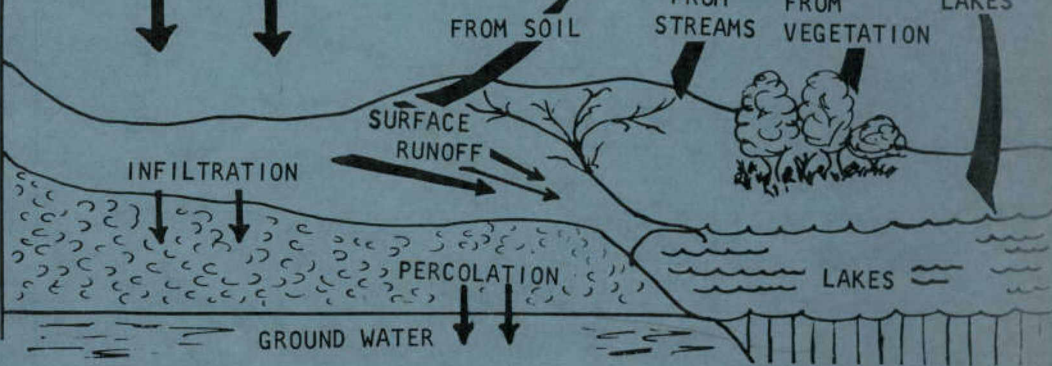
NORTH DAKOTA GROUND-WATER STUDIES
NO. 61

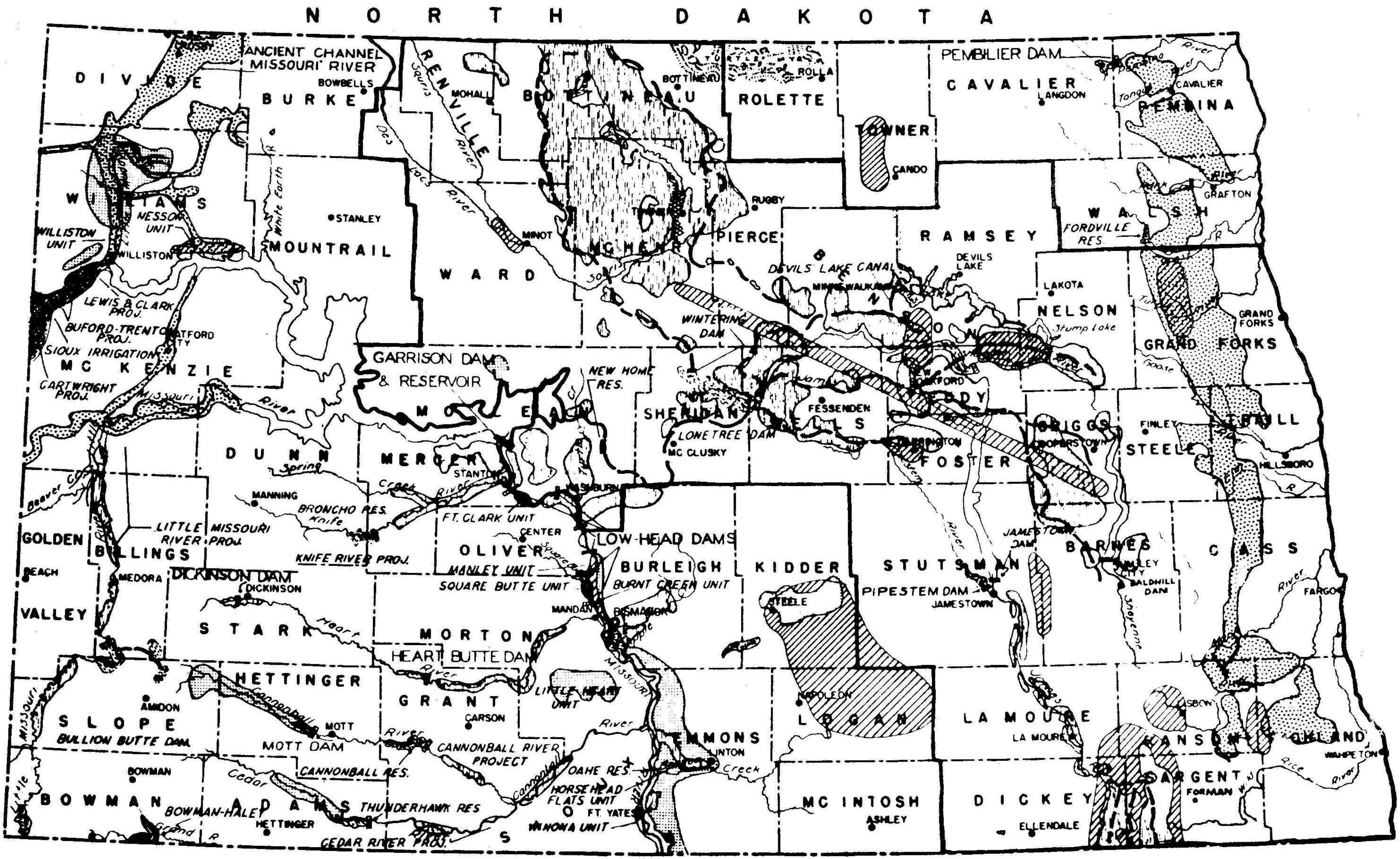
By
Milton O. Lindvig
Ground-water Engineer

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

1965

HYDROLOGIC CYCLE





NORTH DAKOTA STATE WATER CONSERVATION COMMISSION

WATER RESOURCES DEVELOPMENT PLAN

LANDS UNDER IRRIGATION
AREAS CONSIDERED IRRIGABLE
AREAS BEING INVESTIGATED
PROPOSED FOR INVESTIGATION

DAM & RESERVOIR SITES: EXISTING; UNDER CONSTRUCTION OR PROPOSED

PROPOSED CANALS

GARRISON DIVERSION CONSERVANCY DISTRICT BOUNDARY

GROUNDWATER AQUIFERS

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SWC Project No. 750

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GROUND WATER IN THE ELLENDALE AREA
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INTRODUCTION

Purpose and Scope

At the request of the Ellendale City Council the North Dakota State Water Commission in cooperation with the U. S. Geological Survey conducted a ground-water survey in the Ellendale area. The purpose of this survey was to determine the availability and quality of ground water for a municipal supply.

The test drilling for the initial investigation was done in July 1957 by Mr. George McMasters operating a state-owned Failing 1500 rotary drill rig. He also wrote a brief sample description for each test hole. On September 23-25, 1957 personnel of the U. S. Geological Survey conducted an aquifer test on a well located at or very near the present site of city well 1.

In May 1964 the North Dakota State Water Commission entered into an agreement with the City of Ellendale to supplement the previous work by further investigation of the area. This work consisted of 955 feet of test drilling, installation of one observation well and the collection of water samples for chemical analysis. The costs of this investigation were shared equally by the City of Ellendale and the North Dakota State Water Commission.

The 1964 test drilling was done by Peckham, Inc. of Oakes, North Dakota and the sample descriptions were written by the author. The North Dakota State Laboratories of Bismarck performed the chemical analysis of the water samples.

Special thanks are owed to Mr. Earl H. Redlin, Mayor of Ellendale, and Mr. Art Schlenker, City Water Plant Manager, for their assistance during the supplemental investigation.

Location and General Features

The Ellendale area as described in this report is located in south-central Dickey County. It is included in the Central Lowland Physiographic Province as shown in figure 1. The area is characterized by a very low relief sag-and-swell topography with a deranged drainage pattern.

The City of Ellendale, population 1800 (1960 census), is approximately in the center of the 20 square mile study area. It is located on U. S. Highway 281 and is served by Great Northern Railroad and the Chicago, Milwaukee, St. Paul and Pacific Railroad. Based on a 65 year record U. S. Weather Bureau Annual Summary of Climatological Data For 1963 shows that at Ellendale the mean annual temperature is 42.6°F and the average annual precipitation is 19.11 inches (U. S. Department of Commerce, 1964).

Ellendale is principally an agricultural community. The primary occupation in the area is dryland farming supplemented by the raising of livestock. The main crops are small grains and forage for livestock. A State Teachers College is also located here.

Previous Investigations

Simpson (1929, p. 115-116) briefly discusses the Ellendale area in his report entitled Geology and Ground-Water Resources of North Dakota. Abbott and Voedisch (1938, p. 54-55), in their study of municipal ground-water supplies in North Dakota, include a chemical analysis of a water sample collected from a well in Ellendale completed in an aquifer of the Dakota Group. The North Dakota State Department of Health include three chemical analyses of water from city wells 1 and 2 and the treated water in Chemical Analyses of Municipal Waters in North Dakota (Anon. 1964).

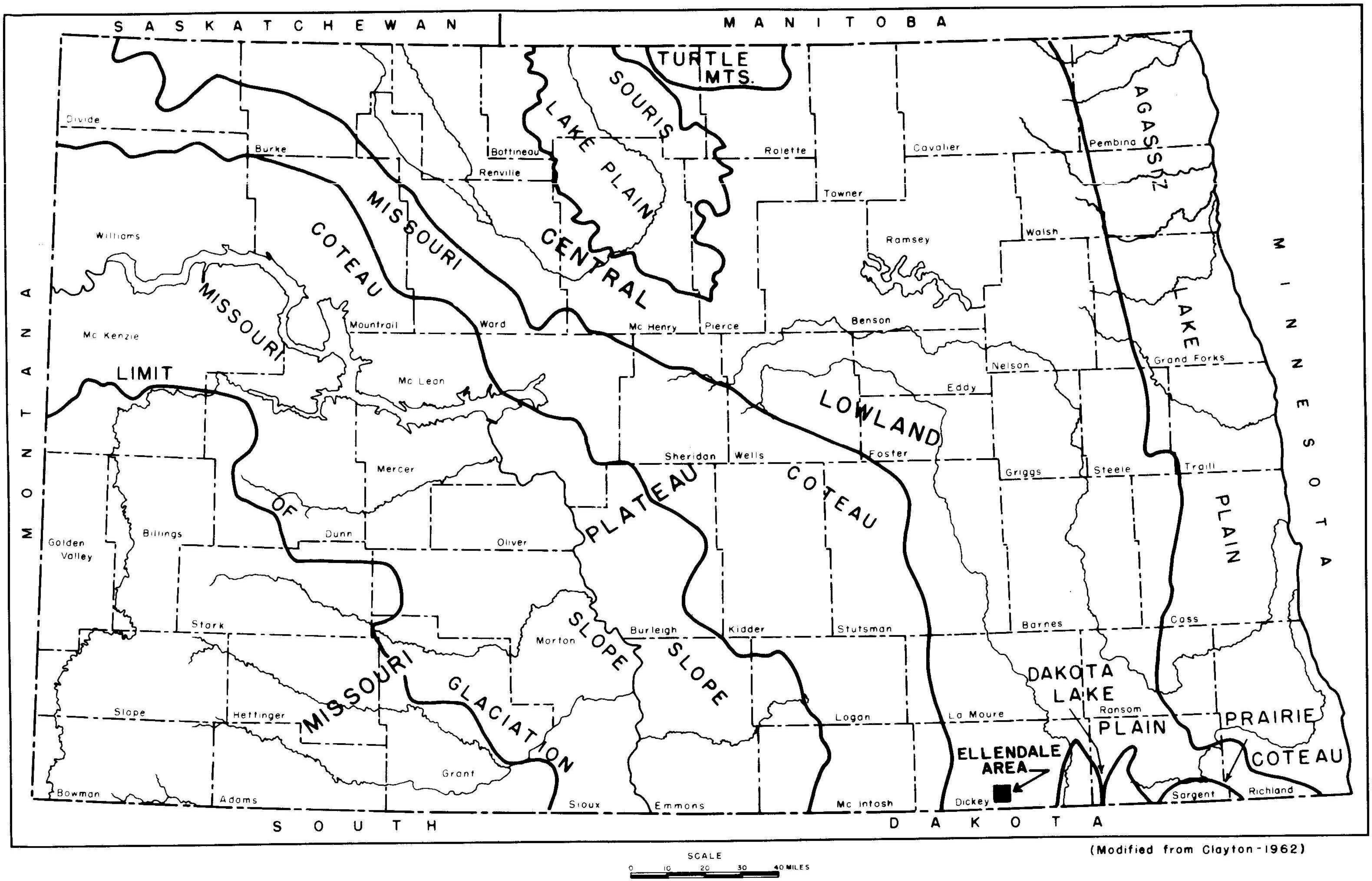

FIGURE 1--MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC UNITS AND LOCATION OF THE ELLENDALE AREA

Well-numbering System

The well-numbering system used in this report, illustrated in figure 2, is based on the location of the well in the Federal system of rectangular surveys of public lands. The first number denotes the township north of the base line that passes laterally through the middle of Arkansas; the second number denotes the range west of the fifth principal meridian. The third number denotes the section in which the well is located. The letters a, b, c and d designate respectively the northeast, northwest, southwest and southeast quarter sections, quarter-quarter sections and quarter-quarter-quarter sections (10-acre tracts). Consecutive terminal numerals are added if more than one well is located in a 10-acre tract. Therefore, a well located 129-62-15daa would mean NE$\frac{1}{4}$NE$\frac{1}{4}$SE$\frac{1}{4}$ Section 15, Township 129 North, Range 62 West.

Present Water Supply

The Ellendale water supply is currently (1964) obtained from three wells. Except for emergencies all water is pumped from two wells located on the east side of Dry Branch southeast of the city. Well 1 (129-62-18bba), drilled in October 1957, is 30 feet deep. Well 2 (129-62-18bcb), drilled in November 1959, is 29 feet deep. Both wells are 12 inches in diameter with 10-foot Johnson Evurdur screens. A well completed in an aquifer of the Dakota Group is used for emergencies. It is located approximately in the center of the city.

By the fall of 1959 the water level in well 1 had become very low. Consequently, the North Dakota State Water Commission in a jointly financed project with the City of Ellendale placed an underground clay core across Dry Branch in the southern part of Section 24, Township 129 North, Range 63

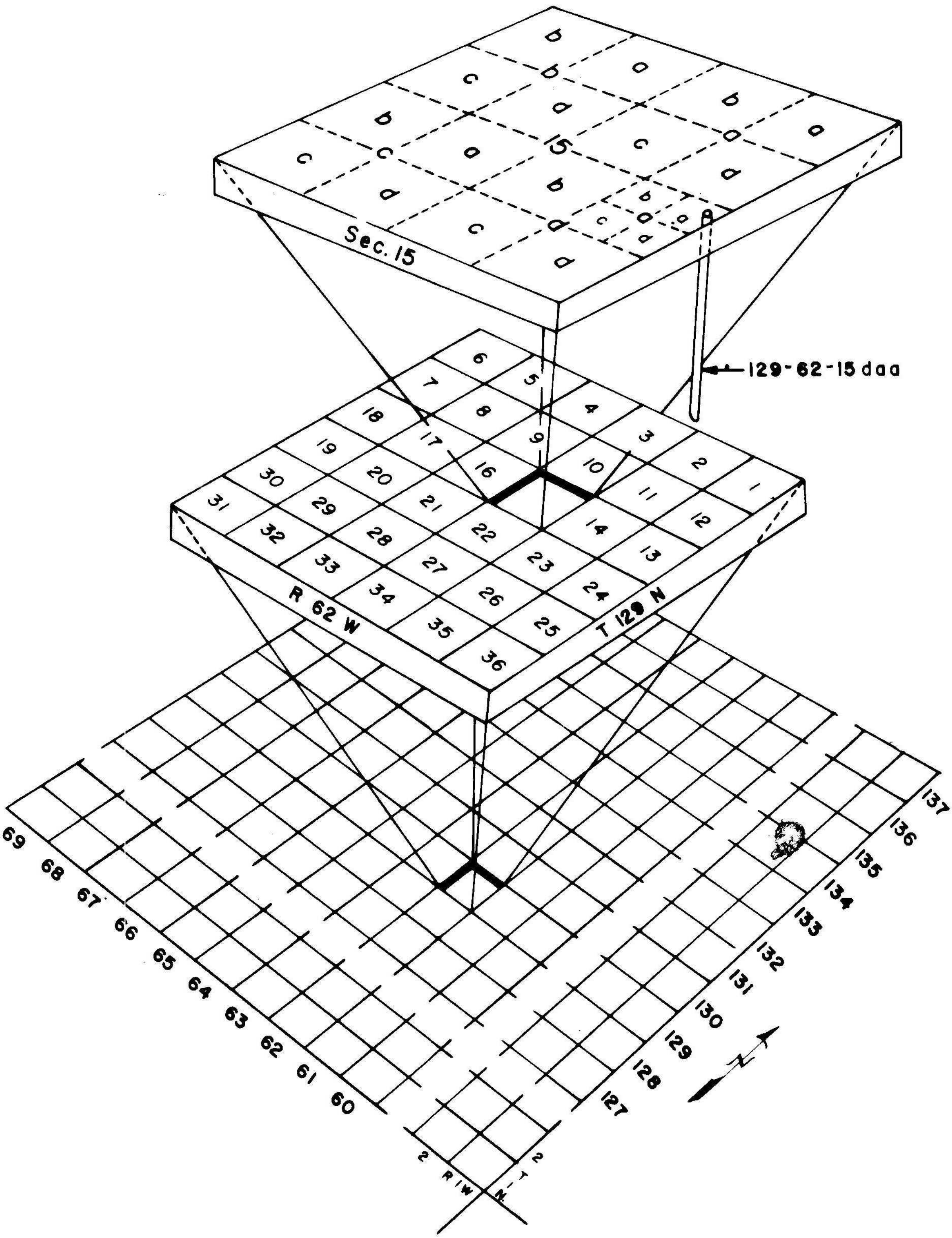

FIGURE 2--SYSTEM OF NUMBERING WELLS AND TEST HOLES.

West. This core was intended to prevent the downstream percolation of ground water and, in so doing, raise the water table.

The water table did not raise a sufficient amount so a surface dam was constructed on top of the clay core. It was completed in the spring of 1961. With the top of the flash boards in the spillway at an elevation of 1412 feet (2 flash boards), the capacity of the reservoir is 246 acre-feet. Under present rates of withdrawal (1964) the reservoir will store adequate water for recharge to the aquifer.

The total capacity of city wells 1 and 2 is about 190 gallons per minute. The average consumption is approximately 123,000 gallons per day, and during peak periods it will reach as high as 200,000 gallons per day (Art Schlenker, 1964, oral communication). At an average of 123,000 gallons per day the per capita consumption is about 70 gallons. This is about 140 acre-feet per year.

The storage capacity of the Ellendale water system is 100,000 gallons. Water is chlorinated at the well sites and pumped to the treatment plant located on the southeast edge of the city where the iron and mangenese are removed.

GEOLOGY

Bedrock

The Pierre Shale deposited during Late Cretaceous time immediately underlies the glacial drift in the study area. This shale is dark-greenish-gray to dark-blackish-gray, brittle and fissile. Figures 4 and 5 indicate that the preglacial topography was probably rolling. The highest elevation above sea level at which Pierre Shale was encountered was 1369 feet in test

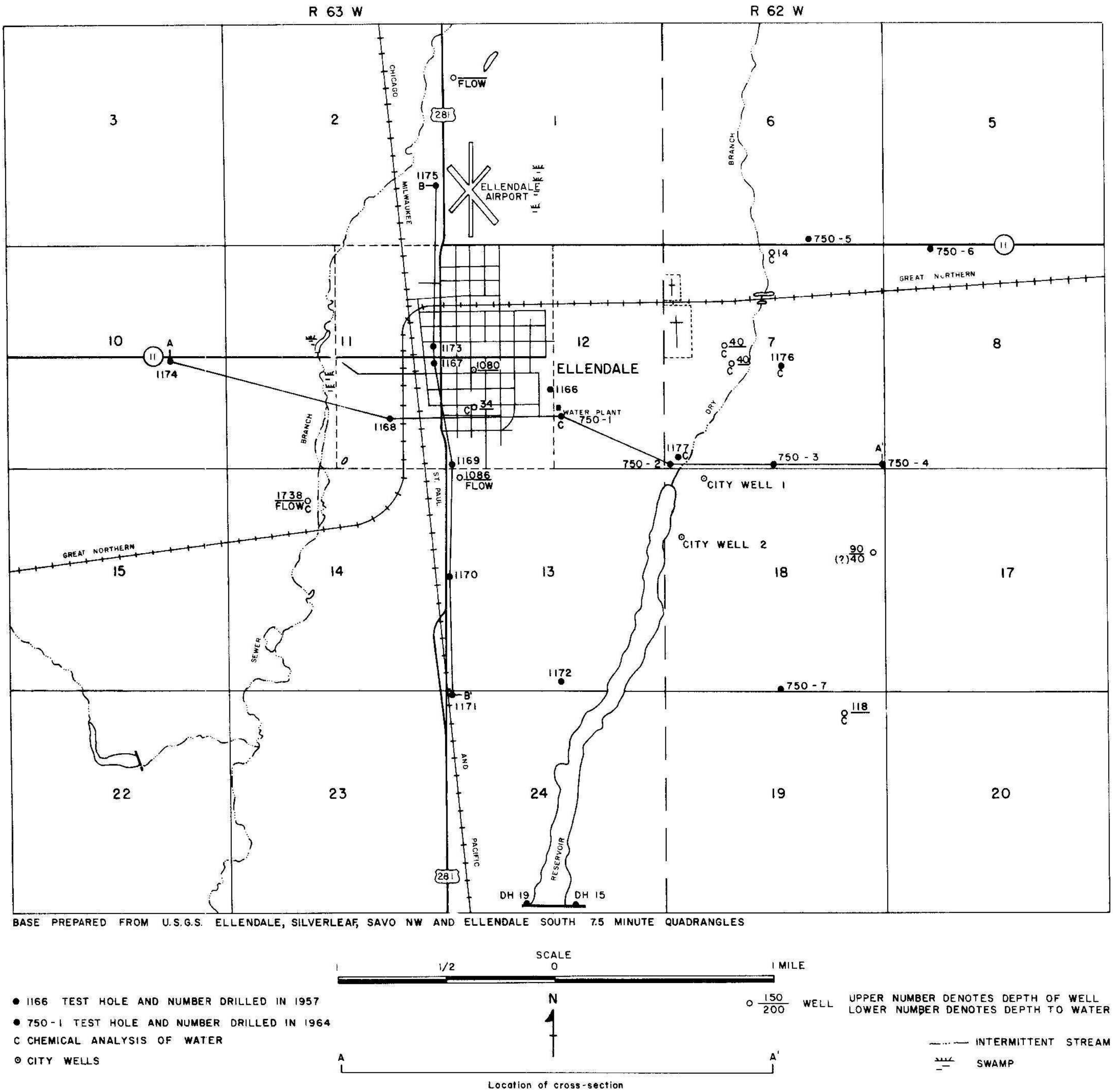

FIGURE 3--MAP OF STUDY AREA SHOWING LOCATION OF TEST HOLES, SELECTED WELLS AND GEOLOGIC CROSS-SECTIONS.

hole 1174 (129-63-10dab), and the lowest was 1293 feet in test hole 750-4 (129-62-7ddd).

Along with the Pierre Shale, and in descending sequence, other members of the Cretaceous System which are present in the Ellendale area are the Niobrara Formation, Greenhorn Formation and the Dakota Group. Below these are the Red River Formation and Winnipeg Group which are of Ordovician age (Strassberg, 1954).

Glacial Drift

The glacial drift in the study area was deposited primarily as ground moraine with some outwash in the channels of Dry Branch and Sewer Branch (Colton and others, 1963). Test hole data show that the thickness of the drift ranges from 93 feet to 148 feet. The composition is mainly till, which is a heterogeneous, unstratified mixture of material ranging from clay size particles to boulders. The remainder of the drift is composed of glacio-fluvial deposits of sand and gravel.

The areal relief is approximately 70 feet. The highest elevation of 1480 feet above sea level is in the northwest corner of the study area and the lowest elevation of approximately 1410 feet is in the southeast corner of the area. The local relief is 5 to 10 feet except where the southward-flowing intermittent streams have incised 10 to 20 feet into the glacial drift.

The outwash along the Dry Branch is the only such deposit that was explored during this study. It was deposited while Dry Branch served as a glacial melt water channel during a glacial recession. According to Lemke and Colton (1958, p. 41-57) the age of this deposit would be Post-Cary Maximum Advance No. 1. The thickest known section is 30 feet at the site of city well 1 with 29 feet being penetrated at the site of city well 2.

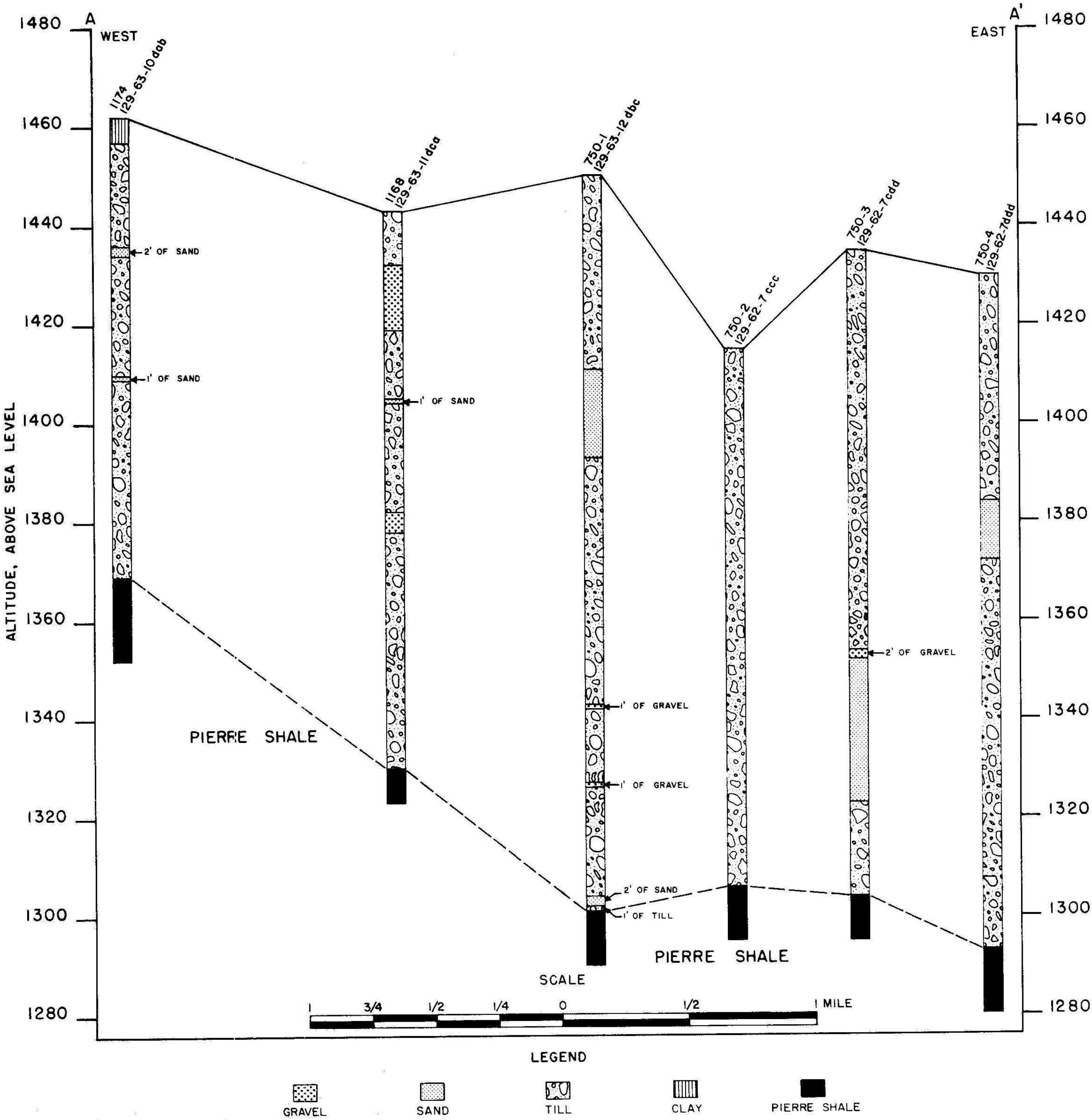

FIGURE 4--GEOLOGIC CROSS-SECTION A-A' IN THE ELLENDALE AREA

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

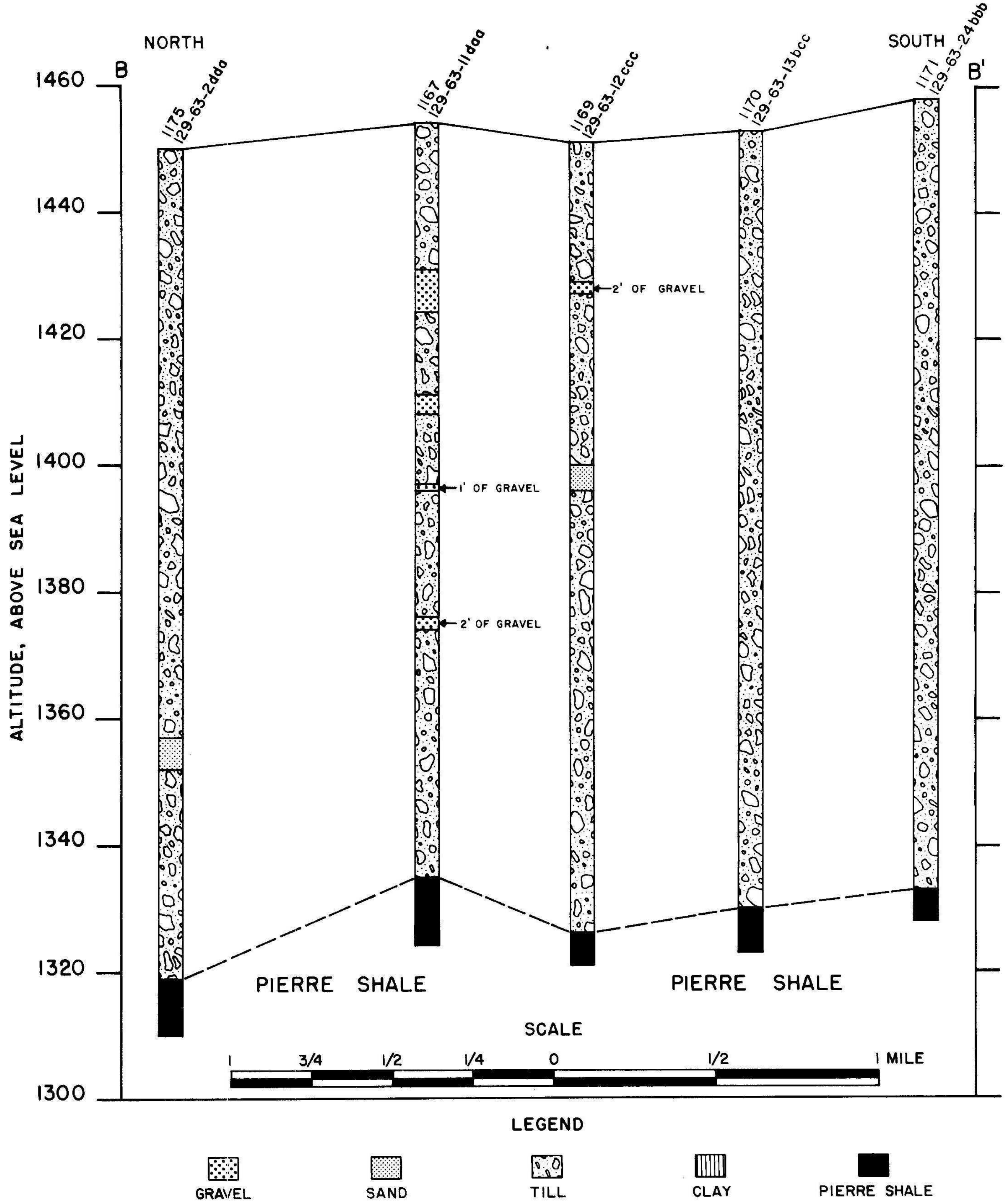

FIGURE 5--GEOLOGIC CROSS-SECTION B-B' IN THE ELLENDALE AREA

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

From a series of holes drilled across the channel for a foundation study at the dam site the greatest thicknesses of outwash were 14 feet in test hole DH 15 (129-63-24dcc) and 19 feet in test hole DH 19 (129-63-24cdd).

OCCURRENCE OF GROUND WATER

Bedrock

Aquifers of the Dakota Group serve as an emergency source of water for the residents of Ellendale as well as supplying water to many farms in the area. The original artesian head of about 335 feet at the land surface (Simpson, 1929, p. 115) is largely depleted in the area. The city well no longer flows, but most wells on surrounding farms still flow in adequate quantities to provide water for household and livestock uses. It was reported by several farmers that their wells stop flowing when the well in Ellendale is pumped. The water from aquifers of the Dakota Group is of generally poor quality (Table 2).

An oil test well (129-63-14bad) was completed as a flowing water well at a depth of 1738 feet (Industrial Commission of the State of North Dakota, Sundry Notices and Reports on Wells, Hanson Oil Syndicate #1 John Bell, 1954). According to Clarence G. Carlson of the North Dakota Geological Survey this well is probably completed in the Black Island Formation of the Winnipeg Group (Oral Communication, January 1965). The well was inspected by the author and estimated to have an artesian head of about 40 to 60 pounds per square inch at the land surface. The quality of the water is poor (Table 2).

Glacial Drift

In most parts of the study area wells in glaciofluvial deposits of sand and gravel supply adequate quantities of water for domestic and livestock uses. Two wells in the outwash along Dry Branch are the present source of water supply for the City of Ellendale. However, the aquifer is not extensive enough to provide a dependable source of water to Ellendale without recharge from the reservoir.

The thickest section of sand and gravel encountered in the course of the study was 31 feet in test hole 750-3 (129-62-7cdd). A temporary observation well was completed at this site, and a water sample was obtained for chemical analysis (Table 2). The water level was about 12 feet below the land surface.

Test hole 750-1 (129-63-12dbc) also had a significant thickness of saturated sand and gravel. The aquifer was encountered from 39 feet to 57 feet in depth. An observation well was completed at this site. A water sample was obtained for a chemical analysis (Table 2), and the water level was about 13 feet below the land surface.

AQUIFER TEST ANALYSIS

An aquifer test was conducted on a prospective city supply well on September 23-25, 1957 by personnel of the U. S. Geological Survey. The well was either very near or at the present site of city well 1. It was pumped for a period of 24 hours at a rate which varied between 94 and 111 gallons per minute. The average rate was taken to be 100 gallons per minute. Observations of drawdown and recovery of water levels were made at periodic intervals.

Three observation wells were used in this test. The following table gives distances from the production well and values of drawdown and recovery at the indicated times for the respective wells.

Well	Distance from production well (Ft.)	Initial Water Level	Water Level after 24 hrs. pumping	Water Level after 24 hours recovery
Production Well		4.34	8.75	4.63
Obs. Well O-1	14.3	4.98	7.01	5.38
Obs. Well O-2	84.5	6.39	8.22	7.25
Obs. Well O-3	111	4.00	5.22	4.33

All water levels are in feet below the top of the casing.

The ability of an aquifer to convey water is expressed as transmissibility. The coefficient of transmissibility, T, is defined as the rate of flow of water in gallons per day through a vertical strip of the aquifer one foot wide and extending the full saturated height under a hydraulic gradient of 100 per cent. It is expressed in gallons per day per foot of aquifer width.

TABLE I. Summary of Aquifer Test Results on Prospective City Supply Well.

Well	Transmissibility	
	Drawdown	Residual Drawdown
Production Well	20,000	39,400
Obs. Well O-1	26,400	40,600
Obs. Well O-2	22,600	33,400
Obs. Well O-3	26,200	

From the results of this aquifer test a maximum pumping rate cannot be ascertained for the present city wells because with the addition of the reservoir a recharging boundary is formed. However, the maximum pumping rate for city well 1 as determined by this test would be about 75 gallons per minute. This rate would allow for the general lowering of the water table during periods of inadequate recharge. With the addition of the reservoir, recharge is assured as long as there is adequate water in the reservoir. Therefore the maximum pumping rate could be somewhat higher.

The minimum distance between producing wells in the aquifer should be about 600 feet. At this spacing there should be little or no interference between wells while minimizing the length of pipeline needed.

WATER QUALITY

In the course of this study nine water samples were obtained by the author and analyzed by the North Dakota State Laboratories Department. Six analyses of water samples were obtained from the North Dakota State Health Department and previous publications (North Dakota State Health Department, 1964) (Abbott and Voedisch, 1938, p. 54-55) (Simpson, 1929, p. 282-283).

Ground water in the Ellendale area can be generally classified as slightly saline (Robinove and others, 1958), as all but two samples contained more than 1000 parts per million total dissolved solids. The water from the glacial drift is generally quite hard with moderate concentrations of sodium, bicarbonate and sulfate. Water from the bedrock aquifers has moderate to high concentrations of sulfate, sodium and chloride.

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

Silica (SiO_2) - No physiological or esthetic significance.

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

Calcium and Magnesium (Ca) and (Mg) are the primary causes of hardness. Over 125 ppm magnesium may have a laxative effect on persons unaccustomed to this type of water.

Sodium (Na) - No physiological or esthetic significance except for persons on salt-free diets.

Potassium (K) - Small amounts are essential to animal nutrition.

Bicarbonate and Carbonate (HCO_3 and CO_3) - No definite significance in natural water, there are, however, certain standards to be maintained in water treatment plants. A water with high bicarbonate content will tend to have a flat taste.

Sulfate (SO_4)- A 250 ppm limit is set by the U. S. Public Health Service, however, a survey by the North Dakota State Department of Health indicates no laxative effect is noticed until sulfates reach 600 ppm. Over 750 ppm there is generally a laxative effect. The following is a classification established by the North Dakota State Department of Health:

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

Chloride (Cl) - Over 250 ppm may have a salt taste to persons unaccustomed to high concentrations. People may become accustomed to higher concentrations.

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

Nitrate (NO_3) - Over 45 ppm can be toxic to infants, much larger concentrations can be tolerated by adults. Nitrate in excess of 200 ppm may have a deleterious effect on livestock health.

Boron (B) - No physiological or esthetic significance.

Total Dissolved Solids - 500 to 1000 ppm is the limit set by the U. S. Public Health Service; persons may become accustomed to water containing 2000 ppm or more total dissolved solids. The following is a classification established by the North Dakota State Department of Health survey:

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

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

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

pH - Should be between 7.0 and 9.0 for domestic consumption.

According to the above classifications the water from city wells 1 and 2 would be very high in sulfate, high in reference to the total dissolved solids and it would be very high in hardness.

Analyses indicate that since 1959 the quality of the water from city wells 1 and 2 has deteriorated. The total dissolved solids, calcium, sulfate and hardness as $CaCO_3$ have increased significantly. This could be partially due to the alternate dewatering and resaturation of a section of the aquifer. With the dewatering of the aquifer the decomposition of the

TABLE 2 -- Chemical analyses of water from selected wells, test holes and springs

(Analytical results in parts per million except as indicated)

Location	Well Depth (Feet)	Aquifer	Date of Collection	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Sum	Dissolved solids: Residue on evaporation at 180° C	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium-adsorption-ratio	Specific conductance (micromhos at 25° C)	pH
129-62-7abb**	14	Sand & Gravel	2-11-64	18	0.44	178	94	152	7.8	439	0.0	677	100	0.5	1.0	0.95	1,440	1,520	830	470	28.3	2.3	2,030	8.1
129-62-7bcd**	40	Sand & Gravel	2-11-64	18	0.17	141	70	41	7.0	244	0.0	267	122	0.4	114	0.0	900	940	640	440	12	0.7	1,480	8.0
129-62-7cab**	40	Sand & Gravel	2-11-64	21	0.26	109	86	92	4.0	386	0.0	380	92	0.6	4.0	0.83	950	1,030	625	309	31	1.6	1,520	8.1
129-62-7ccc**	18	Gravel	7-22-57		1.3							267	96					948	495					7.7
129-62-7cdd**	83	Sand & Gravel	5-27-64	18	0.20	96	40	427	14	556	0.0	581	197	0.9	30	0.90	1,660	1,770	405	0.0	61	9.2	2,600	8.1
129-62-7dbb**	28	Gravel	7-11-57		0.7							244	96					945	500					7.9
City Well 1 129-62-18bba*	30	Sand & Gravel	10-16-59		1.7	160	77	200		580	0.0	550	75	Trace	0.0			1,643	716					7.2
City Well 1 /1 129-62-18bba	30	Sand & Gravel	'62 or '63		4.1	298	91	134		476	0.0	850	112	0.2	0.0			1,961	1,120					7.0
City Well 2 /1 129-62-18bcb	29	Sand & Gravel	'62 or '63		5.0	286	103	148		488	0.0	850	152	0.3	0.0			2,027	1,140					7.3
City Well 2 129-62-18bcb**	29	Sand & Gravel	1-18-65	16	6.6	326	108	188	15	464	0.0	1,050	152	0.2	0.0	0.35	2,090	2,180	1,260	881	24	2.3	2,610	7.1
129-62-19aab**	118	Sand & Gravel	5-15-64	22	4.6	71	24	646	16	843	0.0	456	375	0.7	20	0.73	2,050	2,220	275	0.0	83	17	3,090	7.9
129-63-12(City) /2	1,080	Dakota Grp.		28	0.5	29	9.8	993		591		435	939	3.2	6.2			2,777	114					
129-63-12c /3 (City)	1,087	Dakota Grp.	6-28-21	19	2.0	30	13	990		495	0.0	236	1,150		Trace			2,700	128					
129-63-12c /3 (City)	1,385	Dakota Grp.	6-28-21	17	2.3	204	64	320		171	0.0	1,200	70		Trace			2,079	772					
Block 11, Lot 6 NW Corner ** 129-63-12(City)	34	Sand & Gravel	5-28-64	22	0.24	374	114	248	18	432	0.0	1,030	387	0.8	2.0	0.0	2,410	2,720	1,410	1,050	27	2.9	3,240	7.8
129-63-12dbc**	44	Sand & Gravel	5-28-64	21	0.26	176	68	554	17	563	0.0	1,300	84	1.0	40	0.50	2,640	2,760	720	259	62	8.8	3,480	8.1
129-63-14bad**	1,738	Black Island Fm.(?)	2-11-64		0.90	92	24	1,254		195	0.0	1,850	685	1.9	0.0		3,730		330	170			5,500	8.0

* Analysis by North Dakota State Health Department
** Analysis by North Dakota State Laboratories Department

/1 North Dakota State Health Department, 1964, pp 6-7
/2 Abbott and Voedisch, 1938, pp 54-55
/3 Simpson, 1929, pp 282-283

materials would be accelerated, making soluble salts more readily available. As the dewatered part of the aquifer is resaturated, the salts go into solution, thereby changing the chemical composition of the water. The shale in the aquifer material may be a source of the sulfate and chloride.

Evaporation from the reservoir could cause a higher concentration of total dissolved solids in the water, which in turn would affect the quality of the water pumped from the city wells. Transpiration could also be a factor adversely affecting the water quality.

RECOMMENDATIONS

At present (1964) city wells 1 and 2 are capable of supplying adequate quantities of water to the residents of Ellendale. During periods of normal precipitation and runoff, the reservoir will receive and store sufficient quantities of water for recharge to the aquifer. However, in the event of a sustained period of drought it is questionable whether this aquifer with the reservoir would provide sufficient quantities of water for the municipality. A problem of inadequate water as a result of a drought could be compounded by a significant increase in consumption.

In order to obtain additional water there are two alternatives. One or more wells could be drilled on the east side of the reservoir and south of the present city wells. A well in this area would receive more immediate recharge during periods of low water levels in the reservoir.

The second alternative would be to explore the extent of the aquifer found in test hole 750-3 (129-62-7cdd). Additional test drilling should be done with perhaps the installation of a test well so that an aquifer test could be conducted to determine the characteristics of this aquifer. A chemical analysis (Table 2) shows that the water from test hole 750-3 is of significantly better quality than that from the present city wells.

In the event that a better quality or a much greater quantity of water be desired over and above present sources or known potential sources within the study area there are possibly three alternatives:

1. Water could be piped to Ellendale from the Elm River Reservoir located 7 miles west of the city. The existing reservoir would be capable of providing approximately 400 acre-feet of water annually (Glover, 1964, unpublished report).

2. A dam could be constructed on the Maple River about 5 miles east of Ellendale. Even though dam construction and pipe line costs would be quite high, it would provide a dependable source of water.

3. A more extensive ground-water survey could be made that would cover at least 70 or 80 square miles around the City of Ellendale.

TABLE 3.--Logs of Test Holes

Formation	Material	Thickness (feet)	Depth (feet)
	129-62-6dcd **Test Hole 750-5** **Elevation - 1425**		
Glacial Drift:	Till, silty to sandy, brownish yellow, oxidized, moderately cohesive, slightly plastic, calcareous; drills easy	16	16
	Till, silty to sandy, olive gray, moderately cohesive, slightly plastic, moderately soft, calcareous; pebbles and boulders, abundant lignite from 34 to 35 feet	76	92
	Till, as above, with shale fragments 2 to 3 inches thick, hard, dark olive gray, noncalcareous; limestone boulder from 99 to 103 feet	24	116
Pierre Shale:	Shale, dark greenish gray, brittle, fissile	4	120
	129-62-7ccc **Test Hole 750-2** **Elevation - 1415**		
Glacial Drift:	Topsoil, black	1	1
	Till, silty to sandy, brownish yellow, oxidized, moderately cohesive, calcareous	13	14
	Till, silty to sandy, olive gray, moderately cohesive, moderately soft, slightly calcareous; limestone and granite pebbles; interbedded with streaks of coarse sand, mainly limestone, shale, and granitic rock; abundant lignite from 66 to 70 feet.	77	91
	Till, sandy, olive gray, moderately calcareous, brittle; limestone and shale pebbles; drills hard	18	109
Pierre Shale:	Shale, dark blackish gray, brittle, fissile, noncalcareous	11	120

TABLE 3.--Logs of Test Holes - continued

Formation	Material	Thickness (feet)	Depth (feet)
	129-62-7ccc2 Test Hole 1177 Elevation-1415		
Glacial Drift:	Topsoil, black	1	1
	Clay, yellow	4	5
	Gravel, fine to medium; much shale	6	11
	Gravel, coarse; much shale, some cobbles.	7	18
	129-62-7cdd Test Hole 750-3 Elevation - 1435		
Glacial Drift:	Till, sandy, brownish yellow, oxidized, slightly cohesive, moderately soft, calcareous; boulders; drills easy	23	23
	Till, silty to sandy, olive gray, moderately cohesive, slightly plastic, moderately hard, moderately calcareous; a few boulders	58	81
	Gravel, fine to coarse, sandy, poorly sorted, subangular to subrounded, mainly limestone, shale and granitic rock	2	83
	Sand, medium to very coarse, moderately sorted, subangular to subrounded, mainly shale, granitic rock and limestone, a few particles of lignite; interbedded with thin clay layers from 95 to 112 feet	29	112
	Till, silty tosandy, olive gray, brittle, moderately calcareous	19	141
Pierre Shale:	Shale, dark blackish gray,noncalcareous, brittle, fissile	9	140
	129-62-7dbb Test Hole 1176 Elevation-1434		
Glacial Drift:	Topsoil, black	2	2
	Gravel, fine to coarse	26	28
	Till, gray; fine to medium gravel	2	30

TABLE 3.--Logs of Test Holes - continued

Formation	Material	Thickness	Depth
	129-62-7ddd **Test Hole 750-4** **Elevation - 1430**		
Glacial Drift:	Till, silty to sandy, brownish yellow, oxidized, moderately cohesive, noncalcareous...........................	16	16
	Till, silty, olive gray, moderately cohesive and plastic, moderately soft, calcareous; pebbles of granitic rock; thin layer of medium sand at 18 feet......................	30	46
	Sand, coarse to very coarse, gravelly, moderately sorted, subangular; 50-60 percent shale, balance limestone with some granitic rock; thin clay layers from 54 to 58 feet.............	12	58
	Till, silty to sandy, olive gray, moderately cohesive, moderately plastic, moderately hard, highly calcareous; drills easy; shale fragments from 93 to 137 feet, 2 to 3 inches thick, hard, silty, bluish gray, noncalcareous, slightly fissile............................	79	137
Pierre Shale:	Shale, dark blackish gray, brittle, noncalcareous, fissile.................	13	150
	129-62-8bba **Test Hole 750-6** **Elevation - 1430**		
Glacial Drift:	Topsoil, black..........................	1	1
	Till, silty to sandy, brownish yellow, oxidized, slightly cohesive, moderately soft, moderately calcareous; limestone and granitic pebbles, boulders........	20	21
	Sand, coarse, gravelly, moderately sorted, subangular to subrounded, brownish yellow; primarily limestone and igneous rock with some shale......	13	34
	Till, silty, olive gray, moderately cohesive and plastic, highly calcareous...........................	7	41
	Gravel, fine to medium, slightly sandy, subangular to subrounded, moderately sorted; composed of shale, limestone and granitic rock....................	5	46

TABLE 3.--Logs of Test Holes - continued

Formation	Material	Thickness (feet)	Depth (feet)
	129-62-8bba-continued Test Hole 750-6 Elevation - 1430		
Glacial Drift:	Till, silty to sandy, olive gray, moderately cohesive and plastic, moderately calcareous................	5	51
	Gravel, fine to medium, slightly sandy, subangular to subrounded, moderately sorted; approximately 50% shale with remainder as limestone and granitic rock................................	2	53
	Till, silty to sandy, olive gray, moderately cohesive and plastic, moderately calcareous................	30	83
	Sand, medium to coarse, moderately sorted, subangular to subrounded, primarily limestone and shale with some granitic rock.................	7	90
	Till, sandy, olive gray, moderately cohesive, slightly plastic, moderately hard, moderately calcareous; drills hard................................	38	128
Pierre Shale:	Shale, dark blackish gray, brittle, noncalcareous, fissile.................	7	135
	129-62-18dcc Test Hole 750-7 Elevation - 1431		
Glacial Drift:	Topsoil, black.........................	1	1
	Till, silty, grayish yellow, oxidized, moderately cohesive and plastic; pebbles and boulders.................	18	19
	Till, silty to sandy, olive gray, moderately cohesive, slightly plastic, moderately calcareous, moderately soft; shale fragments from 52 to 58 feet, 2 to 3 inches thick, hard, bluish gray, noncalcareous; abundant lignite from 52 to 53 feet......................	39	58
	Till, silty to sandy, olive gray, moderately cohesive and plastic, moderately soft, moderately calcareous; pebbles of granitic rock; drills easy................................	47	105

TABLE 3.--Logs of Test Holes - continued

Formation	Material	Thickness (feet)	Depth (feet)
	129-62-18dcc-continued Test Hole 750-7 Elevation - 1431		
Glacial Drift:	Till, very silty to sandy, olive gray, very slightly cohesive, moderately calcareous; limestone and granitic boulders	12	117
Pierre Shale:	Shale, greenish gray, brittle, non-calcareous, fissile	13	130
	129-63-2dda Test Hole - 1175 Elevation - 1450		
Glacial Drift:	Till, yellow; fine to coarse gravel	16	16
	Till, sandy, gray	10	26
	Till, gray; fine to medium gravel, some lignite	44	70
	Till, gray; fine to medium shale pebbles, some coal	23	93
	Sand, fine to coarse, "dirty"; some lignite	5	98
	Till, gray; fine to medium gravel; some shale pebbles and lignite	33	131
Pierre Shale:	Shale	9	140
	129-63-10dab Test Hole - 1174 Elevation - 1462		
Glacial Drift:	Clay, brown, smooth	5	5
	Till, yellow; fine to medium gravel	11	16
	Till, gray; fine to medium gravel with shale pebbles	10	26
	Sand, fine to coarse; "dirty"	2	28
	Till, gray; fine to medium gravel, shale pebbles, some lignite; medium to coarse sand from 52 to 53 feet	42	70
	Till, gray; contains fine to medium gravel, some shale pebbles and lignite	23	93
Pierre Shale:	Shale	17	110

TABLE 3.--Logs of Test Holes - continued

Formation	Material	Thickness (feet)	Depth (feet)
	129-63-11add Test Hole - 1173 Elevation - 1454		
Glacial Drift:	Topsoil, black	2	2
	Till, yellow; fine to coarse gravel	9	11
	Clay, blue, "smooth"	3	14
	Sand, coarse, gravelly; abundant shale, some lignite	5	19
	Till, gray; fine to medium gravel, some shale pebbles and lignite	71	90
	129-63-11daa Test Hole - 1167 Elevation - 1454		
Glacial Drift:	Earth fill	3	3
	Clay, yellow, "smooth"	8	11
	Till, yellow; fine to medium gravel	6	17
	Till, gray; fine to medium gravel, some shale and lignite	4	21
	Sand, fine to medium, gravelly	9	30
	Till, gray; fine to medium gravel, some shale pebbles	13	43
	Gravel, fine to medium, abundant shale	3	46
	Till, gray; abundant lignite and some fine gravel from 57 to 58 feet	32	78
	Gravel, fine to coarse; some lignite	2	80
	Till, gray; fine to medium gravel, some lignite	39	119
Pierre Shale:	Shale	11	130
	129-63-11dca Test Hole - 1168 Elevation - 1443		
Glacial Drift:	Topsoil, black	2	2
	Till, yellow; fine to medium gravel	9	11
	Gravel, fine to coarse, sandy	13	24
	Till, gray; fine to coarse gravel, some lignite, "dirty" sand from 38 to 39 feet	37	61
	Gravel, fine to coarse; some lignite	4	65
	Till, gray; abundant fine to medium gravel, some shale and lignite	48	113
Pierre Shale:	Shale	7	120

TABLE 3.--Logs of Test Hole - continued

Formation	Material	Thickness (feet)	Depth (feet)
	129-63-12cad **Test Hole - 1166** **Elevation - 1453**		
Glacial Drift:	Topsoil, black	3	3
	Till, yellow; fine to medium gravel	16	19
	Till, gray; fine to medium gravel, some shale	10	29
	Sand, fine to coarse; gravelly, some shale	19	48
	Till, gray; fine to medium gravel, some shale and lignite	52	100
	Gravel, fine to medium, sandy	5	105
	Till, gray; fine to medium gravel	22	127
	Sand, fine to medium; "dirty"	3	130
	Till, gray; fine to medium gravel, some shale and lignite	11	141
Pierre Shale:	Shale	19	160
	129-63-12ccc **Test Hole - 1169** **Elevation - 1451**		
Glacial Drift:	Till, yellow; fine to medium gravel	22	22
	Gravel, fine to coarse	2	24
	Till, gray; fine to medium gravel	27	51
	Sand, fine to coarse; abundant shale	4	55
	Till, gray; fine to medium gravel, some shale	70	125
Pierre Shale:	Shale	5	130

TABLE 3.--Logs of Test Holes - continued

Formation	Material	Thickness (feet)	Depth (feet)
	129-63-12dbc Test Hole 750-1 Elevation - 1450		
Glacial Drift:	Topsoil, black	1	1
	Till, silty to sandy, brownish yellow, moderately cohesive, slightly plastic; drills easy	18	19
	Till, silty to sandy, dark olive gray, moderately cohesive, slightly plastic, moderately soft; pebbles of granitic rock	20	39
	Sand, very coarse, gravelly, subangular, moderately sorted; mainly limestone and granitic rock, small amounts of shale and lignite	18	57
	Till, very silty, olive gray, slightly cohesive; drills easy; poor sample return	50	107
	Gravel, coarse, subrounded, poor sample return	1	108
	Till, silty, olive gray; poor sample return	15	123
	Sand, very coarse; poor sample return	1	124
	Till, silty, olive gray; poor sample return	2	126
	Till, silty, olive gray; abundant lignite in thin layers	3	129
	Till, silty to sandy, olive gray, brittle, calcareous; drills hard	17	146
	Sand, coarse, subangular, moderately well sorted; mainly limestone with shale and igneous rock	2	148
Pierre Shale:	Shale, dark gray, very slightly silty, slightly cohesive, very slightly calcareous, fissile; drills hard	12	160
	129-63-13bcc Test Hole - 1170 Elevation - 1453		
Glacial Drift:	Topsoil, black	2	2
	Clay, yellow, "smooth"	14	16
	Till, gray; fine to medium gravel, lignite fragments	107	123
Pierre Shale:	Shale	7	130

TABLE 3.--Logs of Test Holes - continued

Formation	Material	Thickness (feet)	Depth (feet)
	129-63-13dcc Test Hole - 1172 Elevation - 1434		
Glacial Drift:	Topsoil, black	1	1
	Till, yellow; fine to medium gravel	2	3
	Sand, coarse, gravelly	14	17
	Till, gray; fine to medium gravel, some shale	6	23
	Gravel, fine to medium; about 2/3 shale	7	30
	Till, gray; fine to medium gravel, some shale and lignite, a few cobbles from 80 to 91 feet	66	96
Pierre Shale:	Shale	4	100
	129-63-24bbb Test Hole - 1171 Elevation - 1458		
Glacial Drift:	Clay, yellow, "smooth"	14	14
	Till, brown; fine gravel, slight amount of lignite	8	22
	Till, gray; fine to medium gravel, a few boulders	103	125
Pierre Shale:	Shale	5	130
	129-63-24cdd Test Hole D.H. 19 Elevation - 1414		
Glacial Drift:	Topsoil	1	1
	Clay, white	2	3
	Clay, reddish yellow	3	6
	Sand, gravelly	4	10
	Sand, gray, fine; "dirty"	9	19
	Till, gray; gravel	7	26

TABLE 3.--Logs of Test Holes - continued

Formation	Material	Thickness (feet)	Depth (feet)
	129-63-24dcc Test Hole D.H. 15 Elevation-1412		
Glacial Drift:	Topsoil	1	1
	Clay, white	1	2
	Clay, yellow	1	3
	Sand and gravel	11	14
	Till, gray; gravel	10	24

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