GROUND-WATER SURVEY OF THE WILLOW CITY AREA

BOTTINEAU COUNTY, NORTH DAKOTA

SWC PROJECT NO. 1463

NORTH DAKOTA GROUND-WATER STUDIES

NO. 70

By

Charles E. Naplin
Ground-Water Geologist

Published By

North Dakota State Water Commission
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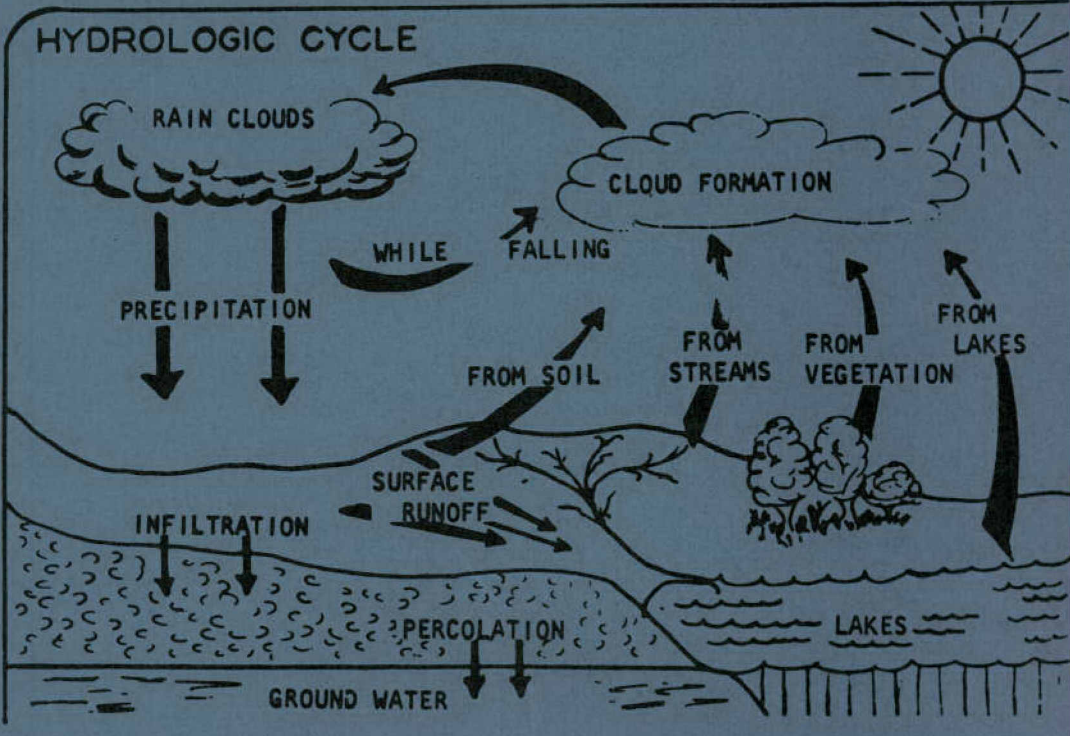

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INTRODUCTION

PURPOSE AND SCOPE

In April 1967, the Willow City City Council requested that the State Water Commission place the City of Willow City on their ground-water survey schedule. The necessary financial requirements were completed and the investigation was conducted early in July 1967.

The survey consisted of a partial well inventory, test drilling, installation of observation wells, chemical analyses of selected water samples, and the preparation of this report. Twenty-five test holes were drilled with the State-owned hydraulic rotary drilling machine to determine the presence and characteristics of subsurface strata. Information obtained from subsurface exploration was supplemented by data acquired from topographic maps, soil surveys, aerial photographs and geologic reports in determining the geohydrologic characteristics of the area.

Test drilling and associated field work was under direct supervision of the author. Test drilling was done by Lewis Knutson and Hugh Jacobson. Chemical analyses were preformed by Donald Delzer and Garvin Muri, State Water Commission Chemists, at the North Dakota State Laboratories in Bismarck. Special acknowledgement is extended to Mr. Roy Henes, Mayor of Willow City, and the numerous local residents for their information concerning wells and water facilities.

LOCATION AND GENERAL FEATURES

The Willow City area, as described in this report, consists of 56 square miles in portions of Townships 159 and 160 North, Ranges 74 and 75 West in southeastern

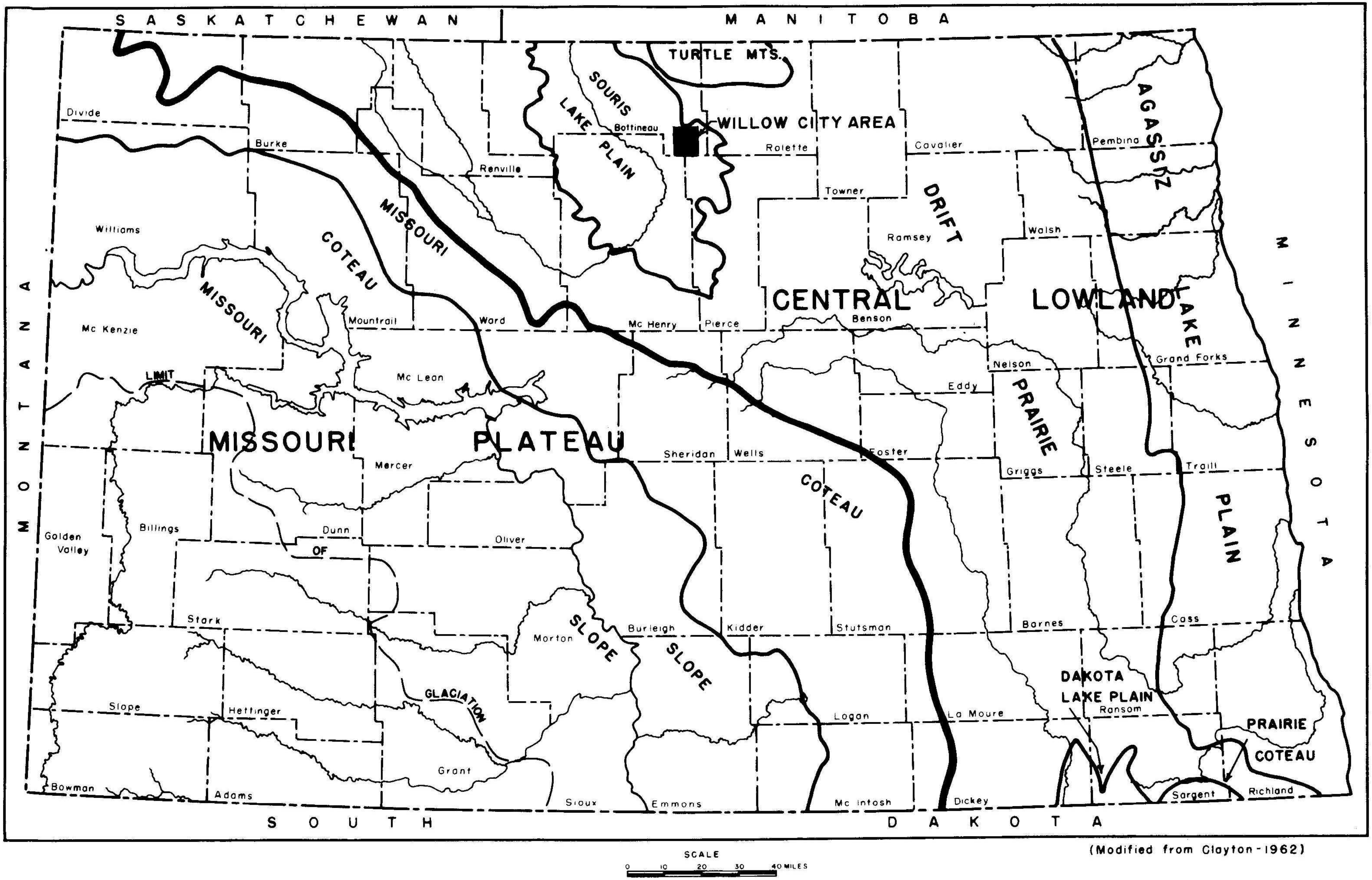


FIGURE I--MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC PROVINCES AND LOCATION OF THE WILLOW CITY AREA

Bottineau County. This area is located in the Souris Lake Plain division of the Central Lowlands Physiographic Province of North Dakota as shown in Figure 1. Surface elevations vary from 1,523 feet above mean sea level in the NW$\frac{1}{4}$ of Section 29, Township 160 North, Range 74 West to 1,454 feet about mean sea level at a benchmark in the SW$\frac{1}{4}$ of Section 33, Township 160 North, Range 75 West. The general absence of topographic relief in the area is due to Glacial Lake Souris which at one time covered this part of North Dakota.

Willow Creek, together with two of its tributaries, Ox Creek and Miller Creek, drains the area. Miller Creek is intermittent throughout most of the year with Willow Creek and Ox Creek maintaining small amounts of flow except during unusually dry periods.

Willow City, an agricultural community, has a population of 494 (1960 Census). The city is served by North Dakota Highway 60 and a branch line of the Great Northern Railroad. Climatological data based on a 75-year period of U. S. Weather Bureau records at Willow City, shows the average temperature to be 37.60° F. Average annual precipitation based on the same period of record is 15.28 inches (U. S. Department of Commerce, 1966).

PRESENT WATER SUPPLY

At present, Willow City is obtaining its municipal water supply from two wells. Well No. 1 is located next to the Great Northern Railroad tracks west of the elevator complex in the southeastern portion of the city. This well is 38 feet deep and is completed with 6 inch steel casing and 10 feet of steel screen at the bottom. The well is not gravel packed resulting in the infiltration of fine sand. A 5 h.p. electric motor powers the vertical turbine pump with a rating of 15-20 gpm (gallons per minute). Well No. 2, located within the City Fire Hall, is 31 feet deep and is cased with 1$\frac{1}{4}$ inch pipe with a sand point. Power for the 8-10 gpm centrifugal pump is furnished by a 2 h.p. electric motor. This well is used only during the summer months when additional water is required. Oxidization and consequent encrustation produced by iron-reducing bacteria requires the periodic removal of the sand point for cleaning. Water is supplied to the 50,000 gallon storage tank on a 24-hour basis from Well No. 1.

Well No. 3 was drilled in the fall of 1966 by Mr. Liston Grider. The well, located one block west of the public school, is 38 feet deep and is cased with 6-inch steel pipe, with the bottom part slotted. The well is equipped with a pump-jack powered with a small electric motor and pumps at a rate of 8-10 gpm. However, this well is not being used because of the objectionable "rotten-egg" odor and the corrosive character of the water. Contamination from a broken sewer main or residual waste material from an old livery stable (personal communication with Mr. Roy Henes, Mayor, and others) may be causing the problem. The well was pumped intermittently throughout the fall of 1966 and during the spring and summer months of 1967 in an attempt to alleviate the problem. Underground seepage of wastes, such as from a leaking sewer main, can cause widespread contamination of an aquifer over a period of time.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report, illustrated in Figure 2, is based upon the location of the well in the Federal system of rectangular surveys of public lands. The first number denotes the township north of the base line which passes laterally through the middle of Arkansas; the second number denotes the range west of the fifth principal meridian; the third number denotes the section in which the well is located. The letters a, b, c and d designate respectively the northeast, northwest, southwest and southeast quarter section, quarter-quarter section and quarter-quarter-quarter section (10-acre tract). Consecutive terminal numerals are added if more than one well is located in a 10-acre tract. Thus well 160-75-15 daa is in the NE$\frac{1}{4}$NE$\frac{1}{4}$SE$\frac{1}{4}$ Section 15, Township 160 North, Range 75

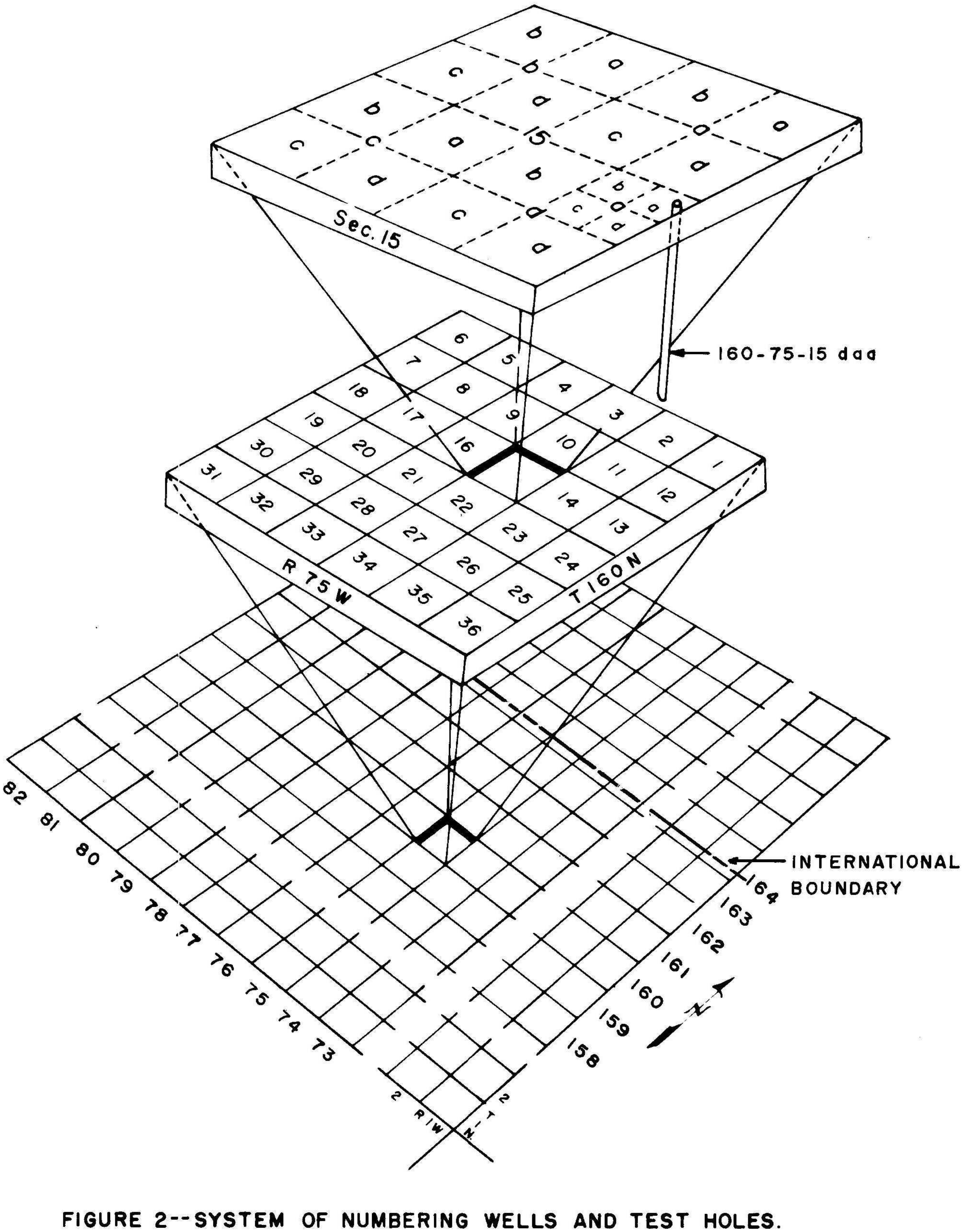


FIGURE 2--SYSTEM OF NUMBERING WELLS AND TEST HOLES.

West.

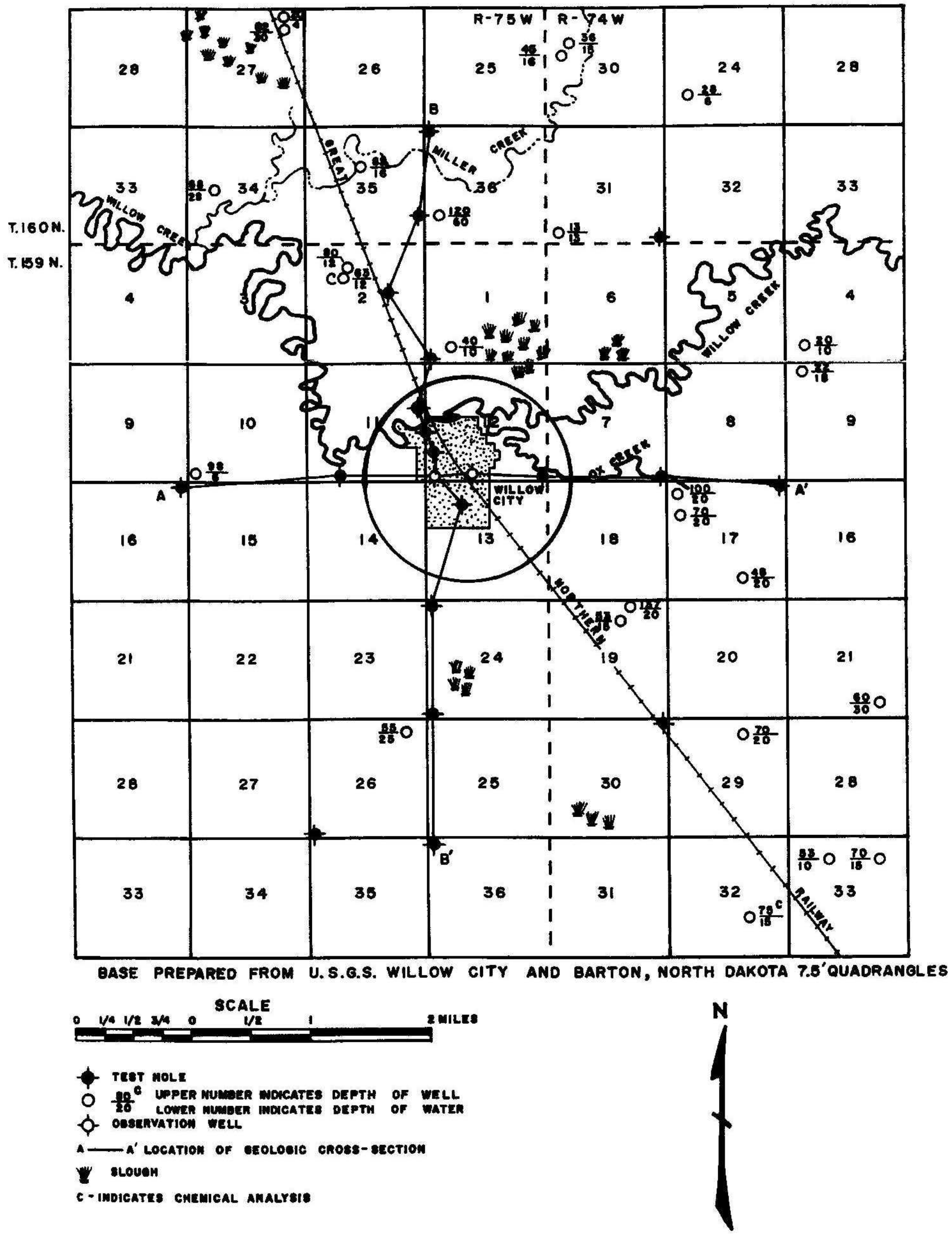
GEOLOGY AND GROUND-WATER CONDITIONS

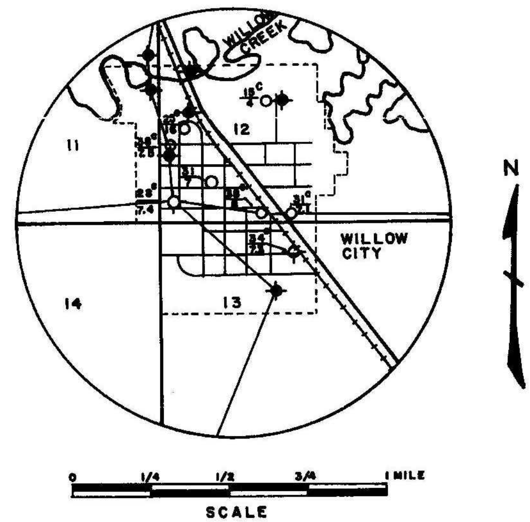
GEOLOGIC HISTORY

Before glaciation the Willow City area probably resembled the present day Badlands of southwestern North Dakota with Tertiary and Upper Cretaceous sedimentary rocks exposed at the surface. With the passage of time decomposition of these sedimentary strata by erosional agents; wind, rain, differential constraction and expansion of rocks through variation in temperature, subsidence and upheaval of the earth's crust; topographic relief became accentuated. Numerous streams and rivers established drainage courses northward into Canada.

Approximately 20 percent of the earth's surface was glaciated during the Pleistocene Epoch. This Epoch lasted from about 1,000,000 years to less than 10,000 years ago. Four stages of glaciation, from oldest to youngest: Nebraskan Kansan, Illinoian and Wisconsin, took place during this time. Glacial stages have been subdivided into substages by geologists. The exposed glacial deposits of the Souris River area have been placed in the Mankato substage of the Wisconsin stage of Pleistocene glaciation by Lemke (1960, p. 42).

As climatic changes occurred and temperatures moderated the glacial ice retreated northward into Canada. Natural drainage was terminated for a period of time by retreating glacial ice, resulting in the confinement of melt waters and subsequent formation of Glacial Lake Souris. Eventually, the waters of glacial Lake Souris found a southern outlet and flowed southeastward to glacial Lake Agassiz. Post-glacial drainage was finally established after the glacial ice had retreated far into northern Canada and glacial Lake Souris was drained. The area once occupied by Lake Souris now appears as a gently undulating lacustrine plain mantled by clay, silt, and sand.





INSERT OF WILLOW CITY AREA
SECT'S 11,12,13,14, TWP.159N., RG.75W.

FIGURE 3--MAP OF WILLOW CITY AREA SHOWING THE LOCATION OF TEST HOLES, WELLS, AND RELATED FEATURES.

BEDROCK FORMATIONS

Glacial deposits overlie more than 6,000 feet of stratified sedimentary rocks collectively termed bedrock in the Willow City area. Each distinct rock unit which can be mapped areally and is consistent in lithologic composition is called a formation. Formations such as the Fox Hills and the Pierre, described in this report, are known to have been deposited during late Cretaceous time. Large inland seas covering an estimated 600,000 square miles (Tourtelot, 1962, p. 3) occupied much of the western interior or the North American Continent including all but the extreme eastern margin of the Williston Basin. Transportation of material from western source areas and the consequent sedimentation of sand, silt and clay during many successive transgressive and regressive fluctuations of Cretaceous seas, produced various formations of sedimentary rock.

Pierre Formation:

The Pierre Formation is geologically the oldest formation encountered during the test drilling phase of the investigation. Data from oil test holes in Bottineau and Pierce Counties indicates that the Pierre Formation may range in thickness from approximately 800 to 1000 feet in southeastern Bottineau County (Lemke, 1960, p.22-23).

Two test holes penetrated the underlying Pierre Formation to varying depths. Test hole 2 (159-74-17aaa) and test hole 12 (159-75-12ccb$_2$) penetrated 8 feet and 24 feet, respectively, into the Pierre Formation. Drill cuttings indicated a brownish black to black, indurated, non-calcareous shale with a few thin, light gray bentonite layers. In some areas of North Dakota the Pierre Formation is fractured a few feet to several feet in its uppermost section. The fractured zone may have resulted from differential pressure changes initiated by the removal of overburden by glaciation or from the frictional stresses and weight of slowly moving glacial ice. The fractured zone in some localities will yield small quantities of fair to good quality ground water. However, in the Willow City area a fractured zone was not observed.

Fox Hills Formation:

The Fox Hills Formation, which conformably overlies the Pierre Formation, was penetrated to varying depths in 21 of the 25 test holes in the Willow City area. Drill cuttings indicated that the Formation is a light gray to medium light gray, sandy, generally non-calcareous siltstone. Interbedding within the formation was indicated in a few of the holes where the predominant siltstone constituent is intermittently layered with light gray, calcareous mudstone and medium bluish gray sandstone. Some sandy, brownish gray to dark greenish gray, non-calcareous shale was encountered in 8 test holes. The Fox Hills Formation ranged in thickness from 185 feet in test hole 2 (159-74-17aaa) to 276 feet in test hole 12 (159-75-12ccb$_2$). These were the only two test holes that completely penetrated the Fox Hills Formation. Very few wells in the Willow City area obtain water from the formation due to its poor water-yielding properties. All lithologic data obtained during drilling operations indicates that the Fox Hills Formation underlies the entire Willow City area.

GLACIAL DRIFT

Throughout the Pleistocene Epoch glaciers moved south and southeastward over the Willow City area. The slowly moving glaciers became heavily laden with bedrock materials and glacial debris which had been broken loose and pulverized by the shearing force and overlying weight of accumulating ice. When climatic conditions changed and temperatures moderated the glaciers retreated northward leaving a mantle of rock material on the previously ice-covered terrain. Meltwater streams, carrying glacial debris from the margins of retreating glaciers, cut numerous channels through previously deposited drift, leaving large quantities of silty clay and in some instances sand and gravel.

The present land surface in the Willow City area is a combination of glacial till overlain with sand, silt and clay deposited as sediments from Glacial Lake Souris. These deposits are collectively termed glacial drift.

Glacial drift refers to all stratified or unstratified materials deposited directly or indirectly by glacial action. Glacial drift in the Willow City area ranges in thickness from 40 feet in test hole 12 (159-75-12ccb$_2$) to 204 feet in test hole 23 (160-74-31ddd), and has an average thickness of approximately 83 feet.

Till and Associated Sand and Gravel Deposits:

The greatest percentage of glacial drift in the Willow City area is made up of till. Till is defined as an unconsolidated, unstratified, heterogeneous mixture of clay, silt, sand, gravel, cobbles and boulders. These materials have been deposited directly by melting ice with little or no transportation by water. Till, or "blue clay" as it is frequently referred to in laymen's terms, appears olive gray in color when encountered below the water table. Till may also be yellowish brown in color, reflecting chemical changes which have occurred in the "zone of oxidization" above the water table. Till which has been oxidized is termed locally as "yellow clay". Generally the major constituents of till, clay, and silt, are relatively impermeable and will not readily yield water to wells.

In the Willow City area there are numerous thin lenses of stratified sand and gravel deposits which are associated with till. Sand and gravel, ranging in thickness from 2 feet to 12 feet, were encountered in several test holes (Figures 4a and 4b). These deposits provide water for numerous farm wells in the area, but will not yield sufficient quantities of water for a municipality, due to their limited areal extent and complete dependence upon percolation and infiltration of ground water for recharge through the overlying, relatively impermeable till.

Glaciolacustrine Deposits:

Glaciolacustrine deposits consist of all sediments associated with lakes marginal to a glacier. Materials of this depositional origin in the Willow City area consist of layered clay, silt and sand deposited over glacial till. During the existence of Glacial Lake Souris sediment was transported into Lake Souris by numerous streams and rivers and later settled out of liquid suspension to accumulate

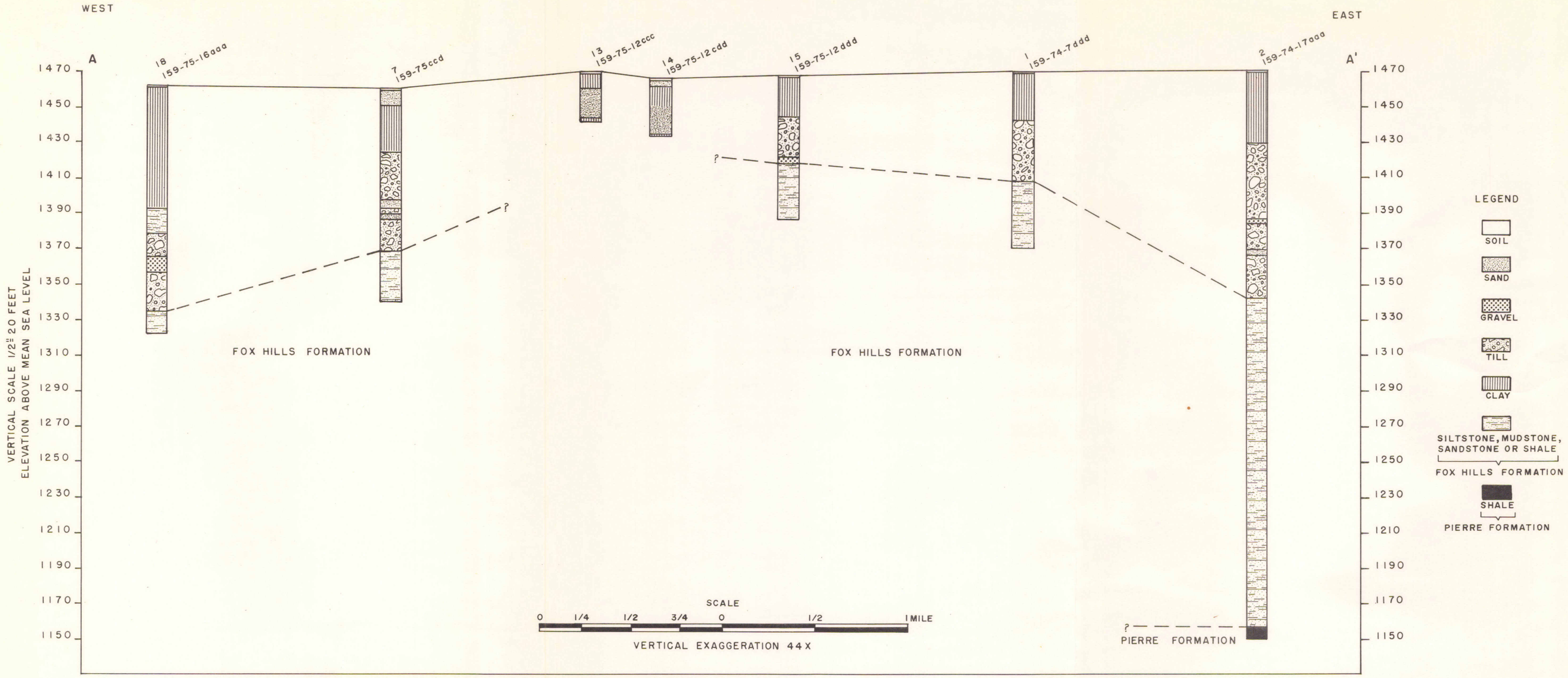


FIGURE 4a--GEOLOGIC CROSS-SECTION A-A' IN THE WILLOW CITY AREA

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

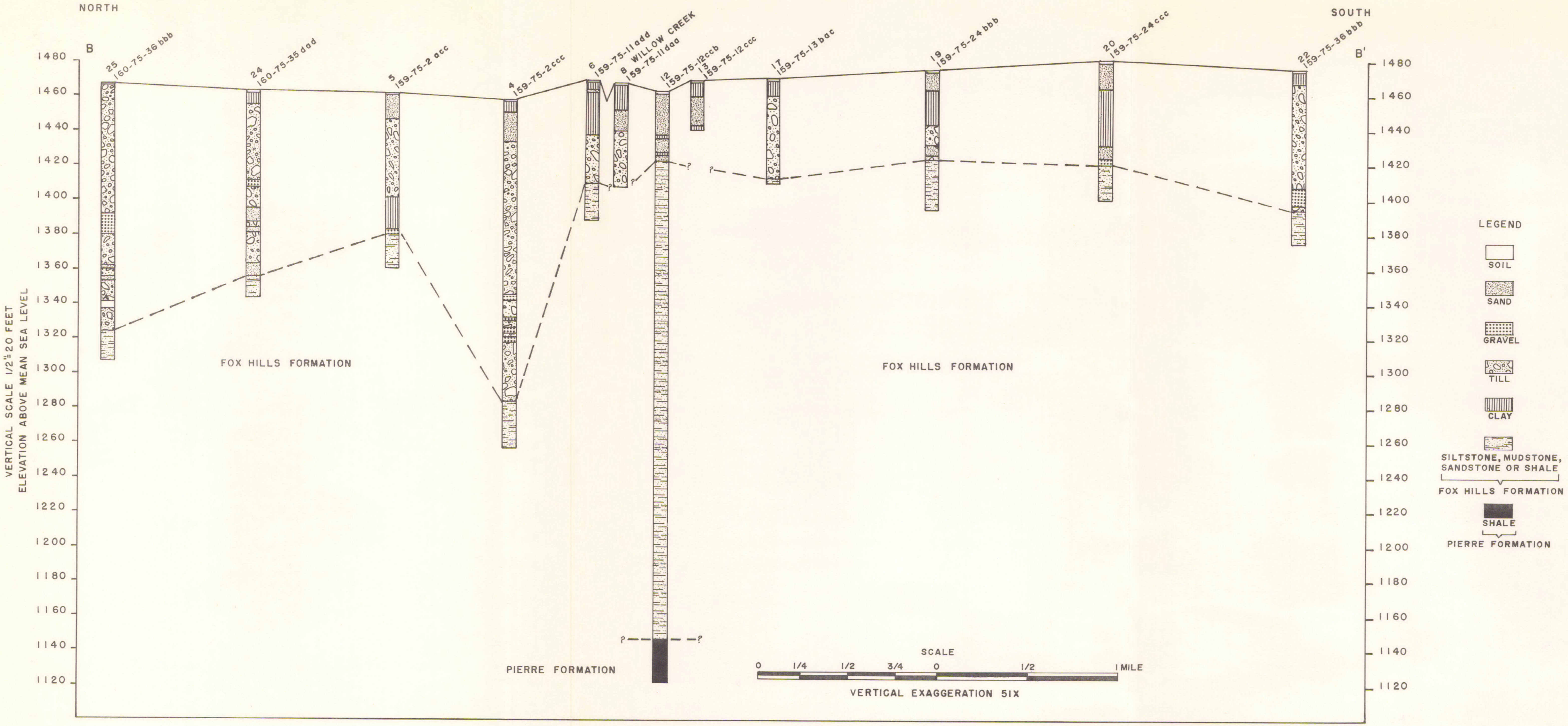


FIGURE 4b--GEOLOGIC CROSS-SECTION B-B' IN THE WILLOW CITY AREA

(LOCATION OF SECTION B-B' SHOWN IN FIGURE 3) on the lake bottom. Clay and silt are, generally, not a source of ground water because they are relatively impermeable.

Commonly associated with lacustrine deposits of clay and silt are beach or near-shore deposits of sand which are the result of wave action upon materials near or adjacent to the margins of lakes. Beach deposits may extend for several miles and often yield sufficient quantities of ground water for domestic and stock usage. In the Willow City area a beach or near-shore deposit of sand was found to exist in the vicinity of test hole 23 (160-74-31ddd). Test hole 23 was drilled as close as possible to the center of the deposit, but only 8 feet of oxidized sand was encountered.

Deposition of the very fine to fine-grained sand in a shallow lake bottom depression underlying Willow City and the immediate vicinity may have been associated with the post-glacial drainage of Glacial Lake Souris. The sand may also have been deposited in conjunction with a low velocity proglacial stream discharging into Lake Souris from the northeast during a low stage of the lake. Generally, glaciolacustrine deposits are characterized by the deposition of permeable and sand and/or gravel associated with clay and silt.

HYDROLOGIC CONCEPTS

Contrary to the popular belief that ground water occurs in "veins" or underground rivers and lakes, scientific subsurface investigations have clearly indicated that almost all continental areas on earth are underlain at varying depths with porous materials saturated with water. Any formation or stratum that will yield water to wells in sufficient quantity to be of importance as a source of supply is called an "aquifer".

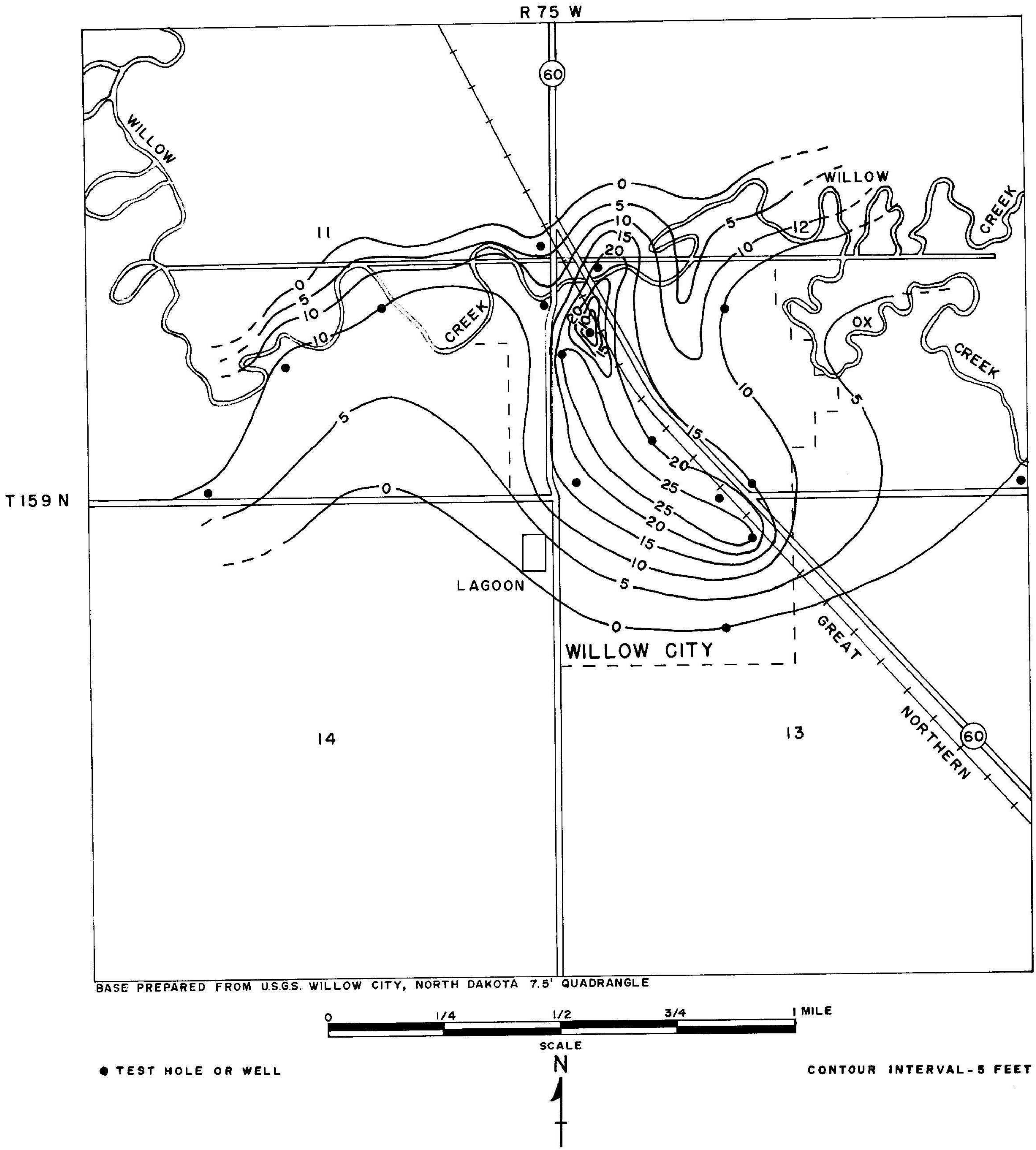


FIGURE 5--ISOPACH MAP OF THE WILLOW CITY AQUIFER

Permeability, Storage Capacity and Water-Yielding Characteristics of Aquifers:

Porous materials, such as sand and/or gravel, are permeable because water can percolate or infiltrate directly through the pore spaces between grains, granules and pebbles. The porosity and permeability of sand and gravel deposits are directly related to the grain size, and relative angularity or roundness of the composite material. Sand or gravel deposits, in which a majority of the material is rounded or well rounded, possess a larger pore space area and thus provide a greater storage volume for ground water, than will deposits where the majority of grains are angular or poorly rounded. The very fine to fine-grained sand common to the glaciolacustrine deposit in the Willow City area is generally subangular to subrounded. Interpretation of the relative angularity and grain size of this sand deposit reveals, in part, that its storage capacity for ground water is less than that of a deposit possessing the same angularity, but having a larger grain size. Grain size, angularity, sorting and compressibility determine permeability and influence the storage capacity and water-yielding properties of an aquifer.

Recharge and Discharge:

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

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

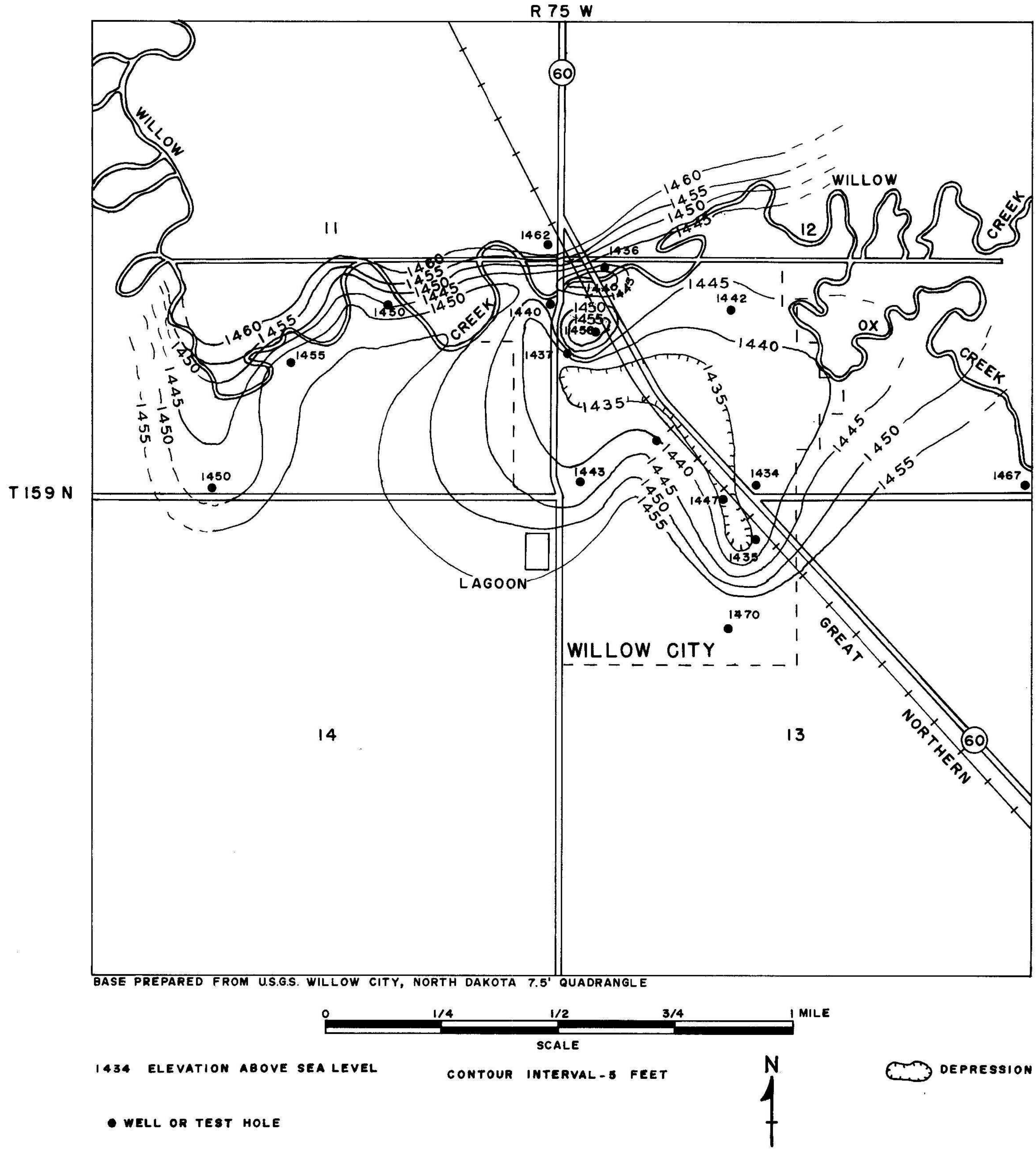


FIGURE 6--CONTOUR MAP SHOWING BASE OF THE WILLOW CITY AQUIFER

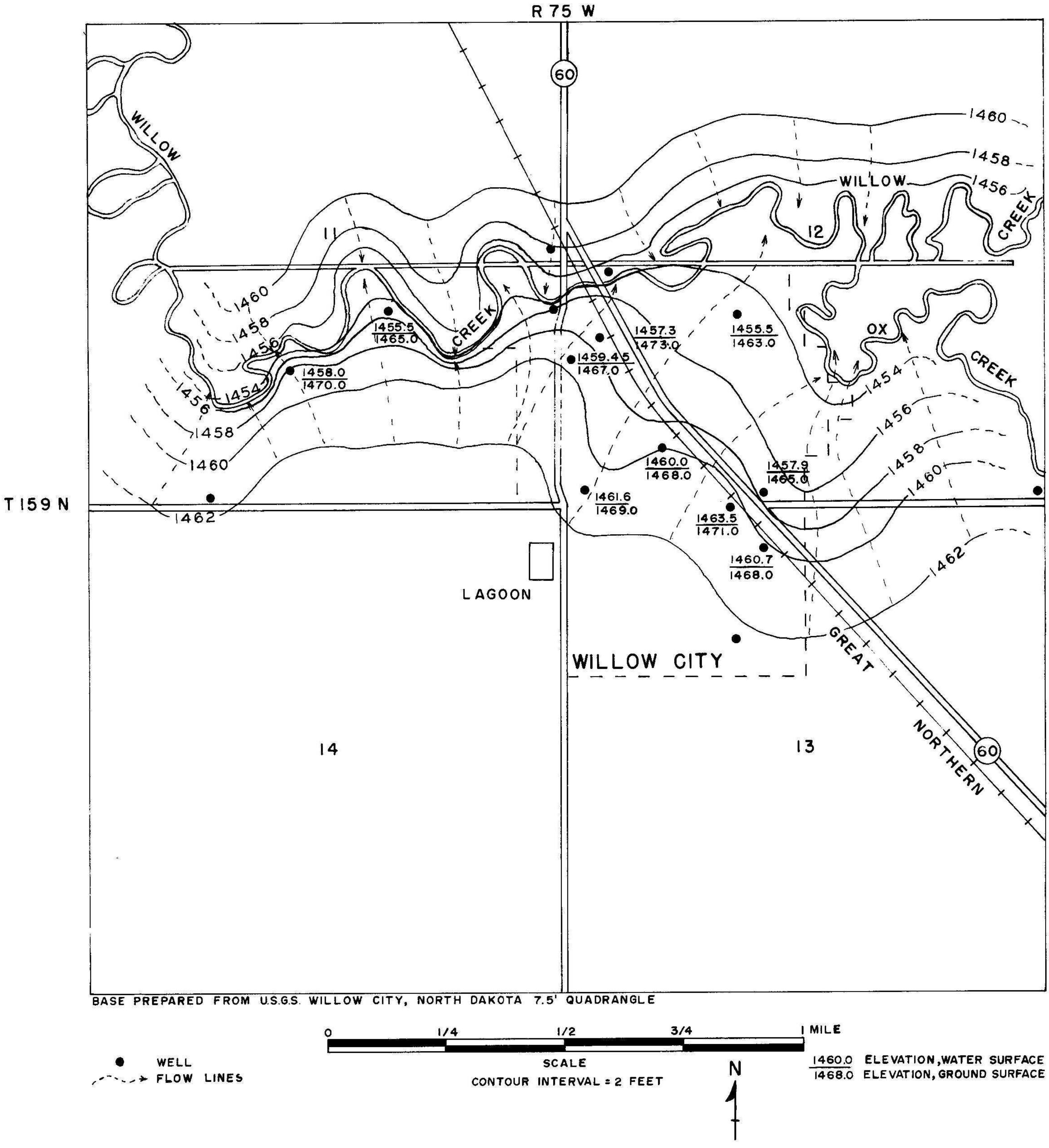


FIGURE 7--CONTOUR MAP OF THE WATER-TABLE SURFACE SHOWING THE DIRECTION OF GROUND MOVEMENT IN THE WILLOW CITY AREA

The Willow City Aquifer:

The glaciolacustrine deposit described in this report is here called the Willow City aquifer. Cross-sections A-A' and B-B', as shown in Figures 4a and 4b, indicate a surficial deposit of sand ranging in thickness from 2 feet in test hole 6 (159-75-11add) to $24\frac{1}{2}$ feet in test hole 12 (159-75-12ccb$_2$). Test hole 16 (159-75-13baa) encountered 26 feet of sand from 7 feet to 33 feet below land surface. Approximate thicknesses of sand in the area of the Willow City aquifer are indicated in Figure 5.

The Willow City aquifer is a surficial deposit of very fine to fine-grained sand. Grain size and angularity of the sand common to the aquifer are consistent throughout. Test hole data indicates considerable variability in thickness but the aquifer appears to be continuous.

The surficial sand deposit receives most of its recharge through direct infiltration of precipitation. Periodic fluctuations of water levels in wells tapping the aquifer reflect changes in seasonal precipitation, suggesting water-table conditions. The ground water contained within a "water-table aquifer" is not confined by impermeable strata, as is an "artesian aquifer", and removal of water by pumping will lower the water level in the vicinity of the well due to gravity drainage.

A contour map of the water-table in the Willow City aquifer (Figure 7) illustrates the sloping surface of the water-table. Flow lines drawn at right angles to the contour lines indicate probable paths of individual water particles. As can be seen in Figure 7, the general pattern of ground-water movement is toward Willow Creek and Ox Creek. Comparing Figure 7 with the contour map of the bottom of the aquifer, Figure 6, indicates that the water-table slopes in the same direction as the bottom of the aquifer. However, Figure 6 illustrates a depression within the 1,435 foot contour line, which suggests an area where ground-water movement if minimal.

WATER QUALITY

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

During the investigation at Willow City, eight water samples were collected for complete chemical analysis. Results of the analyses are recorded in Table 1.

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

Silica (SiO_2):

No physiological or esthetic significance.

Iron (Fe):

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

Calcium and Magnesium (Ca) and (Mg):

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

Sodium (Na):

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

Potassium (K):

Small amounts are essential to animal nutrition.

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.

Percent Sodium; Sodium Absorption Ratio; Specific Conductance:

Are factors used in determining irrigation feasibility.

In general, water quality varies considerably within the Willow City aquifer. The water quality can be summarized as average to very high in hardness, low to very high in sulfate content, and average to high in total dissolved solids. According to the above classifications, the water from city well 1 would be low in sulfate, average in total dissolved solids, and very high in hardness.

TABLE I - CHEMICAL ANALYSES *

(Analytical results in parts per million except as indicated)

Location	Well Depth (feet)	Aquifer	Date of Collection	Silica (SiO_2)	Total Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved Solids		Hardness as $CaCO_3$		% Sodium	Sodium absorption-ratio	Specific Conductance (micromhos 25°C)	pH
																	Sum	Residue on Evaporation at 180° C	Calcium, Magnesium	Noncarbonate				
159-75-2baa$_2$	63	Sand & Gravel	7- 7-67	20	3.3	77	5.8	433	3.2	781	0.0	39	284	0.5	98	1.40	1370	1300	216	0.0	81	13	2200	7.8
159-75-12cab	15	Sand	7- 7-67	15	0.08	86	64	156	2.3	437	0.0	308	35	0.6	134	0.55	1020	998	478	120	41	3.1	1470	7.7
159-75-12cbc$_2$	25	Sand	7- 7-67	25	0.36	133	18	69	3.9	503	0.0	116	18	0.2	0.0	0.16	636	605	404	0.0	27	1.5	979	7.5
159-75-12ccb$_1$	38	Sand	7-6-67	18	1.1	109	35	127	5.0	534	0.0	193	33	0.4	0.5	0.16	785	831	415	0.0	40	2.7	1170	7.8
159-75-12ccc	26	Sand	7-17-67	22	4.5	241	63	301	7.9	621	0.0	892	89	0.2	0.0	0.02	1930	1940	861	352	43	4.5	2530	7.7
159-75-12cdc*	38	Sand	7-17-67	17	0.08	132	41	97	8.3	486	0.0	276	25	0.2	0.1	0.00	835	843	500	102	29	1.9	1210	8.0
159-75-12cdd	31	Sand	7- 7-67	20	0.04	194	76	154	8.2	601	0.0	463	119	0.3	1.0	0.35	1330	1420	795	303	29	2.4	1880	7.9
159-75-13baa	33	Sand	7-17-67	23	0.90	105	18	87	5.0	511	0.0	78	17	0.2	0.0	0.06	586	580	335	0.0	36	2.1	913	8.0

* Analysis of Willow City Municipal Well

* Analysis by North Dakota State Laboratories Department

CONCLUSION AND RECOMMENDATIONS

At present (1968) Willow City wells 1 and 2 are capable of supplying adequate quantities of water for the municipality. Well 1 is used continuously, whereas, well 2 is used only during the warmer months when greater quantities of water are required. The City has experienced numerous problems in past years when their wells have pumped excessive sand necessitating periodic rejuvenation of wells, pumps and water facilities. Corrosion has also caused difficulties by rendering well screens inoperative, particularly in well 2 located in the fire hall.

Test drilling during the field investigation indicated the presence of an aquifer underlying almost all of Willow City and, to some extent, adjacent areas. Annual precipitation supplies the majority of water for recharge to the aquifer and no shortage of water was experienced by the city during the extremely dry summer months of 1967. It was not determined, however, what effect several successive periods of drought would have on ground-water availability in the area.

It is recommended that if serious problems develop from the excessive in-filtration of very fine sand into the well bore of well 1 rendering it inoperative, that the well be reworked by a competent well driller or well drilling firm. May it also be suggested, that in the future, a graded gravel pack should be installed around the well screen to prevent the infiltration of sand into the well.

Increased demands for water by Willow City in the future may necessitate the installation of an additional well. If or when this situation develops, thoughtful planning in the selection of a well site and correct well design should be initiated. Any new wells should not be located in the vicinity of the city waste disposal facility. Figure 7 indicates ground-water movement and subsequent discharge northeasterly towards Willow Creek. Lagoonal seepage, especially during periods when the water-table is near ground-level, may follow the same northeasterly gradient. The absence of nitrates in water sampled from an observation well (test hole 13, 159-75-12ccc) located less than one-quarter mile from the lagoon did not indicate contamination.

TABLE 2 - RECORDS OF WELLS AND TEST HOLES

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

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

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

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

Remarks: C.A., chemical analysis.

Location (1)	Owner (2)	Depth (feet) (3)	Diameter (inches) (4)	Type (5)	Date Completed (6)	Depth to water below land surface (feet) (7)	Date of Measurement (8)	Use of water (9)	Aquifer (10)	Remarks (11)
159-74-4cc$_1$	Glen Diebold	20	24-18	Bo	1948	10	4- 4-63	S	Sand	Hard
159-74-4cc$_2$	Glen Diebold	93	24-18	Bo	1948	45	4- 4-63	S		Hard
159-74-5cca$_1$	Jerry Feucrelm	15	5	Dr				S	Sand	Hard
159-74-5cca$_2$	Jerry Feucrelm	250	5	Dr				U		Dry Hole
159-74-7ddd	Test Hole 1	100	4 3/4	Dr	7-11-67			T		See Log
159-74-9bbb	Glen Diebold	22	36	Bo	1953	18	4- 4-63	D	Sand	Hard
159-74-17aaa	Test Hole 2	320	4 3/4	Dr	7-10-67			T		See Log
159-74-17bb$_1$	Walter Sherwin	100	18	Bo		20	4- 2-63	S		Hard
159-74-17bb$_2$	Walter Sherwin	70	18	Bo	1961	20	4- 2-63	S		Hard
159-74-17dcb	Albert Tweten	48	36-24	Bo	1926	20	4- 4-63	U	Gravel	Hard

TABLE 2 - RECORDS OF WELLS AND TEST HOLES (Cont.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
159-74-19ab$_1$	Fred Getzlaff	137	4	Dr	1946	20	4-17-63	D		Soft
159-74-19ab$_2$	Fred Getzlaff	53	24	Bo	1956	15	4-17-63	S		Medium Soft
159-74-21dcd	John Medalen	60	18	Bo		30	4- 3-63	S		Hard
159-74-29ab$_1$	Gerald Sanderson	70	4	Dr	1947	20	4- 3-63	D,S		Soft
159-74-29ab$_2$	Gerald Sanderson	70	4	Dr	1954	20	4- 3-63	D,S		Soft
159-74-30aaa	Test Hole 3	80	4 3/4	Dr	7-12-67			T		See Log
159-74-32dbb	Walter Rockvoy	75	4	Dr	1952	15	4-16-63	D,S		Soft
159-74-33abd	Melvin Stutrud	70	4	Dr	1960	15	5-18-63	S		Soft
159-74-33bad	Albert Wittmeier	53	18	Bo	1945	10	5-24-63	D,S		Soft
159-75-1ccc	Test Hole 4	200	4 3/4	Dr	7-13-67			T		See Log
159-75-1ccd	Kenneth Erdmann	40	30-18	Bo	1964	10	7- 7-67	D,S	Sand	Hard
159-75-2acc	Test Hole 5	100	4 3/4	Dr	7-13-67			T		See Log
159-75-2baa$_1$	Henry Hanson	80	24-18	Bo	1963	12	7- 7-67	S	Sand & Gravel	Hard
159-75-2baa$_2$	Henry Hanson	63	24-18	Bo	1963	12	7- 7-67	D	Sand & Gravel	C.A.
159-75-3dad	Marvin Hanson	20		Bo				D,S	Gravel	
159-75-10aa			36			11.59	7- 7-67	U		
159-75-10ccc	Clifford Johnson	98	6	Dr	1941	6	7- 7-67	D,S	Gravel	Soft
159-75-11add	Test Hole 6	80	4 3/4	Dr	7-14-67			T		See Log

TABLE 2 - RECORDS OF WELLS AND TEST HOLES (Cont.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
159-75-11cad	Conrad Schuster	66	24	Bo	1961	12	7- 7-67	D,S	Sand	Hard
159-75-11ccd	Test Hole 7	120	4 3/4	Dr	7-12-67			T		See Log
159-75-11daa	Test Hole 8	60	4 3/4	Dr	7-14-67			T		See Log
159-75-12caa	Test Hole 9	80	4 3/4	Dr	7-14-67			T		See Log
159-75-12cab	Donald Wittmeier	15	1 1/4	Dv	1966	4		D	Sand	C.A.
159-75-12cbb	Test Hole 10	100	4 3/4	Dr	7-12-67			T		See Log
159-75-12cbc$_1$	Test Hole 11	80	4 3/4	Dr	7-14-67			T		See Log
159-75-12cbc$_2$	Vincent Schuchard	25	1 1/4	Du	1967	16	7- 7-67	D	Sand	C.A
159-75-12ccb$_1$	Willow City No. 3	38	6	Dr	1966	7.54	7-11-67	U	Sand	"rotten-egg" odor, C.A.
159-75-12ccb$_2$	Test Hole 12	340	4 3/4	Dr	7-11-67			T		See Log
159-75-12ccc	Test Hole 13	26	1 1/4	Dr	7-17-67	7.40	7-17-67	T	Sand	See Log, C.A.
159-75-12ccd	Willow City No. 2	31	1 1/4	Dv		7	7-17-67	PS	Sand	Corrosive
159-75-12cdc	Willow City No. 1	38	6	Dr		8	7-17-67	D	Sand	C.A.
159-75-12cdd	Test Hole 14	31	1 1/4	Dr	7-11-67	7.10	7-11-67	T	Sand	See Log, C.A.
159-75-12ddd	Test Hole 15	80	4 3/4	Dr	7-11-67			T		See Log
159-75-13baa	Test Hole 16	33	1 3/4	Dr	7-17-67	7.30	7-17-67	T	Sand	See Log, C.A.
159-75-13bac	Test Hole 17	60	4 3/4	Dr	7-17-67			T		See Log
159-75-13ccb	H. E. Getzlaff	30		Bo				D	Sand	Moderately Hard
159-75-16aaa	Test Hole 18	140	4 3/4	Dr	7-12-67			T		See Log

TABLE 2 - RECORDS OF WELLS AND TEST HOLES (Cont.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
159-75-22aad	Russell Thompson	70	24	Du				D,S	Gravel	Hard
159-75-24bbb	Test Hole 19	80	4 3/4	Dr	7-12-67			T		See Log
159-75-24ccc	Test Hole 20	80	4 3/4	Dr	7-12-67			T		See Log
159-75-26bbb	Sanderson	55		Dr		25	7- 7-67	D,S	Sand	Soft
159-75-26ccc	Test Hole 21	100	4 3/4	Dr	7-12-67			T		See Log
159-75-27aad$_1$	F. W. Thompson	50		Dr				S		Hard
159-75-27aad$_2$	F. W. Thompson	105		Dr				S		Hard
159-75-36bbb	Test Hole 22	100	4 3/4	Dr	7-12-67			T		See Log
160-74-29cbc	Frank Bollinger	28	2	Du		6	4- 3-63	D,S	Sand	Hard
160-74-30bca$_1$	Joseph Cote	36	8	Dr	1949	15	5-15-63	S		Soft
160-74-30bca$_2$	Joseph Cote	45	6	Dr	1953	16	4- 7-63	D,S	Sand	Soft
160-74-31ccc	Joseph Cote	13	1 1/4	Dv		13	4- 7-63	D,S	Sand	Hard
160-74-31ddd	Test Hole 23	220	4 3/4	Dr	7-14-67			T		See Log
160-74-33cbc	Edwin C. Becker,Jr.							S	Sand	Soft
160-75-26daa	Cliff Knoke	90	4	Dr	1950			D,S	Sand	Moderately Soft
160-75-27aa$_1$	Arthur Vollmer	20	24	Du	1940	4	4-27-63	D	Sand	Hard
160-75-27aa$_2$	Arthur Vollmer	82	18		1918	30	4-27-63	S	Sand & Gravel	Hard, Salty
160-75-34ca$_1$	Charles Hanson	68	24	Bo	1962	28	5- 9-63	S	Gravel	Hard

TABLE 2 -- RECORDS OF WELLS AND TEST HOLES (Cont.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
160-75-34ca2	Charles Hanson	68	24		1925-26	28	5-9-63	D,S	Gravel	Moderately Hard
160-75-35bda	Robert Pullman	82	24			16	7-7-67	D,S	Sand	Hard
160-75-35dad	Test Hole 24	120	4 3/4	Dr	7-13-67			T		See Log
160-75-36bbb	Test Hole 25	160	4 3/4	Dr	7-13-67			T		See Log
160-75-36ccb	Amie Senechal	120	14-9	Dr	1934-35	60	5-9-63	D	Gravel	Moderately Soft

TABLE 3 - LOGS OF TEST HOLES

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

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

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

Elevations are based on mean sea level datum as represented on the Willow City and Barton, North Dakota, United States Geological Survey topographic maps.

159-74-7ddd
Test Hole 1
Elevation 1470 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty loam, brownish black -----	1	0	1
	Clay, silty, sandy, light olive brown to olive brown, plastic, moderately cohesive, calcareous, oxidized -------	26	1	27
	Clay, sandy, olive gray, cohesive, calcareous (till) ----------------------	35	27	62
Fox Hills Formation:				
	Sandstone, silty to clayey, medium bluish gray to dark greenish gray, slightly indurated, non-calcareous ------------	25	62	87
	Shale, silty, medium gray to medium dark gray -------------------------------	13	87	100

Electric Log

159-74-17aaa
Test Hole 2
Elevation 1470 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, sandy loam, grayish black ------	2	0	2
	Clay, very silty, yellowish brown, moderately cohesive, plastic, oxidized --	9	2	11

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	159-74-17aaa Test Hole 2 (Cont.) Elevation 1470 Feet			
	Clay, sandy, olive gray to medium dark gray, cohesive, calcareous -----------	29	11	40
	Clay, silty with sand grains and pebbles, olive gray, moderately cohesive, calcareous (till) ----------------------	43	40	83
	Gravel, clayey, medium to coarse, angular to subangular, poorly sorted, mostly limestone and granitic constituents --	2	83	85
	Clay, silty with medium size sand grains, olive gray, moderately cohesive, calcareous (till) ----------------------	15	85	100
	Sand, fine to medium grained, angular to subrounded, fair sorting ------------	3	100	103
	Clay, silty, sandy, olive gray, cohesive, calcareous (till) -------------------	24	103	127
Fox Hills Formation:				
	Siltstone, clayey, medium light gray, non-calcareous, moderately indurated -----	53	127	180
	Claystone, silty, brownish black to dark grayish black, moderately indurated, slightly calcareous -----------------	36	180	216
	Siltstone, silty to sandy, medium light gray to medium dark gray, indurated, non-calcareous ---------------------	64	216	280
	Siltstone, sandy, medium light gray, moderately indurated, non-calcareous ----	32	280	312
Pierre Formation:				
	Shale, dark gray to black, well indurated, non-calcareous ----------------	8	312	320
	Electric Log and Gamma Ray			
	159-74-30aaa Test Hole 3 Elevation 1488 Feet			
Glacial Drift:				
	Topsoil, sandy, brownish black ----------	1	0	1
	Sand, very fine to fine grained, subangular to subrounded, well sorted, > 75% quartz, remaining portion being shale, limestone, and granitics, oxidized to yellowish brown throughout ------------------------------	5	1	6

Formation	Material	Thickness (feet)	Depth (feet) From	To
	159-74-30aaa **Test Hole 3 (Cont.)** **Elevation 1488 Feet**			
	Clay, silty, pebbly, moderate yellowish orange upper 10 feet, lower 21 feet olive gray to medium gray, moderately cohesive, calcareous (till) ----------	31	6	37
	Mudstone and sandstone, yellowish gray, interbedded, indurated, calcareous ---	3	37	40
	Sand, very fine to fine grained, angular to subangular, well sorted, dark greenish gray, > 30% quartz with remaining portion being shale, lignite, limestone, and granitics -----------------	21	40	61
Fox Hills Formation:				
	Siltstone, clayey, light gray with some grayish blue laminations, moderately well indurated, non-calcareous -------	19	61	80
	Electric Log			
	159-75-1ccc **Test Hole 4** **Elevation 1458 Feet**			
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ---	1	0	1
	Clay, silty, medium yellowish orange, moderately cohesive, calcareous, oxidized ----------------------------	6	1	7
	Sand, very fine to fine, subangular to subrounded, well sorted, > 70% quartz with remaining portion being shale, limestone and lignite ----------------	17	7	24
	Clay, silty, pebbly, olive gray to medium dark gray, cohesive, calcareous (till)-	88	24	112
	Cobbles and boulders, gravelly, predominantly granitic and limestone rocks ---	4	112	116
	Clay, silty, olive gray, cohesive, calcareous (till) ----------------------	9	116	125
	Cobbles and boulders, gravelly, limestone, dolostone, and granitic rocks --------	2	125	127
	Clay, silty, pebbly, medium light gray, cohesive, calcareous (till) ----------	4	127	131
	Cobbles and boulders, gravelly, limestone, dolostone and granitic rocks ---------	3	131	134

159-75-1ccc
Test Hole 4 (Cont.)
Elevation 1458 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	Clay, sandy, silty, pebbly, medium light gray to olive gray, cohesive, calcareous (till) -------------------------	2	134	136
	Cobbles and boulders, gravelly, limestone, dolostone, shale and granitic rocks --	4	136	140
	Clay, sandy, gravelly, olive gray to medium dark gray, cohesive, calcareous (till) ------------------------------	34	140	174
Fox Hills Formation:				
	Shale, sandy, light gray to greenish gray, layered, well indurated, calcareous to non-calcareous -------------------	26	174	200

Electric Log

159-75-2acc
Test Hole 5
Elevation 1461 Feet

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
Glacial Drift:				
	Topsoil, silty, sandy, grayish black ----	1	0	1
	Sand, very fine to fine, subangular to subrounded, well sorted, oxidized to yellowish brown upper 3 feet, > 70% quartz with remaining portion being shale, limestone and granitics -------	14	1	15
	Clay, sandy, pebbly, olive gray to medium light gray, cohesive, calcareous (till) ------------------------------	45	15	60
	Clay, silty, medium light gray, very lignitic from 66 to 68 feet and 76 to 78 feet -----------------------	18	60	78
	Gravel, medium to coarse, angular to subangular, poorly sorted, numerous cobbles and boulders ------------------------	3	78	81
Fox Hills Formation:				
	Siltstone, sandy, light gray, well indurated, non-calcareous -----------------	19	81	100

Electric Log

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	159-75-11add **Test Hole 6** **Elevation 1468 Feet**			
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ---	1	0	1
	Clay, silty, sandy, medium yellowish orange, moderately cohesive, plastic, very calcareous, oxidized -----------	3	1	4
	Sand, very fine to fine, subangular to subrounded, moderately well sorted, > 50% quartz with remaining portion being shale, limestone and granitics, oxidized ---------------------------	2	4	6
	Clay, silty, sandy, medium yellowish orange to olive gray, cohesive, calcareous ----------------------------	25	6	31
	Clay, silty, lignitic, medium light gray to medium dark gray, moderately cohesive, calcareous (till) --------------	28	31	59
Fox Hills Formation:				
	Shale and siltstone, interbedded, brownish black to medium light gray, indurated, calcareous (siltstone) to non-calcareous (shale) --------------	21	59	80
	Electric Log			
	159-75-11ccd **Test Hole 7** **Elevation 1460 Feet**			
Glacial Drift:				
	Topsoil, silty, sandy loam, brownish black -------------------------------	1	0	1
	Sand, very fine to fine grained, subangular to subrounded, moderately well sorted, > 70% quartz with remaining constituents being limestone and granite, oxidized -------------------	9	1	10
	Clay, silty, olive gray, cohesive, calcareous -----------------------------	13	10	23
	Clay, sandy, silty, olive gray, cohesive, calcareous -------------------------	13	23	36
	Clay, silty, sandy, pebbly, olive gray, cohesive, calcareous (till) ----------	27	36	63

Formation	Material	Thickness (feet)	Depth (feet) From	To
	159-75-11ccd Test Hole 7 (Cont.) Elevation 1460 Feet			
	Sand, gravelly, coarse to very coarse, subangular to subrounded, moderately well sorted, > 50% quartz, some lignite and limestone	5	63	68
	Clay, sandy, pebbly, olive gray, cohesive (till)	3	68	71
	Sand, silty and clayey, medium to coarse, angular to subangular, poorly sorted	3	71	74
	Clay, silty, pebbly, medium light gray, moderately cohesive, calcareous (till)	18	74	92
Fox Hills Formation:				
	Shale, sandy to silty, brownish gray, moderately indurated, non-calcareous	28	92	120
	Electric Log			
	159-75-11daa Test Hole 8 Elevation 1467 Feet			
Glacial Drift:				
	Topsoil, silty,sandy, brownish black	1	0	1
	Clay, silty, medium yellowish orange upper 12 feet (oxidized) to olive gray bottom 2 feet, moderately cohesive, calcareous	14	1	15
	Sand, very fine to fine, subangular to subrounded, moderately well sorted, oxidized upper 10 feet, > 60% quartz	12	15	27
	Clay, silty, sandy, olive gray to medium dark gray, cohesive, calcareous (till)	33	27	60
	159-75-12caa Test Hole 9 Elevation 1470 Feet			
Glacial Drift:				
	Topsoil, silty, sandy, grayish black	1	0	1
	Clay, silty, moderate yellowish brown upper 8 feet (oxidized) to medium dark gray, cohesive, calcareous	17	1	18

Formation	Material	Thickness (feet)	Depth (feet) From	To
	159-75-12caa **Test Hole 9 (Cont.)** **Elevation 1470 Feet**			
	Sand, very fine to fine, angular to subangular, moderately well sorted, > 60% quartz with remaining portion being limestone, shale and granitics -------	10	18	28
	Clay, silty, sandy, pebbly, olive gray, lignitic from 45 to 55 feet, cohesive, calcareous (till) -------------------	40	28	68
Fox Hills Formation:				
	Sandstone and siltstone, interbedded, dusky yellow (siltstone) to medium bluish gray (sandstone), well indurated, non-calcareous ----------------	12	68	80
	Electric Log			
	159-75-12cbb **Test Hole 10** **Elevation 1460 Feet**			
Glacial Drift:				
	Topsoil, silty, sandy, grayish black ----	1	0	1
	Clay, silty, medium yellowish orange, moderately cohesive, calcareous, oxidized ---------------------------	2	1	3
	Sand, fine to medium grained, subangular to subrounded, moderately well sorted, > 60% quartz with remaining portion being shale, limestone and granitics -	21	3	24
	Clay, silty, sandy, pebbly, medium gray to medium light gray, cohesive, calcareous ----------------------------	31	24	55
Fox Hills Formation:				
	Siltstone, clayey, light gray to medium light gray with a few medium bluish gray layers, moderately well indurated, non-calcareous ----------------------	45	55	100

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To

159-75-12cbc$_1$
Test Hole 11
Elevation 1473 Feet

Formation	Material	Thickness (feet)	From	To
Glacial Drift:				
	Topsoil, silty, sandy, grayish black ----	1	0	1
	Clay, silty, moderate yellowish brown, slightly cohesive, oxidized, calcareous --------------------------------	6	1	7
	Sand, very fine to fine, angular to subangular, moderately well sorted, slightly oxidized, > 50% quartz ------	7	7	14
	Clay, silty, sandy, olive gray, cohesive, plastic, calcareous -----------------	20	14	34
	Clay, silty, pebbly, olive gray to medium dark gray, cohesive, moderately plastic, lignitic, calcareous (till) ----------	31	34	65
Fox Hills Formation:				
	Sandstone and siltstone, interbedded, moderate reddish brown (oxidized) to light gray, well indurated, non-calcareous -	15	65	80

Electric Log

159-75-12ccb$_2$
Test Hole 12
Elevation 1462 Feet

Formation	Material	Thickness (feet)	From	To
Glacial Drift:				
	Topsoil, sandy loam, brownish black -----	½	0	½
	Sand, fine to medium grained, angular to subangular, well sorted, > 80% quartz with remaining constituents being limestone and granite, oxidized upper 15 feet ----------------------------	24½	½	25
	Clay, sandy with lignite grains, olive gray to medium dark gray, moderately cohesive --------------------------	2	25	27
	Sand, fine to medium grained, angular to subangular, well sorted -------------	8	27	35
	Clay, sandy, olive gray to medium dark gray, cohesive ---------------------	2	35	37
	Sand, fine to medium grained, angular to subangular, moderately well sorted ---	3	37	40
Fox Hills Formation:				
	Claystone and siltstone, interbedded, sandy, light gray to medium dark gray, soft to indurated, calcareous to non-calcareous -------------------------	140	40	180

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	159-75-12ccb2 Test Hole 12 (Cont.) Elevation 1462 Feet			
	Siltstone, clayey, medium light gray, slightly indurated, slightly calcareous to non-calcareous, siderite ($FeCo_3$) concretions from 197 to 216 feet	40	180	220
	Siltstone, clayey, sandy, medium light gray, slightly indurated, non-calcareous	96	220	316
Pierre Formation:				
	Shale, brownish black to black, indurated, non-calcareous, thin bentonite layers throughout	24	316	340
	Gamma Ray			
	159-75-12ccc Test Hole 13 Elevation 1469 Feet			
Glacial Drift:				
	Topsoil, silty, grayish black	1	0	1
	Clay, silty, sandy, dark yellowish orange upper 4 feet (oxidized) to medium light gray, cohesive, calcareous	8	1	9
	Sand, very fine to fine, subangular to subrounded, well sorted, > 70% quartz with remaining portion being shale, limestone, and granitics	17	9	26
	Clay, silty, olive gray to medium light gray, very cohesive, plastic, calcareous	2	26	28
	Observation Well			
	159-75-12cdd Test Hole 14 Elevation 1465 Feet			
Glacial Drift:				
	Topsoil, silty, brownish black	1	0	1
	Sand, very fine to fine, subangular to subrounded, well sorted, > 60% quartz with remaining portion being shale, limestone, and granitics, oxidized	3	1	4

Formation	Material	Thickness (feet)	Depth (feet) From	To
	159-75-12cdd **Test Hole 14 (Cont.)** **Elevation 1465 Feet**			
	Clay, silty, sandy, dark yellowish orange upper 4 feet (oxidized) to olive gray, moderately cohesive, calcareous	12	4	16
	Sand, very fine to fine, predominantly subrounded, well sorted, unoxidized, > 60% quartz	15	16	31
	Clay, silty, olive gray, cohesive, calcareous	1	31	32
	Observation Well			
	159-75-12ddd **Test Hole 15** **Elevation 1467 Feet**			
Glacial Drift:				
	Topsoil, silty loam, brownish black	1	0	1
	Clay, silty, sandy, light olive brown to moderate olive brown, cohesive, calcareous, oxidized	22	1	23
	Clay, silty with sand and pebbles, olive gray, cohesive, moderately plastic, calcareous (till)	23	23	46
	Gravel, silty, clayey, fine to medium, angular to subangular, poorly sorted, predominantly limestone and shale constituents	3	46	49
Fox Hills Formation:				
	Shale, sandy, silty, greenish, black, moderately indurated, non-calcareous, interbedded with thin layers of medium bluish gray sandstone	51	49	80
	Electric Log			

Formation	Material	Thickness (feet)	Depth (feet) From	To
	159-75-13baa Test Hole 16 Elevation 1468 Feet			
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ---	1	0	1
	Clay, silty, dark yellowish orange, moderately cohesive, calcareous, oxidized ---------------------------	6	1	7
	Sand, very fine to fine, subangular to subrounded, well sorted, > 60% quartz with remaining portion being shale, limestone, and granitics -------------	26	7	33
	Clay, silty, olive gray to medium dark gray, cohesive, calcareous -----------	1	33	34
	Observation Well			
	159-75-13bac Test Hole 17 Elevation 1470 Feet			
Glacial Drift:				
	Topsoil, silty, grayish black -----------	1	0	1
	Clay, silty, dark yellowish orange, cohesive, calcareous, oxidized -------	8	1	9
	Clay, silty, pebbly, olive gray to medium dark gray, moderately cohesive, calcareous (till) ----------------------	48	9	57
Fox Hills Formation:				
	Shale, dark greenish gray to brownish gray, well indurated, non-calcareous, laminated --------------------------	3	57	60
	159-75-16aaa Test Hole 18 Elevation 1462 Feet			
Glacial Drift:				
	Topsoil, silty, sandy, grayish black ----	1	0	1
	Clay, silty, sandy, dark yellowish orange, slightly cohesive, calcareous, oxidized ---------------------------	10	1	11
	Clay, silty, olive gray to light olive gray, cohesive, calcareous -----------	24	11	35

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	159-75-16aaa Test Hole 18 (Cont.) Elevation 1462 Feet			
	Clay, very sandy, olive gray, moderately cohesive, calcareous ----------------	35	35	70
	Sandstone, clayey, medium bluish gray, slightly indurated, non-calcareous, not cemented, (boulder or block dropped by melting glacial ice) ----------	14	70	84
	Clay, sandy, pebbly, medium light gray, calcareous, cohesive (till) ----------	13	84	97
	Gravel, medium to coarse, angular to subrounded, fairly well sorted ----------	9	97	106
	Clay, silty, gravelly, olive gray, cohesive, calcareous, lignitic (till) --	16	106	122
	Clay, silty, gravelly with a few cobbles and boulders, olive gray, moderately cohesive (till) ---------------------	6	122	128
Fox Hills Formation:				
	Siltstone, light gray to medium light gray, interbedded with a few brownish gray shale layers, non-calcareous, poorly indurated --------------------	12	128	140
	Electric Log			
	159-75-24bbb Test Hole 19 Elevation 1475 Feet			
Glacial Drift:				
	Topsoil, silty and sandy, brownish gray -	1	0	1
	Sand, very fine to fine, subangular to subrounded, well sorted, > 80% quartz, oxidized to yellowish brown upper 8 feet --------------------------------	10	1	11
	Clay, silty, olive gray, cohesive, plastic ----------------------------	21	11	32
	Clay, silty, sandy, pebbly, medium light gray to medium gray, cohesive, moderately plastic, calcareous (till) ---	11	32	43
	Sand, coarse to very coarse grained, angular to subrounded, fair sorting, unoxidized --------------------------	6	43	49
	Clay, silty, sandy, medium light gray, slightly calcareous, cohesive (till) -	2	49	51

Formation	Material	Thickness (feet)	Depth (feet) From	To
	159-75-24bbb Test Hole 19 (Cont.) Elevation 1475 Feet			
Fox Hills Formation:				
	Siltstone, sandy, light gray, moderately indurated, non-calcareous ------------	29	51	80
	Electric Log			
	159-75-24ccc Test Hole 20 Elevation 1480 Feet			
Glacial Drift:				
	Topsoil, sandy, silty, brownish black ---	1	0	1
	Sand, very fine to fine grained, subangular to subrounded, well sorted, > 70% quartz, oxidized to yellowish brown upper 8 feet of section --------	15	1	16
	Clay, silty, lignitic, light gray to medium light gray, very cohesive, calcareous --------------------------	33	16	49
	Sand, gravelly, coarse to very coarse, subangular to subrounded, fair to good sorting ------------------------	7	49	56
	Gravel, very clayey, fine to medium, angular, poorly sorted ---------------	4	56	60
Fox Hills Formation:				
	Sandstone, light gray, unconsolidated, not cemented, non-calcareous ---------	20	60	80
	Electric Log			
	159-75-26ccc Test Hole 21 Elevation 1475 Feet			
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ---	1	0	1
	Clay, silty, sandy, dark yellowish orange, slightly cohesive, calcareous, sand occurs in thin layers ----------------	6	1	7
	Clay, silty, pebbly, medium light gray to medium gray, cohesive, calcareous (till) -------------------------------	58	7	65

Formation	Material	Thickness (feet)	Depth (feet) From	To
	159-75-26ccc Test Hole 21 (Cont.) Elevation 1475 Feet			
	Gravel, medium to coarse, angular to subangular, poorly sorted, mostly limestone and shale	3	65	68
	Clay, silty, sandy, pebbly, olive gray, cohesive, moderately plastic, calcareous (till)	17	68	85
Fox Hills Formation:				
	Sandstone, clayey, medium bluish gray with bluish-white calcareous layers, generally non-calcareous, unconsolidated, not cemented	15	85	100
	Electric Log			
	159-75-36bbb Test Hole 22 Elevation 1475 Feet			
Glacial Drift:				
	Topsoil, silty, brownish black	1	0	1
	Clay, very sandy, silty, yellowish brown to yellowish orange, cohesive, moderately plastic, oxidized	7	1	8
	Clay, sandy, pebbly, lignitic, olive gray to medium dark gray, cohesive, calcareous (till)	60	8	68
	Gravel, sandy, medium, angular to subangular, poorly sorted	10	68	78
	Clay, silty, pebbly, medium light gray to light gray, cohesive, calcareous (till)	3	78	81
Fox Hills Formation:				
	Sandstone, clayey, medium bluish gray with a few light gray layers, slightly consolidated, non-calcareous	19	81	100
	Electric Log			

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	160-74-31ddd **Test Hole 23** **Elevation 1472 Feet**			
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ---	1	0	1
	Sand, coarse to very coarse, subangular to subrounded, well sorted, > 50% quartz, oxidized --------------------	8	1	9
	Clay, silty, olive gray to medium dark gray, moderately cohesive, calcareous-	31	9	40
	Clay, silty, pebbly, medium gray to medium dark gray, cohesive, calcareous (till) ------------------------	58	40	98
	Clay, silty, pebbly, medium dark gray, lignitic, cohesive, calcareous (till) ----------------------------	8	98	106
	Clay, silty, sandy, pebbly, olive gray to medium dark gray, cohesive, calcareous grading to non-calcareous bottom 10 feet (till) ---------------	98	106	204
Fox Hills Formation:				
	Shale, clayey, grayish black to brownish black, well indurated, non-calcareous-	16	204	220
	Electric Log			
	160-75-35dad **Test Hole 24** **Elevation 1463 Feet**			
Glacial Drift:				
	Topsoil, silty, brownish black ----------	1	0	1
	Clay, silty, medium yellowish orange, cohesive, oxidized, calcareous -------	7	1	8
	Clay, sandy, pebbly, medium light gray to olive gray, cohesive, moderately plastic, calcareous (till) -----------	44	8	52
	Gravel, sandy, fine, angular to subrounded, moderately well sorted ------	4	52	56
	Clay, silty, sandy, medium light gray, cohesive, calcareous (till) ----------	12	56	68
	Sand, very fine to fine, angular to subrounded, moderately well sorted, > 70% quartz -----------------------------	8	68	76
	Clay, sandy, pebbly, olive gray, cohesive, calcareous, (till) -------------------	3	76	79

Formation	Material	Thickness (feet)	Depth (feet) From	To
	160-75-35dad **Test Hole 24 (Cont.)** **Elevation 1463 Feet**			
	Sandy, very fine to fine, angular to subrounded, well sorted, > 70% quartz ---	3	79	82
	Clay, sandy, pebbly, olive gray, cohesive, lignitic, calcareous (till) ----------	18	82	100
	Sand, medium to coarse grained, subangular to subrounded, moderately well sorted, > 80% quartz -----------------------	8	100	108
Fox Hills Formation:				
	Shale, dark greenish gray, well indurated, non-calcareous ----------------------	12	108	120
	Electric Log			
	160-75-36bbb **Test Hole 25** **Elevation 1470 Feet**			
Glacial Drift:				
	Topsoil, silty, sandy, brownish black ---	1	0	1
	Clay, silty, sandy, medium yellowish orange, moderately cohesive, oxidized, calcareous (till) -------------------	20	1	21
	Clay, sandy, pebbly, olive gray to medium light gray, cohesive, calcareous (till) -----------------------------	54	21	75
	Gravel, sandy, medium to coarse, angular to subrounded, fair sorting, predominantly limestone and dolomite with some stained (limonitic, light brown) quartz -----------------------	12	75	87
	Clay, sandy, lignitic, olive gray to medium light gray, cohesive, calcareous (till) ------------------------	18	87	105
	Sand, very fine to fine, angular to subrounded, fair sorting, > 80% quartz --	2	105	107
	Clay, sandy, lignitic, medium gray, cohesive, slightly plastic, calcareous (till) -----------------------------	5	107	112
	Sand, very fine to fine, angular to subrounded, fair sorting, > 80% quartz --	2	112	114
	Clay, gravelly, medium light gray, cohesive, slightly plastic, calcareous (till) -----------------------------	12	114	126

Formation	Material	Thickness (feet)	Depth (feet) From	To
	160-75-36bbb Test Hole 25 (Cont.) Elevation 1470 Feet			
	Gravel, medium to coarse, angular to sub-angular, poorly sorted ----------------	4	126	130
	Clay, sandy, pebbly, medium dark gray to dark gray, cohesive, calcareous (till)-	13	130	143
Fox Hills Formation:				
	Shale, sandy, brownish gray to brownish black, well indurated, non-calcareous--	17	143	160

Electric Log

REFERENCES

Cobb, W. B., and others, 1915, Soil Survey of Bottineau County, North Dakota: U. S. Department of Agriculture, Bureau of Soils, 54 p.

Froelich, Larry L., 1963, Investigations of Ground Water Conditions in the Bottineau Area, Bottineau County, North Dakota: North Dakota Ground Water Studies No. 52, 60 p.

Goddard, E. N., and others, 1963, Rock-Color Chart: Geological Society of America.

Lemke, R. W., 1960, Geology of the Souris River Area, North Dakota: U. S. Geological Survey Prof. Paper 325, 138 p.

Pettijohn, F. J., 1967, Sedimentary Rocks: New York, Harper and Brothers, p. 15-51.

Schmid, Roger W., 1965, Water Quality Explanation: North Dakota State Water Commission, unpublished report, file number 989.

Simpson, Howard E., 1929, Geology and Ground-Water Resources of North Dakota: U. S. Geological Survey Water-Supply Paper 598, p. 80-90.

Tourtelot, Harry A., 1962, Preliminary Investigation of the Geological Setting and Chemical Composition of the Pierre Shale Great Plains Region: U. S. Geological Survey Prof. Paper 390, 74 p.

U. S. Department of Commerce, 1966, Climatological Data (of) North Dakota: U. S. Department of Commerce, Weather Bureau, Annual Summary 1965, V. 73, no. 13, p. 196-198.