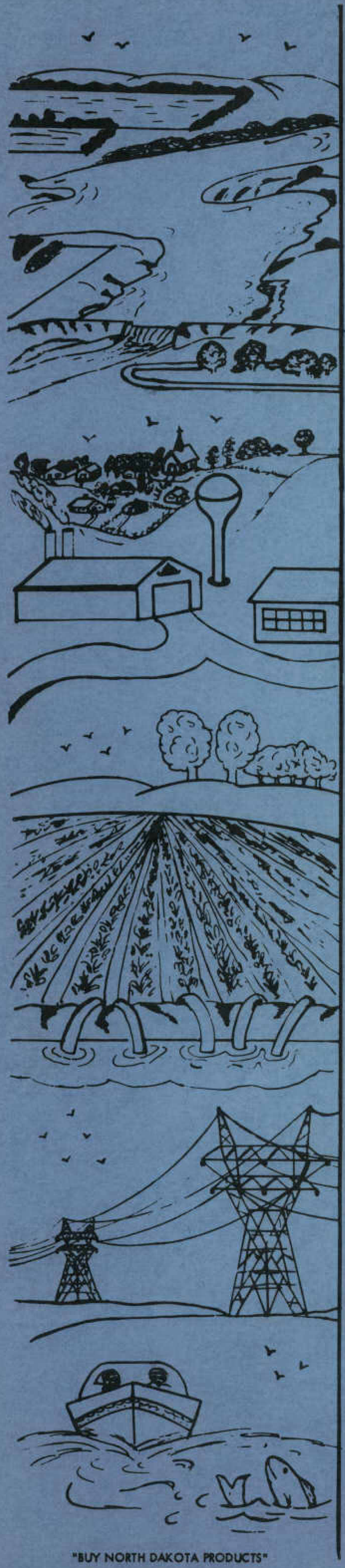


"BUY NORTH DAKOTA PRODUCTS"

GROUND WATER IN THE ROLLA AREA
ROLETTE COUNTY, NORTH DAKOTA
SWCC PROJECT NO. 797

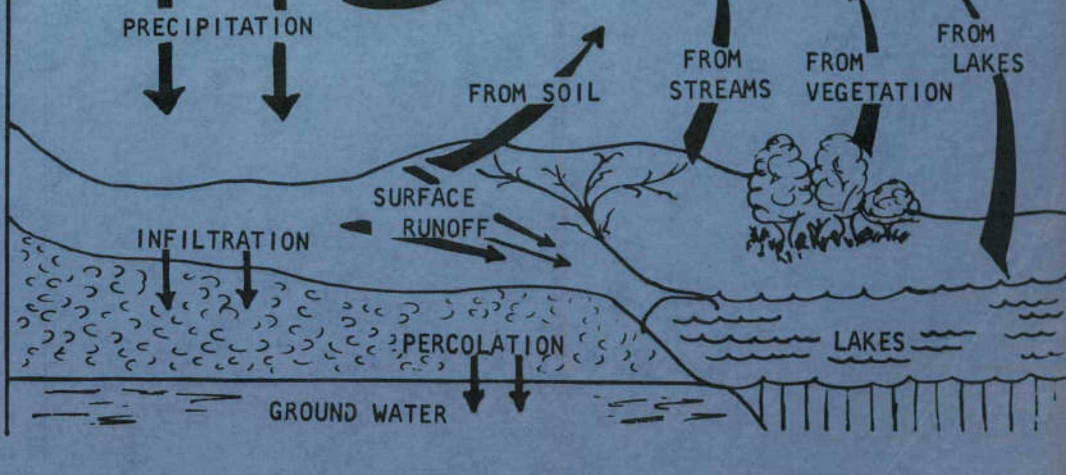
BY
R. W. SCHMID, GEOLOGIST
WITH
PUMP TEST ANALYSES
BY
MILTON O. LINDVIG, GROUND-WATER ENGINEER

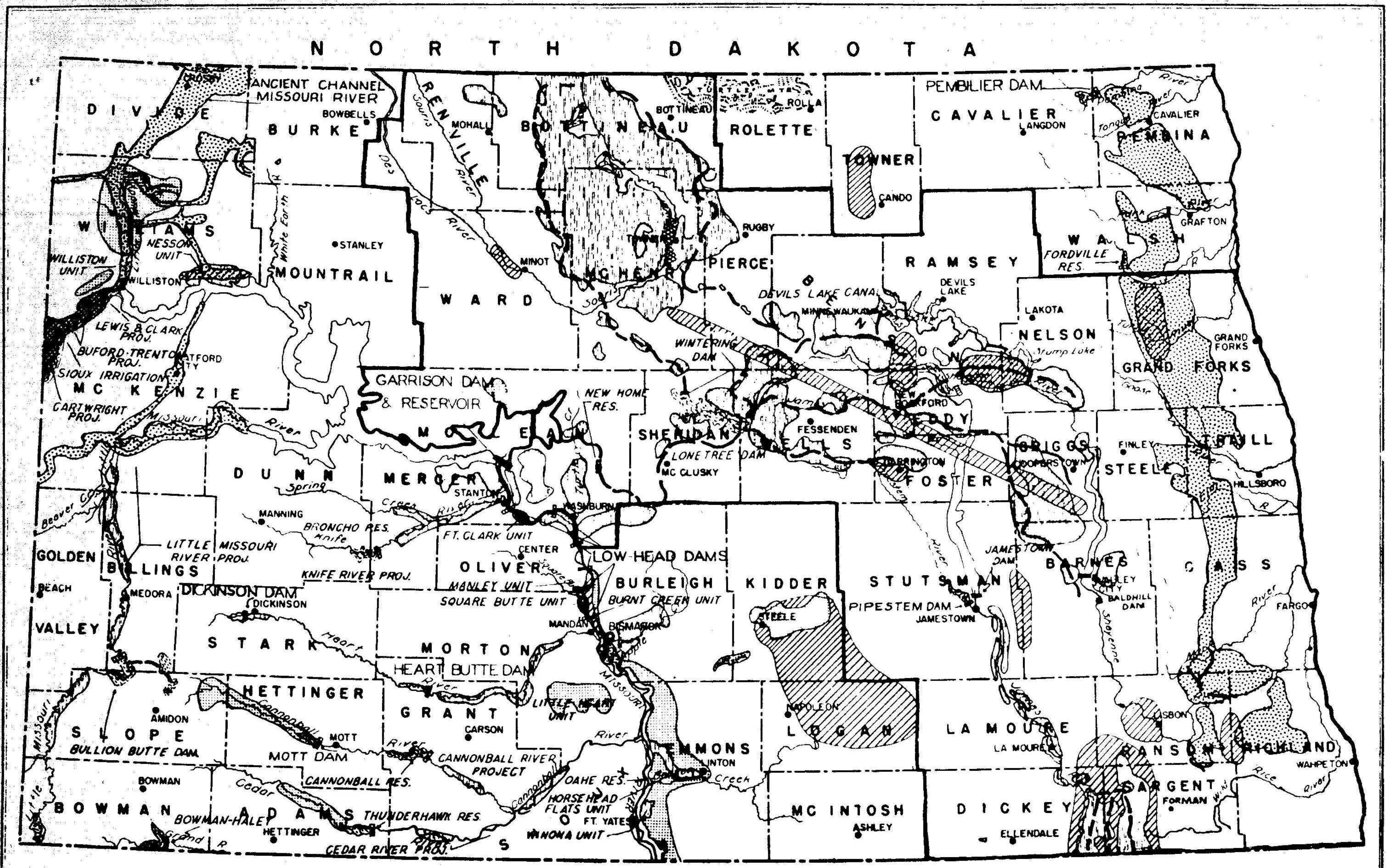
NORTH DAKOTA GROUND WATER STUDIES

NO. 57

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

1964





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

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GROUND WATER IN THE ROLLA AREA, ROLETTE COUNTY, NORTH DAKOTA SWCC PROJECT NO. 797

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ILLUSTRATIONS AND BASIC DATA TABLES

GROUND WATER IN THE ROLLA AREA, ROLETTE COUNTY, NORTH DAKOTA

by
Roger W. Schmid, Geologist

INTRODUCTION

Rolla, population 1,398 (1960 census), is in northeastern Rolette County. The City is served by the Great Northern Railroad and is located at the intersection of State Highways 30 and 5. Rolla is situated near the center of the 48 square mile study area (fig. 1 and 3).

The average annual precipitation, from 1938 to 1955, recorded by the U.S. Weather Bureau at Rolla was 17.56 inches, yearly totals from 1955 to 1962 ranged from 13.40 to 20.09 inches. Most of the precipitation occurs during the growing season. The mean annual temperature for the 18 year period was 37.2° F. Yearly averages from 1955 to 1962 departed less than 2 degrees from this mean. The extreme high temperature from 1955 to 1962 was 100° F., while the lowest temperature recorded for that period was -35° F. (Weather Bureau, 1956-1962).

This study was made by the State Water Commission during July of 1963 for the purpose of locating additional acceptable water supplies for Rolla. The City now obtains most of its municipal supply from three low capacity shallow wells. In emergencies a high capacity deep well is used; however, its poor quality water is unacceptable for general use.

Simpson (1929, p. 214-217) briefly discussed the ground-water resources of Rolette County in a general study of the whole state. Abbott and Voedish (1938, p. 74-75) made analyses of well water from Rolla in a study of municipal ground-water supplies in the state. Brookhart and Powell (1961, p. 6-34) assembled data

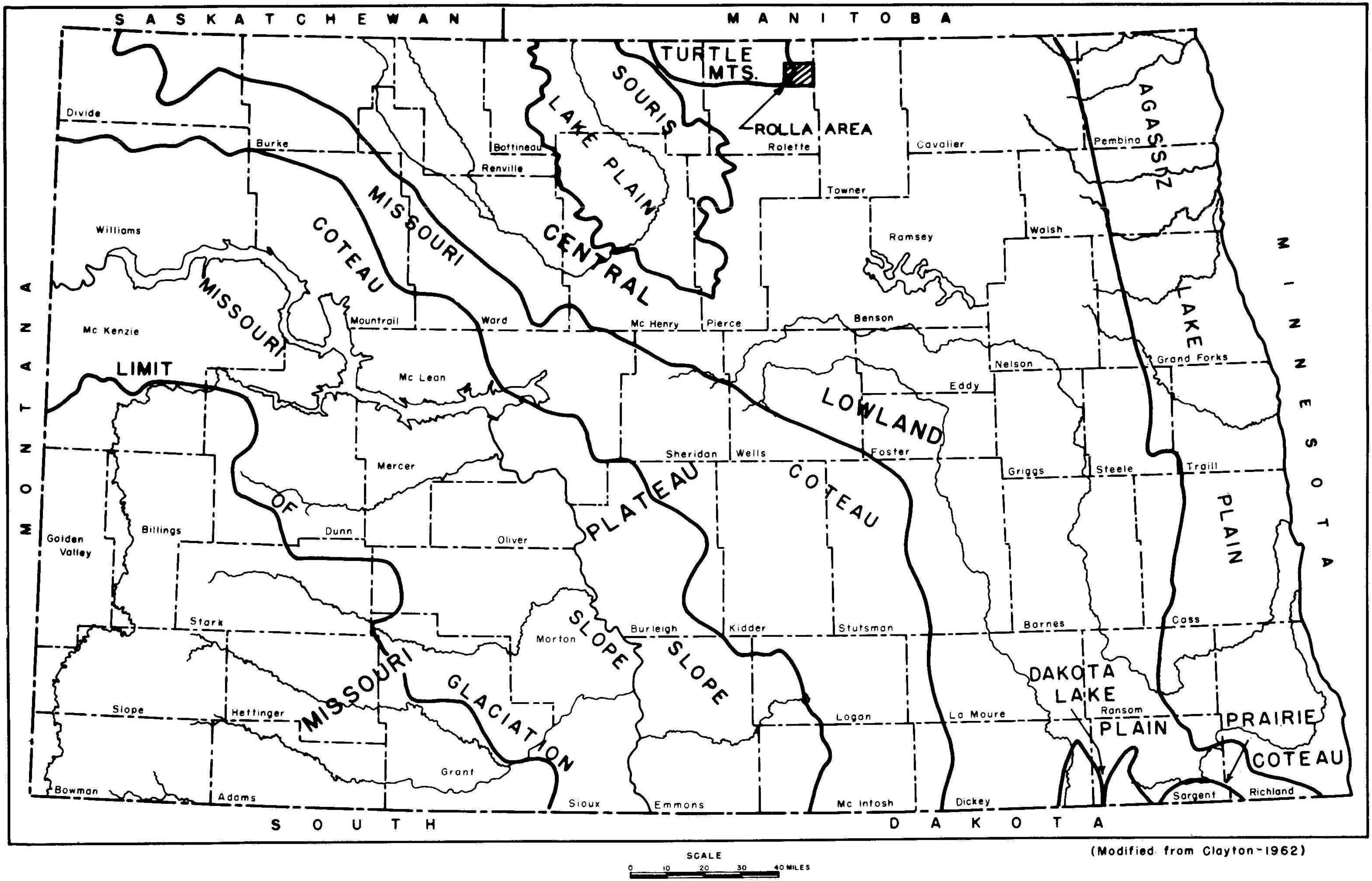


FIGURE I--MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC UNITS AND LOCATION OF THE ROLLA AREA for a reconnaissance report on the ground-water and geology in the Rolla-St. John area.

The cooperation of City Auditor Victor C. Jackson, Mayor Elmer Larson, other members of the City Council, and residents of the area was of considerable assistance to this project. Data from the earlier U.S. Geological Survey study of the area (Brookhart & Powell, 1961) was quite valuable in preparing this report.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report is illustrated in Figure 2 and is based upon the location of the well within the grid established by the U.S. Bureau of Land Management's survey of the area. The first numeral denotes the township north of the base line which extends laterally across the middle of Arkansas; the second numeral denotes the range west of the fifth principal meridian; and the third numeral denotes the section in which the well is located. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarter sections, quarter-quarter sections, and quarter-quarter-quarter sections (10-acre tracts). Consecutive terminal numerals are added when more than one well is located within a given 10-acre tract. Thus, well 162-69-15daa is in the NE¼ NE¼ SE¼ of Section 15, Township 162 North, Range 69 West. Similarly, well 162-69-8 dcd2 is the second well located in the SE¼ SW¼ SE¼ of Section 8, Township 162 North, Range 69 West.

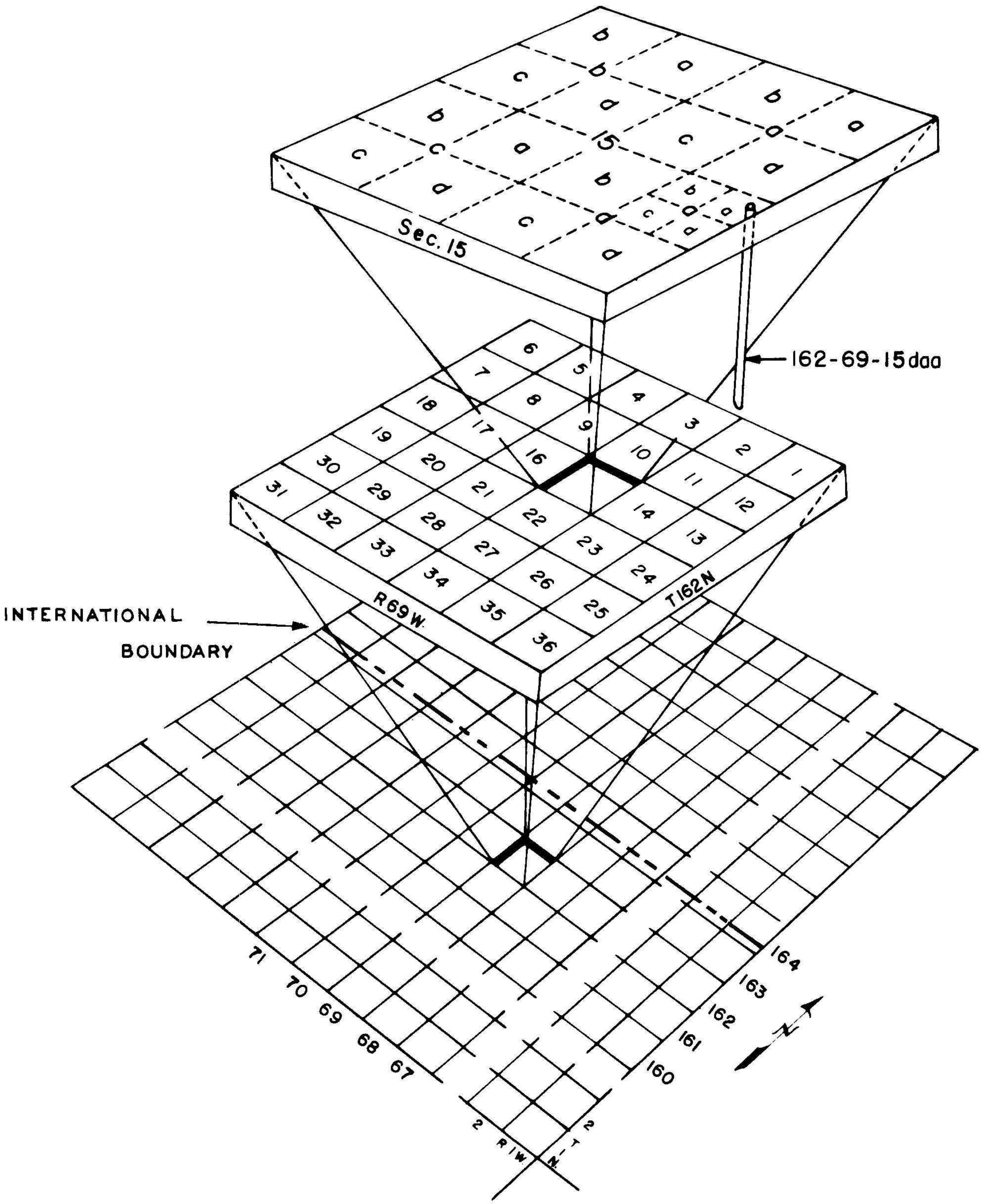


FIGURE 2--SYSTEM OF NUMBERING WELLS AND TEST HOLES.

GLACIAL GEOLOGY

The area studied is located in the Western Young Drift section of the Central Lowland physiographic province (Fenneman, 1938, p. 559-588). The northwestern corner of the area is in the Turtle Mountains, an outlier of the Missouri Plateau (fig. 1).

Drainage is fairly well developed with most of the heavy runoff eventually entering Devils Lake by way of Mauvais Coulee. Extreme knob and kettle topography coupled with dense vegetation generally prevents surface runoff in the Turtle Mountains, except as one lake is filled and overflows to another.

The topography of the Rolla area consists primarily of the ground moraine, an east-southeast sloping plain with a few potholes and intermittent streams providing a local relief of less than 25 feet. The Turtle Mountains, which constitute about 1/10 of the total study area, have a local relief of 50 to 100 feet on the knob and kettle topography of this stagnation moraine. The outer edge of the Turtle Mountains and the adjacent ground moraine slope away from the Turtle Mountains at a rate of 50 to 100 feet per mile.

The present topography in the Rolla area is primarily the result of glaciation during the Pleistocene or "Ice Age". Test holes (fig. 3 and table 3) indicate there is 87 to 310 feet of glacial drift in the study area. Glacial drift consists predominately of till, a heterogenous mixture of clay, silt, sand and gravel which was deposited by the ice. Other constituents of drift are water sorted sand and gravel deposits and the clays and silts which were deposited in standing water.

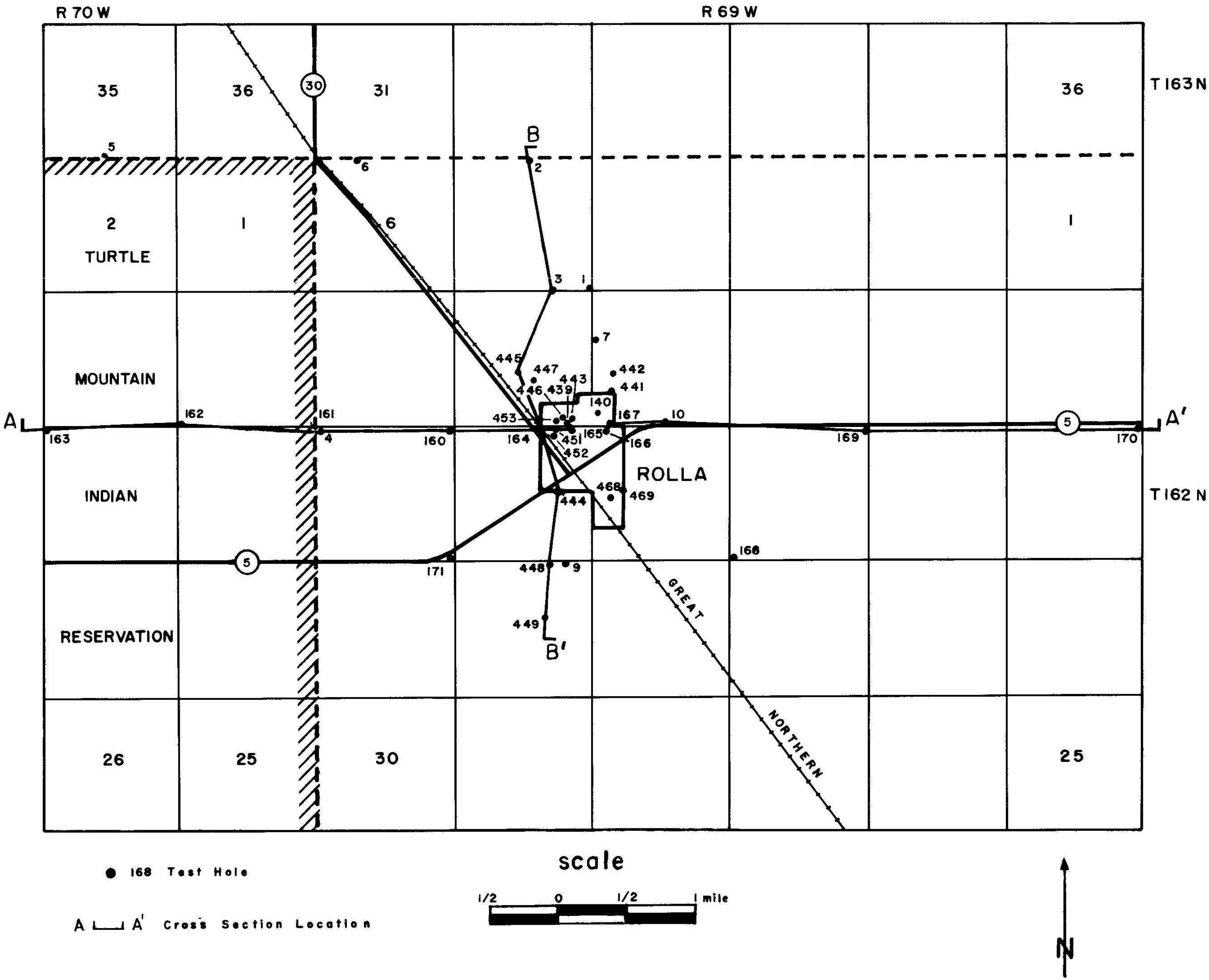


FIGURE 3 TEST HOLE LOCATIONS

The preglacial topography of the Rolla area (fig. 4 and 5) consisted of the Turtle Mountain plateau, a deep valley on the east side of the plateau and a southeasterly sloping plain over the remainder of the area. The preglacial valley west of Rolla was probably being rapidly eroded by melt water from the encroaching glaciers as the ice moved into the area.

The bedrock or preglacial formations in this area are classified in Table 2 as Undifferentiated Bedrock, which, according to Hansen (1956), are probably the Paleocene Tongue River and Cannonball formations and the Cretaceous Fox Hills Formation. These formations are thin in this area and probably absent in the deeper test holes such as 161, 4-797, and 170 (162-70-12ddd, 162-69-18bbb, and 162-69-13aaa). The Cretaceous Pierre Shale forms the preglacial surface in the areas of low bedrock elevations, as in the three locations listed above, and underlies the Fox Hills Formation in the remainder of the area.

The Rolla area has been glaciated numerous times. Each advance and subsequent retreat of the glacial ice eroded portions of the previous surface and deposited new drift. The present surface of the area (fig. 6) originated as the last ice sheet retreated. Ground moraine is the result of an orderly retreat of a glacier in which the ice front melts faster than the glacier moves forward. A stagnation moraine results from a glacier stagnating, that is, the ice becomes thinner than the minimum thickness required for ice flow within a glacier. The melting of stagnated ice results in a rough knob and kettle topography as in the Turtle Mountains and the Missouri Coteau (fig. 1). Outwash results as melt waters from an ice front or a body of stagnant ice deposit sand and gravel. These sand and gravel deposits

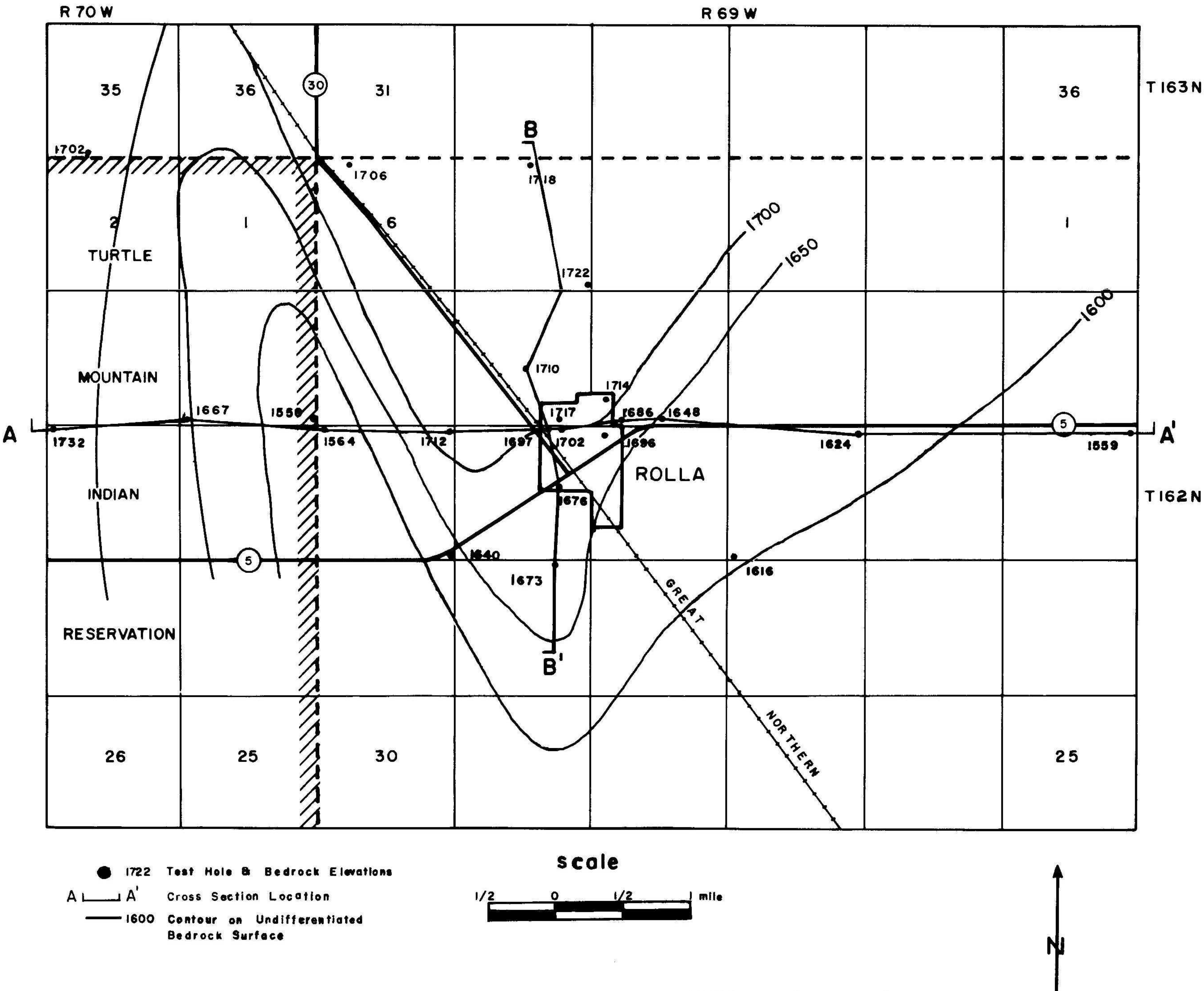


FIGURE 4 PREGLACIAL TOPOGRAPHY

are quite variable in thickness and areal extent. Outwash because of its excellent subsurface drainage, is generally recognizable by a lack of potholes and surficial drainage channels.

At least three major glacial retreats, including the present time, have occurred in the Rolla area. These different glaciations are recognized in the subsurface by zones of oxidation or weathering (fig. 5). Oxidation seldom occurs beneath the water table but is generally restricted to the zone of aeration (Thornbury, 1954). Buried zones of oxidation, therefore, indicate the presence of a former land surface. In many cases these weathered surfaces are eroded by the next advance of glacial ice. Only four test holes in the Rolla area have the three zones of oxidation preserved in the glacial drift (1-797, 6-797, 4-797, and 161 at 162-69-5ddd, 162-69-6bab, 162-69-18bbb, and 169-70-12ddd). Two other test holes (165 and 164 at 162-69-17aab and 162-69-17abb) revealed two zones of oxidized drift plus a weathered bedrock surface. Other locations contain zones of partially weathered material which could indicate either partially oxidized drift or oxidized drift that has been reworked by glacial action.

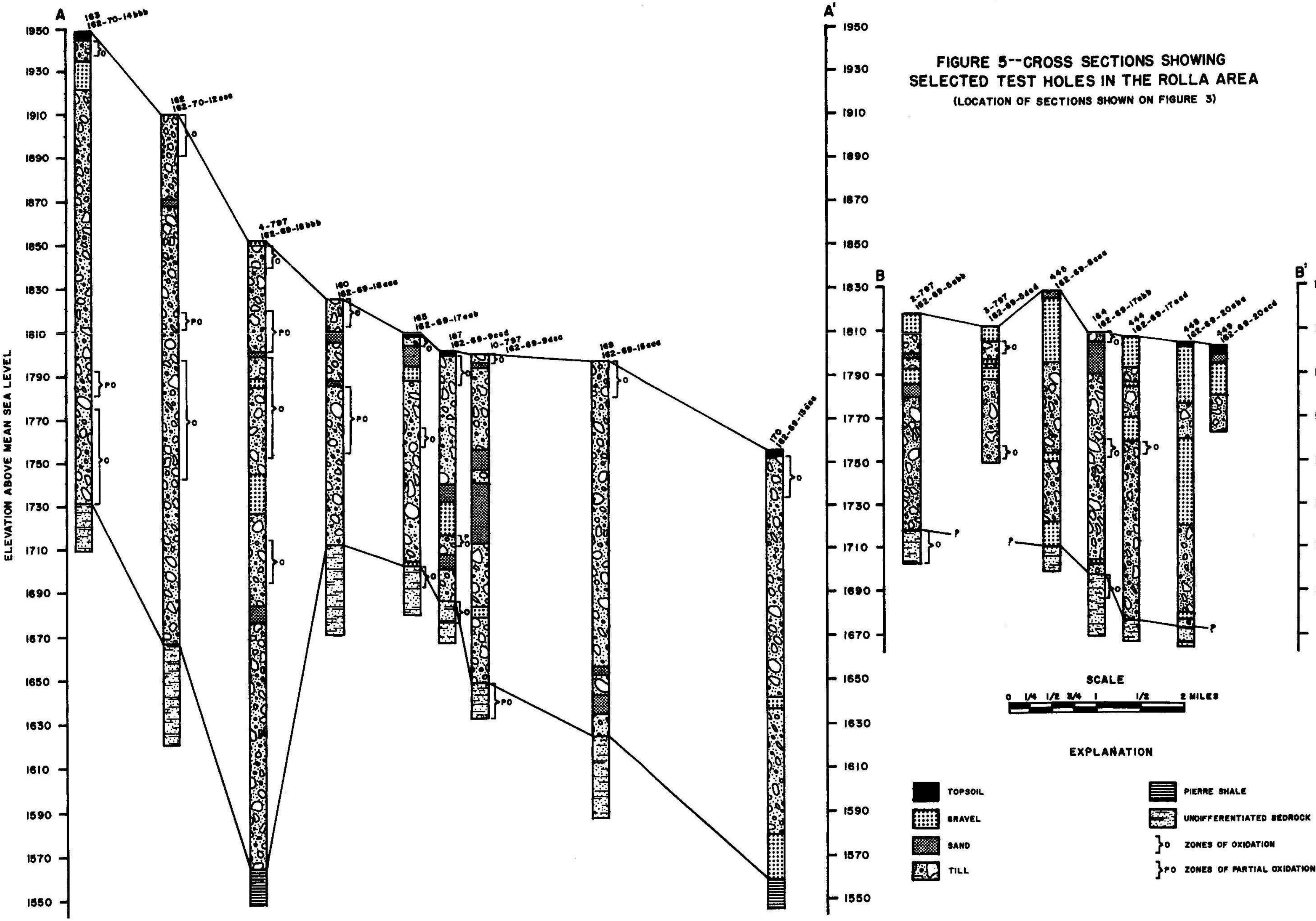


FIGURE 5--CROSS SECTIONS SHOWING SELECTED TEST HOLES IN THE ROLLA AREA

(LOCATION OF SECTIONS SHOWN ON FIGURE 3)

WATER QUALITY

Water quality determinations were made on a number of water samples taken while the field work at Rolla was in progress. Other analyses were obtained from the State Health Department and the earlier U.S. Geological Survey study of the area. Chemical analyses of water from the Rolla area are shown in Table 1 and water quality standards are given in Table 2.

Water in the Rolla area, while fairly good in most respects, has a number of bad aspects which result in rather poor quality. Only six of the water samples analyzed for iron and sulphates included these constituents in less than the maximum permissible amounts. Eleven of the samples exceeded the water quality standards for total dissolved solids. Nearly all of the water is quite hard and requires softening. Other constituents of the waters of the area are generally within the permissible concentrations set forth by the Sanitary Engineering Services of the State Department of Health (table 2).

Hardness and iron can be economically removed by a water treatment plant. No satisfactory means of removing sulphates or lowering the total dissolved solids has been devised, present methods are complicated and expensive. Although 1000 to 1500 ppm total dissolved solids are the maximum permissible, more highly mineralized water can be used if nothing better is available. The human body, however, has difficulty becoming accustomed to water containing over 2000 ppm total dissolved solids. Sulphates constitute the major water quality problem in the Rolla area. Sulphates can be tolerated beyond the permissible limit of 250 ppm but only to somewhat less than 1000 ppm. People in the Rolla area could probably tolerate sulphates of up to 650 or 700 ppm if the total dissolved solids were less than 1500 ppm. In any case, a sulphate content of less than 500 ppm is certainly desirable.

SURFICIAL GEOLOGY OF NORTHEASTERN ROLETTE COUNTY

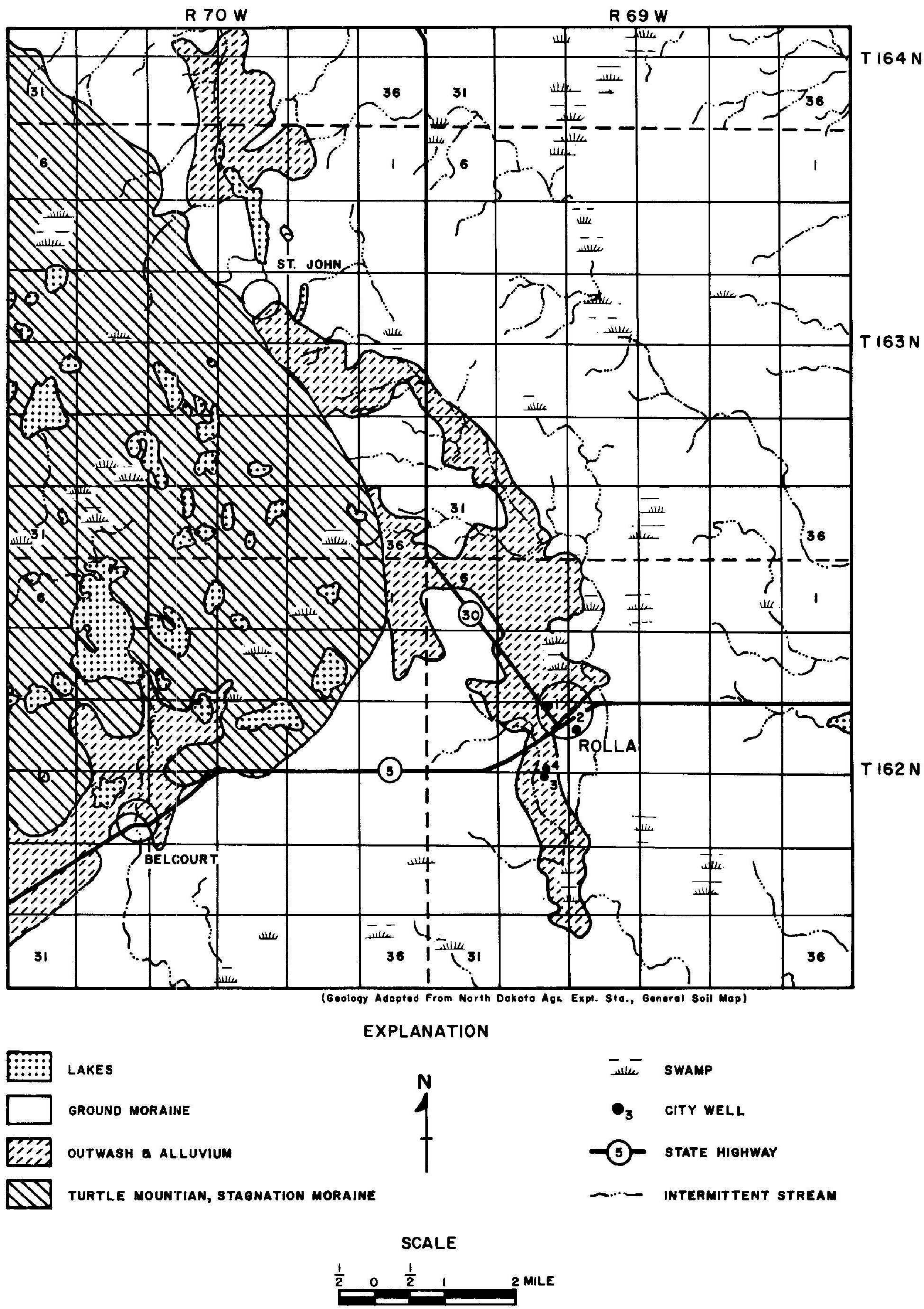


FIGURE 6

HYDROLOGY

Rolla has four city wells at present (page 1). The three shallow wells normally supply all the water needed by Rolla. The deep, 106 foot, city well 2 (162-69-16bcc2) is pumped only in emergencies. City well 1, the 30 foot well in town (162-69-17abb), is a large pit dug in the late 1930's. The other two shallow wells, 3 and 4 (162-69-20aba and 162-69-17dcd) are about 180 feet apart across the section line road south of Rolla. City well 3, on the south side of the road was drilled in 1954 on the site of the U. S. Geological Survey test hole 448. City well 4 was drilled on the north side of the road in 1962.

A preliminary general soils map of Rolette County, prepared by the North Dakota Agricultural Experiment Station (unpublished) indicates that outwash and alluvial areas extend, from Rolla, west to the Turtle Mountains and north nearly to St. John (fig. 6). These outwash and alluvial areas are underlain by sand and gravel which readily allow precipitation to enter the ground and thereby recharge the shallow aquifer at Rolla. Discharge from the aquifer takes place by pumping from wells, by evaporation and by plant transpiration. Evaporation and transpiration take place in low areas where the water table is above or near ground level. The swamp just north of Rolla and the swampy area 2 to 2½ miles south of town probably account for a large portion of the total discharge from the aquifer.

RECOMMENDATIONS

Rolla should further investigate the shallow aquifer that is now being pumped by city wells 1, 3, and 4 in order to obtain an adequate supply of acceptable ground water.

Water level readings should be taken to correlate with precipitation and water meter data. These correlations would indicate the effects of recharge and discharge on the aquifer.

The discharge rate of well 3 should be ascertained as soon as possible. Calculations by Lindvig (Pumping test analyses) indicate that well 3 is probably not pumping as much as is believed. If this is the case, the well should be cleaned again as it was in 1960. If the well is pumping 30 to 40 gpm there is probably considerable line loss and this situation should be corrected.

The rather large amount of sand cleaned from well 3 in 1960 (C. A. Simpson and Son, 1960) indicates that the well screen slots are too large. Smaller slots, as used in well 4, evidently eliminate a significant amount of the sand movement.

To decide the correct location of any additional wells, the aquifer should be closely examined by a reputable well driller and a competent consulting engineer; both should be familiar with the water problems of Rolla. An east-west cross section should be drilled across the entire width of the aquifer near city wells 3 and 4. This cross section will give the shape and width of the aquifer. Water levels and test hole elevations will show the configuration of the water table.

A well field should be placed at right angles to the direction of ground-water movement to obtain the maximum amount of water from the aquifer. Wells 3 and 4, being in the line of flow, probably have more interference between their cones of depression than if they were positioned at right angles to the direction of flow.

Water level readings and a cross section of the aquifer would determine if it is necessary and feasible to construct a subsurface impoundment across the aquifer. Such an impoundment would retain water in the area of city wells that would normally flow on south to evaporate from the swamp. A low surface dam could impound spring runoff until the ground thaws sufficiently to allow percolation of the surface water to the aquifer. The surface dam would merely be a surface extension of the subsurface clay core.

PUMP TEST ANALYSES

By
Milton O. Lindvig, Ground-Water Engineer

Three pumping tests have been performed on the shallow aquifer in the immediate vicinity of or on city wells 3 and 4 (fig. 6).

The first test was performed in September 1953 on a 4 inch test well by personnel of the U. S. Geological Survey. City well 3 was later drilled about 10 feet away. The level of the water prior to pumping was 6.86 feet below the land surface. The well was pumped at a rate of 52.5 gpm for 167 hours with a total drawdown of 10.62 feet. An observation well 20 feet from the pumped well had a total drawdown of 0.97 feet. Observation well 2,100 feet from the pumped well, had a total drawdown of 0.52 feet.

The second pumping test was done in June 1954 on city well 3. The 10 inch well was pumped for 24 hours at a rate of 274 gpm. The water level was 2.57 feet prior to pumping and the total drawdown was 12.50 feet. Three observation wells, located 10.2, 11.1 and 93.1 feet from the pumped well, were used.

The third pumping test was performed by C. A. Simpson and Son well drilling firm on the 10 inch city well 4 in June 1962. The well was pumped at a rate of 70 gpm for 24 hours. The initial water level was 11.46 feet below the land surface and the total drawdown was 6.13 feet. City well 3 was pumping throughout this test. Measurements were also made in an observation well located 260 feet north of the pumped well, however water from the pumped well was soaking into the ground nearby making the readings of little value. Water level measurements were also made during the recovery.

The pumping test data was evaluated by the use of the Jacob Formula which is a variation of the Theis Method. This formula is based on the nonequilibrium equation commonly used for the evaluation of aquifers in ground-water hydrology. This equation assumes that the following things are true:

1. The aquifer is homogeneous and has the same permeability in all directions.
2. The aquifer has an infinite areal extent.
3. The well penetrates the entire aquifer and the well diameter is infinitesimal.
4. The aquifer has the same thickness in all places.
5. The water flows into the well bore immediately with a lowering of the water table.
6. The aquifer does not receive recharge from any source.

As can be seen an aquifer does not meet these conditions entirely so there will be a certain amount of error in the final analysis.

The Jacob Method is a graphical method which assumes that the "cone of depression" is parabolic. The "cone of depression" can be determined by plotting the distance from the pumped well versus the drawdown at these particular distances. When the distance versus drawdown or time versus drawdown is plotted on semi-logarithmic paper, the curve becomes a straight line with a definite slope. This slope is the hydraulic gradient of a particular aquifer created by pumping. It is used in determining the hydraulic characteristics of an aquifer and is known as Δh. The slope of the distance versus drawdown curve is two times that of the time versus drawdown curve.

The transmissibility, T, of an aquifer is calculated by using the formula, $T = \frac{264Q}{\Delta h}$ where Q is the pumping rate expressed in gallons per minute, 264 is a constant and Δ h is the slope of the time versus drawdown curve. Transmissibility is expressed in gallons per day per foot of aquifer width.

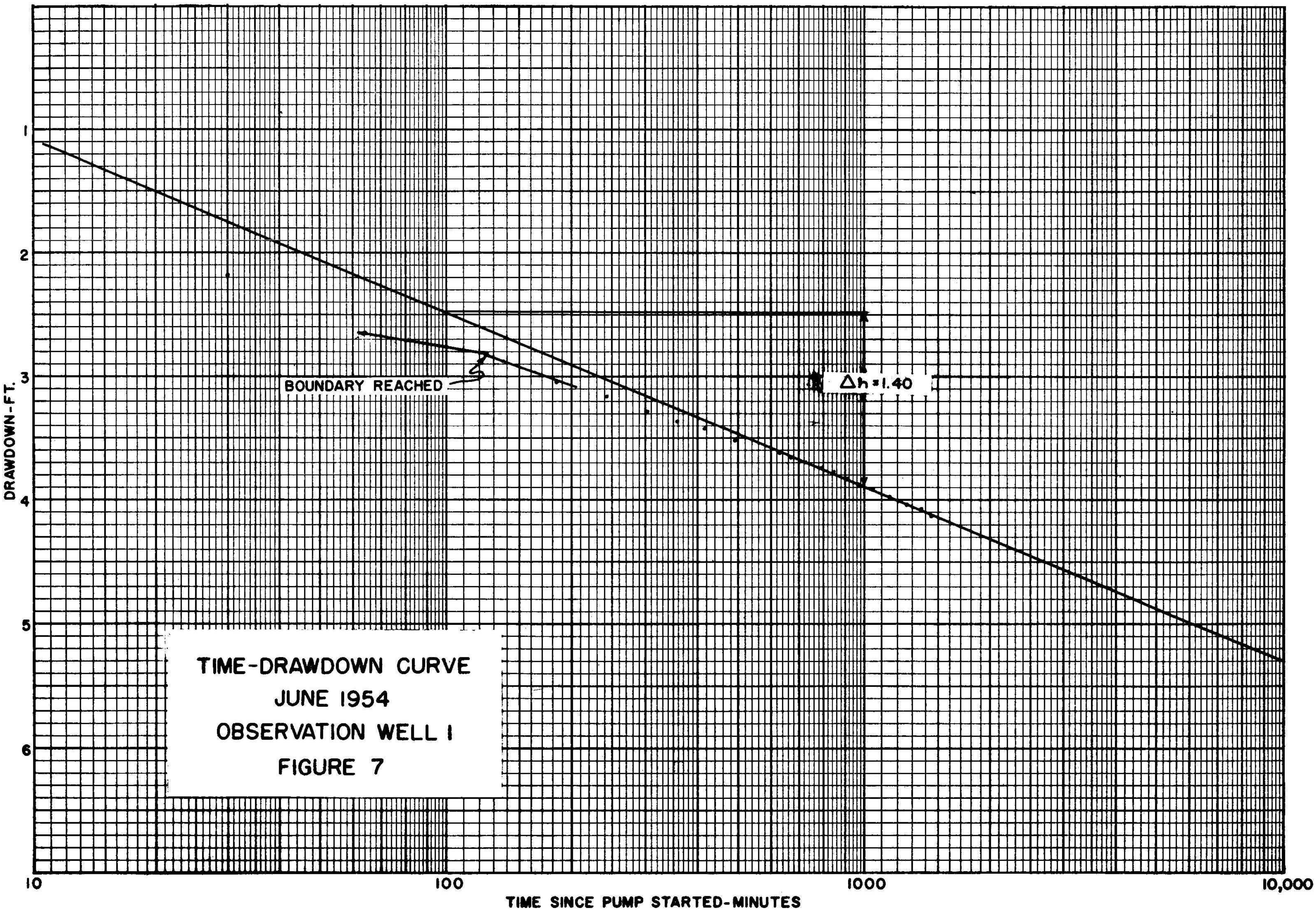
From the graph for observation well 1 (fig. 7) it is found that Δ h =1.40.

$$T = \frac{264 \times 274}{1.40} = 51{,}600 \text{ gal./day/ft.}$$

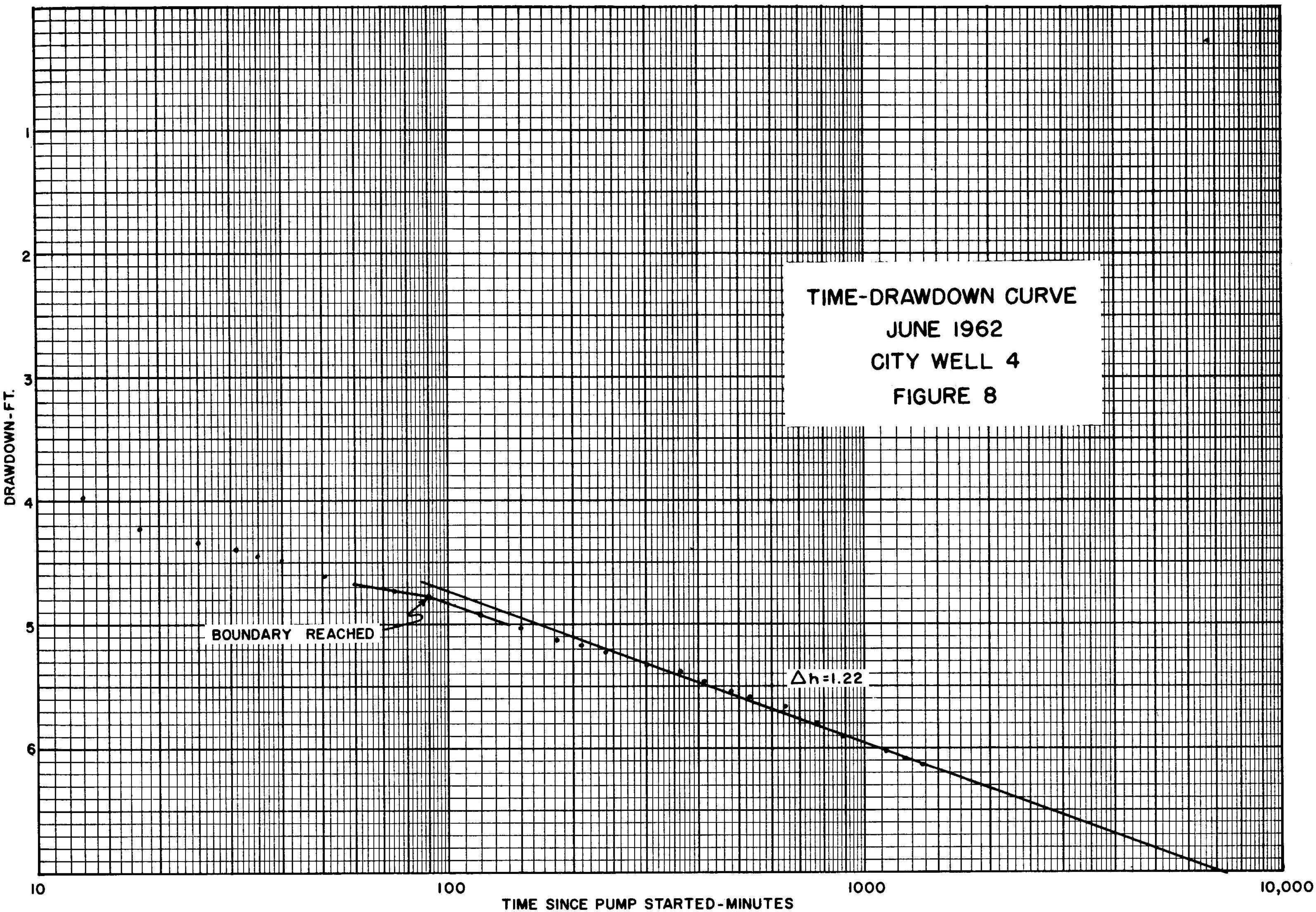
A supplementary method was used to check the transmissibilities as well as how near the aquifer conformed to certain original assumptions. This was done by using the residual drawdown curve. The residual drawdown is the measured difference between the static water level in the well prior to pumping and the water level at any given time during the recovery of the well after pumping has stopped. These differences are plotted on semi-logarithmic paper against a ratio of time since the pumping test started, t, and the time since the pumping test stopped, t'. If the curve conditions adhere reasonably close to the assumptions made for the Jacob Formula, it will pass through the origin or at a value of less than 2.5 on the graph as it does in figs. 9 and 10. Therefore it can be assumed that the aquifer was receiving negligible or no recharge during the pumping test. (Johnson Drillers Journal, July-August, 1961, pp 9-10.)

The transmissibility can be calculated by using the slope, Δ h, of the residual drawdown curve and the formula, $T = \frac{264Q}{\Delta h}$.

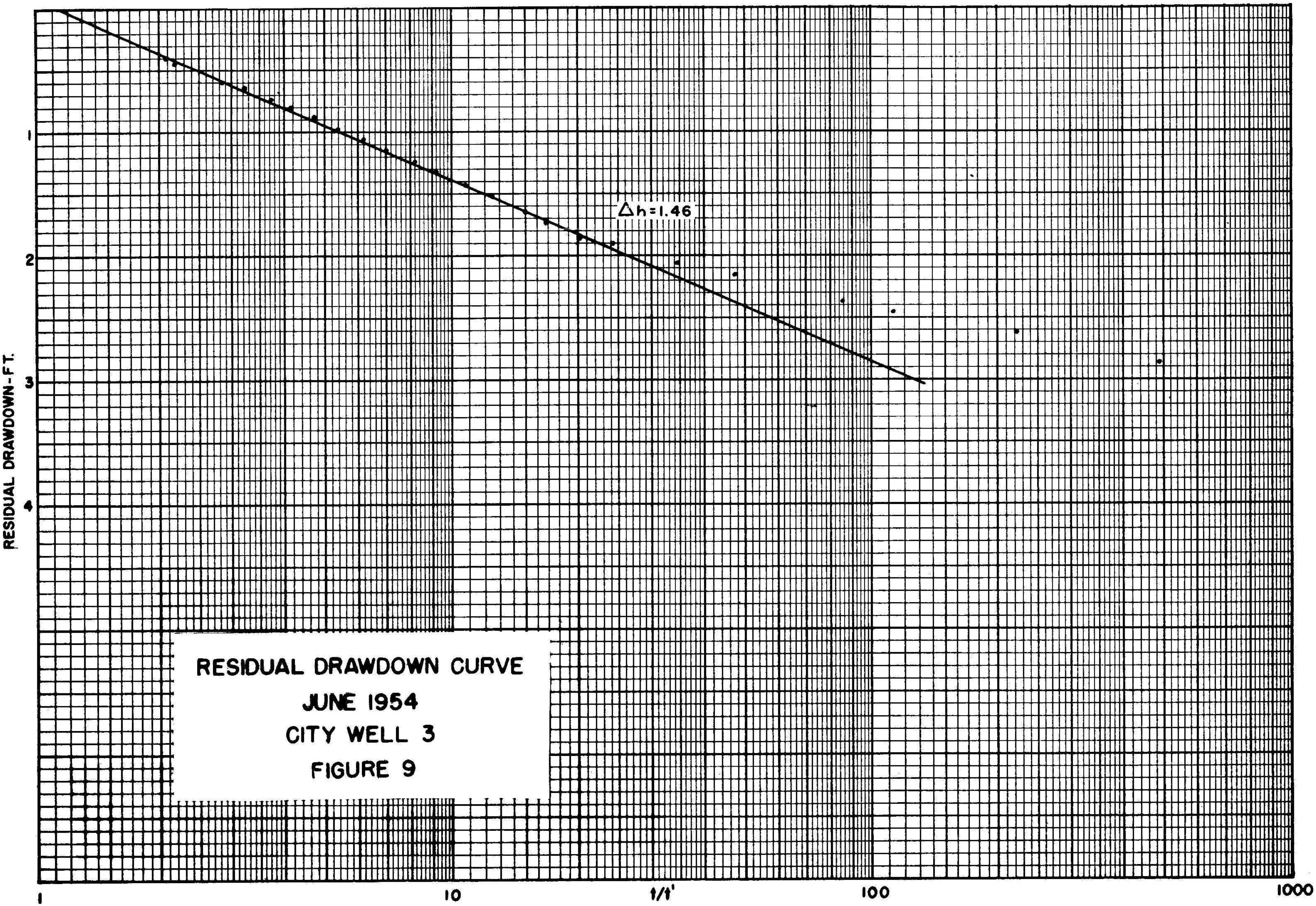
From data obtained during the September 1953 and the June 1954 pumping



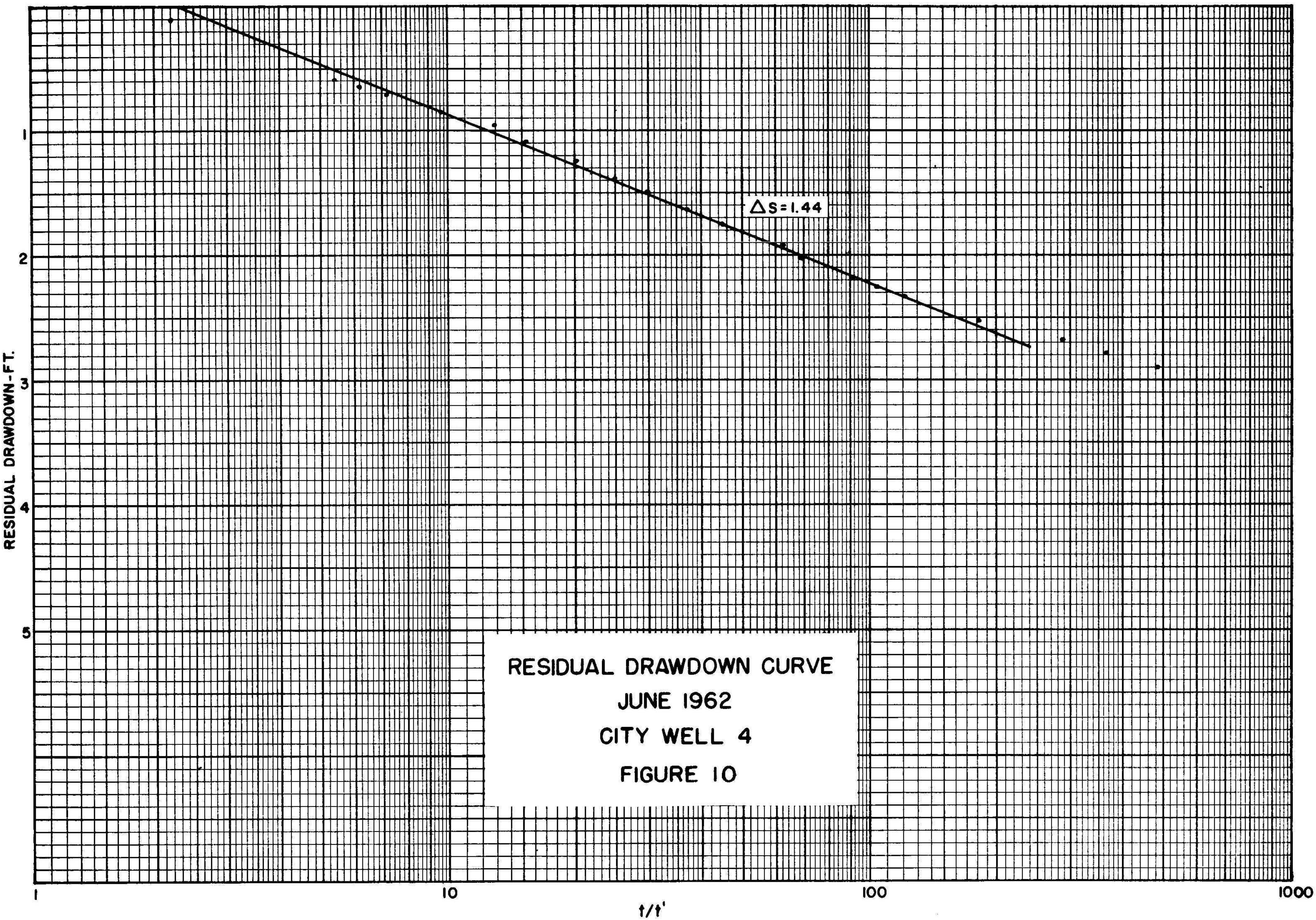
TIME-DRAWDOWN CURVE
JUNE 1954
OBSERVATION WELL I
FIGURE 7



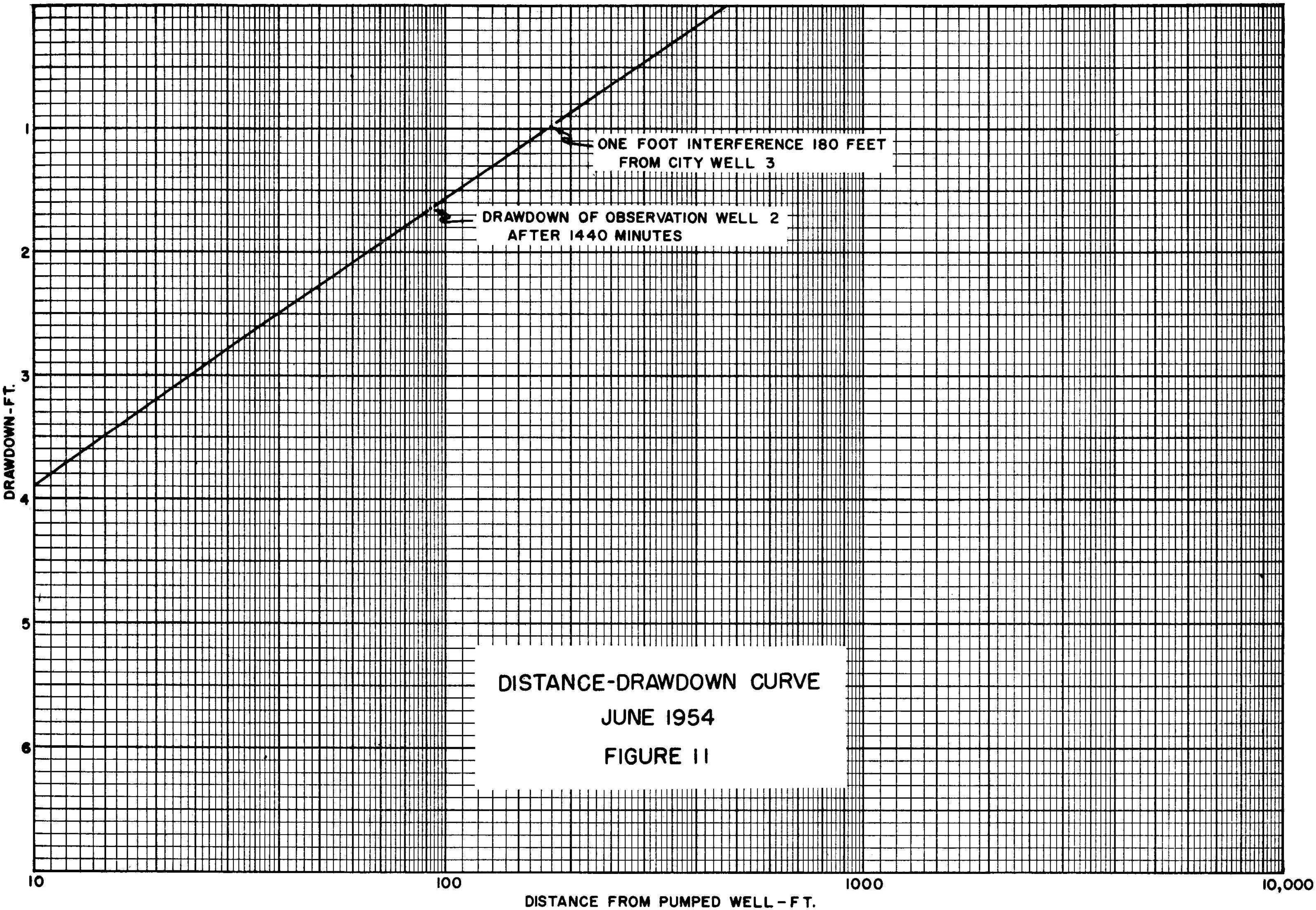
TIME-DRAWDOWN CURVE
JUNE 1962
CITY WELL 4
FIGURE 8
DRAWDOWN-FT.
1
2
3
4
5
6
BOUNDARY REACHED
Δh=1.22
10
100
1000
10,000
TIME SINCE PUMP STARTED-MINUTES



RESIDUAL DRAWDOWN CURVE
JUNE 1954
CITY WELL 3
FIGURE 9



RESIDUAL DRAWDOWN CURVE
JUNE 1962
CITY WELL 4
FIGURE 10



DISTANCE-DRAWDOWN CURVE
JUNE 1954
FIGURE 11

tests the transmissibility of the aquifer was found to be reasonably constant. From the September 1953 test data the transmissibilities ranged from 49,500 to 59,700 gallons per day per foot with an average of 55,600 gallons per day per foot. Transmissibilities calculated from the June 1954 test data ranged from 50,500 to 62,300 gallons per day per foot with an average of 54,600 gallons per day per foot.

However, the transmissibilities calculated from the Simpson pumping test data were found to be much less. It was calculated by using the Jacob Formula and also by using the slope from the residual drawdown curve. The values obtained were 12,800 and 15,100 gallons per day per foot with an average of 13,950 gallons per day per foot. This is only about 30 percent of the average transmissibilities obtained from the previous two pumping tests.

The wide variation could be caused by two factors or their combination. City well 4 is in a small area of lower permeability than that of other parts of the aquifer and closer to a boundary than well 3. The latter is indicated by the times a change in slope takes place on the curves in figures 7 and 8. It appears that the boundary condition is reached about 35 minutes sooner in well 4 than in observation well 1 used for the June 1954 pumping test. The log of test hole 9 suggests that a boundary condition could exist here. Even though there is 25 feet of sand and gravel in this hole, the base of it is 5 or more feet higher than the base of the aquifer in either well 3 or 4. Therefore there is less saturated aquifer. The drawdown curve would intercept the thinner zone of saturation thus forming a boundary condition. However, it appears that this boundary should not be significant enough to cause the great difference in transmissibilities between the two wells.

It is the opinion of the writer that well 4 is located in a small area of low permeability. The September 1953 pumping test was run for 167 hours and no significant boundary condition was indicated on the time versus drawdown curves. The June 1954 pumping test which was run for only 24 hours but at a much higher pumping rate indicated only what is believed to be the boundary mentioned previously.

The factor that expresses the storage function of the aquifer is called the coefficient of storage. It is defined as and its value represents "the amount of water released from storage from a vertical column 1-ft. square and of a height equal to the thickness of the aquifer when the water level is pulled down a distance of 1 foot." (The Johnson Drillers Journal, July-August, 1961, p. 8.)

The coefficient of storage is calculated from the formula:

$$S = \frac{0.3T\ t_0}{r^2}$$

where t_0 is the time indicated by the time versus drawdown curve at the zero-drawdown point, expressed as a fraction of a day, and r is the distance from the observation well to the pumped well.

The coefficient of storage was calculated from the June 1954 pumping test data with three observation wells being used. The coefficient as calculated from the data of observation well 1, the 4 inch test well and observation well 2 are .144, .03 and .069 respectively with an average of .081. The values for a water table aquifer should fall in the range from 0.05 to 0.20 in most cases, thus the average value obtained here is reasonable. However, it may be somewhat low due to the fact that one value is low.

Even though city well 3 was pumped at a rate of 274 gpm, it will not stand up under this rate. In January 1964 Mr. Victor Jackson, City Auditor, (oral communication) stated that city employees believed the well to be pumping about 35 gpm. However, it may be considerably less. In one year 29 million gallons of water were billed and city well 4 pumped 22,867,000 gallons. City well 1 produced about 15,000 gallons per day. The total number of gallons pumped for the year was estimated to be about 32 million by assuming that 10 percent of the water pumped is not billed. From this it was determined that well 3 was pumping about 15 gpm for the 18 hour daily pumping period.

At the end of one 18 hour pumping period the water level in well 3 was 16.25 feet below the land surface and in 6 hours it recovered to within 13.42 feet of the land surface. The water level at the end of the pumping period was only .25 feet above the top of the screen (Victor Jackson, oral Communication). Therefore a higher pumping rate is not advisable under these conditions.

A high pumping rate apparently causes sand to move into the gravel pack thus clogging it. In March 1960 C. A. Simpson and Son well drilling firm cleaned and reworked this well by the use of high velocity jet nozzles and chemicals. This brought about 6 feet of sand into the well bore. For short pumping periods the well delivered 73 gpm with the water level 13.44 feet below the land surface at the end of the period. At 56 gpm the water level was 12.75 feet below the land surface. (C. A. Simpson and Son, 1960). Enough sand has probably been moved into the gravel pack and the surrounding area so that the transmissibility as determined by the September 1953 and June 1954 pumping tests will not be obtained. However, by periodic cleaning and reworking this well should be made to consistently yield 40 to 50 gpm.

From the June 1962 pumping test the permissible pumping rate for city well 4 should be about 50 gpm over an extended period of time. In January 1964 Mr. Victor Jackson (oral communication) stated that well 4 pumped 22,867,000 gallons from January 17, 1963 to January 17, 1964. This reduces to an average of 58 gpm for an 18 hour pumping period each day. After 18 hours of pumping the water level was 16 feet below the land surface and after 6 hours of recovery the water level came to within 12 feet of the land surface. For periods up to 48 hours this well could be pumped at 70 gpm. This rate should not cause the water level to drop below 18 feet. (See fig. 8) However, this would be somewhat dependent upon the time of the year as the water level will fluctuate with the seasons.

From the June 1954 pumping test the radius of influence of well 3 was found to be about 450 feet (fig. 11). This would cause an interference of about one foot in well 4 which is 180 feet away. During the June 1962 pumping test there was a drawdown of .66 feet in well 3. After well 4 was shut off, well 3 continued to drawdown to a total of 1.04 feet before it began to recover. In 1200 minutes it recovered to within .10 feet of the level before well 4 began pumping. Well 3 was pumping during the test.

TABLE 1.-------

Analyses in parts per million except pH

Location	Source	Depth	* Source of Analysis	** Year	Total Dissolved Solids	Total Alkalinity ($CaCO_3$)
162-69-5abb	T.H. 2-797	34	State	1963	1248	---
162-69-5dda	City Airport	60	State	1963	2286	---
162-69-7add	O. Dunlop	15	State	1963	1663	---
162-69-8dcc	M. D. Ferris	47	State	1963	1594	---
162-69-8dcd1	Mrs. Jollifee	35	Health	1952	513	194
162-69-8dcd2	Tom Haggar	18	Health	1951	706	246
162-69-9cbc	F. Gelpheus	87	Health	1951	658	332
162-69-11cbc	M. Kyle	120	Health	1950	1140	---
162-69-16bcc1	T. H. 468	106	Health	1952	2061	462
162-69-16bcc2	City Well #2	106	Health	1961	1859	490
162-69-16dba	Bruce Theel	57	Health	1951	1420	224
162-69-17aab	T. H. 165	130	Health	1950	1414	264
162-69-17adb	City Well #1	30	State	1963	966	380
162-69-17adb	City Well #1	30	Health	1963	1136	390
162-69-17ada	Rolla Creamery	83	Health	1951	1930	333
162-69-17daa1	G. Jorgenson	22	Health	1951	1790	430
162-69-17daa2	Jorgenson & Keegan	78	Health	1952	1490	452
162-69-17dcd	City Well #4	28	Health	1963	1342	350
162-69-18bbb	T.H. 4-797	121	State	1963	1844	---
162-69-20aab	T.H. 9-797	80	State	1963	1330	391
162-69-20aba1	City Well #3	29	Health	1963	1361	350
162-69-20aba2	City Test	20	Health	1953	1020	482
162-69-20aba3	City Test	69	Health	1953	1806	452
162-69-20daa	N. Johnson	42	Health	1961	1899	465
162-69-29dcd	A. Albrecht	14	State	1963	589	---
162-70-2dcc	F. Wilkie	14	State	1963	361	---
162-70-3ddd	Houle School	400	Health	1952	2076	372

* Analyses done by the State Laboratories Department (State) or the North Dakota State Department of Health (Health).

** Due to improved laboratory techniques the more recent analyses should be considered more accurate.

Chemical Analyses of Water From the Rolla Area

Total Hardness $(CaCO_3)$	Iron (Fe)	Sulphate SO_4	Sodium Na	Magnesium Mg	Chloride Cl	Fluoride F	Nitrates NO_3	Calcium Ca	Bicarbonate HCO_3	Silica SiO_2	Potassium K	pH
720	.9	686	147	71	28	.4	1	172	360	19	13	8.0
1110	3.8	1172	241	126	80	.6	4	236	385	19	14	8.1
1040	.7	887	129	129	40	.7	50	129	400	18	8	7.9
800	.8	800	214	75	35	.6	3	75	488	22	15	7.8
430	.4	- - -	- -	44	44	- - - -	87	44	237	--	--	8.4
530	.4	- - -	- -	50	69	.2	174	103	266	--	--	8.5
430	.6	118	5	60	4	- - - -	- - -	74	378	--	--	8.4
224	.6	130	285	43	114	.2	4.3	19	540	--	--	7.6
300	2.6	845	499	Trace	28	Trace	2.1	120	564	--	--	7.2
950	19.0	750	147	94	24	- - - -	Trace	226	598	--	--	--
780	1.6	745	119	78	20	- - - -	4.3	183	273	--	--	8.0
360	4.8	664	282	43	12	Absent	- - -	69	322	--	--	8.1
700	.3	312	40	68	64	Absent	6	168	464	17	6.6	7.7
720	Trace	332	39	74	38	.4	11	166	476	--	--	7.2
841	3.6	960	244	92	30	- - - -	8.6	185	405	--	--	8.0
1010	4.4	798	124	121	18	- - - -	2.1	206	520	--	--	7.0
850	3.4	546	94	108	22	- - - -	2.1	163	551	--	--	7.3
645	.2	570	78	66	50	.2	Absent	150	427	--	--	7.5
1130	.6	1250	- -	- -	20	- - - -	65	- -	264	--	--	8.2
836	.6	688	133	89	22	.6	Absent	188	478	18	16	8.0
690	Absent	600	62	62	36	.1	Absent	174	427	--	--	7.5
716	- - -	65	- -	- -	150	- - - -	2.1	- -	590	--	--	--
912	7.6	754	103	85	26	.1	Trace	280	551	--	--	7.3
980	1.6	775	195	62	24	- - - -	22	250	567	--	--	--
500	.1	125	19	64	24	.2	50	94	410	15	5.8	7.9
360	.2	29	2	50	10	.1	4	62	390	20	2.3	8.0
1152	15.6	1030	150	109	24	Trace	13	281	454	--	--	7.1

TABLE 2.--Water Quality Standards
From North Dakota State Department of Health
Sanitary Engineering Services

Characteristic	Permissible Concentrations (Parts per million except pH)	Objections to Excessive Concentrations
Iron (Fe)	0.3	Esthetic Staining of Laundry
Magnesium (Mg)	125	Possible Laxative Effect
Sodium (Na)	250	Possible Physiological Effect
Sulphates (SO_4)	250	Possible Laxative Effect
Chloride (Cl)	250	Possible Laxative Effect
Fluoride (F)	1.5	Mottled Teeth
Nitrate (NO_3)	43.4	Possible Physiological Effect (toxic to infants)
Total Solids	1000-1500	Possible Laxative Effect
pH	Less than 10.6	Possible Laxative Effect

TABLE 3--Logs of Test Holes

Test holes 1-797 through 10-797 (drilled by the State Water Commission, 1963) in the following table are a composite of information from the drillers logs, the geologist's sample descriptions, and resistivity and potential electric logs. Color nomenclature, from Goddard and others (1951), indicates the color of wet samples. The grain size classification is C. K. Wentworth's scale from Pettijohn (1957). Elevations are to mean sea level as approximated from an altimeter survey using two bench marks in the Rolla area.

Test holes 160 through 171, 439 through 453 plus 468 and 469 (drilled by the United States Geological Survey, 1949 through 1951) in the following table are the author's interpretation of the driller's logs, and the geologic sample description. Elevations are to mean sea level as given by Brookhart and Powell (1961).

162-69-5abb
T.H.2-797
Elevation 1818 feet

Formation	Material	Thickness (feet)	Depth (feet)
Glacial Drift:			
	Soil	1	1
	Gravel, granule to pebble, sandy, subangular to rounded	8	9
	Till, olive gray, calcareous	9	18
	Sand, granular, angular to rounded, predominately quartz and shale	2	20
	Till, olive gray, calcareous	5	25

TABLE 3--Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-69-5abb T.H.2-797 Elevation 1818 feet (continued)		
	Gravel, granule to pebble, sandy, subrounded to rounded..............	7	32
	Sand, fine to very coarse, gravelly..	6	38
	Till, olive gray, calcareous.........	62	100
Undifferentiated	Bedrock:		
	Silt, light olive brown, lignitic calcareous, oxidized..............	10	110
	Silt, light olive brown, sandy, calcareous,oxidized...............	5½	115½
	162-69-5dcd T.H.3-797 Elevation 1812 feet		
Glacial Drift:			
	Soil................................	1	1
	Gravel, granule to pebble, sandy, subangular to rounded.............	6	7
	Till, moderate yellowish brown, calcareous, oxidized..............	5	12
	Till, olive gray, calcareous.........	3	15
	Gravel, granule to pebble, sandy rounded......................	2	17
	Till, olive gray, calcareous.........	2	19
	Gravel, granule to pebble, sandy, rounded..........................	5	24
	Till, olive gray, calcareous..........	31	55
	Till, moderate yellowish brown, calcareous, oxidized..............	6	61
	Till, greenish gray, calcareous......	2	63

TABLE 3-Logs of Test Holes-Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-69-5ddd T.H.1-797 Elevation 1809 feet		
Glacial Drift:			
	Soil..................................	1	1
	Till, moderate yellowish brown, calcareous, oxidized...............	10	11
	Till, olive gray, calcareous..........	18	29
	Till, dusky yellow, calcareous, oxidized...........................	6	35
	Silt, dusky yellow, calcareous, oxidized...........................	4	39
	Silt, olive gray, clayey, calcareous..	5	44
	Till, olive gray, calcareous (medium to very coarse sand from 51 to 52').	21	65
	Till, dark yellowish orange, calcareous, oxidized...........................	22	87
Undifferentiated Bedrock:			
	Silt, dark yellowish orange, sandy, slightly calcareous, oxidized.......	13	100
	Silt, bluish gray, sandy, calcareous..	13	113
	Silt, yellowish gray through dark greenish gray, clayey, calcareous...	21	134
	Shale, greenish gray, silty, calcareous............................	29	163
	Shale, brownish gray to brownish black, abundant lignitic laminae, slightly calcareous.................	5	168
	162-69-6bab T.H.6-797 Elevation 1862 feet		
Glacial Drift:			
	Soil..................................	1	1
	Till, moderate yellowish brown, calcareous, oxidized................	25	26
	Gravel, granule to pebble, sandy, angular to rounded, poorly sorted...	2	28
	Till, olive gray, calcareous..........	7	35

TABLE 3--Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-69-6bab T.H.6-797 Elevation 1862 feet (continued)		
	Sand, medium to very coarse, gravelly, angular to rounded, unsorted.........	1	36
	Till, olive gray, calcareous...........	3	39
	Gravel, granule to pebble, sandy, rounded, unsorted....................	3	42
	Till, olive gray, calcareous...........	5	47
	Till, grayish olive, calcareous, partially oxidized, (probably reworked oxidized till)..............	4	51
	Till, light olive brown, calcareous, oxidized............................	43	94
	Gravel, granule to pebble, subangular to rounded..........................	5	99
	Till, olive gray, calcareous (sandy, granule to pebble, gravel from 103' to 106')............................	20	119
	Till, light olive brown, calcareous, oxidized............................	15	134
	Till, light olive gray, calcareous, partially oxidized..................	12	146
Undifferentiated	Bedrock:		
	Silt, light olive brown, clayey, calcareous, oxidized................	11	157
	Silt, greenish gray, clayey, calcareous..........................	5	162
	Sand, bluish gray, very fine to fine, silty, calcareous..................	4	166
	Sandstone, bluish gray, calcareous.....	2	168
	162-69-8caa T.H. 445 Elevation 1828 feet		
Glacial Drift:			
	Soil.................................	1/2	1/2
	Sand, clayey to gravelly, oxidized.....	2½	3
	Gravel, granule to pebble, sandy......	30	33

TABLE 3--Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-69-8caa T.H. 445 Elevation 1828 feet (continued)		
	Till, gray	40	73
	Gravel, granule to pebble, sandy, predominantly shale	4	77
	Till, gray	29	106
	Gravel, granule to pebble, sandy, predominantly shale	12	118
Undifferentiated Bedrock:			
	Shale, gray	12	130
	162-69-8dbc T.H. 447 Elevation 1820 feet		
Glacial Drift:			
	Soil	2	2
	Sand, clayey to gravelly	3	5
	Gravel, granule to pebble	13	18
	Till, yellow, oxidized	1	19
	Till, gray,	11	30
	162-69-8dcd1 T.H.446 Elevation Unknown		
Glacial Drift:			
	Road fill	2	2
	Sand, medium to very coarse, gravelly...	36	38
	Till, gray	18	56
	Till, yellow, oxidized	4	60
	162-69-8dcd2 T.H.453* Elevation 1816 feet		
Glacial Drift:			
	Sand, fine to coarse	3	3
	Gravel, granule to pebble, sandy, angular	13	16
	Till, gray	14	30

*T.H.450, at same location, has similar lithology but no elevation.

TABLE 3--Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-69-8ddc1 T.H. 443 Elevation 1845 feet (continued)		
Glacial Drift:			
	Sand, very clayey, gravelly............	3	3
	Gravel, granule to pebble, sandy.......	43	46
	Till, gray.............................	32	78
	Till, yellow, oxidized.................	13	91
	Till, gray.............................	37	128
Undifferentiated	Bedrock:		
	Clay, yellow, silty, oxidized..........	36	164
	Shale, gray............................	6	170
	162-69-8ddc2 T.H. 439 Elevation 1810 feet		
Glacial Drift:			
	Soil...................................	1/2	1/2
	Sand, medium to very coarse, gravelly..	19½	20
	Till, gray.............................	10	30
	162-69-9bcb T.H. 7-797 Elevation 1807 feet		
Glacial Drift:			
	Till, moderate yellowish brown, calcareous,oxidized	3	3
	Sand, medium to very coarse, granular, angular to well rounded..............	3	6
	Till, moderate yellowish brown, calcareous, oxidized................	3	9
	Till, olive gray, calcareous...........	50	59
	162-69-9cba T.H. 442 Elevation 1813 feet		
Glacial Drift:			
	Sand, gravelly.........................	3	3
	Gravel, granular to pebble, sandy......	17	20
	Till, yellow, oxidized.................	6	26
	Till, gray.............................	14	40

TABLE 3 --Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-69-9cbd T.H. 441 Elevation 1819 feet		
Glacial Drift:			
	Soil....................................	1	1
	Sand, clayey to gravelly................	2	3
	Gravel, granule to pebble, sandy........	24	27
	Till, gray..............................	13	40
	162-69-9ccb T.H. 440 Elevation 1811 feet		
Glacial Drift:			
	Gravel, granule to pebble, sandy.......	3	3
	Gravel, granule to cobble..............	12	15
	Till, gray.............................	77	92
Undifferentiated	Bedrock:		
	Clay, yellow, oxidized.................	29	121
	Shale, gray............................	29	150
	162-69-9ccd T.H. 167 Elevation 1802 feet		
Glacial Drift:			
	Soil....................................	2	2
	Till, yellow, oxidized.................	14	16
	Till, gray.............................	46	62
	Sand, medium to very coarse, gravelly...	8	70
	Gravel, granule to pebble..............	15	85
	Till, brown, partially oxidized........	5	90
	Till, gray.............................	4	94
	Sand, very coarse, gravelly............	7	101
	Till, gray.............................	15	116
Undifferentiated	Bedrock:		
	Clay, yellow, oxidized.................	10	126
	Shale, gray............................	9	135

TABLE 3--Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-69-9dcc T.H. 10-797 Elevation 1800 feet		
Glacial Drift:			
	Soil	1	1
	Till, moderate yellowish brown, calcareous, oxidized	3	4
	Sand, medium, predominantly quartz	2	6
	Till, olive gray, calcareous	38	44
	Sand, fine to very coarse, gravelly, subrounded	9	53
	Till, olive gray, calcareous	6	59
	Sand, fine to very coarse, gravelly, angular to rounded, with small clay lenses	28	87
	Till, olive gray, calcareous	29	116
	Gravel, granule to pebble, sandy, subangular to well rounded	5	121
	Till, olive gray, calcareous	11	132
	Till, very gravelly, olive gray, calcareous	20	152
Undifferentiated Bedrock:			
	Silt, greenish gray, clayey, a few slightly oxidized areas, calcareous	16	168
	162-69-13aaa T.H. 170 Elevation 1756 feet		
Glacial Drift:			
	Soil	2	2
	Sand, silty	1	3
	Till, yellow, oxidized	19	22
	Till, gray	92	114
	Gravel, granule to pebble, sandy	5	119
	Till, gray	57	176
	Gravel, granule to pebble, sandy, clayey.	21	197
Undifferentiated Bedrock (Pierre Shale?)			
	Shale, gray	13	210

TABLE 3--Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-69-15aaa T.H. 169 Elevation 1797 feet		
Glacial Drift:			
	Soil	1	1
	Till, yellow, oxidized	16	17
	Till, gray (sand from 141 to 145 feet)	137	154
	Sand, very coarse, gravelly	9	163
	Till, gray	10	173
Undifferentiated Bedrock:			
	Shale, gray	37	210
	162-69-15ccc T.H. 168 Elevation 1807 feet		
Glacial Drift:			
	Soil	1	1
	Till, yellow, oxidized	14	15
	Till, gray	41	56
	Till, green and yellow, partially oxidized or reworked oxidized till	9	65
	Till, yellow, oxidized	8	73
	Till, gray	6	79
	Sand, medium to very coarse, gravelly	6	85
	Till, gray	39	124
	Sand, coarse to very coarse, gravelly	57	181
Undifferentiated Bedrock:			
	Shale, gray	19	200
	162-69-16bbb T.H. 166 Elevation 1807 feet		
Glacial Drift:			
	Till, yellow, oxidized	12	12
	Sand, medium to very coarse, gravelly	12	24
	Till, gray	31	55
	Till, gray and brown, partially oxidized	5	60
	Till, gray(gravel from 76 to 79 feet)	51	111
Undifferentiated Bedrock:			
	Clay, yellow, oxidized	11	122
	Shale, gray	8	130

TABLE 3--Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-69-16bcc		
	T.H. 468		
	Elevation Unknown		
Glacial Drift:			
	Soil....................................	2	2
	Till, yellow, oxidized..................	10	12
	Till, gray (medium to very coarse sand from 12 to 13 feet)..............	39	51
	Gravel, granule to pebble, sandy........	31	82
	Sand, very clayey to gravelly...........	18	100
	162-69-16bcd		
	T.H. 469		
	Elevation Unknown		
Glacial Drift:			
	Soil....................................	2	2
	Till, yellow, oxidized..................	12	14
	Till, gray..............................	35	49
	Sand, medium to very coarse, gravelly...	21	70
	Gravel, granule to pebble, sandy........	22	92
	Gravel, pebble to cobble.................	3	95
	162-69-17aab		
	T.H. 165		
	Elevation 1809 feet		
Glacial Drift:			
	Soil....................................	2	2
	Till, yellow, oxidized..................	3	5
	Sand, medium to very coarse, gravelly...	10	15
	Gravel, granule to pebble, sandy........	6	21
	Till, gray..............................	20	41
	Till, yellow, oxidized..................	11	52
	Till, gray..............................	53	105
	Gravel, granule.........................	2	107
Undifferentiated Bedrock:			
	Clay, yellow, oxidized..................	10	117
	Shale, gray.............................	13	130

TABLE 3--Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-69-17aba1 **T.H. 451** **Elevation 1813 feet**		
Glacial Drift:			
	Fill and Soil.........................	4	4
	Sand, medium to very coarse, gravelly..	13	17
	Till, gray............................	10	27
	Gravel, granule to pebble.............	7	34
	Till, gray............................	6	40
	162-69-17aba2 **T.H. 452** **Elevation 1811 feet**		
Glacial Drift:			
	Soil..................................	2	2
	Till, brown, oxidized.................	2	4
	Sand, medium to coarse, gravelly.......	3	7
	Sand, clayey to gravelly..............	7	14
	Till, gray............................	7	21
	Sand, medium to very coarse, gravelly..	7	28
	Till, gray............................	11	39
	Till, yellow, oxidized................	1	40
	162-69-17abb **T.H. 164** **Elevation 1809 feet**		
Glacial Drift:			
	Soil..................................	1	1
	Till, yellow, oxidized................	3	4
	Sand, medium to very coarse, gravelly..	15	19
	Till, gray............................	30	49
	Till, yellow, oxidized................	8	57
	Till, gray (gravel from 105 to 107 feet)	55	112
Undifferentiated Bedrock:			
	Clay, yellow, oxidized................	10	122
	Shale, gray...........................	18	140

TABLE 3--Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-69-17acd **T.H. 444** **Elevation 1807 feet**		
Glacial Drift:			
	Gravel, granule to cobble, sandy........	14	14
	Till, gray (gravel from 21 to 23 feet)..	23	37
	Gravel, granule to pebble, clayey.......	11	48
	Till, yellow, oxidized..................	6	54
	Till, gray..............................	77	131
Undifferentiated	Bedrock:		
	Shale, gray.............................	9	140
	162-69-18aaa **T.H. 160** **Elevation 1825 feet**		
Glacial Drift:			
	Soil....................................	1	1
	Till, yellow, oxidized..................	11	12
	Till, gray..............................	2	14
	Sand, medium to very coarse, gravelly...	5	19
	Till, gray..............................	18	37
	Sand, medium to very coarse, gravelly...	2	39
	Till, brown to gray, partially oxidized.	31	70
	Till, gray..............................	43	113
Undifferentiated	Bedrock:		
	Silt, gray, sandy.......................	20	133
	Shale, gray.............................	17	150
	162-69-18bbb **T.H. 4-797** **Elevation 1852 feet**		
Glacial Drift:			
	Gravel, granule to pebble, sandy, subangular to rounded.................	2	2
	Till, moderate yellowish brown, calcareous, oxidized..................	10	12
	Till, olive gray, calcareous............	20	32
	Till, dusky yellowish brown to olive black, calcareous, partially oxidized (may be reworked,oxidized.... till)................................	19	51

TABLE 3--Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-69-18bbb T.H. 4-797 Elevation 1852 feet (continued)		
	Sand, clayey, rounded quartz	1½	52½
	Till, moderate yellowish brown, calcareous, oxidized	10½	63
	Gravel, granule to pebble, sandy, subangular to rounded	4	67
	Till, moderate yellowish brown, calcareous, oxidized	33	100
	Till, olive gray, calcareous	7	107
	Gravel, granule to cobble, sandy, very angular to rounded	18	125
	Till, olive gray, calcareous	12	137
	Till, light olive brown, calcareous, oxidized	21	158
	Till, olive gray	10	168
	Sand, clayey to gravelly	8	176
	Till, olive gray, calcareous	112	288
Pierre Shale:			
	Shale, dark greenish gray, silty, non-calcareous	16½	304½
	162-69-18ddd T.H. 171 Elevation 1836 feet		
Glacial Drift:			
	Soil	1	1
	Till, yellow, oxidized	17	18
	Sand, medium to very coarse, gravelly	21	39
	Till, gray	17	56
	Till, brown, oxidized	15	71
	Till, gray (finer grained from 144 to 189 feet)	118	189
	Sand, gravelly	1	190
	Till, gray	6	196
Undifferentiated Bedrock:			
	Shale, gray	14	210

Formation	Material	Thickness (feet)	Depth (feet)
	162-69-20aab T.H. 9-797 Elevation 1808 feet		
Glacial Drift:			
	Till, moderate yellowish brown, calcareous, oxidized................	2	2
	Gravel, granule to cobble, sandy.......	25	27
	Till, olive gray, calcareous...........	26	53
	Gravel, granule to cobble, very angular chips to rounded pebbles.....	11	64
	Till (?), olive gray, calcareous.......	3	67
	Gravel, granule to cobble, sandy (clay lenses from 82 to 94 feet).....	27	94
	162-69-20aba T.H. 448 Elevation 1804 feet		
Glacial Drift:			
	Soil..................................	2	2
	Gravel, granule to pebble, sandy.......	26	28
	Till, gray............................	16	44
	Gravel, granule to pebble, sandy.......	37	81
	Till, gray............................	43	124
	Gravel, granule, sandy................	3	127
	Till, gray............................	4	131
Undifferentiated Bedrock:			
	Shale, gray...........................	9	140
	162-69-20acd T.H. 449 Elevation 1803 feet		
Glacial Drift:			
	Soil..................................	4	4
	Sand, medium to very coarse, gravelly..	4	8
	Gravel, granule.......................	15	23
	Till, gray............................	17	40

TABLE 3--Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-70-11baa T.H. 8-797 Elevation 2000 feet		
Glacial Drift:			
	Fill..................................	6	6
	Sand, medium to very coarse, gravelly...	6	12
	Till, moderate yellowish brown, calcareous, oxidized.................	6	18
	Till, olive gray, calcareous...........	45	63
	162-70-12ccc T.H. 162 Elevation 1910 feet		
Glacial Drift:			
	Soil..................................	1	1
	Till, yellow, oxidized.................	18	19
	Till, gray.............................	20	39
	Sand, gravelly.........................	3	42
	Till, gray.............................	48	90
	Till, brown, partially oxidized (may be reworked oxidized till).......	8	98
	Till, gray.............................	14	112
	Till, yellow, oxidized.................	55	167
	Till, gray.............................	76	243
Undifferentiated Bedrock:			
	Clay, light gray.......................	30	273
	Shale, gray............................	17	290
	162-70-12ddd T.H. 161 Elevation 1848 feet		
Glacial Drift:			
	Soil..................................	1	1
	Till, yellow, oxidized.................	7	8
	Sand, medium to very coarse, gravelly...	6	14
	Till, gray.............................	17	31
	Sand, medium to very coarse, gravelly...	9	40
	Till, gray.............................	10	50
	Till, yellow, oxidized.................	32	82
	Till, gray.............................	21	103

TABLE 3--Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	162-70-12ddd		
	T.H. 161		
	Elevation 1848 feet		
	(continued)		
	Gravel, granule to pebble, sandy........	25	128
	Till, gray.............................	13	141
	Till, yellow, oxidized.................	19	160
	Till, gray.............................	130	290
Pierre Shale:			
	Shale, gray............................	30	320
	162-70-14bbb		
	T.H. 163		
	Elevation 1949 feet		
Glacial Drift:			
	Soil...................................	4	4
	Till, yellow, oxidized.................	7	11
	Till, gray.............................	3	14
	Gravel, granule to pebble, sandy........	13	27
	Till, gray.............................	129	156
	Till, brown, partially oxidized (may be reworked oxidized till)......	12	168
	Till, gray.............................	7	175
	Till, yellow, oxidized.................	42	217
Undifferentiated:			
	Silt, gray, clayey to sandy, could be till or bedrock.......................	23	240
	163-70-35cdd		
	T.H. 5-797		
	Elevation 2012 feet		
Glacial Drift;			
	Gravel, granule to pebble, sandy........	5	5
	Till, moderate yellowish brown, calcareous, oxidized..................	7	12
	Till, olive gray, calcareous............	28	40
	Silt, olive gray, calcareous............	21	61
	Silt, olive gray, clayey, calcareous....	111	172

TABLE 3--Logs of Test Holes--Continued

Formation	Material	Thickness (feet)	Depth (feet)
	163-70-35cdd T.H. 5-797 Elevation 2012 feet (continued)		
	Till, olive gray, calcareous...........	83	255
	Silt, olive gray with dark yellowish orange, oxidized areas, calcareous...	20	275
	Silt, olive gray, calcareous...........	13	288
	Till, olive gray, contains silty lenses..............................	22	310
Undifferentiated Bedrock:			
	Shale, light gray with brownish black lignitic areas, calcareous.....	15½	325½

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