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COUNTY GROUND WATER STUDIES 3

GEOLOGY AND GROUND WATER RESOURCES

of Burleigh County, North Dakota

PART III

GROUND WATER RESOURCES

By

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Geological Survey
United States Department of Interior

Prepared by the United States Geological Survey in cooperation with the North Dakota State Water Commission, North Dakota Geological Survey and Burleigh County Board of Commisioners.

GRAND FORKS, NORTH DAKOTA, 1966

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of Burleigh County, North Dakota

PART III – GROUND WATER RESOURCES

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ABSTRACT

Burleigh County ground-water resources are obtained from Cretaceous and Tertiary bedrock deposits and Quaternary drift and alluvial deposits. The Quaternary drift and alluvial deposits include 7 major aquifers in buried ancient channel deposits, 4 major aquifers in surficial outwash deposits, and 4 major aquifers in alluvial deposits. The bedrock aquifers are more widely distributed, but the drift and alluvial aquifers will provide higher yields and better quality water.

About 70 percent of the domestic and stock wells obtain water from the Tertiary and Cretaceous bedrock aquifers. Such supplies may generally be obtained at depths of less than 300 feet and are preferred for household use because the water is softer than that which may be obtained from the overlying drift deposits. Yields per well are not large from the near-surface bedrock aquifers, but the Dakota Sandstone, present at depths of about 2,800 to 3,200 feet, could provide large quantities of sodium sulphate type water.

The seven major aquifers in buried ancient channel deposits generally consist of sand and gravel that average 30 feet in thickness. Thickest accumulations are along the northeastern flanks of the channels. Ground-water movement is west to southwest. The best areas for development are along the central axis of the channels and as near as possible to the recharge areas.

Surficial outwash deposits consisting of sand and gravel generally less than 20 feet thick form four major aquifers. At places these serve as excellent recharge areas for deeper aquifers.

There are four major aquifers composed of alluvium mixed with outwash sand and gravel in the stream valleys along the western border of the county. The best areas for development are near the Missouri River where the river supplies recharge which improves the quality of the water.

Hydrographs of water-level fluctuations in Burleigh County show that highest levels were observed during April and May in areas of

irrigation development, and during July in areas having no large withdrawals. Most wells recover during the annual recharge cycle to a level of the previous year.

About 7 million acre-feet of water is stored in Quaternary drift and alluvial aquifers underlying almost 150,000 acres in Burleigh County. About half of this water would be available to properly constructed wells. The study indicates that a large quantity of water is continuously moving in, through, and out of the aquifer system.

Six aquifer tests were performed using wells developed in Quaternary drift and alluvial aquifers. The transmissibilities range from 10,000 to 350,000 gallons per day per foot. The wide range is attributed to variations in grain size, sorting, and thickness within the aquifer. This range is typical of fluvial deposits in the area. Pumping rates for the aquifer tests ranged from 200 to 970 gallons per minute for periods of 1 to 3 days. All tests revealed one or more boundary conditions within the area of influence of each pumping well. At the time of this study, 14 irrigation wells are producing from 200 to more than 2,000 gallons per minute each from Quaternary drift and alluvial aquifers.

INTRODUCTION

Purpose and Scope of the Investigation

This report is the result of an investigation by the U. S. Geological Survey in cooperation with the North Dakota State Water Commission, North Dakota Geological Survey, and Burleigh County. The purpose was to study the availability, quantity, and quality of the ground-water resources in Bureigh County.

The investigation upon which this report is based was begun in July 1960. The geology of the county was studied by the North Dakota Geological Survey and was published in Part I of this bulletin (Kume and Hansen, 1965). The basic data report was published as Part II of this bulletin (Randich, 1965) and includes logs of tests holes, records of wells, periodic and continuous water-level measurements, and chemical analyses of ground water. This part (Part III) of the report determines the location, extent, chemical quality, and general yields of ground-water resources, and discusses their suitability for irrigation, municipal, industrial, domestic, and stock uses. In addition, generalized information is presented on the surface-water resources. Technical terms used but not defined in the text are explained in the definition of terms section near the end of this report.

The classification and nomenclature of the rock units conform to the usage of the North Dakota Geological Survey and also, except for the Fort Union Group and its subdivisions, to that of the U. S. Geological Survey, which regards the Fort Union as a formation.

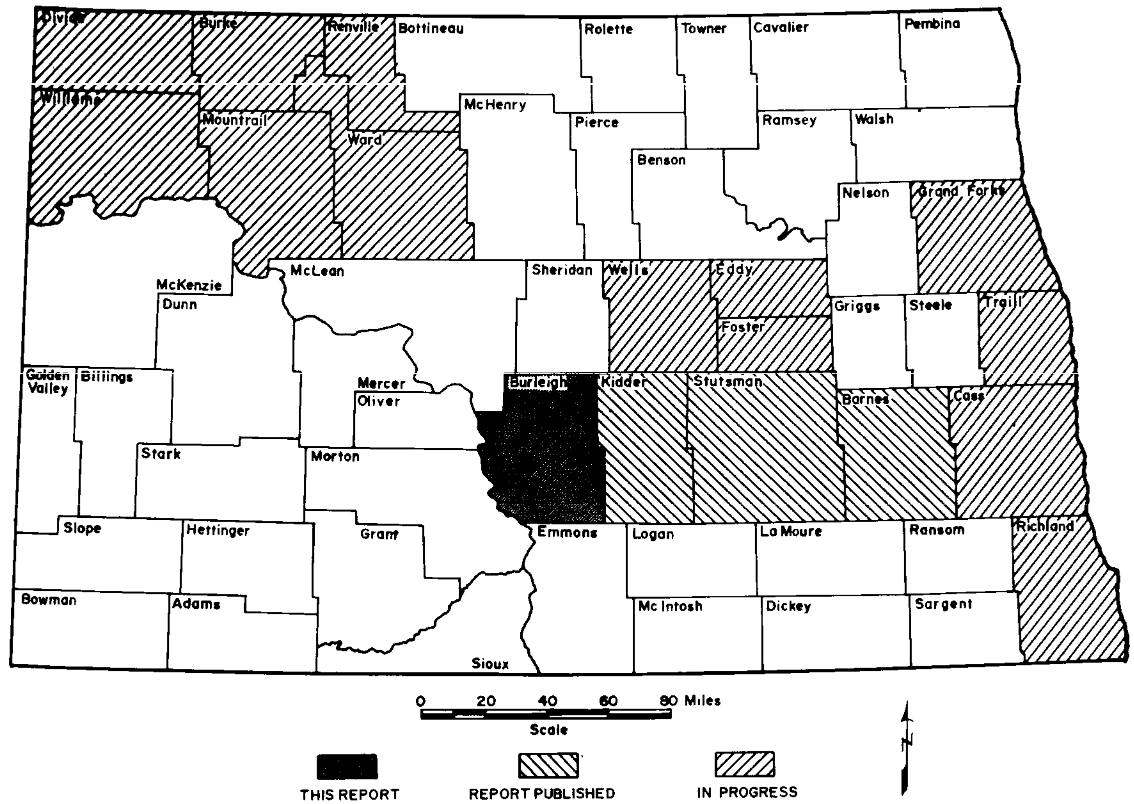


Figure 1.—County ground-water studies in North Dakota.

The Fort Union Group as used by the North Dakota Geological Survey includes the Ludlow, Cannonball, and Tongue River Formations.

Location and Extent of the Area

Burleigh County covers about 1,650 square miles in the south-central part of North Dakota (fig. 1), and includes all of 44 and parts of 6 townships. It is bounded on the west by the Missouri River and is within that area known as the glaciated Missouri Plateau. This is the third county-wide ground-water investigation to be completed in North Dakota.

Previous Investigations

A general discussion of artesian water east of Bismarck is found in an old report by Darton (1896, p. 661-670). Simpson (1929, p. 94-97) described the general water-bearing properties of alluvial gravels, and some bedrock formations. Logs and chemical analysis of selected wells are included in Simpson's report. A reconnaissance report on the Missouri River between Bismarck and the Garrison Dam by Greenman (1953) was made to determine the possibility of irrigating pumping units from a ground-water source. Robinove, Langford, and Brookhart (1958, p. 9-25) gave a general discussion of the saline water in some aquifers and streams in the county. General information on ground water in North Dakota has been summarized by Paulson (1962).

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 numeral denotes the township north of the base line, the second denotes the range west of the fifth principal meridian, and the third 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 sections, and quarter-quarter-quarter sections (10-acre tracts). Thus a typical well 137-76-15 daa is in the NE¼NE¼SE¼ sec. 15, T. 137 N., R. 76 W.

Climate and Surface-Water Supplies

Burleigh County has a semi-arid continental climate marked by a generally low relative humidity, light rainfall confined largely to the warmer half of the year, abundant sunshine, prevailing northwester-

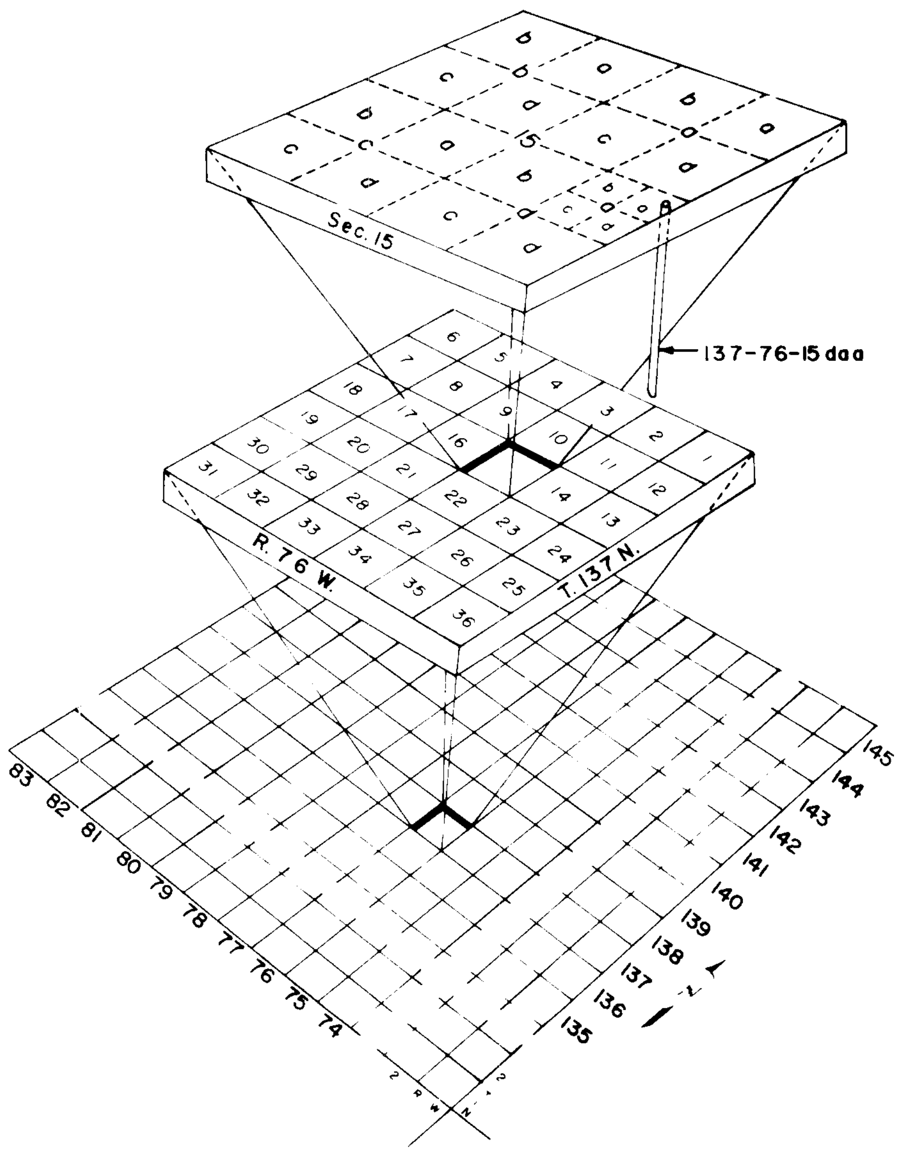


Figure 2.—System of numbering wells and test holes.

ly winds, moderate snowfall,wide diurnal range in temperature, and pronounced seasonal extremes of temperatures. The last killing frost in the spring occurs in the middle of May, and the first in the fall generally occurs late in September. The normal growing season is 135 days. Frost generally penetrates 4 to 5 feet below land surface in most parts of the county.

Precipitation, runoff, and recharge to the ground water are interrelated—one cannot be discussed adequately without recognizing the effect of the others. The greatest recharge to the aquifers takes place during periods of major precipitation and heavy runoff. The river and stream valleys act as collectors for precipitation that arrives too fast to be absorbed into the ground. Areas of surficial sand or gravel deposits have very little runoff because most of the water percolates into the ground and recharges the aquifers. In such areas, some intermittent streams flow only a short distance before disappearing by percolation into the ground. Examples of these short streams are located along the eastern one-third of the county (fig. 7).

U. S. Weather Bureau Stations are located at the Bismarck Airport (station located in Bismarck until 1943), 12 miles east-northeast of Bismarck, and 4 miles southeast of Moffit (formerly located at the railroad station at Moffit). The average annual precipitation is 16.5 inches for Burleigh County. About 50 percent of the time the county can expect less than 16 inches annual precipitation. Data from these stations show that 70 percent of the annual precipitation occurs during the growing season, and about 50 percent of the total occurs from May through July (fig. 3). During the drought years (1933-1940) most of the precipitation occurred during the spring, and a lesser amount in the fall, usually in October or November. The driest months are December, January, and February when about 0.5 inch of precipitation is received each month as snow. During the 80 years of record, 1934 and 1936 were the only years in which less than 10 inches of annual precipitation was received.

Precipitation data for the three stations show that variations of 2 to 3 inches are common within a 15-mile radius for the same month and year.

Most lakes and potholes are located in and along the distal side of the morainal areas in the northern and eastern half of the county (figs. 6 and 7). In these areas drainage generally is not integrated and water is locally collected in depressions until it is removed by evapotranspiration and (or) by percolation into the water table. Some of the named natural water bodies of this type shown on figure 7 are: Long Lake, McKenzie Slough, Clear Lake, Harriet Lake, Lone Tree Lake, Twin Lake, Canfield Lake, Grass Lake, Horseshoe Lake, O'Brien Lake, Bunce Lake, Florence Lake, Pelican Lake, and Salt Lake. Some of the manmade water bodies are: Sterling Reservoir (138-76-4), Random Creek Reservoir (138-77-11 and 14), and numerous stock ponds throughout the county.

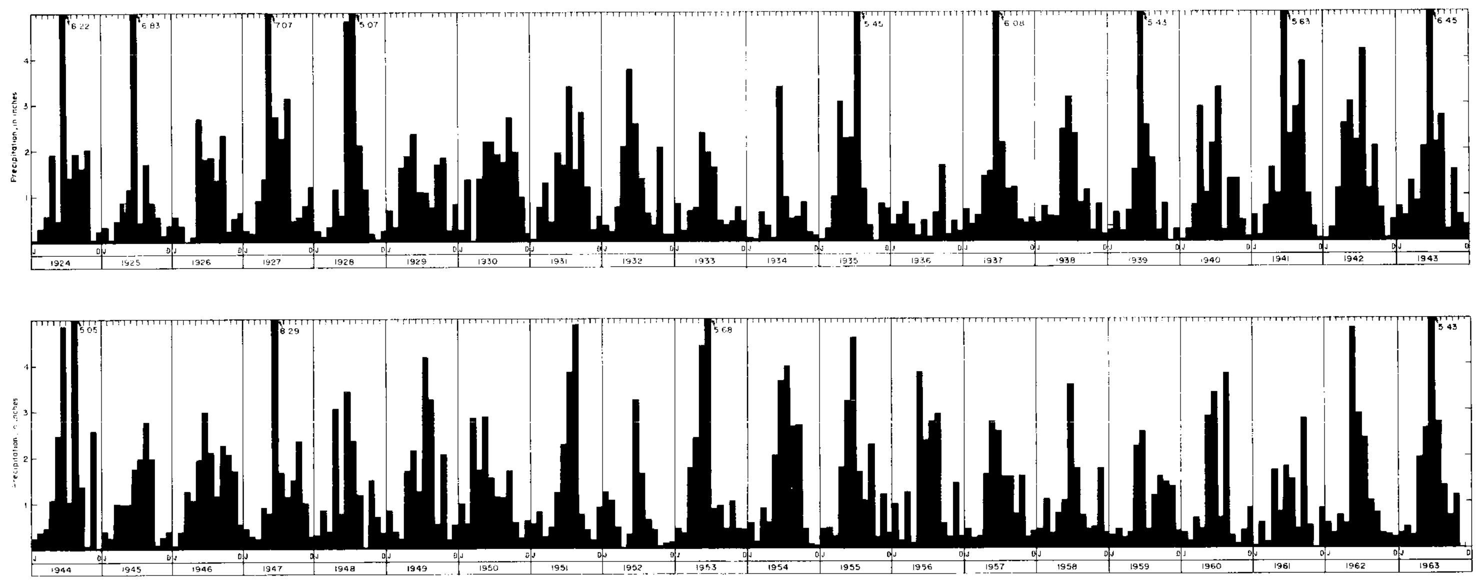


Figure 3.—Monthly precipitation at Bismarck.

Several auger holes were drilled adjacent to potholes and others some distance from these potholes in Burleigh County (fig. 7) to determine the thickness and character of the glacial drift in these areas. Till in the vicinity of potholes was found to be saturated to depths of more than 100 feet in places, and was found to be dry only a short distance further from the pothole. In places where sand or gravel zones were found under a pothole, the materials were generally saturated; indicating the potholes contribute recharge to ground-water supplies.

During periods of low precipitation and high evapotranspiration, most aquifers in Burleigh County discharge water by effluent seepage to potholes and streams. Stream valleys at times may have no flow on the surface, but beneath the surface the water moves as underflow in the direction of the ground-water gradient. The water movement is reversed during periods of high flow when the stream level is near or above the flood plain, allowing the water to be recharged to the underlying aquifers as influent seepage or bank storage. During flood stages intermittent streams in Burleigh County are believed to contribute large amounts of their flow to ground-water storage throughout their reach.

The major streams in central and western Burleigh County are the Missouri River and its tributaries. The Missouri River, which borders the county on the west, is a perennial stream. Measurement of its discharge has been made by the U. S. Geological Survey for 34 years; the gaging point is located at 139-80-31dbd, 40 feet upstream from the Bismarck city water filtering plant intake (fig. 7). The average discharge for the period of record is 20,620 cfs (cubic feet per second), or about 14.9 million acre-feet of water annually. The minimum discharge at the station was about 1,800 cfs on January 3, 1940, and the maximum discharge was 500,000 cfs on April 6, 1952. Since the installation of Garrison Dam (1954), approximately 70 miles north of Bismarck, the records mainly reflect releases from the reservoir, except during periods of high precipitation that most frequently occur in the spring of the year (May-July).

Apple Creek is of major importance because its drainage area encompasses approximately 1,680 square miles (about 500 square miles is probably noncontributing) and has most of its drainage area in Burleigh County. Through most of its length it drains areas that overlie the major aquifers in the county. Should another source of water be added to Apple Creek to sustain a constant flow, a large part would help recharge aquifers and conserve the ground-water supply.

Methods of Analysis and Interpretation of Data

Five hydrofacies maps were made to aid in calculating storage and in interpreting and delineating the discharge, recharge, and potential development areas of principal aquifers in Burleigh County. A unit thickness of 50 feet was chosen to show the overall complexity and thickness of the area beginning at an altitude of 1,750 feet above sea level and ending at 1,500 feet. The basis of hydrofacies maps is a rock texture percentage triangle using the end member concept. The triangle is a modification of the normal 100 percent triangle diagram and delineates nine composite lithologic aspects (Krumbein and Sloss, 1953, p. 275, 406). The maps show relative percentage differences in clay and silt, sand, and gravel using the apex of each corner of the rock texture percentage triangle to represent 100 percent for the named constituent. For purposes of this report the following textural classification is used.

Lithology	**Percentage**
Gravel	>90 gravel
Sand	>90 sand
Sandy gravel	50-80 gravel, 20-50 sand, clay and silt
Gravelly sand	50-80 sand, 20-50 gravel, clay and silt
Clayey gravel	50-80 gravel and sand, 20-50 clay and silt
Clayey sand	50-80 sand and gravel, 20-50 clay and silt
Gravelly clay	50-80 silt and clay, 20-50 gravel and sand
Sandy clay	50-80 silt and clay, 20-50 sand and gravel
Clay and silt	>80 clay and silt

Ratio or percentage lines were added to the triangle to determine the relationships between the coarse materials (sand and gravel) and the fine materials (clay and silt). For example, the ratio line 1/4 isolates an area at the top of the triangle where material having 80 percent or more clay and silt will be plotted. The ratio line of 1 represents a 1-to-1 ratio of sand or gravel to clay and silt. Material that plots between the ratio lines 2 and 8 generally has a relatively high permeability, and that which plots in the range from 8 to ∞ (infinity means all sand and gravel) generally has even higher permeability and would be an excellent aquifer or transmitter of water. When using the maps, a similar lithology can be traced through the section by overlaying one upon another starting with either the 1,700-1,750 foot or 1,500-1,550 foot interval map, and progressing in sequence through the section. The continuity of similar lithologies is directly related to the hydrologic connection between map intervals.

An annual rise and fall of the water table corresponds to an annual cycle of changes in the relative quantities of ground water in storage. The water in storage was estimated by calculating the approximate volume of saturated material within the aquifer and multiplying it by the assumed porosity. This was accomplished by (1) using the lines shown on figures 28 through 32, (2) calculating water in storage for each 50-foot section, and (3) adding the quantities of water obtained for all these sections together to obtain a value for each aquifer. Storage for aquifers outside the area covered by the hydrofacies maps was computed from estimates of average saturated thicknesses and porosity based on cores and test hole logs.

An aquifer test consists of pumping one well while recording the drawdown and recovery in the well and in nearby observation wells. The water levels in the pumped well and observation well are measured before an aquifer test is begun to determine the static water-level trend. Thus, the water-level change due to pumping may be determined. During the test, the well generally is pumped at a rate that is as uniform as possible and for a period of at least several days. When a well is pumped, the water level in the vicinity of the well declines and a cone of depression is formed. The slope of the cone is greatest near the well and decreases at progressively greater distances from the well.

Aquifer tests can be used for the following purposes: (1) to determine the water-bearing properties of an aquifer in a given area, such as transmissibility, permeability, and coefficient of storage or specific yield; (2) as an aid in determining the location and character of subsurface geologic boundaries; (3) to delineate areas and directions of major recharge, including recharge from streams if any; (4) to determine the amount of well interference ; and (5) as a guide in spacing of wells for the utilization and management of a well field.

The following discussion briefly describes the procedures used to analyze the aquifer test data. The Theis nonequilibrium formula (Theis, 1935, p. 520) involves an analysis of the rate of water-level decline as pumping proceeds. The nonequilibrium formula is based upon the following assumptions: (1) the water-bearing formation is homogenous and isotropic, (2) the formation has an indefinite areal extent, (3) the pumped well penetrates the entire thickness of water-bearing formation, (4) the coefficient of transmissibility is constant at all places and at all times, (5) the pumped well has an infinitesimal diameter, (6) the initial nonpumping piezometric surface is horizontal, (7) the impervious bed underlying the water-bearing bed is horizontal, and (8) water is taken from storage instantaneously by the decline in head. The degree to which these assumptions are fulfilled varies for each aquifer test and governs the accuracy of coefficients determined by the test.

The Theis equation, in nondimensional form, for the discharge of a well in an areally infinite homogenous aquifer may be written:

$$(1)\quad T = \frac{Q}{4\pi s}\int_{u}^{\infty}\frac{e^{-u}}{u}\,du = \frac{Q}{4\pi s}W(u)$$

where W(u), which is called the "well function of u," is an abbreviated form of the integral expression, and where

$$(1a)\quad u = \frac{r^2 S}{4Tt}$$

In units commonly used by the U. S. Geological Survey, equation (1) and (1a) may be written as follows:

$$T = \frac{114.6\ Q}{s} W(u) \qquad (2)$$

$$u = \frac{1.87\ (r^2/t)S}{T} \qquad (2a)$$

where

T = coefficient of transmissibility, in gallons per day per foot;
Q = discharge of pumped well, in gallons per minute;
s = drawdown or recovery at any point in the cone of influence, in feet;
S = coefficient of storage;
r = distance of observation point from pumped well, in feet;
t = time since pumping started, in days;
e = natural logarithm base.

The only variables in equation (2) are s and W(u); the only variables in equation (2a) are r, t, and u. The similar form of these two equations is demonstrated readily if they are rewritten as follows:

$$W(u) = \left[\frac{T}{114.6\ Q}\right] s \qquad (3)$$

$$u = \left[\frac{1.87\ S}{T}\right] r^2/t \qquad (3a)$$

As the terms in brackets are constant, W(u) will vary with the term u in the same manner as s will vary with r^2/t. Values for the terms r, s, and t were obtained from using a composite type curve for analyzing aquifer test data (Bentall, 1963b, p. C1-C3).

When the data from the test are collected and a logarithmic plot of s against r^2/t is prepared, a solution for the Theis formula is found by superimposing the composite type curve on the data plot, keeping the coordinate axis parallel, and shifting the plots until the best fit is found (Bentall, 1963b, p. C1-C3). After the best fit is found, a match point coincident with one log cycle of the composite type curve is plotted on the graph sheet, and values for W(u), u, s, and r^2/t are found for computing the coefficient of transmissibility and the coefficient of storage from equations (2) and (2a), respectively.

The modified nonequilibrium Theis formula described by Jacob (1940) also was used to determine coefficients of transmissibility and storage. The method is referred to in this report as the semilog solution. Values of s are plotted on the linear scale of semilog graph paper, and values for t, t/r^2 or r^2/t are plotted on the logarithmic scale. The slope of the straight line that can be drawn through the plotted points may be determined from the change in drawdown (Δs) over one log cycle of t (for which the change in $\log_{10} t$ is unity);

hence, Jacob's simplified equations, expressed in units used by the U. S. Geological Survey (Bentall, 1963b, p. C33-C37) are:

$$T = \frac{264\ Q}{\Delta\ s}$$

and

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

where t_o = time in days, at which zero drawdown appears to occur. To use the above equation, pumping must continue until it becomes large enough for the plotted points to define a straight line. Theoretically, this should occur when the value of u becomes smaller than 0.02. Deviations from the straight line indicate various changes in aquifer conditions.

The depths to water in 28 selected wells were measured periodically. Continuous water-level records in two wells were obtained by water-level recorders. Of these wells, 20 were used for observation only, 9 were irrigation wells, and 1 was a stock well. Altitudes of all of the observation well sites were determined in order to make a piezometric surface map and to construct an electric analog model of the aquifers in the area.

A series of steady-state, two-dimensional electric analog models of individual aquifers and the aquifer system as a whole were constructed using conductive graphite-coated paper. The results aided in determining: (1) shape of the piezometric surface, (2) aquifer boundaries, (3) source of ground water and direction of flow, (4) recharge-discharge relationship of aquifers, and (5) location of ground-water divides. These results are included in sections dealing with the appropriate subject or in the aquifer descriptions. As more development takes place in these aquifers, an electric analog model of three-dimensional flow in the area would be a valuable aid for the ground-water users and managers in Burleigh County.

Principles of Ground-Water Occurrence

Essentially all water in or moving through the area is derived from precipitation. Water in the form of rain or snowmelt enters the ground by direct percolation or by percolation from streams and lakes that lie above the water table. The water is contained in open spaces in rocks called pores or interstices. This water, when it has reached the zone of saturation, may be recovered through wells and springs. The capacity of a rock to hold water is determined by its porosity, but its capacity to yield water is determined by by its permeability. Deposits commonly found in channels or stream valleys such as silt or clay, may have a high porosity, but because of the minute size of the interstices they transmit water very slowly. Other deposits, such as well-sorted gravel or sand, contain many interconnected openings which transmit water rapidly. Part of the water in any deposit does not flow into wells by gravitational drainage because it is held against this force by capillarity.

The upper surface of the zone of saturation is called the water table if it is not confined by an overlying impermeable stratum. Wells dug or drilled into the zone of saturation become filled with ground water to the level of the water table. Water-table conditions occur in most surficial outwash, alluvial, and dune deposits in Burleigh County.

Artesian conditions exist where permeable strata are between less permeable strata, and ground water becomes confined under pressure. Water enters the aquifer at its outcrop and percolates slowly down to the water table and then laterally down the dip of the water-bearing material beneath the overlying confining bed. The water exerts pressure against the confining bed, so that when a well is drilled through the confining bed the pressure is released and water rises above the level at which it is found. This level is referred to as the piezometric surface. If the elevation of the well head is lower than the level of the surface intake, the pressure may be sufficient to cause the water to flow naturally from the well. Artesian conditions prevail in most water-bearing bedrock formations and buried channel deposits in the report area.

The water-yielding potential of an aquifer is governed by its permeability, volume, capacity to store and release water, and rate of recharge. Recharge to the aquifer must be adequate if the water supply is to last indefinitely; even a small rate of withdrawal will eventually deplete the water in storage unless there is equal or greater recharge. Aquifers that are highly permeable but small in areal extent and completely enclosed in a relatively impermeable material can be pumped dry in a comparatively short time. The rather high initial yield of a well may give an erroneous impression that a great volume of water is available from the aquifer indefinitely. Thus, before a ground-water development is made, sufficient test drilling, aquifer testing, interpretation of water levels and quality of water records, and related studies should be made to determine the capabilities and recharge conditions of the aquifer.

Chemical Quality of Ground Water

Water dissolves some of the gases and other soluble materials that it contacts as it moves through the atmosphere and soil. It also dissolves soluble minerals after it reaches the water table. The dissolved materials in the water determine its chemical quality. Bacterial action and base exchange can modify or remove some of the dissolved materials and thus also affect the chemical quality of ground water.

Source of water: Qal, alluvium; Qd, glacial drift; Kfh, Cretaceous Fox Hills Sandstone; Khc, Cretaceous Hell Creek Formation; Tc, Tertiary Cannonball Formation; Ttr, Tertiary Tongue River Formation.

[Analytical results in parts per million except as indicated]

No.	Location	Depth (feet)	Source of water	Date of collection	Temperature (°F)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Sum	Dissolved solids: Residue on evaporation at 180°C	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium-adsorption-ratio	Specific conductance (micromhos at 25°C)	pH	Color
1	142-81- 4adc b	435	Kfh	8-62	..	12	0.15	4.0	2.2	761	2.1	1,140	0	1.8	517	2.3	0.3	2.7	1,870	1,910	21	0	99	72	3,180	8.1	...
2	138-78-15bcc a	190	Khc	9-17-63	47	24	1.08	.....	.....	580	22	989	33	413	13	.8	0	2.55	.....	1,600	22	0	96	60	2,357	8.5	30
3	141-75-30bda a	200	Tc	9-18-63	50	11	.52	.....	.....	475	8.0	738	0	435	0	.5	1.0	2.15	.....	1,440	20	0	97	32	2,000	8.1	45
4	138-75- 4cba a	302	Khc	9-17-63	40	27	.96	14	11	500	14	720	0	420	124	.6	0	2.85	1,470	1,568	80	0	92	24	2,307	8.1	10
5	143-76-13ccd a	180	Tc	9-18-63	48	15	.30	.....	.....	211	9.2	566	0	110	2.0	0	2.0	.15	.....	628	108	0	79	8.2	1,071	7.9	5
6	140-80-17bbb a	365	Ttr	9-17-63	49	7.5	2.13	.....	.....	97	10	464	0	48	16	.3	2.0	0	.....	509	224	0	47	2.8	875	8.1	0
7	137-78-33aba b	185	Qd	8-6-62	48	31	.27	65	21	394	7.6	829	0	360	23	.5	2.5	1.4	1,320	1,340	247	0	77	11	1,930	7.8	...
8	138-76- 7add b	147	Qd	11-10-61	46	29	.34	54	15	402	6.2	737	0	422	25	.4	.3	1.9	1,320	1,360	198	0	81	12	1,950	7.6	...
9	138-76-33bbb b	110	Qd	8-6-62	45	30	.17	103	36	277	9.8	588	0	436	8.2	.4	4.8	.80	1,250	1,270	405	0	59	6.0	1,770	7.6	...
10	138-77-25bbd$_1$ a	78.2	Qd	4-23-64	48	21	.16	66	19	257	4.5	667	0	231	15	.6	.0	2.1	942	964	245	0	69	7.1	1,450	7.1	...
11	138-80- 9bcd b	105	Qd	9-8-61	47	25	11	134	50	375	6.8	882	0	514	68	.6	.0	.75	1,610	1,630	542	0	60	7.0	2,320	7.4	...
12	138-80-22aac b	131	Qd	9-8-61	47	29	4.8	85	23	179	6.8	626	0	151	15	.6	.1	.43	.....	814	305	0	55	4.5	1,230	7.5	...
13	138-80-24cac$_1$ b	80	Qd	9-9-61	47	31	.38	53	16	259	6.2	701	0	168	5.1	.6	.1	.90	.....	899	196	0	73	8.1	1,350	7.6	...
14	138-80-25dac a	155	Qd	7-2-63	48	21	5.44	212	46	15	2.5	737	0	140	0	.4	1.0	.35	805	849	720	115	5	.3	1,269	7.6	125
15	139-78-27cbb b	225	Qd	8-3-62	54	26	.36	49	18	370	9.2	697	0	335	48	.5	1.4	1.6	1,200	1,220	196	0	79	12	1,810	7.7	...
16	139-81-11adc b	104	Qal	9-8-61	46	26	9.2	133	40	161	6.2	704	0	266	12	.4	.0	.30	1,010	1,010	532	0	39	3.0	1,500	7.6	...
17	140-81- 5aaa b	90	Qal	8-62	47	27	1.6	100	34	357	8.2	996	0	156	116	.7	5.2	.94	1,300	1,300	389	0	66	7.9	2,010	7.7	...
18	Bismarck c	Missouri River untreated		62-63	..	..	.0	44	28	58	....	195	0	185	10	.5	0	....	.....	.....	224	64	..	1.7	.....	8.0	...
19	Bismarck c	Missouri River treated		62-63	..	..	.0	30	10	63	....	68	2	175	18	1.2	0	....	.....	.....	116	57	..	2.5	.....	8.4	...
20	Maximum value of constituent or property of water supplies in 100 largest cities of United States d			1962	..	72	1.30	145	120	198	30	380	26	572	540	7.0	23	.59	.....	1,580	738	446	..	....	1,660	10.5	24
21	Criterion value d			....	..	30	.25	50	20	50	5	150	1	100	50	1.0	5	.10	.....	500	200	75	..	....	500	9	10
22	Number of 100 largest cities with less than criterion value d			....	..	94	98	93	96	93	93	91	86	93	93	92	93	94	.....	97	94	94	..	....	93	90	96
23	U. S. Public Health Service recommended limits e			....	..	..	.3	.....	.....	...	....	.....	..	250	250	1.7	45	.....	.....	500	...	...	..	....	.....	....	15

a Analyzed by North Dakota State Laboratories Department, Bismarck, N. Dak.
b Analyzed by U. S. Geological Survey, Lincoln, Neb.
c Analyzed by North Dakota State Health Department, Bismarck, N. Dak.

d Durfor, C. N., and E. Becker
e U. S. Public Health Service

LQW-60

Table 1.—Selected analyses of water in Burleigh County, North Dakota

[Analytical results in parts per million except as indicated]

Location			Date of collection	Temperature (°F)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Nitrate (NO_3)	Boron (B)	Sodium-adsorption-ratio	Specific conductance (micromhos at 25°C)
138-77-23ddb1[b]	McKenzie No. 1	3 min.	10-31-61	48	0.87	23	13	299	684	198	0.1	1.7	12	1,450
Do.	do.	15 min.	do.	48	....	..	..	...	...	...	.....	...	....	1,470
Do.	do.	30 min.	do.	48	....	..	..	...	...	...	.....	...	....	1,480
Do.	do.	1 hr.	do.	48	....	..	..	...	...	...	.....	...	....	1,490
Do.	do.	4 hr.	do.	48	....	..	..	...	...	...	.....	...	....	1,490
Do.	do.	8 hr.	do.	48	....	..	..	...	...	...	.....	...	....	1,500
Do.	do.	24 hr.	11-1-61	48	....	..	..	...	...	...	.....	...	....	1,490
Do.	do.	48 hr.	11-2-61	48	....	..	..	...	...	...	.....	...	....	1,490
Do.	do.	70 hr.	11-3-61	47	....	48	14	309	772	207	.1	...	10	1,540
138-77-25bbd1[b][a]	..	....	9-9-61	47	1.2	71	21	260	736	202	.1	1.4	6.9	1,480
Do.	..	....	9-18-63	47	.46	..	..	248	720	210	1.0	.45	6.8	1,500
Do.	McKenzie No. 2	12 min.	4-20-64	48	.10	68	21	248	694	211	.0	2.3	6.7	1,450
Do.	do.	2 days	4-22-64	48	.16	64	21	257	669	231	.0	2.1	7.1	1,450
Do.	do.	3 days	4-23-64	48	.16	66	19	257	667	231	.0	2.1	7.1	1,450
138-80-17acd1[b]	..	....	9-8-61	47	8.3	113	39	134	596	201	.0	.31	2.8	1,250
Do.	Bismarck No. 1	1 min.	11-12-62	47	11	141	49	135	672	248	5.9	.27	2.5	1,440
Do.	do.	5 min.	do.	..	....	134	48	133	...	...	.....	.28	2.7	.....
Do.	do.	15 min.	do.	..	....	120	49	133	...	...	.....	.28	2.6	1,350
Do.	do.	1 hr.	do.	..	....	...	..	...	...	...	.....	...	....	1,350
Do.	do.	2 hr.	do.	..	....	...	..	...	...	...	.....	...	....	1,350
Do.	do.	3 hr.	do.	..	....	...	..	...	...	...	.....	...	....	1,330
Do.	do.	8 hr.	do.	..	....	123	44	133	...	...	.....	.31	2.6	1,330
Do.	do.	24 hr.	11-13-62	..	....	...	..	...	...	...	.....	...	....	1,320
Do.	do.	48 hr.	11-14-62	..	....	125	45	133	...	...	.....	.31	2.3	.....
Do.	do.	52 hr.	do.	47	6.6	125	46	133	640	229	5.6	.30	2.5	1,360
138-80-22aac[b]	..	....	9-8-61	47	4.8	85	23	179	626	151	.1	.43	4.5	1,230
Do.	Bismarck No. 2	0 min.	10-10-51	..	....	...	..	124	...	...	.....	...	....	1,290
Do.	do.	5 min.	do.	..	....	103	34	131	626	175	.....	.39	2.9	1,220
Do.	do.	15 min.	do.	..	....	...	..	158	...	...	.....	...	....	1,220
Do.	do.	1 hr.	do.	..	....	...	..	174	...	...	.....	...	....	1,210
Do.	do.	3 hr.	do.	..	....	...	..	175	...	...	.....	...	....	1,200
Do.	do.	8 hr.	do.	..	....	...	..	175	...	...	.....	...	....	1,200
Do.	do.	24 hr.	10-11-61	..	....	...	..	176	...	...	.....	...	....	1,200
Do.	do.	48 hr.	10-12-61	..	....	...	..	176	...	...	.....	...	....	1,200
Do.	do.	53.3 hr.	do.	49	....	84	20	176	634	146	.....	.48	4.5	1,200
138-80-24cac1[b][a]	..	....	9-9-61	47	.38	53	16	259	701	168	.1	.90	8.1	1,350
Do.	Lower Apple Creek	1 min.	4-22-63	..	1.14	41	22	267	698	169	30	1.15	8.7	1,529
Do.	do.	5 min.	do.	..	....	...	..	265	...	...	.....	1.15	....	1,529
Do.	do.	15 min.	do.	..	....	...	..	265	...	...	.....	1.15	....	1,529
Do.	do.	1 hr.	do.	..	....	...	..	267	...	...	.....	1.15	....	1,529
138-80-24cac1[b][a] (Cont.)	Lower Apple Creek	3 hr.	4-22-63	..	....	...	..	267	...	...	.....	1.15	....	1,529
Do.	do.	5 hr.	do.	..	....	...	..	266	...	...	.....	1.15	....	1,529
Do.	do.	8 hr.	do.	..	....	...	..	267	...	...	.....	1.15	....	1,529
Do.	do.	12 hr.	do.	..	....	...	..	267	...	...	.....	1.15	....	1,529
Do.	do.	25 hr.	4-23-63	..	....	...	..	267	...	...	.....	1.15	....	1,529
Do.	do.	36 hr.	do.	..	....	...	..	267	...	...	.....	1.15	....	1,529
Do.	do.	50 hr.	4-24-63	..	0.04	43	21	267	703	170	0	1.15	8.7	1,529
138-80-25dac[a]	Soo Channel	0 min.	7-1-63	48	7.10	212	46	16	737	145	1.0	.35	.3	1,296
Do.	do.	5 min.	do.	..	....	...	..	14	...	...	.....	....	....	1,305
Do.	do.	15 min.	do.	..	....	...	..	14	...	...	.....	....	....	1,272
Do.	do.	1 hr.	do.	..	....	...	..	14	...	...	.....	....	....	1,246
Do.	do.	3 hr.	do.	..	....	...	..	14	...	...	.....	....	....	1,246
Do.	do.	8 hr.	do.	..	....	...	..	14	...	...	.....	....	....	1,246
Do.	do.	12 hr.	do.	..	....	...	..	14	...	...	.....	....	....	....
Do.	do.	23.3 hr.	7-2-63	48	5.44	212	46	15	737	140	1.0	.35	.3	1,269

a Analyzed by North Dakota State Laboratories Department, Bismarck, North Dakota.
b Analyzed by U. S. Geological Survey, Lincoln, Nebraska.

Table 2.—Partial chemical analyses of water from aquifer test wells

The chemical analyses of 145 water samples collected during this study and of 20 samples collected prior to the study provided information to describe the chemical quality of the ground water and evaluate its suitability for domestic, stock water, industrial, and irrigation purposes. Many of these analyses were published by Randich (1965). Seventeen of the analyses were selected as representative of the types of water that were found in the major aquifers of Burleigh County and are tabulated in table 1. Table 2 lists partial analyses of water samples obtained to determine the changes in chemical quality that occurred during pumping tests.

The chemical quality of water from the several aquifers and the changes in quality that occurred during pumping tests is discussed in the section that describes the water-bearing properties of the geologic units. The predominant dissolved constitutents determines the "type" of water used to describe the general chemical character. Thus, a sodium bicarbonate type of water is one that has a sodium concentration greater than 50 percent of the cation equivalents per million (epm) and a bicarbonate concentration greater than 50 percent of the anion equivalents per million. If the sodium did not exceed 50 percent, then the next most abundant cation is also given, for example—sodium calcium bicarbonate.

The majority of the samples were collected in quart glass jars and analyzed by the North Dakota State Laboratory in Bismarck. The sample containers may have contributed small amounts of silica, sodium, and iron to the sample after it was collected. Samples are now collected in polyethylene bottles. The analytical methods that were used are described by Rainwater and Thatcher (1960); however, the State Laboratories Department modified some these methods and determined chloride concentrations with a titrimeter and silver-silver chloride electrodes. These modifications may account for some anomolous calcium and magnesium concentrations and the reported absence of chloride in a few samples in spite of the solubility of chloride and the almost universal presence of a few parts per million of chloride in ground water.

The analytical results are presented as concentrations in parts per million. A part per million (ppm) is a unit weight of a constituent in a million unit weights of water. For example, if the sodium concentration of a particular water is 100 ppm, 100 pounds of sodium would be present in 1 million pounds of water.

The data obtained during the Burleigh County study are compared with the data obtained by Durfor and Becker (1964) regarding the water supplies for the 100 largest cities in the United States in 1962. Durfor and Becker assembled the chemical analyses of raw and treated water supplies and document the fact that even though the concentration of a particular constitutent in water may exceed that recommended by the U. S. Public Health Service, the water is being used by a fairly large number of people for domestic purposes. The people have apparently suffered no ill effects. The maximum value of a constituent or property of water supplies in the 100 largest cities and an arbitrary criterion value are listed in table 1. The arbitrary criterion value was taken from Durfor and Becker's summary of chemical analyses of the treated-water supplies. The summary shows that approximately 90 percent of the supplies contained concentrations less than this criterion value. The comparison of Burleigh County data with these values was made because the majority of the water supplies in the county are being used for domestic purposes. Many supplies in North Dakota have concentrations of a particular constituent in excess of the maximum value of the supplies for the 100 largest cities and these supplies are apparently being used without ill effects so one should not consider that a value in excess of the maximum is cause for rejection of a supply.

Specific conductance at 25° C, a physical property of water which is dependent on the character and concentration of the dissolved solids, was measured in the field as well as in the laboratory during this study. The locations of wells for which specific conductances of water samples were available are shown in figure 7. The relationship of specific conductance to the dissolved solids concentration of ground water in Burleigh County is shown in figure 4.

Chemical breakdown of silicates in rocks during the weathering process is responsible for the silica present in the ground water. Only a few samples of ground water in Burleigh County had a silica concentration that exceeded the criterion value of 30 ppm.

Most of the iron (Fe) concentrations were reported as the total iron in the sample. The samples collected in glass jars may not reflect the true iron concentration of water in the aquifer because the analyses may have included some rust from the lids. Also, the samples were not filtered at the time of collection and they may include some contributions of iron from the well casing. However, many samples exceeded 1.3 ppm, which was the maximum concentration among the supplies of the 100 largest cities, and a few were less than the criterion value of 0.25 ppm. About 10 percent of the samples contained 5 to 10 ppm. The source of the iron is iron oxide and iron carbonate as well as other minerals in the soil and in the aquifer materials. Several analyses of filtered samples disclosed that approximately equal amounts of ferrous and ferric iron were present. The precipitate from water containing more than 0.1 ppm of iron stains laundry and plumbing fixtures and imparts objectionable tastes or colors to foods and drinks; however, iron may be removed from water easily by oxidation of the iron and filtration of the water to remove the iron precipitate. Water softeners can remove iron if the concentration is low.

Calcium (Ca) concentrations were extremely variable and ranged from a few parts per million to a few hundred parts per million. The calcium concentration of many samples was less than the maximum

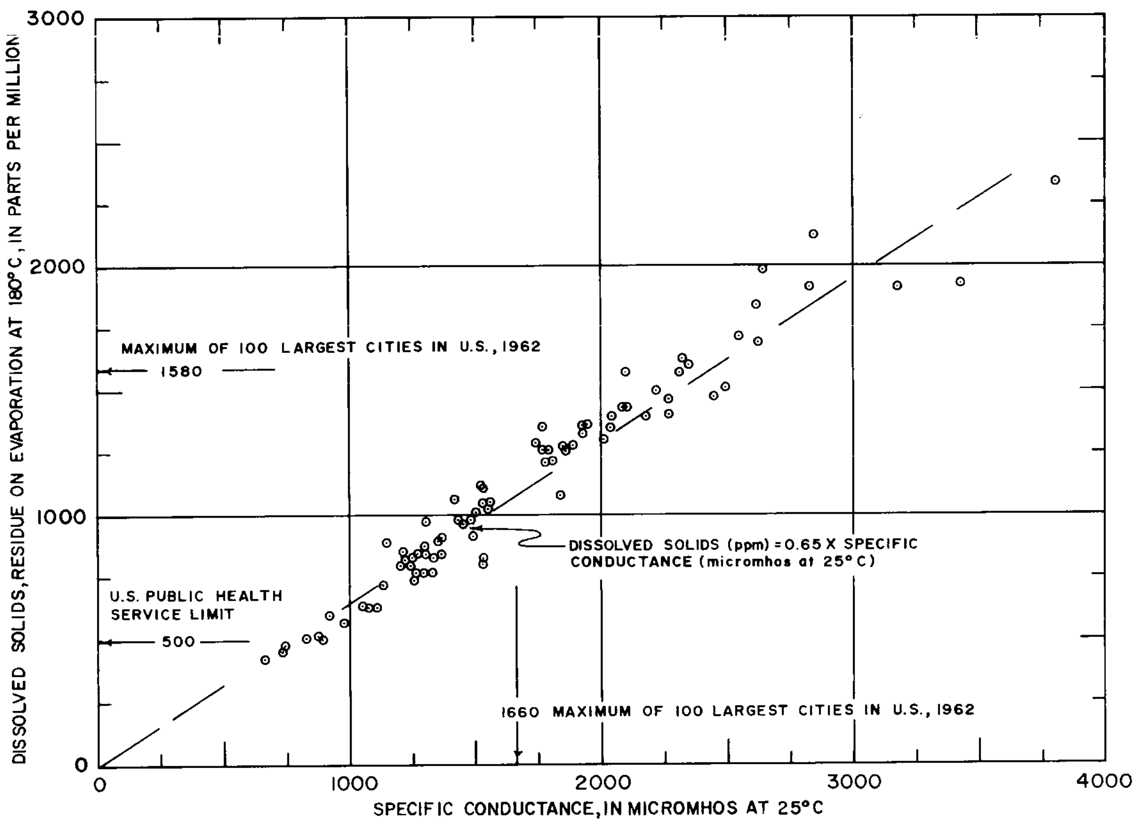


Figure 4.—Specific conductance versus dissolved solids for ground-water samples.

(145 ppm) but more than the criterion value (50 ppm) of the city water supplies study. Calcium carbonate (as cementing material or as limestone fragments) and calcium sulfate in the soil and in the aquifer materials are the main sources of calcium in the ground water.

Several samples had magnesium concentrations lower than the criterion value of 20 ppm. Only one sample had more than the maximum (120 ppm) found in the city supplies study. Magnesium carbonate (magnesite) and the calcium magnesium carbonate (dolomite) are common sources of magnesium (Mg) in ground water.

Many samples contained sodium concentrations several hundred parts per million higher than the maximum (198 ppm) of the city water supplies study, and only a few contained less than the criterion value (50 ppm). The presence of several hundred parts per million of sodium in water would make it unsuitable for use in sodium-restricted diets used as therapy for cardiovascular diseases. Sodium chloride (halite) and sodium sulfate (mirabilite) are sources of sodium that are easily dissolved. Sodium also is present in ground water as a result of the base exchange of some clay minerals. The evaporite mineral, mirabilite, and the base exchange process are believed to be responsible for the presence of sodium, which is, in general, the major cation in ground water of the county.

Potassium (K) values did not exceed the maximum (30 ppm) but were rarely less than the criterion value (5.0 ppm) of the city water supplies study. Potassium is present in many minerals, but during weathering it is removed from water by absorption on clay minerals or by the base exchange process soon after it is dissolved. This accounts for the fact that there is little potassium found in ground water even though the solubility of potassium is similar to sodium.

In general, bicarbonate (HCO_3) is the major anion in the ground water in the county. In fact, the bicarbonate concentration was rarely less than the maximum (380 ppm) of the city water supplies study. Many samples contained more than 600 ppm of bicarbonate and 10 samples contained more than 1,000 ppm. Apparently this water has no ill effect on those who drink it. Bicarbonate in water is said to have a beneficial effect on the drinker as a result of the reaction of the bicarbonate with gastric acids. Few samples had carbonate (CO_3) concentrations in excess of the maximum (26 ppm) and many values were less than the criterion value (1.0 ppm) of the city water supplies study. Carbonate minerals and carbon dioxide are responsible for the bicarbonate and carbonate found in water. The bicarbonate concentrations of most waters are much greater than carbonate concentrations.

The sulfate (SO_4) concentration of a number of samples exceeded the maximum (572 ppm), and most samples had sulfate concentrations which exceeded the criterion value (100 ppm) of the city water supplies study. Although more than one-third of the water samples had sulfate concentrations exceeding the suggested limit (250 ppm) of the U. S. Public Health Service, the water is apparently being used for drinking without ill effects. Calcium sulfate (gypsum) and probably sodium sulfate (mirabilite) are principally responsible for the sulfate.

Only a few samples of water contained chloride (Cl) concentrations which exceeded the maximum (540 ppm) and most were less than the criterion values (50 ppm) of the city water supplies study. Sodium chloride (halite) is probably the source of the chloride.

The fluoride (F) concentrations of all of the samples were less than the maximum (7.0 ppm) and many were less than the criterion value (1.0 ppm) of the city water supplies study. None of the samples had a fluoride concentration higher than the 2.4 ppm that would be grounds for rejection of the supply for drinking purposes (U.S. Public Health Service, 1962, p. 8).

Although several samples had nitrate (NO_3) concentrations in excess of the maximum (23 ppm), many had concentrations of less than the criterion value (5.0 ppm) of the city water supplies study. Water with more than 45 ppm of nitrate should not be used in infant feeding. Nitrates in water have been responsible for serious blood changes in infants resulting in methemoglobinemia, a "blue-baby" disease. Plants which return nitrogen to the soil, sewage, and manure contribute nitrates to ground water.

The boron (B) concentration of most samples exceeded the maximum (0.59 ppm) of the city water supplies study. Few samples had less than the criterion value (0.10 ppm).

The total dissolved solids concentration of the water is determined by evaporating a portion of the water and drying the residue at 180° C for 1 hour. Several samples had dissolved solids concentrations greater than the maximum (1,580 ppm) and only a few had less than the criterion value (500 ppm) of the city water supplies study. All of the samples had a specific conductance greater than the criterion value (500 micromhos).

All of the samples had pH values at the time of analysis that were less than the criterion value (9.0), which means that the water is less alkaline than the water served to the 100 largest cities in the United States.

The results of the color determination may have little significance because the precipitation of iron while the sample was stored may have reduced or altered the color.

Twenty-two samples of water from Quaternary aquifers were analyzed for ferrous and ferric iron and for manganese, copper, zinc, selenium, sulfide, nitrite, and orthophosphate. The results are given in table 4, Part II, Ground-water basic data. The values for iron ranged from 0.15 to 11 ppm and approximately equal quantities of the two ionic forms were present. The majority of the samples had iron concentrations in excess of 0.3 ppm, which is the limit recommended by the U. S. Public Health Service for drinking water. Manganese concentrations ranged from 0.00 to 1.6 ppm and only 5 samples contained less than the U. S. Public Health Service limit of 0.05 ppm. Copper concentrations of the 10 samples analyzed ranged from 0.03 to 0.34 ppm; zinc concentrations ranged from 0.00 to 4.1 ppm and were generally less than 1 ppm; and selenium concentrations were all less than 0.00 ppm. The U. S. Public Health Service limits for these last 3 elements are 1, 5, and 0.01 ppm, respectively. Nitrite concentrations ranged from 0.00 to 0.08 ppm; orthophosphate concentrations varied from 0.04 to 0.36 ppm and sulfide concentrations were less than 0.00 ppm.

Standards for Evaluation of Chemical Suitability

Water used for domestic purposes is frequently evaluated by comparing the concentration of various constituents with limits that have been established by the U. S. Public Health Service and accepted by the American Water Works Association as the minimum standards for public water supplies.

Constituent	Concentrations (in ppm)
Chloride (Cl)	250
Fluoride (F)	1.7 (2.4)
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (No_3)	45
Selenium (Se)	(.01)
Sulfate (SO_4)	250
Total dissolved solids	500
Zinc (Zn)	5

Concentrations of fluoride and selenium in excess of the value in parenthesis in the preceding list constitute grounds for rejection of the drinking water supply (U. S. Public Health Service, 1962, p. 8). Concentrations of the other constitutents should be less than the value in the list unless the supply is the only one available. Many drinking water suppliers in North Dakota that have been used for many years have chloride, sulfate, and total dissolved solids concentrations in excess of those in the list.

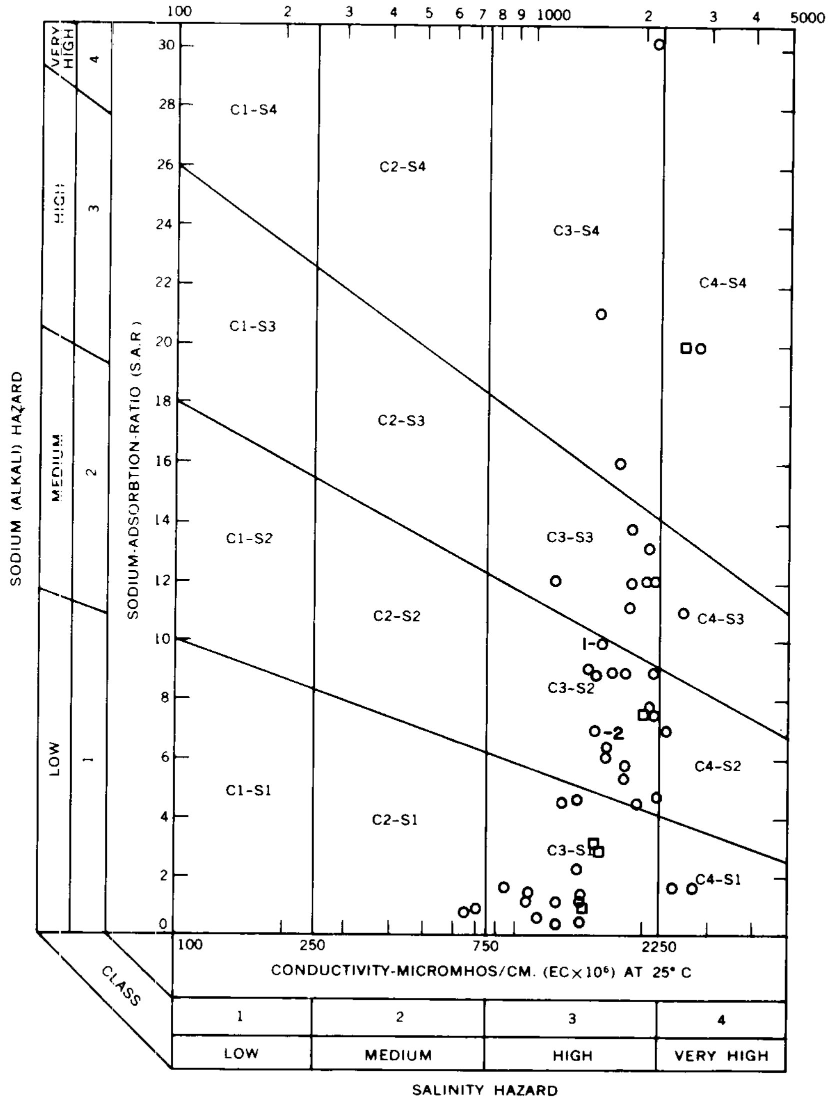
The hardness of water due to the presence of calcium and magnesium ions is expressed as calcium carbonate. Water that is considered hard in some areas may be considered soft in others. The following classification is frequently used to compare hardness. Water with a hardness of 0 to 60 ppm as calcium carbonate is soft; 61 to 120 ppm, moderately hard; 121 to 180 ppm, hard; and more than 180 ppm, very hard. Water can be treated to remove hardness if it is high enough to be objectionable for household or industrial use.

General criteria for the evaluation of water for industrial purposes are difficult to establish because of the many different uses. Water quality requirements of a number of industries and for boiler feed and air conditioning are given by Moore (1940). Generally, water that meets Public Health Standards for drinking water is also suitable for many industrial uses.

Wilcox (1955) has given the quality requirements for water to be used for irrigation. His classification is primarily applicable in the arid regions of western United States. Soil texture, infiltration rate, drainage, quantity of water used, climate, and salt tolerance of the crop are important in determining whether a particular quality of water can be used successfully. Research, as well as practical experience, will provide the basis for the establishment of quality requirements for this area. However, until additional information is available, caution should be used in applying water that is classified as hazardous according to Wilcox.

Figure 5 is adapted from the diagram for classification of irrigation waters (Wilcox, 1955, p. 9), and is based on specific conductance at 25° C and the sodium-absorption ratio (SAR). Data for water samples from aquifers in glacial drift and alluvium are shown in figure 5. These aquifers yield sufficient water for irrigation in some areas of Burleigh County (fig. 7). Figure 5 shows that most of the water samples had a high (C-3) salinity hazard classification. Wilcox (1955) states that high-salinity water cannot be used on soils with restricted drainage, and that even with adequate drainage, special management for salinity control may be required, and plants with good salt tolerance should be selected. The water samples had a low (S-1) to high (S-3) sodium hazard. In general, the more sodium an irrigation water contains, the greater the hazard; however, the Department of Agriculture has determined that calcium and magnesium in the water are important in modifying the effect of sodium on the soil (Wilcox, 1955, p. 4) and has introduced the ratio (SAR) that expresses relative activity of sodium ions in the exchange reaction with soil. Low-sodium water (S-1) can be used on almost all soils with little danger of the development of harmful levels of exchangeable sodium. Medium-sodium water (S-2) may be used on coarse-textured or organic soils that have good permeability. Wilcox (1955, p. 10) reports "High-sodium water (S-3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management — good drainage, high leaching, and additions of organic matter. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity."

Boron also is important in determining the suitability of a water for irrigation. Normal growth of all plants requires a very small quantity of boron. Wilcox (1955, p. 11-12) presents tables of limits of boron and relative boron tolerance of certain plants. Alfalfa, which is classified as one of the tolerant crops, will have maximum growth when irrigated with water containing 1 to 2 ppm of boron, according to the U. S. Salinity Laboratory staff (1954). Water that contains over 1.25 ppm of boron is classified as unsuitable for irrigating sensitive



o-2 **Sample from glacial drift, number is that of aquifer test** □ **Sample from alluvium**

Figure 5.—Classification of selected water samples for irrigation use.

crops such as navy beans and most deciduous fruit and nut trees.

The residual sodium carbonate (RSC), which equals the carbonate equivalent per million (epm) plus bicarbonate epm in excess of the calcium epm plus magnesium epm, is important in determining the suitability of water for irrigation. Wilcox (1955, p. 11) states that waters with more than 2.5 epm of residual sodium carbonate are not suitable for irrigation while those with less than 1.25 residual sodium carbonate are probably safe. He also reports "It is believed that good management practices and proper use of amendments might make it possible to use successfully some of the marginal waters for irrigation." About 50 percent of the water samples from aquifers in glacial drift and alluvium as well as most of the samples from bedrock aquifers had 2.5 epm or more of residual sodium carbonate. Thus it will be important for a potential irrigator to check the RSC of the water he plans to use and if the value is high to give close attention to the exchangeable sodium of his soil.

GEOLOGIC UNITS AND THEIR WATER-BEARING PROPERTIES

The surficial geologic formations are shown on figure 6 and the general occurrence of ground water in them is described in table 3.

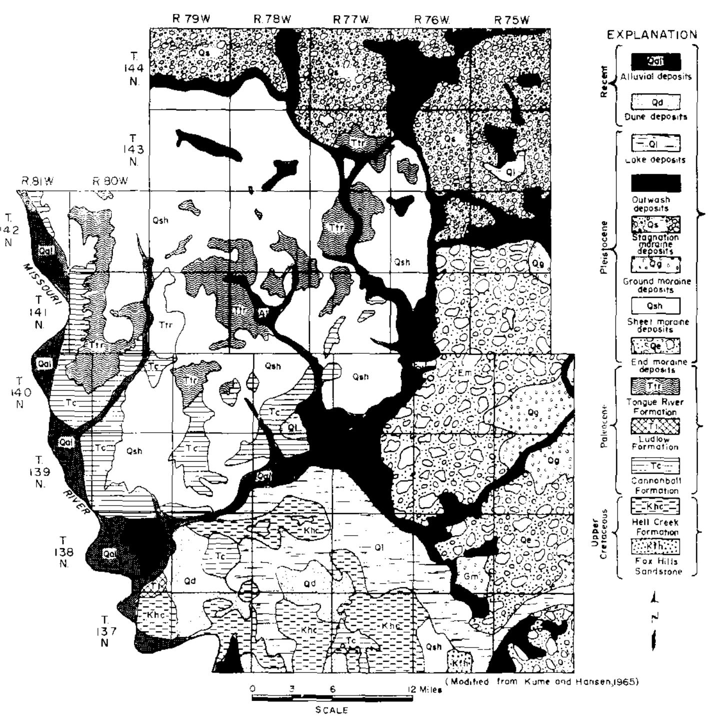


Figure 6.—Generalized surficial geology.

Era	System	Series	Geologic unit	Physical character	Thickness (feet)	Water-bearing characteristics
Cenozoic	Quaternary	Recent	Dune sand	Unconsolidated sand deposits characterized by dune topography, generally contains sand blowouts.	30 ±	Permeable. Collects and transmits water vertically and laterally to underlying and adjacent aquifers.
			Alluvium	Detrital deposits (chiefly stream) in valleys. Sand, silt, clay, and gravel, generally stratified.	150 ±	Generally permeable. Collects, transmits and stores water, and in places yields from 50-150 gpm, except in the Missouri valley where yields of more than 1,000 gpm are obtained.
		Pleistocene (In order of water-bearing potential)	Meltwater channel deposits	Glaciofluvial silts, sands, and gravels in valleys or channels formerly used to transport glacial meltwater runoff. Channels may be cut into bedrock.	225 ±	Permeable. Collects, transmits, and stores large quantities of water, and in places yields from 150 to 1,000 gpm, comprising major aquifers in the area.
			Outwash deposits	Gently undulating to nearly flat accumulations of stratified glacio-fluvial (sand and gravel) material.	70 ±	Permeable. Collects, transmits and stores large quantities of water vertically and laterally to underlying and adjacent aquifers. Generally yields less than 150 gpm.
			Moraine deposits	Gently undulating to hummocky accumulations of drift (chiefly till, locally contains glacio-fluvial material) with moderate to high relief displaying linear patterns in places.	100 ±	Relatively impermeable. Collects, transmits and stores water very slowly. Generally yields small quantities of water for domestic use.
			Lacustrine deposits	Gently undulating to nearly flat accumulations of drift (chiefly glaciolacustrine com-posed of sandy silts and clays) generally stratified.	100 ±	Generally of limited permeability. Collects and stores large quantities of water, but transmits water very slowly. Generally yields small quantities of water to wells.

Table 3.—Geologic units and their water-bearing properties

Era	System	Series	Geologic unit	Physical character	Thickness (feet)	Water-bearing characteristics
Cenozoic	Tertiary	Paleocene	Tongue River Formation	Sandstone, shale, and lignite, exposed in northwestern Burleigh County.	215 ±	Generally of limited permeability. Yields small quantities of water in some areas, generally adequate for domestic and stock use.
			Cannonball Formation	Shales, siltstones and sandstone, extensively exposed in Burleigh County.	300 ±	Permeable. Generally yields adequate supplies from the sandy zones for yields of 10 - 50 gpm.
			Ludlow Formation	Lignitic shales, lignite and sandstone, exposed in southern Burleigh County.	50 ±	Relatively impermeable. Collects and transmits small quantities of water and is not known to produce water in the area.
Mesozoic	Cretaceous	Upper Cretaceous	Hell Creek Formation	Mudstones, sandy shales, sandstones and lignite, exposed in southern Burleigh County.	200 ±	Relatively impermeable. Yields very small quantities of water in the area.
			Fox Hills Sandstone	Sandstones and shales exposed in southeastern Burleigh County.	300 ±	Permeable. Yields generally adequate water supplies from 50 to 150 gpm.
			Pierre Shale	Consolidated bluish-gray to dark-gray marine shale, sandy in places, fossiliferous, contains many concretions in places.	1,000 ±	Relatively impermeable. Yields very small quantities of water normally from sand lenses and fractures common in the upper zone.
			Niobrara Shale	Consolidated medium-gray shale, calcareous and very bentonitic.	300 ±	Impermeable. Is not known to yield water in the area.
			Benton Shale	Consolidated dark-gray shale, dense, calcareous and bentonitic.	1,000 ±	Impermeable. Is not known to yield water in the area.

Table 3.—Geologic units and their water-bearing properties, Continued

Era	System	Series	Geologic unit	Physical character	Thickness (feet)	Water-bearing characteristics
Mesozoic	Cretaceous	Upper Cretaceous	Benton Shale (Cont.)	Consolidated alternating layers of shale, sandstone, and shale.	300 ±	The sandstone yields limited supplies.
		Lower Cretaceous	Dakota Sandstone	Sandstone, fine to coarse grained, angular to rounded quartz grains.	250 ±	Permeable. Yields large quantities of saline water south of this area and would probably yield similar amounts in the project area from depths of 3,000 ± feet.

Table 3.—Geologic units and their water-bearing properties, Continued

The Tertiary and Cretaceous sediments are commonly referred to as bedrock. Bedrockk aquifers yield water to approximately 70 percent of the domestic and stock wells in Burleigh County. The Quaternary sediments, which are of Pleistocene and Recent age, consist of till, clay, silt, sand, and gravel. In places the sand and gravel deposits form major aquifers. Figure 7 (in pocket) shows the range of potential yields from the major Quaternary aquifers in the county. These aquifers locally yield, or are capable of yielding, large quantities of ground water for irrigation, industrial, and municipal uses in Burleigh County (table 3). However, before a large ground-water development is initiated, a detailed site investigation should be conducted.

CRETACEOUS SYSTEM

Dakota Sandstone

The Dakota Sandstone is from about 2,800 to 3,200 feet below the land surface in Burleigh County. The formation is known to yield relatively large quantities of sodium sulfate type water (Randich, 1963, p. 18). Although no samples were obtained from the Dakota Sandstone in Burleigh County, the water in this formation should be similar in quality to that found south of the area in Emmons County where it is soft and contains about 2,400 ppm of dissolved solids. The presence of several parts per million of flouride and iron, which exceed the Public Health Service limits, would also limit the usefulness of this water without treatment. Water of similar quality and quantity could be expected in Burleigh County from properly constructed wells.

Pierre Shale

The Pierre Shale is found at depths of 150 to 200 feet in southeast Burleigh County near Long Lake, and was reached at a depth of 441 feet in a test hole at 138-80-13ccc southeast of Bismarck (Randich, 1965, p. 146). The upper part of the formation yields small quantities of water, generally from sand lenses and fractures in the upper zone.

Fox Hills Sandstone

The Fox Hills Sandstone crops out in the vicinity of 137-76-32, and was reached at a depth of 364 feet in test hole 142-81-4adc west of Wilton. The permeable layers of sandstone generally yield large quantities of sodium bicarbonate chloride or sodium chloride bicarbonate type water to properly constructed wells. The Fox Hills Sandstone underlies the Long Lake, McKenzie, and Glencoe Channel aquifers of southeastern Burleigh County.

Seven analyses of water from the Fox Hills Sandstone showed a range in dissolved solids of 1,500 to 2,500 ppm. The water is relatively soft. A sample near the only outcrop in the county differed from the others in that it was very hard and had a dissolved solids concentration of 503 ppm, which probably reflected the short time that the water was in contact with the aquifer materials. In this sample, the low calcium to magnesium ratio adds support to the hypothesis that clay minerals or organic materials capable of base exchange are present in the Fox Hills and are responsible for the soft water found in other parts of the aquifer. All of the samples, except the one from near the outcrop area, had very low sulfate concentrations (trace to 14 ppm) and high bicarbonate (over 1,000 ppm). These characteristics suggest that sulfate-reducing bacteria may be present in the aquifer.

The concentrations of sodium and chloride are sufficient to cause the water to taste salty to most people. Iron, chloride, and dissolved solids concentrations exceed the limits of the Public Health Service; however, water of this type has frequently been used for drinking without ill effects. People who require a sodium-restricted diet should not use this water. It is satisfactory for stock watering. The salinity and sodium hazards for all of the water except that near the outcrop area are very high and, according to Wilcox (1955, p. 11), would make these waters unsuitable for use for irrigation.

Hell Creek Formation

The Hell Creek Formation crops out extensively in southern Burleigh County and was found 145 feet below the surface in test hole 142-81-4adc (figs. 6 and 7). The formation generally contains sandy members having a high porosity. However, the permeability appears to be low because the formation is not known to yield large quantities of water to wells.

Nine water samples from wells producing from the Hell Creek Formation in Burleigh County had a dissolved solids concentration that ranged from 466 to about 2,100 ppm. Five of the analyses showed a sodium bicarbonate type, 2 were of sodium bicarbonate sulfate type, and 1 was was of sodium bicarbonate chloride type. The water obtained from 6 wells was soft and that from 2 wells was hard. The iron concentration of six samples exceeded the U. S. Public Health Service limits. The chloride for only one sample and the flouride for only one sample exceeded these limits so that the water in the aquifer should rarely exceed the limits for these constituents. Nitrate concentrations did not exceed the limit of 45 ppm. Although some water from the Hell Creek has salinity and sodium hazards low enough to permit its use for irrigation, the residual sodium carbonate exceeds 2.5 epm which would make it unsuitable for irrigation.

TERTIARY SYSTEM

Cannonball Formation

The Cannonball Formation is generally permeable, very porous, and yields a sodium bicarbonate, sodium bicarbonate sulfate, or sodium sulfate bicarbonate type of water to many domestic and stock wells in central and western Burleigh County. Although it is an extensive aquifer, yields obtained are generally less than 50 gpm (gallons per minute).

Sodium is the predominant cation, while bicarbonate and sulfate are the predominant anions in 14 water samples from the Cannonball Formation in Burleigh County. The total dissolved solids concentration for 10 samples ranged from 1,091 to 1,718 ppm. Seven wells yielded soft water and four wells yielded very hard water. Iron concentrations for 12 samples exceeded 0.3 ppm and sulfate concentrations from 11 samples exceeded 250 ppm; however, the chloride, fluoride, and nitrate concentrations for all samples were less than the U. S. Public Health Service limits. Boron concentrations for 11 samples ranged from 0.15 to 3.25 ppm, with most samples containing more than 1 ppm. Most of the water samples from the Cannonball had a classifiaction of very high for salinity and sodium hazards, and the residual sodium carbonate exceeded 2.5 epm, which would make it unfit to use for irrigation.

Tongue River Formation

The Tongue River Formation is one of the major water producers in northern Burleigh County for domestic, stock, and some municipal supply wells. The yields obtained are generally less than 20 gpm.

Four samples were obtained from wells producing water from the Tongue River Formation. Bicarbonate and sulfate were the predominant anions. The water was very hard, and the dissolved solids concentrations ranged from 509 to about 1,900 ppm. The chloride and fluoride concentrations did not exceed the U. S. Public Health Service limits. One sample contained nitrate in excess of these limits. The salinity hazard was high and the sodium hazard was low for three samples. The residual sodium carbonate was sufficient to classify two samples marginal and one sample not suitable for irrigation purposes.

QUATERNARY SYSTEM

As shown on the geologic map (fig. 6), most of Burleigh County is covered by glacail deposits of Pleistocene age. These deposits consist of till, clay, silt, and stratified sand and gravel. In places, recent deposits of alluvium and dunes overlie the drift. These alluivial and dune deposits act as good collectors of water, but are generally too thin to sustain large production wells.

Some of the most productive aquifers in Burleigh County are located in channels that formerly carried glacial melt water (table 3). They have been subdivided into separate units using their hydrologic, geologic, and geographic characteristics, and are referred to in this report as separate aquifers as shown on figure 7. In places, it is difficult to distinguish the glaciofluvial material from Recent alluvium because the alluvium consists predominantly of reworked glaciofluvial deposits. In the Missouri River valley and its tributaries, aquifers usually are comprised of alluvium in their upper parts and glaciofluvial materials in their lower parts.

Samples from 57 wells producing water from glacial drift were analyzed during this study. Sodium bicarbonate, bicarbonate-sulfate, sodium-sulfate-bicarbonate, and calcium bicarbonate types of water were recognized. The dissolved solids concentrations ranged from 419 to 2,130 ppm with only 5 samples greater than the maximum (1,580 ppm) of the city water supplies study. In general, the glacial drift yields water with a dissolved solids concentration of 800 to 1,500 ppm. Although sodium is the principal cation, the water is usually very hard (181 ppm as $CaCO_3$ or more). The maximum hardness of the samples was 1,250 ppm, and a fourth of the samples had a hardness greater than 400 ppm. The iron concentrations varied from 0.11 to 20 ppm, with only 9 samples having less than U. S. Public Health Service limits of 0.3 ppm. The fluoride and chloride concentrations were less than the Public Health Service limits. Water from the glacial drift is characteristically low in chloride (74 ppm was the maximum observed). The majority of the samples had a chloride concentration of less than 30 ppm. Four samples had nitrate concentrations exceeding the limit of 45 ppm. Although most samples had less than 10 ppm of nitrate, it is particularly important to determine nitrate in water from shallow wells in the glacial drift because these may be easily contaminated by human and animal wastes. Poorly constructed deep wells may also have nitrate concentrations in excess of the limit. Most of the water samples have a high salinity hazard classification. The sodium hazard ranges from low to very high with about 40 percent of the samples in the low hazard classification (fig. 5). About half of the samples the waters in the marginal-for-irrigation category. The rest of the had 1.25 to 2.5 epm of residual sodium carbonate, which would place samples were above 2.5 epm in residual sodium carbonate, which would put the waters in the not-suitable-for-irrigation category (Wilcox, 1955).

Melt-Water Channels Overlain by Pleistocene Deposits

Glacial melt-water channels traverse southern and parts of northern Burleigh County. Aquifers in the channels have not been identified or named previously and are shown in figure 7. Channel names (Kume and Hansen, 1966) were used in most cases. In preglacial time the channels in southern Burleigh County were probably eastern courses of the present Heart and Cannonball Rivers. During the early stages of glaciation, these stream courses were changed when the Missouri River was diverted to its southern course through this area. Glacial ice dams caused ponding along the distal side of the glacier. Initial glaciofluvial filling of tributaries on the north side of the Cannonball drainage system deposited the materials for the Sibley and Wing Channel aquifers.

As melting progressed, a reversal in drainage occurred through the Heart and Cannonball system. At approximately this same time two new channels were formed by overflowing waters cutting the Glencoe and Soo Channels into the bedrock. Later melt water flowing from proglacial Lake McKenzie deposited most of the material now comprising the Long Lake, McKenzie, Lower Apple Creek, Glencoe Channel, Soo Channel, and Bismarck aquifers (fig. 7).

McKenzie Aquifer

LOCATION AND EXTENT

The McKenzie aquifer underlies approximately 36 square miles in south-central Burleigh County (fig. 7). The depth to the top of the aquifer ranged from 50 to 130 feet below land surface in 30 test holes.

THICKNESS AND LITHOLOGY

The aquifer is 10 to 100 feet thick, and consists predominately of mixed sand and gravel, or locally of either sand or gravel. Generally, the upper part contains the sand and the deeper part the gravel. The average thickness of the aquifer is 30 feet, but locally the sand and (or) gravel interfingers with clay and silt lenses that reduce the effective thickness. The largest concentrations of sand and gravel extend from the center of the channel toward the northeastern flank. Beds of silt, sand, silty clay, and thin beds of gravel usually less than 10 feet thick are common along the southwestern flank. Locally bedrock highs occur in the channel that reduce the thickness and the water-yielding capability of the aquifer.

RESERVOIR CHARACTERISTICS

Pumping tests and aquifer properties.—Two pumping tests were made on wells in this aquifer. The description and results of the tests are as follows: Aquifer test 1 was made Oct. 31-Nov. 10, 1961, using Mr. Raymond Baeth's irrigation well (138-77-23ddb1). The well is 105 feet deep, with 17-inch inside diameter steel casing having semicircular horizontal slots every 4 inches from 65 to 105 feet. It is gravel packed. The well is equipped with a turbine pump powered by a 60-horsepower electric motor. The water was discharged through a 6-inch pipe to an area 665 feet north of the pumped well. The rate of discharge was measured with an orifice tube and a manometer. A valve at the pump was used to regulate and maintain a constant discharge rate of 970 gpm. Water samples were collected at the point of discharge for chemical analyses after 3 and 15 minutes, and 1, 4, 8, 24, 48, and 70 hours of pumping. A complete analysis was made on the first and last samples taken during the test.

One observation well was drilled 300 feet northwest of the pumped well to a depth of 107 feet (138-77-23ddb3). This well was cased to 99 feet with 1¼-inch plastic pipe slotted every foot from 70 to 99 feet, and gravel packed. Also used as observation wells were: the pumped well; the Anderson irrigation well (138-77-15dcb), 138.4 feet deep; a test well (138-77-22aad) equipped with a continuous water-level recorder, 126 feet deep; the Baeth stock well (138-77-23dbb), 101 feet deep; the Burke stock well (138-77-24caa2), 107.4 feet deep; the Adams irrigation well (138-77-25bbdl), 78.2 feet deep; the McDonald service well (138-77-25dbb), 56 feet deep; and a test well (138-77-26adc), 63 feet deep. No other wells were pumping in the area during the test period.

Water levels were measured with metal tapes in all wells except the pumped well (138-77-23ddbl), which was measured with an electric line, and test well 138-77-22aad, which was read from the recorder chart and periodically checked with tape measurements. Hydrographs of six of the observation wells were plotted from these data and are shown in figure 8. No water-level changes were recorded in wells 138-77-15dcb, 138-77-22aad, and 138-77-25 dbb during the test. Wells 138-77-15dcb and 138-77-22aad had been slowly recovering at the rate of 0.02 foot per day from seasonal pumping of the aquifer prior to the test. During the test they stopped recovering and remained constant until the pump was turned off, at which time they again started the seasonal recovery. Well 138-77-25dbb showed no interference during the test and is believed to be in a perched water table because it is in the vicinity of a pond in a gravel pit; the water level of which did not change in response to withdrawals from the deeper aquifer.

The log and semilog plots of the data from wells 138-77-24caa2 and 138-77-25bbdl are shown in figures 9 and 10. These are representative of data used for analyzing the results of the test, which are given in table 4. All of the computed values for coefficients of transmissibility and storage fall within a reasonable range. The test analysis indicates that the main recharge to the aquifer is from the north and northwest and that the boundary conditions exist south, southeast, and southwest of the pumped well. The boundaries appear to be a combination of gentle sloping bedrock highs, and a lenticular aquitard somewhere between the pumped well and the test hole 138-77-26adc.

The observation wells were located at different distances and directions from the pumped well so that the drawdown data provided a good picture of the cone of depression due to pumping. The area of influence after 3 days pumping from well 138-77-23ddbl is shown on figure 11. The lack of complete recovery indicates that withdrawal

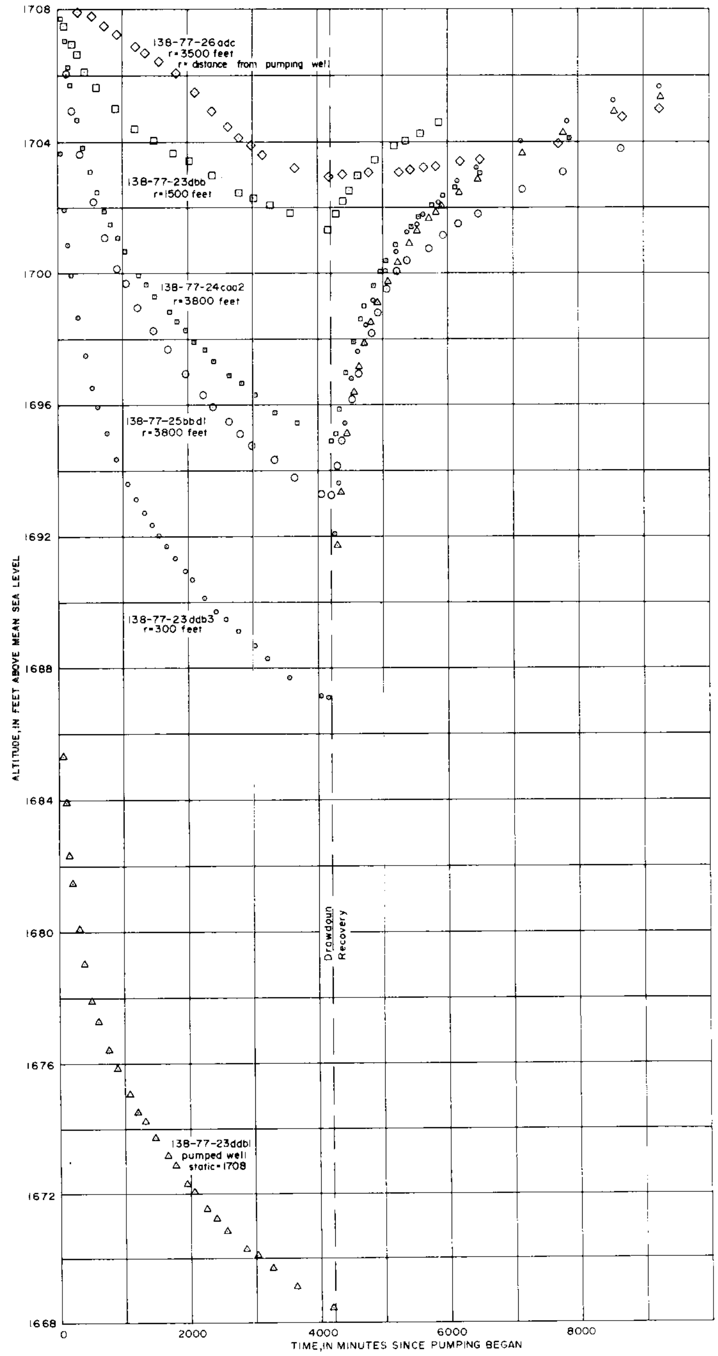


Figure 8.—Drawdown and recovery curves for McKenzie aquifer test 1.

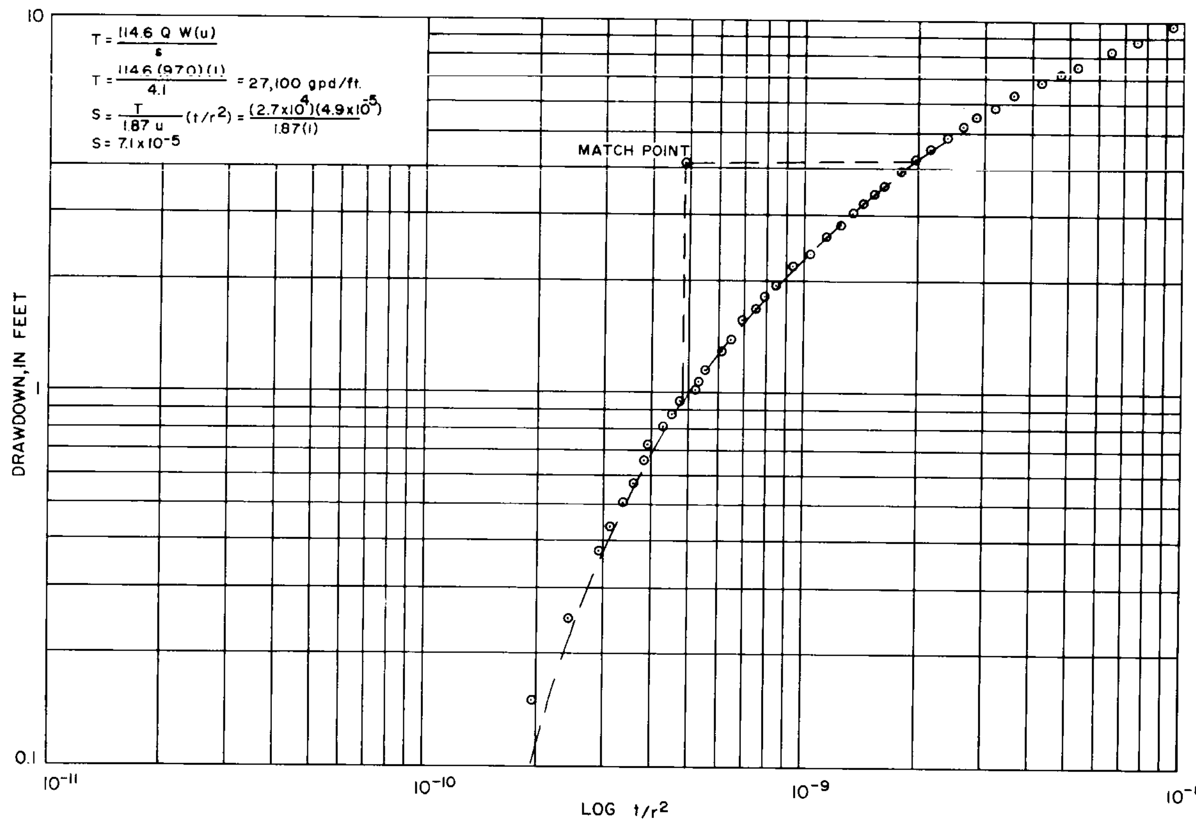


Figure 9.—Log plot of drawdown versus t/r^2 for well 138-77-24caa2, Mc Kenzie aquifer test 1.

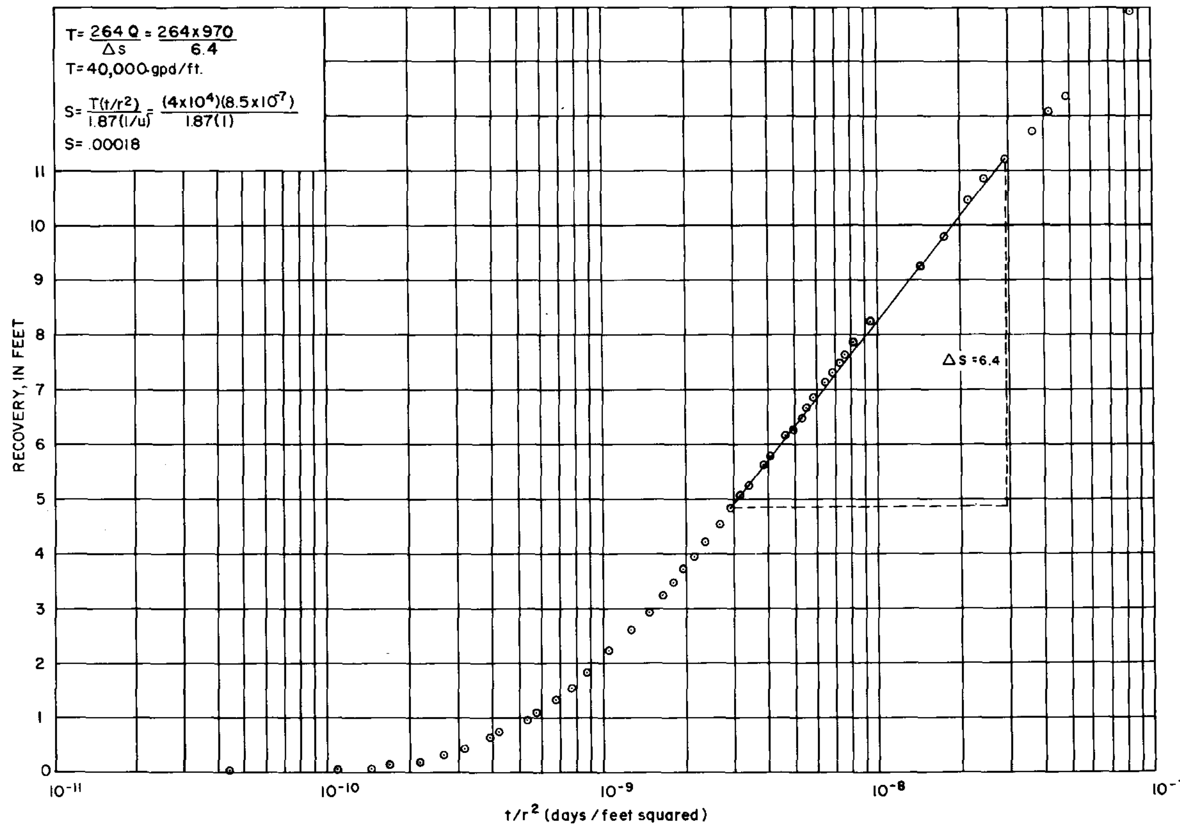


Figure 10.—Semilog plot of recovery versus t/r^2 for well 138-77-25bbdl, McKenzie aquifer test 1.

Discharge well	Observation well	Distance and direction from pumped well "r" (feet)	Coefficient of transmissibility "T" gpd/ft					Coefficient of storage
			Semilog solution		Theis type curve solution		Combined average	
			Drawdown	Recovery	Drawdown	Recovery		
138-77-23ddb1	....	....	30,000	35,000	......	......	32,000	....
	138-77-23ddb3	300 NW	25,000	35,000	40,000	31,000	32,000	.00040
	138-77-24caa2	3,800 NE	26,000	43,000	27,000	36,000	33,000	.00018
	138-77-25bbd1	3,800 SE	27,000	40,000	25,000	35,000	31,000	.00007

Table 4.—Results of McKenzie aquifer test 1

exceeded recharge and that some water was taken from storage during the test.

The test anlysis showed the average transmissibility for the McKenzie aquifer in the test area to be 32,000 gpd per foot. Storage coefficients and lithologic data for the area suggest that the aquifer is under artesian conditions.

Aquifer test 2 was made April 20-26, 1964, using Mr. G. D. Adams'

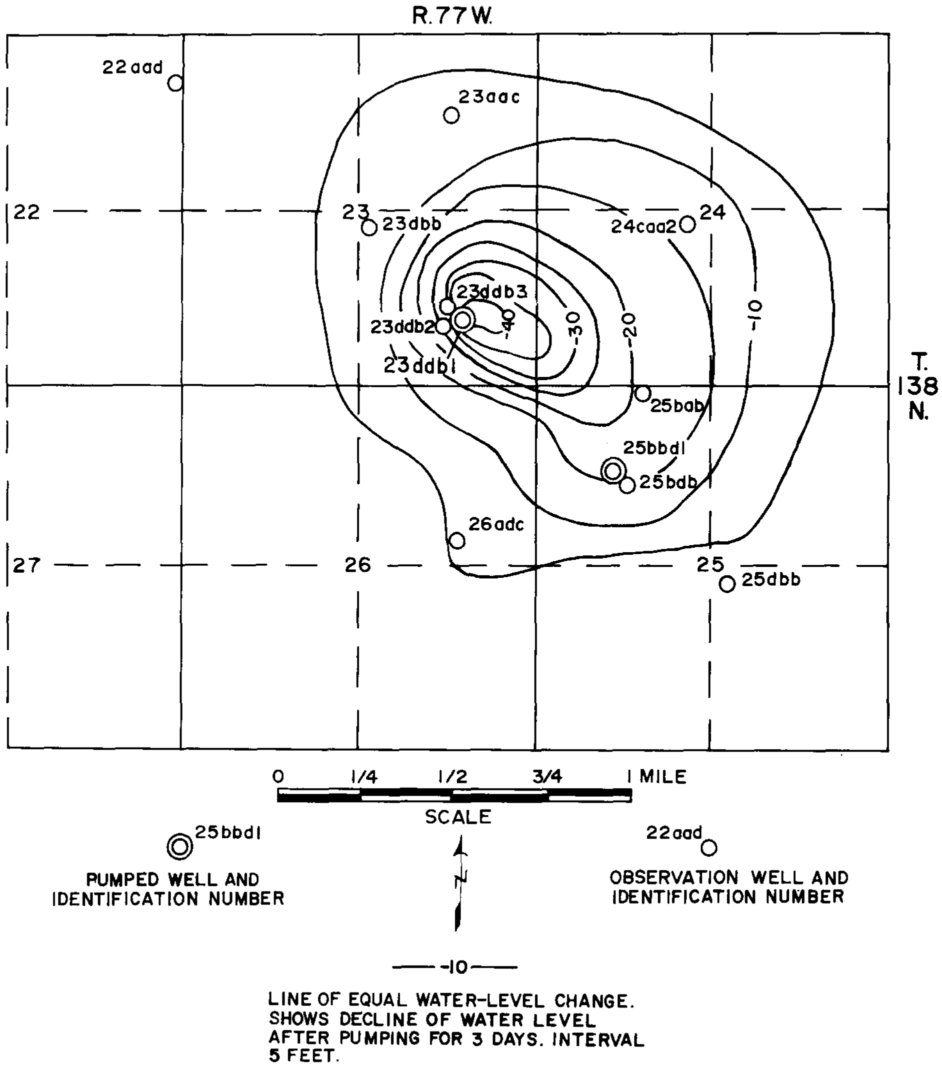


Figure 11.—Location of wells used during McKenzie aquifer tests 1 and 2, and area of influence resulting from test 1.

irrigation well (138-77-25bbdl), in the McKenzie aquifer. The well is 78.2 feet deep, with a 17-inch inside diameter concrete casing and a concrete screen set from 58 to 78 feet. It is gravel packed. The pump is a turbine type, powered by a 100-horsepower electric motor. The water was discharged about 2,400 feet southeast of the pumping well. The discharge, which was measured with an orifice tube and manometer, was maintained at close to 380 gpm throughout the test by using two inline valves. About 41 minutes elapsed after the pump started before a constant discharge was attained. Water samples were collected at the pump head for analysis after 1 minute, 36 and 71 hours of pumping.

Two observation wells were installed for the test. One was drilled 300 feet southeast of the pumped well to a depth of 72 feet (138-77-25bdb). The other was 1,500 feet north of the pumped well to a depth of 37 feet (138-77-25bab). Both were cased with 1¼-inch plastic pipe slotted the bottom 2 feet, and gravel packed. Also used as observation wells were: the pumped well; the McDonald service well (138-77-25dbb), 56 feet deep; a test well (138-77-26adc), 63 feet deep; observation well 138-77-23ddb2, 90 feet deep; a test well (138-77-23aac), 130 feet deep; and a test well equipped with a continuous water-level

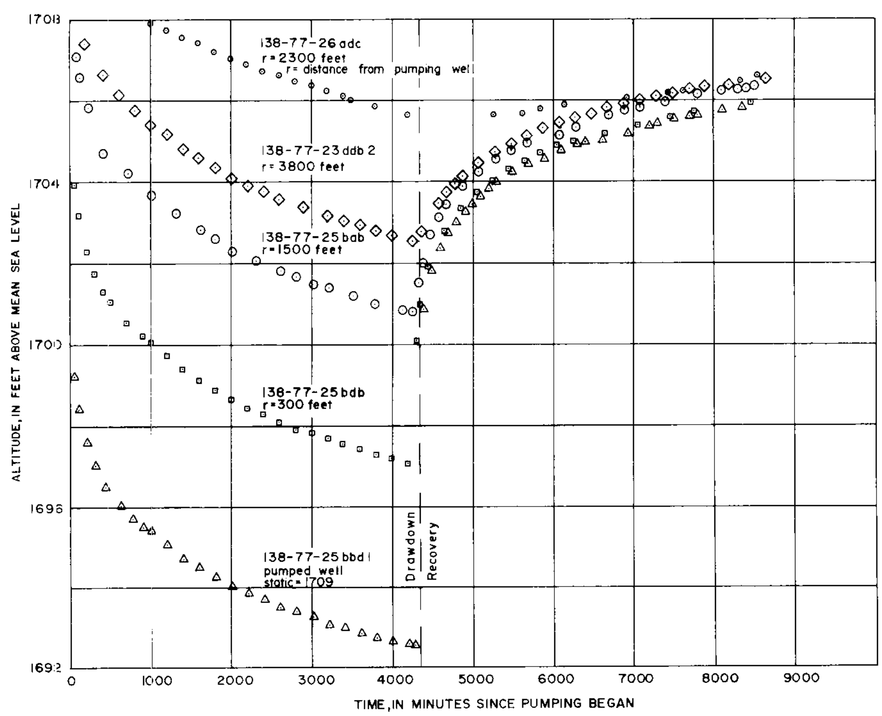


Figure 12.—Drawdown and recovery curves for McKenzie aquifer test 2.

Discharge well	Observation well	Distance and direction from pumped well "r" (feet)	Coefficient of transmissibility "T" gpd/ft					Coefficient of storage
			Semilog solution		Theis type curve solution		Combined average	
			Drawdown	Recovery	Drawdown	Recovery		
138-77-25bbd1	....	.....	23,000	22,000	a/29,000	......	24,000	......
	138-77-25bdb	300 SE	21,000	22,000	26,000	31,000	25,000	.00073
	138-77-25bab	1,500 N	22,000	22,000	27,000	32,000	25,000	.00017
	138-77-26adc	2,300 SW	22,000	22,000	......	......	22,000	......
	138-77-23ddb2	3,800 NW	21,000	22,000	24,000	32,000	24,000	.00035

a/ Computed from residual drawdown.

Table 5.—Results of McKenzie aquifer test 2

recorder (138-77-22aad), 126 feet deep. No other wells were pumping in the area during the test period. Water levels were measured with a metal tape in the pumped well and were recorded on charts with water-level recorders equipped with electric water-level sensing devices in the other wells.

Hydrographs of the five wells having the most significant water-level changes were plotted from these data (fig. 12). There were no water-level changes in wells 138-77-22aad and 138-77-25dbb during the test. The recorder on observation well 138-77-23aac malfunctioned, and water-level data were obtained only at the beginning and end of the test at this site.

The results of the test, which are listed in table 5, indicate that the aquifer at this location is under artesian conditions. Boundary conditions affected the data after 400 minutes pumping. The departures from the type curves and the lack of water-level change in well 138-77-25bbdl indicate impermeable boundaries southeast, south, and southwest of the pumped well. Therefore, the transmissibilities obtained in the early part of the test are much higher than those calculated from the data obtained during the latter part.

Evidently the test was run long enough for the aquifer to approach equilibrium in the vicinity of the pumped well. However, the absence of full recovery indicates that some water was taken from storage. The average transmissibility for this part of the McKenzie aquifer is 24,000 gpd per foot (gallons per day per foot). This is 8,000 gpd per foot less than was obtained during aquifer test 1, the difference resulted from the impermeable boundary effects of a bedrock high in this area.

Recharge.—Most of the recharge to the aquifer is derived from streamflow infiltrating through surficial outwash in the Random Creek valley and in the northern part of the aquifer as shown by the abrupt termination of intermittent streams in these areas. Other sources of recharge include lateral and upward movement of water from adjacent aquifers in till and bedrock. The slough area located 1 mile south of McKenzie and Random Creek reservoir represents the water surface of the aquifer. During periods of above average precipitation recharge is from the ponds, and during periods of below average precipitation the ponds are supported by discharge from the aquifer.

Storage and movement.—Approximately 2,700,000 acre-feet of water is stored in the McKenzie aquifer. However, only about half of this would be available to wells.

The water level in the aquifer is at an altitude of about 1,700 feet, and generally between 5 and 30 feet below the land surface. Figure 13 (in pocket) shows the piezometric surface and general direction of water movement in southern Burleigh County.

Water-level fluctuations.—Hydrographs of water levels (fig. 14) in the aquifer show from 2 to 3 periods of heavy withdrawals; during May, the period from the end of July through early August, and October. The progressive lowering of the water surface indicates that withdrawals exceeded natural recharge during these periods. Most of the water levels in observation wells recover during the present annual cycle to near the water level of the previous years. However, the quantity of water replaced to storage apparently is less than the amount taken out of storage, as evidenced by the progressive

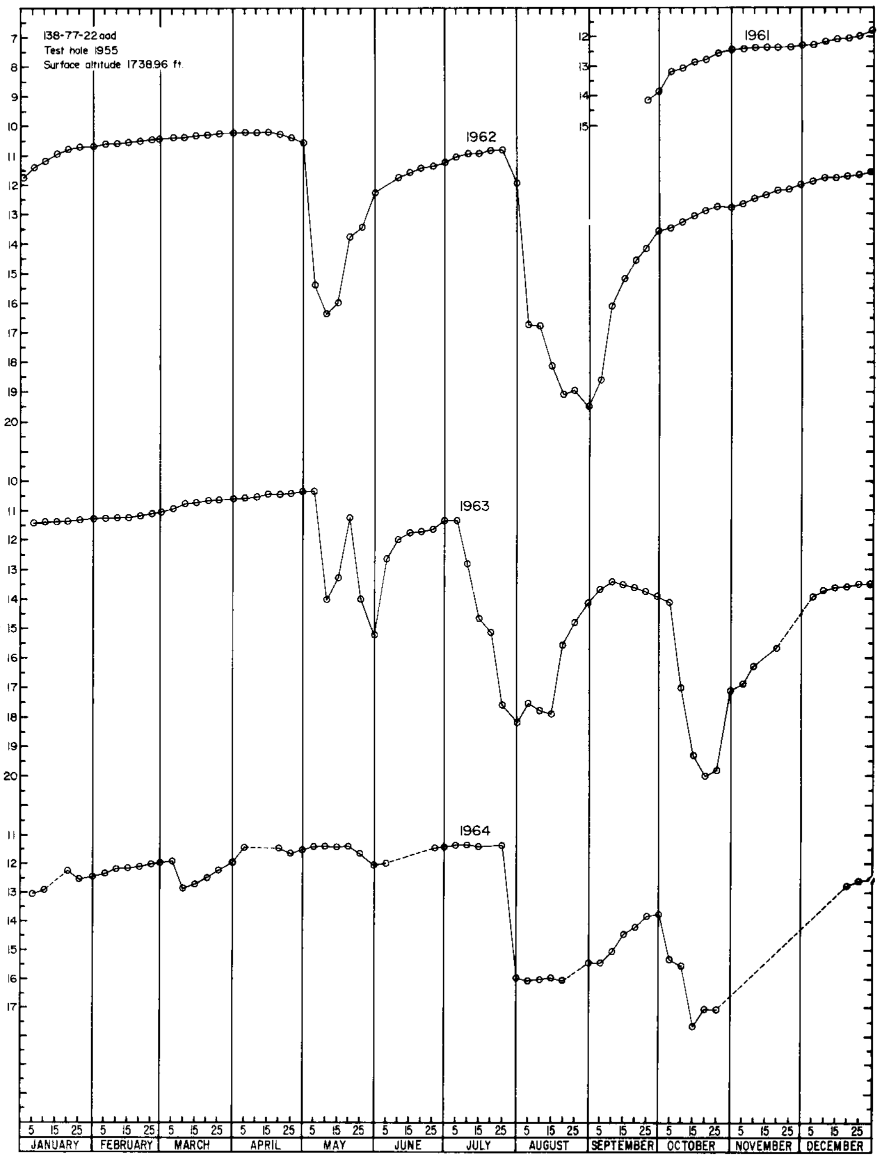


Figure 14.—Seasonal water-level fluctuations in wells in the McKenzie aquifer.

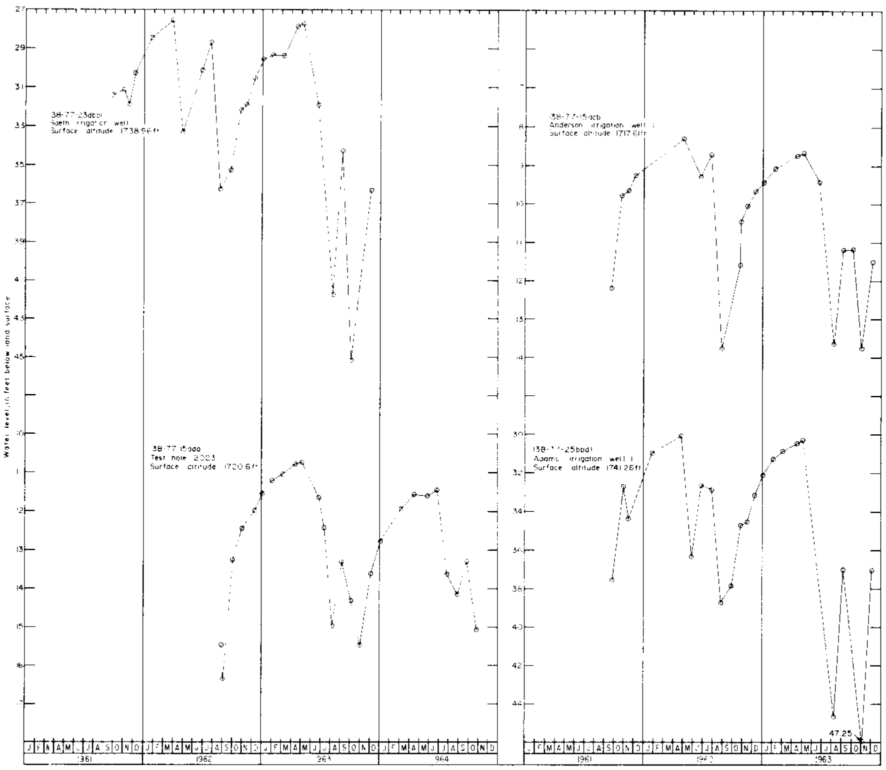


Figure 14.—Seasonal water-level fluctuations in wells in the McKenzie aquifer—Continued.

water-level declines each year when comparing similar withdrawal periods.

Quality of water.—The water in the McKenzie aquifer is a sodium bicarbonate type and generally has a dissolved solids concentration of 1,000 to 1,500 ppm (see analysis 10, table 1).

Partial chemical analysis of samples taken during aquifer test 1 are presented in table 2. (See Randich, 1965, table 3 for complete analyses.) The specific conductance ranged from 1,450 to 1,540 micromhos at 25° C. Approximately half of the change in specific conductance occurred during the first hour of the test. There was no change during the next 47 hours, but a further change took place during the last 22 hours of the test. The total dissolved solids ranged from 980 to 1,050 ppm, increasing approximately 6 percent between the beginning and end of the test. The principal increase was in calcium and bicarbonate concentrations. The sodium-adsorption ratio (SAR) decreased during the test. All of the samples in this area except for those from well number 138-77-25bbd have a higher than 1,000 ppm dissolved solids concentration.

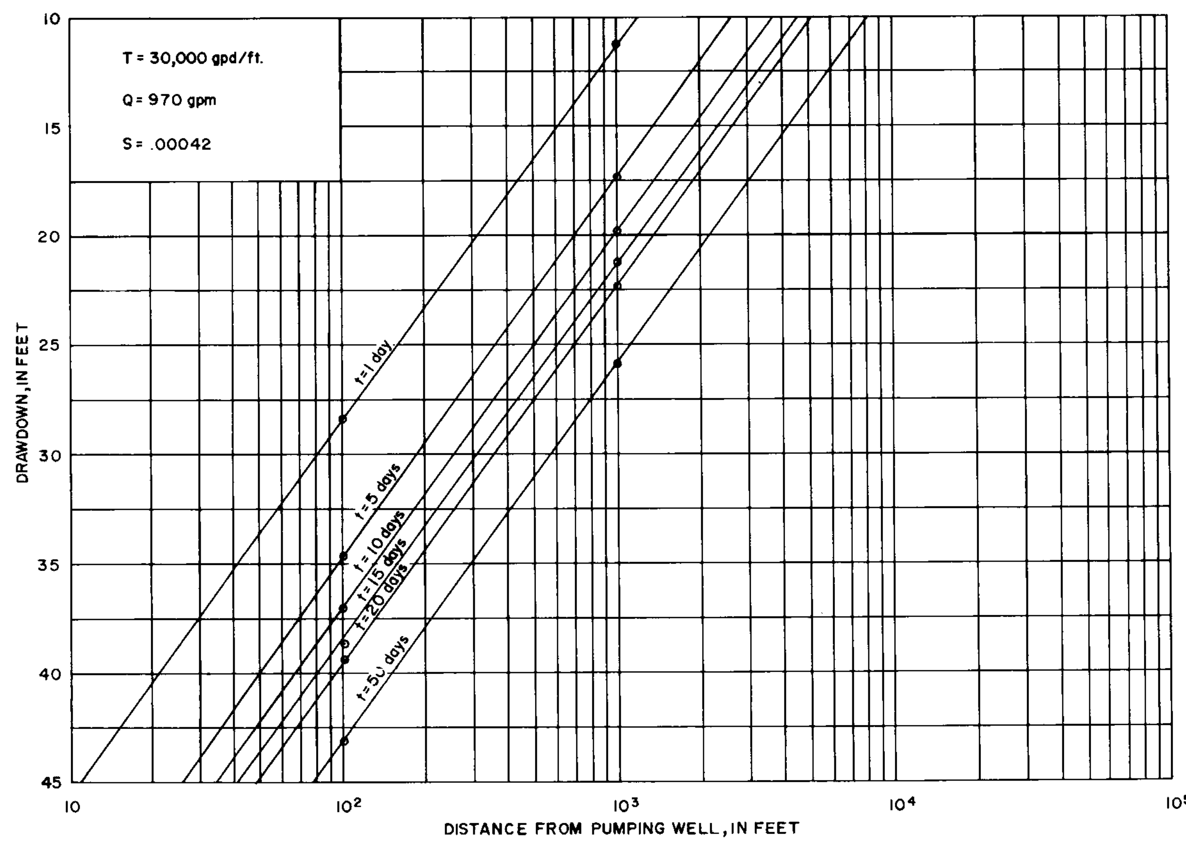


Figure 15.—Predicted drawdown in the McKenzie aquifer in the vicinity of a well discharging 970 gpm for selected periods.

No change in specific conductance occurred during test 2. However, after 2 days of pumping, the bicarbonate concentration had decreased while the sodium and sulfate concentrations had increased. The SAR value increased slightly. Water from sourrounding areas has slightly higher SAR values, so that movement of this water into the test well will result in higher SAR values as pumping continues. An increase in SAR is not desirable if the water is to be used for irrigation.

UTILIZATION AND POTENTIAL FOR DEVELOPMENT

Three irrigation wells had been developed in the McKenzie aquifer at the time this study was completed (1964). They yield from 400 to 1,000 gpm. Some areas of the aquifer will supply large yields to wells for sustained pumpage. However, scattered lenses of less permeable material such as silt and clay will restrict the size of a development. The best potential for sustained yields is in the central to northeastern part of the channel where the aquifer is thickest.

Figure 15 shows the drawdowns that would be produced by a well discharging at a rate of 970 gpm for selected periods of time. As the drawdowns vary directly with the discharge, drawdowns of greater or lesser rates can be computed from the curves. For example, the drawdown 1,000 feet from a well discharging 970 gpm would be 17.5 feet after 5 days of discharge. If the well had discharged 97 gpm for the same length of time, the theoretical drawdown at the same distance would have been one-tenth as much, or 1.75 feet.

Long Lake Aquifer

The Long Lake aquifer underlies approximately 32 square miles in southeastern Burleigh County (fig. 7). The aquifer was penetrated by 10 test holes, and was found approximately 90 to 150 feet below the land surface. The thickness ranged from 5 to 70 feet, and the material consisted of sand and gravel, grading into silt and clay in places. Generally the upper part was sand, silt, and clay and the lower part was gravel. Sand and gravel grade abruptly to silt and clay in many parts of the aquifer. The coarse sand and gravel is concentrated along the northern and northeastern parts of the aquifer, whereas the silt and fine sand is concentrated in the southern and western parts.

The potential aquifer yields are based upon transmissibility and available head (fig. 7). The aquifer, which generally is under artesian conditions, contains approximately 810,000 acre-feet of water in storage. About one-half would be available to wells.

The water level is at an altitude of about 1,715 feet, or in most places less than 10 feet below the land surface. The movement of water in the Long Lake aquifer is shown in figure 13; the major recharge is from Long Lake. Other sources of recharge include precipitation infiltrating through the surficial outwash along the north and northeastern border, and underflow from adjacent deposits of drift and from the Fox Hills Sandstone. Numerous intermittent streams terminate in the outcrop of the aquifer where the streamflow is absorbed into the ground.

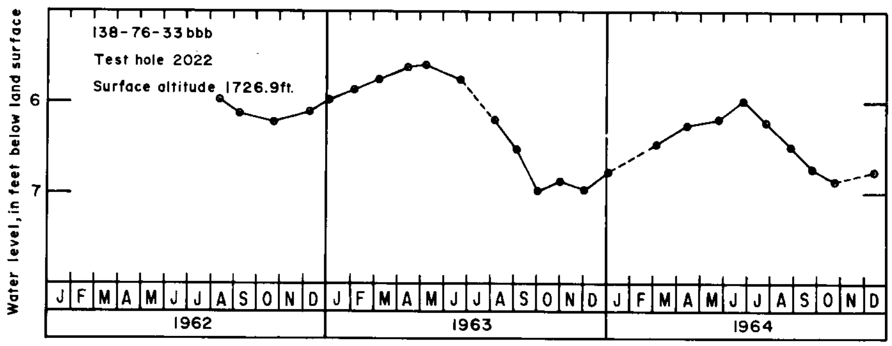


Figure 16.—Water-level fluctuations in a well in the Long Lake aquifer.

Figure 16 shows the natural seasonal water-level fluctuation in the Long Lake aquifer. The highest water levels of each year occurred during May and June, and the lows occurred during October and December. These seasonal variations are caused primarily by ground-water recharge and discharge.

Wells developed in the Long Lake aquifer can be expected to yield a sodium bicarbonate type water containing approximately 1,000 ppm dissolved solids.

No large-yield production wells have been developed as yet (1965), but several domestic and stock wells are producing from the upper part.

Lower Apple Creek Aquifer

The Lower Apple Creek aquifer underlies approximately 21 square miles southeast of Bismarck. It generally follows the present Apple Creek valley from the confluence with the west and east branches to the the confluence with Missouri River (fig. 7). The aquifer, which was penetrated by 15 test holes, lies approximately 40 to 110 feet below the land surface. It ranges in thickness from less than 10 to more than 100 feet and consists predominately of mixed sand and gravel. Generally the upper part consists of sand and the lower part of gravel. However, there are alternating layers of sand, silt, clay, and gravel of varying thicknesses at most sites. The aquifer generally thickens near the McKenzie and Bismarck aquifers.

One pumping test was conducted on this aquifer. The test was made April 22-29, 1963 using Mr. C. P. Yegen's irrigation well No. 1 (138-80-24cacl). The well is 84 feet deep. It has a 17-inch inside diameter concrete casing and 16 feet of screen set in the bottom, gravel packed. The turbine pump is powered by a 30-horsepower electric motor. During the test, the water was discharged through a 6-inch pipe into Apple Creek, 780 feet west of the pumping well. The discharge, which was measured with an orifice tube and manometer, was maintained at a constant rate of 360 gpm using two inline valves.

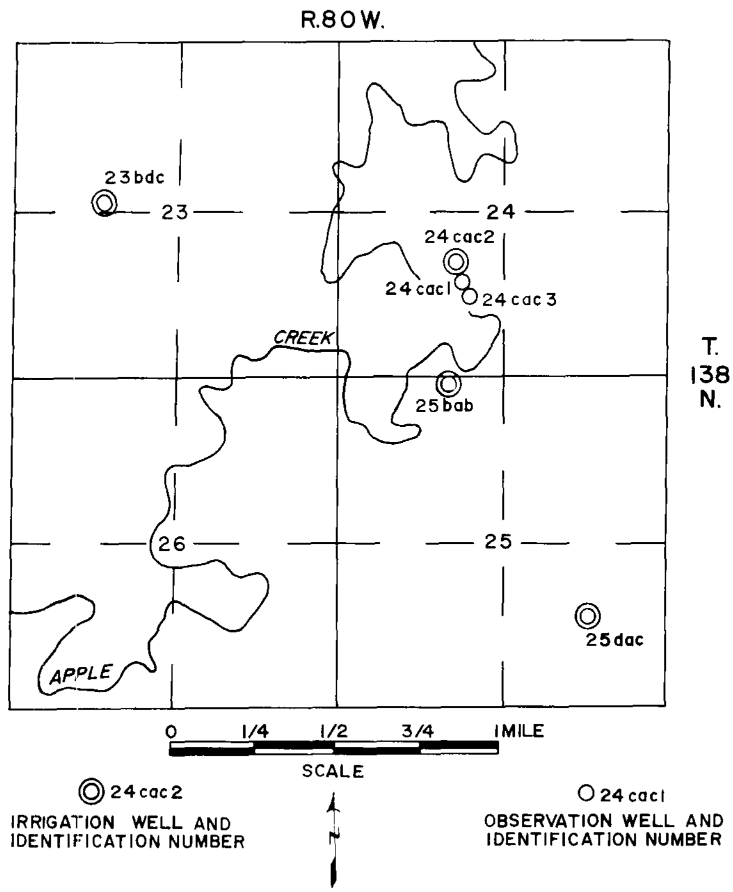


Figure 17.—Location of wells used in Lower Apple Creek and Soo Channel aquifer tests.

Water samples were collected at the pump after 1, 5, and 15 minutes and 1, 3, 5, 8, 12, 25, 36, and 50 hours of pumping. A complete chemical analysis was made on the first and last samples collected.

Two observation wells were drilled at distances of 53 feet (138-80-24cacl) and 160 feet (138-80-24cac2) south of the pumped well (fig. 17). Both are 90 feet deep and have 4 feet of screen at the bottom. Other wells observed during the test were the pumped well (138-80-24cacl) and irrigation well No. 2 (138-80-25bab). Hydrographs of the water level changes in these wells are shown in figure 18.

The results of the test are summarized in table 6. The analysis shows that the aquifer has a transmissibility of 10,000 gpd per foot

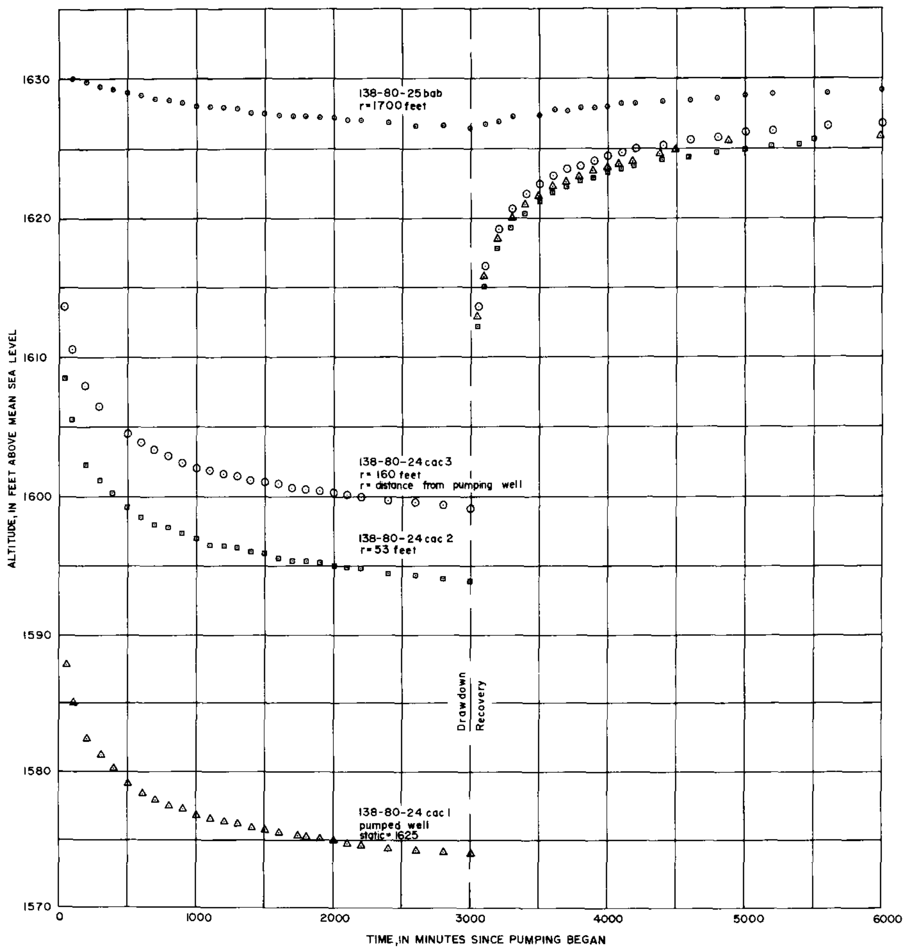


Figure 18.—Drawdown and recovery curves for Lower Apple Creek aquifer test.

Discharge well	Observation well	Distance and direction from pumped well "r" (feet)	Coefficient of transmissibility "T" gpd/ft					Coefficient of storage
			Semilog solution		Theis type curve solution		Combined average	
			Drawdown	Recovery	Drawdown	Recovery		
138-80-24cac1	....	......	10,000	11,000	......	......	10,000	......
	138-80-24cac2	53 S	10,000	10,000	10,000	10,000	10,000	......
	138-80-24cac3	160 S	11,000	11,000	10,000	10,000	11,000	0.016
	138-80-25bab	1,700 S	40,000	48,000	33,000	42,000	41,000	.012

Table 6.—Results of Lower Apple Creek aquifer test

and a coefficient of storage of .012 to .016 in the vicinity of the pumped well (138-80-24cacl). However, the transmissibility increases southwestward toward the vicinity of Yegen irrigation well 2 (138-80-25bab). The aquifer is bounded on the east and north by less permeable zones within 1 mile from the pumped well. The storage coefficients and lithologic data for the area indicate the aquifer is under water-table conditions in places and leaky artesian conditions in others, the latter south and west of the pumped well.

Approximately 620,000 acre-feet of water is stored in the Lower Apple Creek aquifer, of which probably less than half is available to wells.

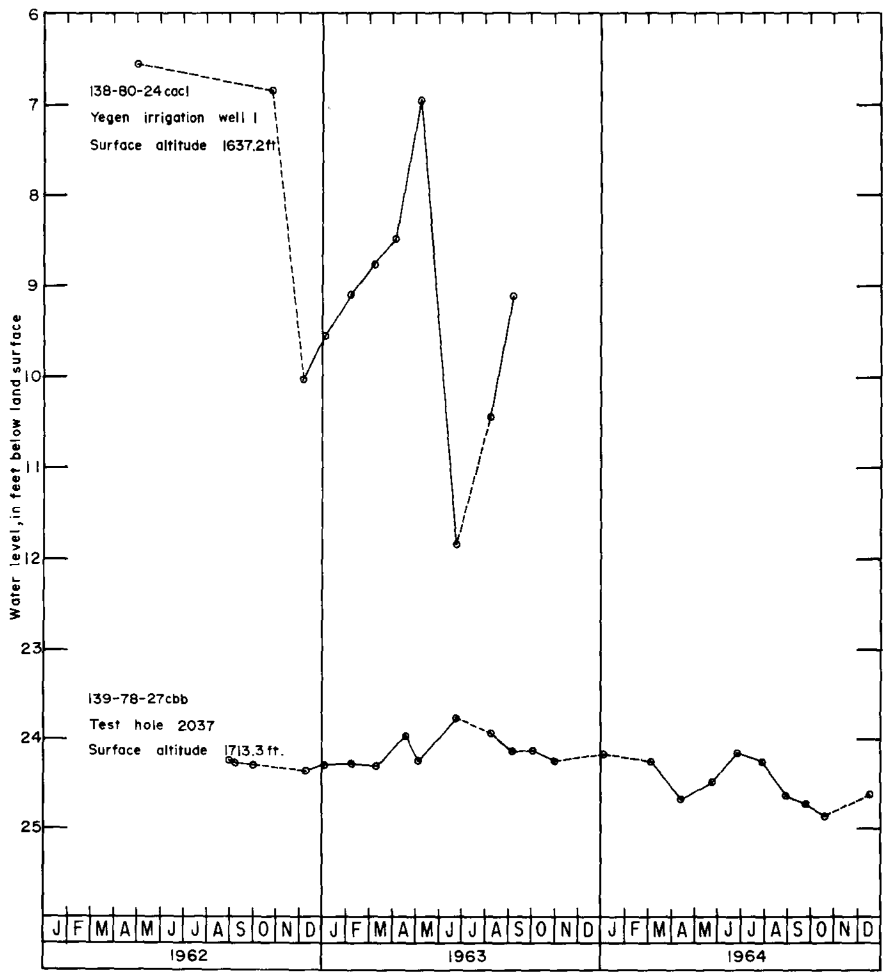


Figure 19.—Water-level fluctuations in wells in the Lower Apple Creek aquifer.

The altitude of the water surface is between 1,615 and 1,715 feet and is from less than 5 to approximately 20 feet below the land surface. Figure 13 shows that the water movement through this aquifer is from east to west.

The major recharge to the Lower Apple Creek aquifer is derived from precipitation infiltrating the surficial materials, from seepage by Apple Creek and its tributaries, by leakage from the McKenzie and Soo Channel aquifers, and from adjacent or underlying bedrock formations. Also, water is absorbed from intermittent streams that terminate in the aquifer along the southeastern boundary from near Menoken southwest toward Bismarck for approximately 8 miles (fig.7). During periods of below average precipitation, Apple Creek discharges water derived primarily from the aquifer system. Figure 19 shows the progressive lowering of the water surface indicating that withdrawals exceeded natural recharge during these periods. Seasonal variations are noticeable on the hydrographs, and are caused primarily by ground-water recharge and discharge to the aquifer.

Most wells developed in the aquifer can be expected to yield a sodium bicarbonate type water containing less than 1,000 ppm dissolved solids (see analysis 13, table 1).

Partial chemical analyses of water samples taken during the pumping test are presented in table 2. (For complete analyses see Randich, 1965, table 3.) The only substantial change during the pumping test was the decrease in nitrate concentration. This may indicate that the well had been slightly contaminated by organic wastes during the winter. A water sample taken in the fall 2 years earlier had lower concentrations of sodium and chloride as well as a lower specific conductance. These differences may indicate either a seasonal change, a permanent change in the quality of water as more water has been withdrawn from the aquifer, or a natural trend in water quality changes in the aquifer. The reported calcium and magnesium differences are believed to be evidence of variations in analytical technique.

Two irrigation wells that yield from 400 to 700 gpm have been developed in the southwestern part of the aquifer, and about 30 domestic and stock wells are widely distributed throughout the aquifer. Because the aquifer is bounded on at least one side by bedrock, and contains local aquitards, a wide range of yields can be expected. Possibly additional large production wells could be developed in the aquifer, but considerable care should be exercised to prevent local overdevelopment.

Glencoe Channel Aquifer

The Glencoe Channel aquifer underlies approximately 26 square miles in south-central Burleigh County (fig. 7). The aquifer was penetrated by 10 test holes, and lies approximately 20 to 60 feet below the land surface. The drilling showed that the aquifer consists mostly of sand, which ranges from 50 to more than 100 feet thick. In some places gravel beds, generally less than 30 feet thick, occur near the bottom of the aquifer. The channel containing the aquifer is narrow, deep and is cut into bedrock.

Approximately 1 million acre-feet of water is stored in the Glencoe Channel aquifer, but only about half of this amount would be available to wells.

The water level in the aquifer is at an altitude of 1,645 to 1,700 feet, and is between 20 and 40 feet below the land surface. The ground-

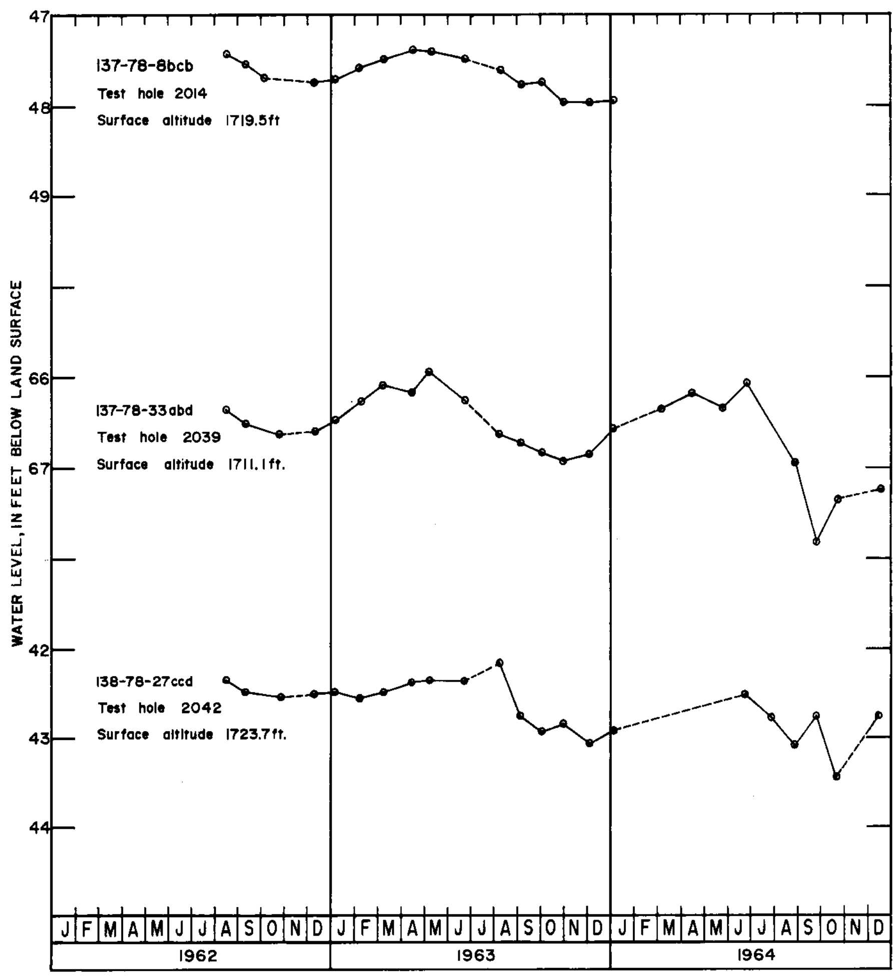


Figure 20.—Water-level fluctuations in wells in the Glencoe Channel aquifer.

water movement through the aquifer is west and south (fig. 13).

The major recharge to the aquifer is derived from precipitation infiltrating the surface materials through the stream valleys. The high permeability of surficial materials is evidenced by the abrupt termination of intermittent streams when they reach an area underlain by the aquifer. Other sources of recharge include discharge from the McKenzie aquifer and, to some extent, from the underlying Fox Hills Sandstone.

April through June. These represent seasonal variations before any large withdrawal is imposed on the aquifer. The variations are caused primarily by ground-water recharge and natural discharge.

Water in the Glencoe Channel aquifer contains approximately 1,500 ppm dissolved solids and is of the sodium bicarbonate type (see analysis 7, table 1). Only a few domestic and stock wells have been developed at the present time (1965). Based on permeabilities, thickness, water levels, and extent, the aquifer probably is capable of yielding large quantities of water to properly constructed wells.

Soo Channel Aquifer

The Soo Channel aquifer underlies approximately 4 square miles in southwestern Burleigh County (fig. 7). Several private test holes have been drilled into the aquifer, of which five are believed to have reached bedrock. All of the test holes were drilled in the northwestern part of the aquifer. Because of the lack of test holes, the areal extent of the aquifer was estimated mainly from surficial geologic data. The test-hole data show that the northwestern part of the aquifer contains alternating layers of silt, sand, clay, and gravel. The coarse materials generally lie between 130 and 200 feet below land surface. The channel is narrow and is cut into bedrock.

A pumping test was made in the Soo Channel aquifer July 1-3, 1963, on Mr. C. P. Yegen's irrigation well 3 (138-80-25dac) (fig. 17). The well was pumped for 23.3 hours. The well is 155 feet deep; it has 105 feet of steel 6-inch inside diameter casing, 50 feet of screen from 105 to 155 feet, and is gravel packed. The turbine pump was powered by a 130-horsepower gasoline engine. The water was discharged at the well site and allowed to drain northwest through a coulee. The discharge, which was measured with an orifice tube and manometer, was maintained at approximately 200 gpm throughout the test. The water level in the pumped well was 54.28 feet below the land surface. Owing to the short duration of the test and the inadequate records from observation wells, the results were inconclusive. However, useful information was obtained concerning the productivity of the aquifer at the well site and the specific capacity of the well. The drawdown in the well after pumping for 1,400 minutes at 200 gpm was 26.6 feet, indicating specific capacity of about 7 gpm per foot of drawdown.

Water samples were collected at the beginning of the test and after 5 and 15 minutes; 1, 3, 8, 12, and 23.3 hours of pumping. A complete analysis was performed on the initial and the final samples.

Water level measurements also were made in the Yegen irrigation well 3 (138-80-25dac), while irrigation wells 1 (138-80-24cacl) and 2 (138-80-25bab) were pumping. After 3 days of pumping wells 1 and 2, which tap the Lower Apple Creek aquifer, the water level in well 3 had declined 6 feet, indicating a considerable loss from this area when withdrawals are made from the Lower Apple Creek aquifer. The interference should be taken into account when calculating a well capacity for additional development in this area (fig. 17).

Partial chemical analyses of water samples are presented in table 2. (See Randich, 1965, table 3 for complete analyses.) The water is a calcium bicarbonate type containing about 900 ppm dissolved solids. The specific conductance decreased slightly during the pumping test; however, these changes may be due to the limitations of the measuring equipment. The only other notable change was the decrease in iron concentration during the test. The initial sample could have contained excessive iron because of corrosion of the well casing, and thus, may not be representative of water in the aquifer.

Sustained yields to wells developed in the Soo Channel aquifer probably would be less than 200 gpm. Even though the quality of this water is more desirable for irrigation than that available in the surrounding area, the quantity available appears to be a limiting factor for large scale development.

Sibley Channel Aquifer

The Sibley Channel aquifer underlies approximately 3 square miles in east-central Burleigh County and a larger but undetermined area in Kidder County (fig. 7). The aquifer was penetrated by 2 test holes; it lies approximately 50 to 80 feet below the land surface. The aquifer is more than 75 feet thick at the sites of the 2 test holes and consists predominately of gravel. The channel, as it is presently known, extends only a short distance into Burleigh County and is believed to be quite narrow.

Approximately 340,000 acre-feet of water is in storage in that part of the aquifer that lies within Burleigh County. As much as 70 percent of this may be available to wells.

The water level in the aquifer is between the altitudes of 1,847 and 1,864 feet, and it is from 15 to 53 feet below land surface. The aquifer is artesian and, as figure 13 indicates, the piezometric surface slopes to the south and southeast. Recharge to the aquifer is by direct percolation of water from precipitation and by underflow from adjacent bedrock formations.

The aquifer has had no development, as yet (1965). However, the water-bearing materials appear to be very permeable, indicating a good potential of obtaining large yields from properly constructed wells. The water is of the sodium bicarbonate sulfate type containing less than 1,500 ppm dissolved solids.

Wing Channel Aquifer

The Wing Channel aquifer underlies approximately 10 square miles in northeastern Burleigh County (fig. 7), and it extends an undetermined distance into Kidder County. The aquifer was penetrated by 5 test holes; it lies approximately 45 to 170 feet below the land surface. The aquifer consists of sand and gravel. The sand is as much as 115 feet thick, and the gravel is as much as 35 feet thick. Test hole 142-75-19ccb penetrated 144 feet of sand and gravel separated in 2 places by 8 and 16 feet of till. However, the thickness is generally less than 20 feet.

Approximately 160,000 acre-feet of water is stored in the Wing Channel aquifer. About half of this would be available to wells.

The aquifer is artesian and the water rises in a cased well to an altitude of 1,885 feet above sea level, or generally to less than 10 feet below land surface. The major recharge is derived from precipitation infiltrating the surficial material, and from downward percolation from streams and lakes overlying the aquifer.

No large yield production wells have been developed in the aquifer at the present time (1965), and only a few shallow domestic and stock wells tap the upper part of the aquifer. The aquifer, which is confined in a channel, contains lenses of less permeable material that usually cause a wide range of yields. A sample of calcium carbonate water containing about 600 ppm dissolved solids was obtained from a test well at 142-75-19ccb. The aquifer probably has a good potential for limited future irrigation development.

Melt-Water Channels Overlain by Recent Deposits

Alluvial deposits in the Upper and Lower Apple Creek aquifers are generally confined to the present stream bed, and commonly are less than 10 feet thick. The deposits consist mainly of sand, but in places contain gravel or silt. They yield only small supplies of water to wells. In most places the alluvium serves as an avenue of recharge to the underlying aquifers.

The thickest alluvial deposits are in the Missouri River valley where the deposits are generally less than 100 feet thick. The classification of aquifers in the Missouri River valley according to mode of deposition is somewhat arbitrary because of gradation of alluvium and outwash and because of reworking of the outwash. For purposes of this report the aquifers located adjacent to and in the Missouri River valley are classified as outwash deposits overlain with alluvium.

The dissolved solids concentrations of the waters from 8 wells producing water from alluvium ranged from 832 to 1,840 ppm. Sodium bicarbonate, calcium bicarbonate, sodium calcium bicarbonate, and sodium bicarbonate sulfate types of water were represented. Except for 1 sample, the waters were very hard, with the hardness as calcium carbonate ranging from 178 to 668 ppm. The iron concentrations of all but 1 sample exceeded the U. S. Public Health Service limit; the maximum concentration was 11 ppm. The chloride, fluoride and nitrate concentrations were less than the limits; whereas sulfate concentrations of two samples exceeded the limit. The salinity hazard of the water is high and the sodium hazard is generally low, although one sample had a very high sodium classification. The residual sodium carbonate of the waters would classify them as marginal to unsuitable for irrigation.

Bismarck Aquifer

LOCATION AND EXTENT

The Bismarck aquifer underlies approximately 25 square miles near Bismarck in southwestern Burleigh County (fig. 7). The aquifer, which was penetrated by 15 test holes, lies approximately 20 to 105 feet below the land surface.

THICKNESS AND LITHOLOGY

The aquifer ranges in thickness from 10 to 105 feet and averages 50 feet; it thins toward the east in places. It consists predominately of mixed sand and gravel and locally of gravel only. Generally the upper part contains the sand and the deeper part the gravel. Locally, the aquifer contains thin lenses of clay, less than 5 feet thick.

RESERVOIR CHARACTERISTICS

Pumping tests and aquifer coefficients.—Two pumping tests were made on this aquifer. The description and results of the tests are as follows:

Aquifer test 1 was made Nov. 12-19, 1962 using Mr. John Peterson's irrigation well (138-80-17acbl) (fig. 21). This well is 90 feet deep, with 17-inch inside diameter concrete casing and concrete screen from 76 to 88 feet. It is gravel packed and plugged at the bottom. The well has a turbine pump powered by a 50 horsepower electric motor. The water was discharged through a 6-inch pipe to a point 450 feet south of the well. The rate of discharge was measured with an orifice tube and manometer. A nearly constant discharge of 900 gpm was maintained during the test using a line valve at the pump. Water samples were collected at the well head after 1, 5, and 15 minutes and 1, 2, 3, 8, 24, 48, and 52 hours of pumping. The first and last samples collected were completely analyzed.

Two observation wells were drilled for the test. One was drilled 300 feet due east of the pumped well to a depth of 72 feet, and the other 300 feet west to a depth of 67 feet. Both were cased with 1¼-inch steel pipe terminating in 4-foot sand points. Wachters' irrigation well (138-80-9bcd), 105 feet deep, and the Fort Lincoln Nursery recorder well (138-80-15cdd), 168 feet deep, were observed during the test. No other wells in the area were pumping during the test period.

Water levels were measured with metal tapes in the pumped well

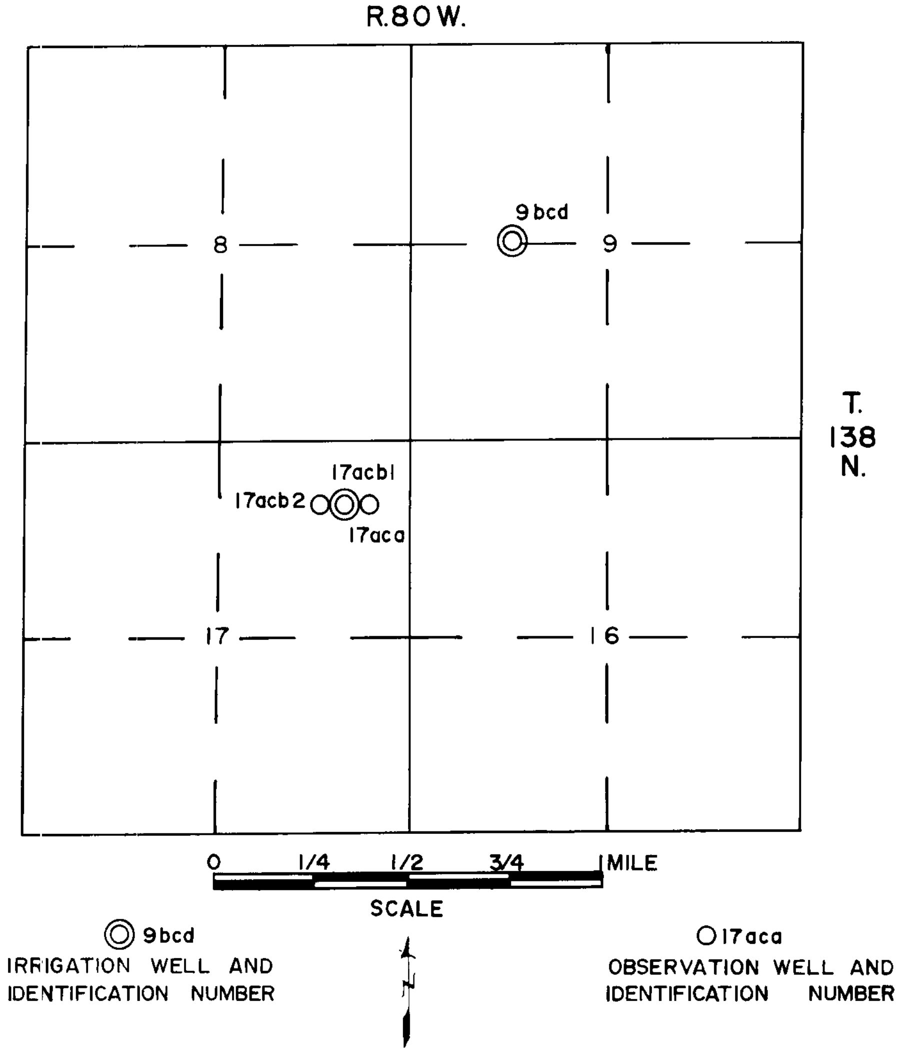


Figure 21.—Location of wells used in Bismarck aquifer test 1.

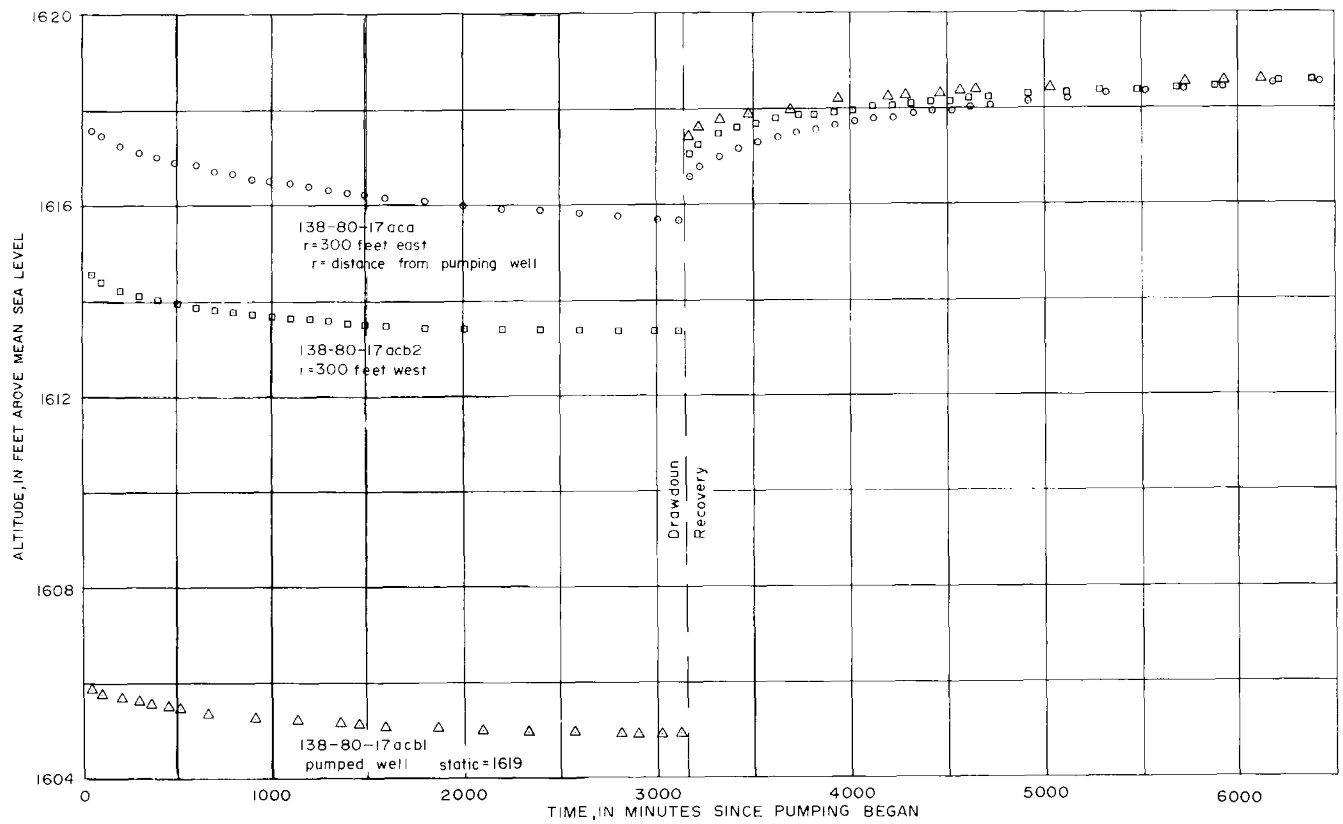


Figure 22.—Drawdown and recovery curves for Bismarck aquifer test 1.

Discharge well	Observation well	Distance and direction from pumped well "r" (feet)	Coefficient of transmissibility "T" gpd/ft					Coefficient of storage
			Semilog solution		Theis type curve solution		Combined average	
			Drawdown	Recovery	Drawdown	Recovery		
138-80-17acb1	....	......	400,000	300,000	....	....	330,000	......
	138-80-17acb2	300 W	600,000	720,000	200,000	150,000	410,000	.00025
	138-80-17aca	300 E	280,000	340,000	260,000	340,000	310,000	.00220

Table 7.—Results of Bismarck aquifer test 1

(138-80-17acbl) and Wachters' irrigation well (138-80-9bcd). Water-level recorders, equipped with electric water-level sensing devices, were installed on observation wells 138-80-17aca and 138-80-17acb2. The permanent observation well, 138-80-15cdd, was equipped with a continuous water-level recorder. Hydrographs of the three most significant wells were plotted from the test data and are shown on figure 22.

Logarithmic plots of drawdown and recovery versus r^2/t and semilog plots of drawdown and recovery versus time were prepared for the observation wells, and the results are given in table 7. The data indicate the aquifer is receiving recharge from the west and northwest from the Missouri River. As pumping progressed, the cone of influence shows an impermeable boundary to the east. This is indicated by the west observation well recovering faster than the east well. The aquifer also seems to be receiving some recharge from above even though it is overlain by a 5-foot layer of clay. The average transmissibility for the aquifer in the test area is 350,000 gpd per foot. The storage coefficients and other data suggest that the aquifer is under leaky artesian conditions. Evidently the test was run long enough for the aquifer to approach equilibrium between recharge and discharge in the vicinity of the pumped well. The absence of a full recovery indicates that some water (probably in the early part of the test) was taken from storage.

Aquifer test 2 was made Oct. 10-19, 1961 using Mr. D. J. McDonald's irrigation well (138-80-22aac) (fig. 23). The well is 131 feet deep with a 17-inch inside diameter concrete casing and 32 feet of concrete screen set in the bottom. It is gravel packed. The well has a turbine pump powered by a 60-horsepower electric motor. The water was discharged through a 6-inch pipe 400 feet southwest of the pumping well. The discharge was measured with an orifice tube and manometer. A nearly constant discharge rate of 760 gpm was maintained during the test. Water samples were collected from the well at the start of the test and after 5 and 15 minutes, and 1, 2, 8, 24, 48, and 53.3 hours of pumping. A nearly complete chemical analysis was made on the first and last samples collected.

Observation wells were drilled at distances of 200, 500, and 2,000 feet northwest of the pumped well (fig. 23). The wells used for observation during the test are: the pumped well (138-80-22aac); test hole 138-80-22abd2, 157.5 feet deep, with 1¼-inch plastic casing slotted the bottom 30 feet and gravel packed; test hole 138-80-22abdl, 157 feet deep, with 1¼-inch plastic casing slotted the bottom 30 feet and gravel packed; test hole 138-80-15cdd, 168 feet deep, with 4.5 inch steel casing slotted the bottom 30 feet and gravel packed, equipped with a continuous water-level recorder; Solberg's irrigation well (138-80-23bdc), 110 feet deep; Fort Lincoln Nursery's irrigation well 1 (138-80-15cba), 164 feet deep; and Fort Lincoln Nursery's irrigation well 2 (138-80-15bbd), 129 feet deep. Water levels were measured with metal tapes in all wells except 138-80-15cdd, which was read from the recorder chart and periodically checked with tape measurement. Hydrographs for these wells are shown in figure 24.

Semilog plots of drawdown and recovery versus time, and logarithmic plots of drawdown and recovery versus r^2/t were prepared for wells 138-80-15bbd, 138-80-15cba, 138-80-15cdd, 138-80-22abd1, 138-80-22abd2, and 138-80-23bdc. The results are tabulated in table 8.

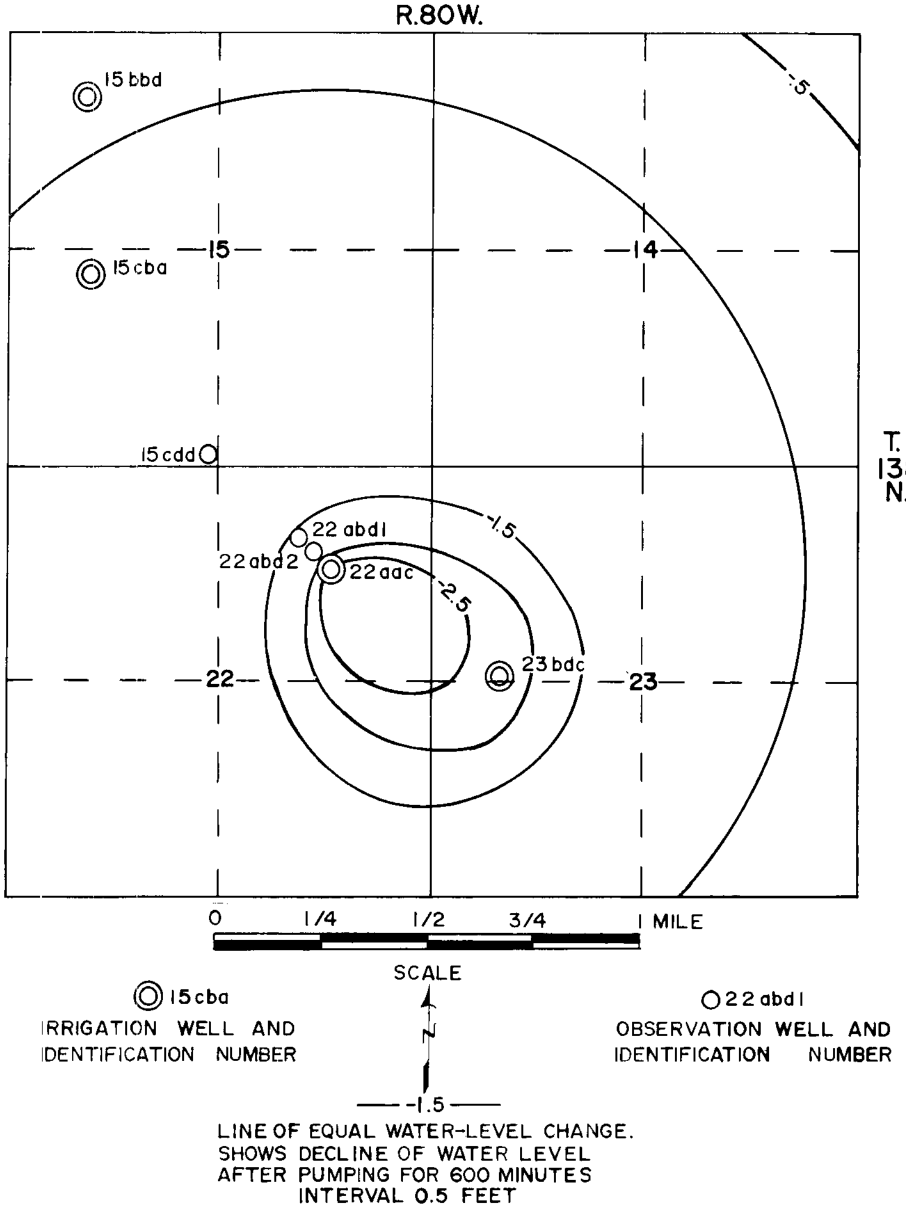


Figure 23.—Location of wells and area of influence for Bismarck aquifer test 2.

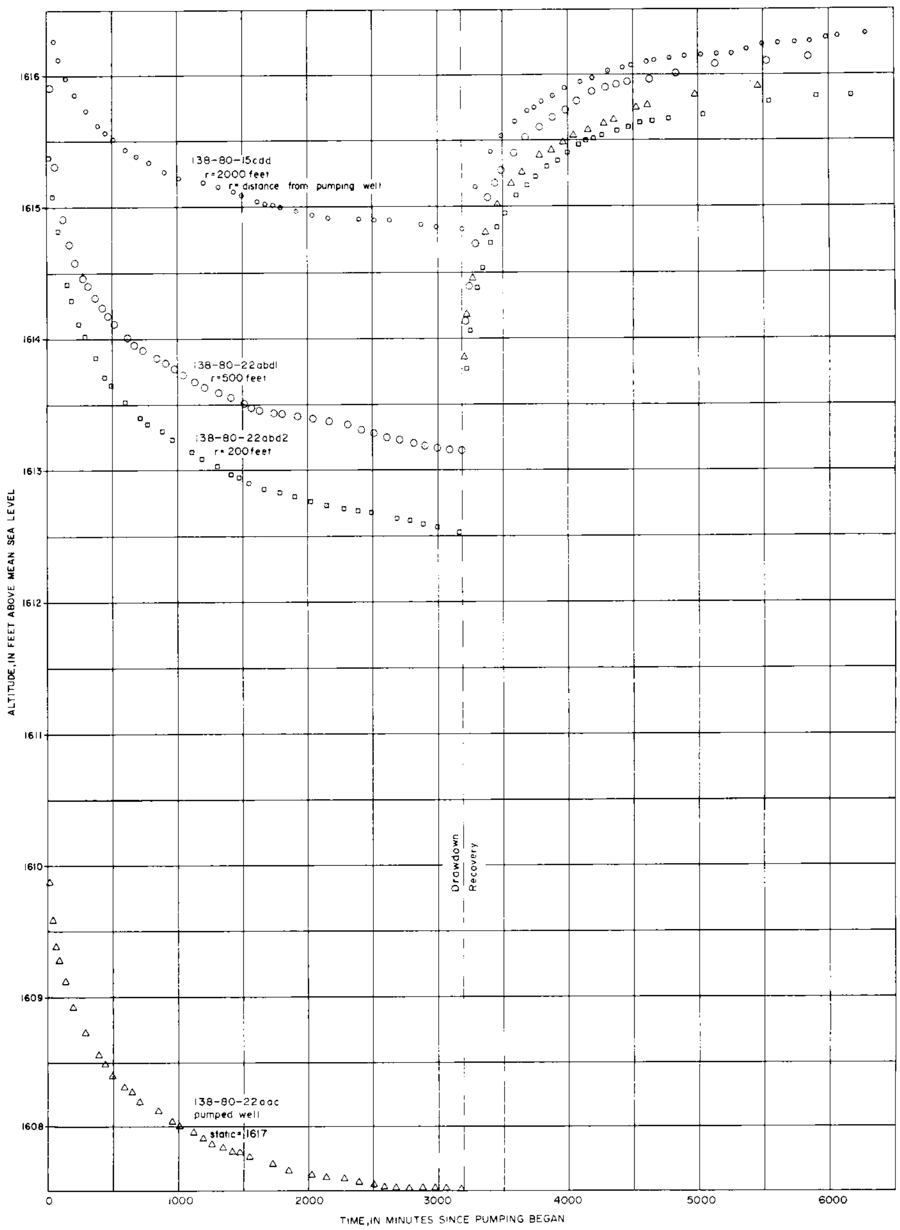


Figure 24.—Drawdown and recovery curves for Bismarck aquifer test 2.

Discharge well	Observation well	Distance and direction from pumped well "r" (feet)	Coefficient of transmissibility "T" gpd/ft					Coefficient of storage
			Semilog solution		Theis type curve solution		Combined average	
			Drawdown	Recovery	Drawdown	Recovery		
138-80-22aac	....	......	150,000	180,000	......	......	170,000	......
	138-80-22abd2	200 NW	180,000	170,000	140,000	180,000	170,000	.00230
	138-80-22abd1	500 NW	180,000	180,000	160,000	180,000	180,000	.00064
	138-80-15cdd	2,000 NW	210,000	240,000	200,000	220,000	220,000	.00012
	138-80-23bdc	2,700 SE	140,000	210,000	110,000	170,000	160,000	.00048
	138-80-15cba	4,700 NW	400,000	400,000	300,000	300,000	350,000	.00054
	138-80-15bbd	6,500 NW	......	360,000	290,000	......	330,000	.00031

Table 8.—Results of Bismarck aquifer test 2

The transmissibility of the Bismarck aquifer in the vicinity of the pumped well is 160,000 gpd per foot. It increases to nearly 300,000 gpd per foot in the northwestern part, and decreases to less than 150,000 gpd per foot in the eastern part (table 8).

The coefficients of storage and other data indicate that artesian conditions exist in the test area. The analyses show that recharge boundaries exist west and northeast of the pumping well. Evidently the test was run long enough for the aquifer to approach equilibrium between recharge and discharge in the vicinity of the pumped well as illustrated by the semilogarithmic plot of drawdown approaching a straight line near the end of the test. The absence of a full recovery indicates that some water (probably in the early part of the test) was taken from storage.

Recharge.—The Bismarck aquifer is overlain by a series of four terrace deposits. The terraces form prominent escarpments trending southeast to northwest (fig. 6). These terrace deposits contain mixtures of silt, sand, and gravel from 10 to 30 feet thick and have a high permeability. The major recharge to the aquifer is derived from precipitation infiltrating through these surface materials.

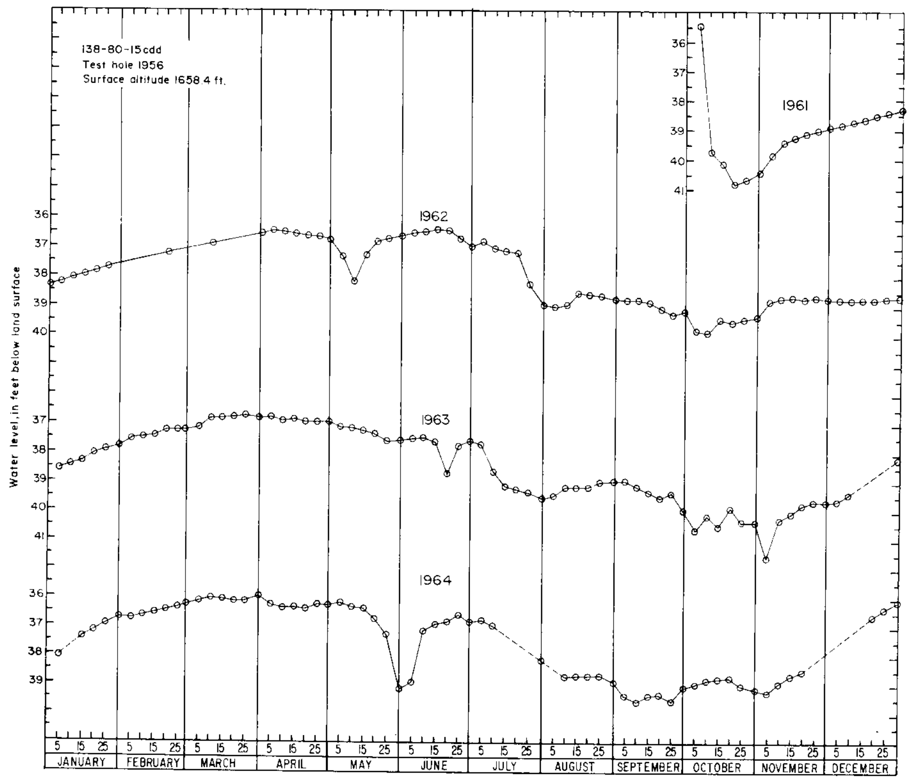


Figure 25.—Water-level fluctuations in wells in the Bismarck aquifer.

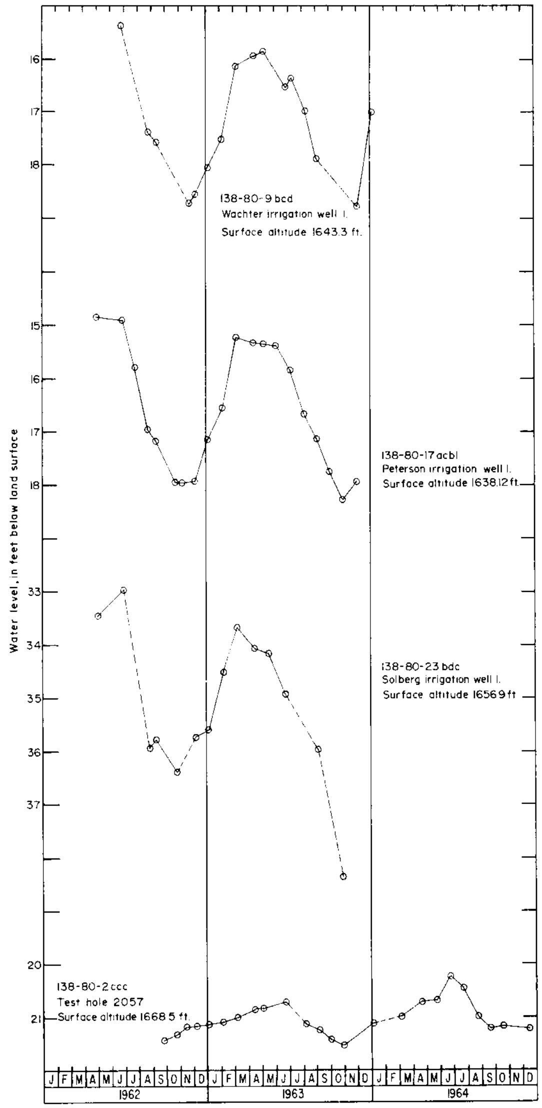


Figure 25.—Water-level fluctuations in wells in the Bismarck aquifer—Continued.

Recharge also is obtained by lateral water movement from the Lower Apple Creek aquifer, adjacent bedrock sources, and the Missouri River. Wells developed within a mile of the river usually receive river recharge, resulting in a better quality water than is found elsewhere in the aquifer.

Storage and movement of water.—Approximately 510,000 acre-feet of water is in storage in the Bismarck aquifer, of which about two-thirds may be available to wells.

The water level in the aquifer is at an altitude of 1,615 to 1,650 feet, or between 20 and 40 feet below the land surface. Figure 13 shows the piezometric surface and general direction of water movement through the aquifer which is south to southwest toward the Missouri River.

Water-level fluctuations.—Figure 25 shows the highest water levels were reached during the period March through June in irrigated areas, and during midsummer in areas of no large withdrawal. The hydrographs of wells in areas of irrigation show lows at times when withdrawal is greatest, followed by a gradual recovery. The recovery rate varies in different aquifers and, at times, varies from place to place within the same aquifer. The seasonal variations shown on the hydrographs are primarily dependent upon nearness to areas of recharge or discharge and on the permeability of materials.

Quality of water.—The water from this aquifer consists of sodium calcium bicarbonate and sodium bicarbonate sulfate types containing 800 to 1,800 ppm dissolved solids (see analysis 11 and 12, table 1).

Water samples collected during aquifer test 1 (table 2) show a 6 percent decrease in specific conductance within the first hour of the test. Iron, calcium, bicarbonate, and sulfate concentrations decreased during the test. The quality of water data indicate recharge from the Missouri River, because samples from the same aquifer in wells to the east have a higher dissolved solids concentration.

Partial chemical analyses of the water samples taken during test 2 (table 2) showed that the specific conductance of the water decreased approximately 6 percent during the first hour of pumping, with the major change taking place in the first 5 minutes. Although the conductance did not change appreciably after the first 5 minutes, the sodium concentration continued to increase, with the major change in sodium concentration occurring 1 hour after pumping began. The calcium, magnesium, and sulfate concentrations decreased during the test, while the sodium, boron, and SAR values increased. The change in quality during this test suggests that water in the lower portion of the aquifer may have a higher sodium concentration as a result of base exchange and that a larger portion of this water is drawn into the well during prolonged pumping.

Utilization and potential for development.—Seven irrigation wells have been developed in the aquifer at the present time (1965), which yield from 500 to 2,000 gpm. Lithologic variations consisting of randomly scattered lenses of less permeable material such as silt and clay will locally restrict the yield. Since no depletion has occurred at the present rate of withdrawal, and considering the high transmissi-

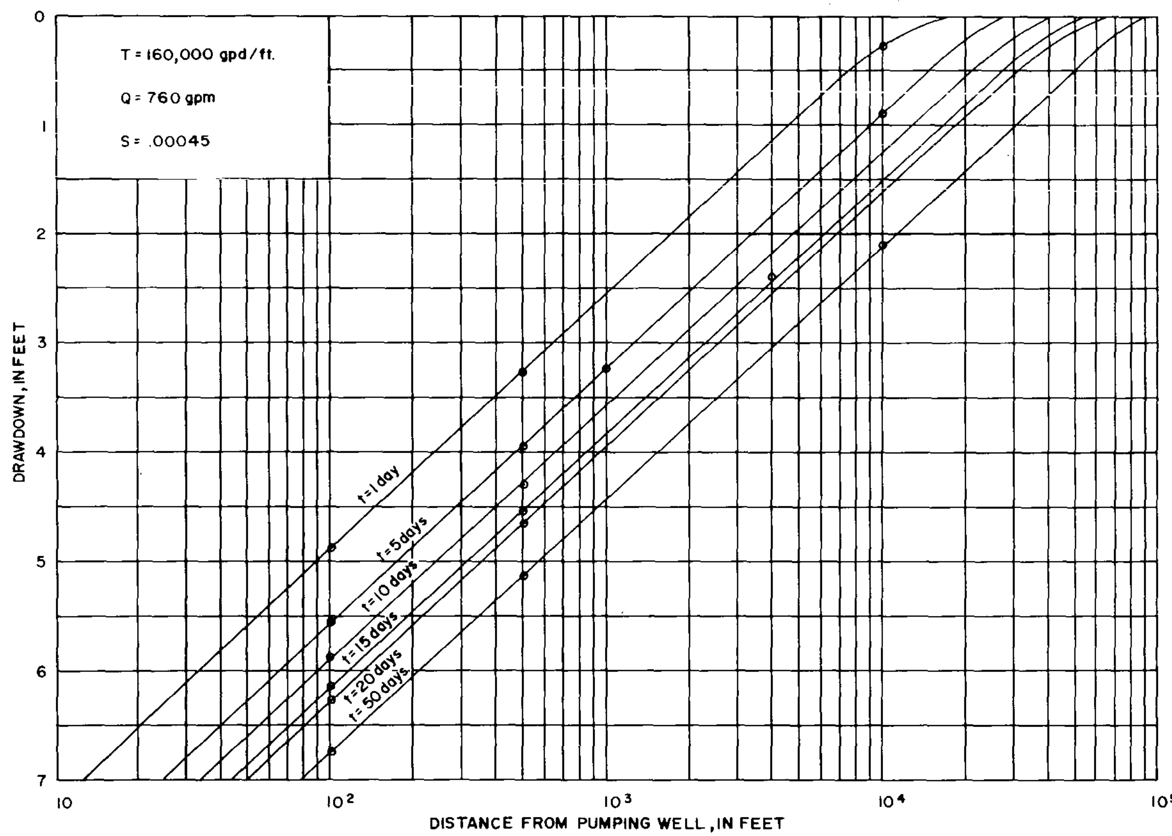


Figure 26.—Predicted drawdowns in the vicinity of a well in the Bismarck aquifer, discharging 760 gpm for selected periods.

bilities, the aquifer will sustain much additional development in future years.

Figure 26 shows the drawdown that would be produced by 1 well discharging from the Bismarck aquifer at a rate of 760 gpm for different lengths of time. Because drawdown varies directly with the discharge, drawdowns of greater or lesser rates can be computed from these curves. For example, assuming that nearly ideal conditions exist in the aquifer, the drawdown 1,000 feet from a well discharging 760 gpm would be 3.2 feet after 5 days of discharge. If the well had discharged 76 gpm for the same length of time, the drawdown at the same distance would have been only one-tenth as much, or 0.3 feet.

Burnt Creek Aquifer

The Burnt Creek aquifer underlies approximately 6 square miles near the Missouri River in west-central Burleigh County (fig. 7). The aquifer was penetrated by three test holes. Test hole 139-81-2cbb penetrated sand from 7 to 28, 32 to 68 feet, and cobbles and boulders from 94 to 106 feet. Two test holes penetrated the aquifer in the upper reaches of Burnt Creek. Here the deposits are less than 20 feet thick and are exposed at the surface.

Approximately 20,000 acre-feet of water is in storage in the Burnt Creek aquifer. About one-half of this amount would be available to wells.

The water level in the aquifer is at an altitude of about 1,635 feet, or between 10 and 20 feet below the land surface. The general movement of water through the aquifer is southwest toward the Missouri River.

Recharge to the aquifer is by seepage from Burnt Creek and the Missouri River, direct infiltration of precipitation, and underflow from bedrock deposits. Only during above average precipitation does Burnt Creek discharge directly to the river. Most of the time flows in the creek are absorbed into the aquifer.

The water is generally a sodium calcium bicarbonate type, containing approximately 1,000 ppm dissolved solids.

One irrigation well (139-81-11adc) developed in the lower part of the aquifer yields more than 2,000 gpm; several domestic and stock wells are developed in the upper part. Additional large yield wells probably can be developed, but they should be properly spaced to avoid excessive interference.

Wagonsport Aquifer

The Wagonsport aquifer underlies approximately 4 square miles along the Missouri River in west-central Burleigh County (fig. 7). The aquifer was partly penetrated by one test hole (140-81-5aaa). The test hole showed almost continuous sand from 4 to 82 feet, and gravel from

82 to 105 feet before it was terminated because of rough drilling conditions. The aquifer, which ranges from 20 to 50 feet thick, is generally exposed at the surface.

Approximately 60,000 acre-feet of water is in storage in the Wagonsport aquifer. Almost one-half of this amount would be available to wells. The water level is generally within 10 feet of the land surface, and water movement through the aquifer is toward the Missouri River. Recharge to the aquifer is derived largely from precipitation infiltrating the surface materials, and lateral movement from adjacent bedrock and the Missouri River.

Figure 27 shows seasonal variations of water levels that are caused primarily by ground-water recharge and discharge. These variations are representative of the aquifer before extensive development.

The water is generally a sodium bicarbonate type containing about 1,300 ppm dissolved solids.

Several domestic and stock wells tap the upper part of the aquifer, but no large yield wells have been developed at the present time (1965). However, it is possible that several large yield wells could be sustained, if properly located and constructed. Also, wells developed near the Missouri River will induce recharge from the river, which probably will result in an improved quality of water.

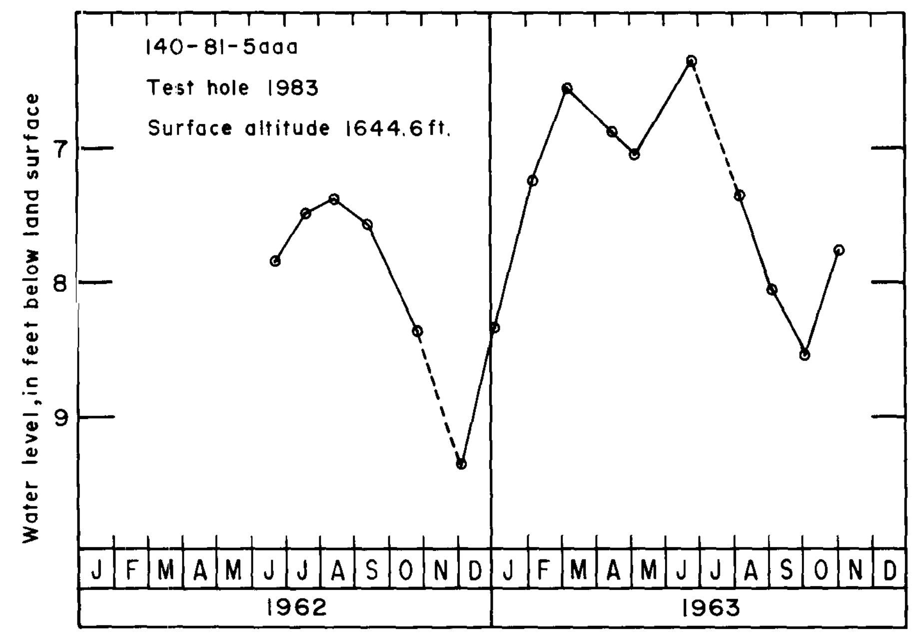


Figure 27.—Water-level fluctuations in a well in the Wagonsport aquifer.

Glenview Aquifer

The Glenview aquifer underlies approximately 5 square miles bordering the Missouri River in northwestern Burleigh County (fig. 7). Although detailed test data are not available, the geologic characteristics indicate that it is comparable to other aquifers adjacent to the Missouri River. The aquifer boundaries and characteristics were defined from the geologic conditions (fig. 6) and well data available for the area.

Approximately 80,000 acre-feet of water is in storage in the Glenview aquifer. About one-half of this amount would be available to wells. The water levels are generally between 10 and 50 feet below the land surface, and the water movement through the aquifer is toward the Missouri River. Recharge to the aquifer is derived largely from precipitation infiltrating the surface materials, and lateral movement from adjacent bedrock and the Missouri River.

The water is generally a sodium bicarbonate sulfate type, containing about 800 ppm dissolved solids.

Several domestic and stock wells tap the upper part of the aquifer, but no large yield wells have been developed at the present time (1965). Possibly a few large yield wells could be sustained if they were properly located and constructed. Also, wells developed near the Missouri River will induce recharge from the river, which probably will result in an improved quality of water.

Outwash Deposits

Surficial outwash deposits, consisting largely of sand and gravel underlie plains and narrow valleys in parts of Burleigh County. The outwash deposits, in addition to being productive aquifers, are effective conduits of recharge to many of the deeper aquifers in the county. These deposits absorb large quantities of water directly from precipitation, and much of the water moves beneath the plains and valleys as underflow. Generally, a calcium bicarbonate type of water containing less than 1,000 ppm dissolved solids has been produced from the outwash deposits. Aquifers consisting largely of outwash deposits are the North Burleigh, Upper Apple Creek, Random Creek, and Painted Woods Creek aquifers (fig. 7). Sodium bicarbonate and sodium bicarbonate sulfate types of water containing less than 1,500 ppm dissolved solids are obtained from these aquifers.

North Burleigh Aquifer

The North Burleigh aquifer underlies approximately 19 square miles in northern Burleigh County (fig. 7). It was penetrated by four test holes and is generally exposed at the surface. It consists of sand and gravel ranging from 10 to 50 feet thick.

Approximately 600,000 acre-feet of water is in storage in the North Burleigh aquifer. Almost two-thirds of this amount would be available to properly constructed wells. The aquifer is under water-table conditions, and the water level is generally between 10 and 30 feet below the land surface.

The major recharge to the aquifer is from direct infiltration of precipitation and from streams and potholes. During periods of precipitation the potholes act as recharge points to the aquifer, and mounds are formed in the water table beneath them. Conversely, the potholes act as discharge points from the aquifer during periods of low precipitation and warm weather when evapotranspiration rates are high. During the warm dry periods the water in the potholes contains a higher concentration of salts than during the wetter periods.

Most wells developed in the aquifer can be expected to yield a sodium bicarbonate type water containing approximately 700 ppm dissolved solids.

Several domestic and stock wells have been developed in the aquifer, and a few properly spaced and constructed wells that would yield moderate quantities of water probably could be developed near the central area of the aquifer.

Upper Apple Creek Aquifer

The Upper Apple Creek aquifer underlies approximately 19 square miles in central Burleigh County (fig. 7). The aquifer, which was penetrated by 10 test holes, underlies the valleys of the west and east branches of Apple Creek. The deposits consist of sand and gravel; they are less than 20 feet thick and are exposed at the surface.

Approximately 3,000 acre-feet of water is in storage in the Upper Apple Creek aquifer. Probably less than half of this amount would be available to wells. The aquifer is under water-table conditions, and the water level is generally between 5 and 20 feet below the land surface.

The major recharge to the aquifer is derived from precipitation infiltrating the surface materials and from leakage of water from adjacent or underlying drift and bedrock deposits. During periods of above average precipitation, Apple Creek provides large quantities of recharge to the underlying aquifer. During periods of little precipitation, the stream is sustained by effluent seepage (discharge) from the aquifer.

Most wells developed in the aquifer can be expected to yield a sodium bicarbonate sulfate type water containing approximately 1,000 ppm dissolved solids.

Several small yield domestic and stock wells have been developed at the present time (1965). Although the aquifer is not believed capable of producing large yields to wells, as much as 100 gpm probably could be obtained in a few places near the centers of the valleys.

Random Creek Aquifer

The Random Creek aquifer underlies approximately 8 square miles in southeastern Burleigh County (fig. 7), which was penetrated by 7 test holes, and ranges in thickness from 5 to 77 feet. It consists predominately of mixed sand and (or) gravel which, in places, is interfingered with layers of till or clay generally less than 5 feet thick. Where a continuous section of sand and gravel is found, the sand comprises the upper part and gravel the lower part of the aquifer.

Approximately 100,000 acre-feet of water is in storage in the Random Creek aquifer. Probably less than half of this amount would be available to wells.

The water level in the aquifer is at an altitude between 1,715 and 1,830 feet, or from about 5 to 15 feet below the land surface. The steep slope of the water table towards the southwest (fig. 13) indicates a large quantity of water is moving from this aquifer to the adjoining McKenzie aquifer.

The major recharge to the aquifer is derived from precipitation infiltrating through the surficial material and from leakage from adjacent or underlying drift and bedrock deposits. Very little flow is observed in Random Creek because most of the water moves into the underlying aquifer. However, substantial quantities of water move through the valley as underflow.

Generally the water is a sodium bicarbonate sulfate type, containing about 1,400 ppm dissolved solids (see analysis 8, table 1).

Only a few domestic and stock wells have been developed in the aquifer at the time of this study, and these are shallow. However, a few properly spaced and constructed large-yield wells could be developed in the southwestern part of the aquifer.

Painted Woods Creek Aquifer

The Painted Woods Creek aquifer underlies approximately 20 square miles in northwestern Burleigh County (fig. 7). The aquifer, which generally follows the valley of Painted Woods Creek, was penetrated by 4 test holes and 3 U. S. Bureau of Reclamation drill holes. It consists of sand and gravel which, in places, have a thickness of as much as 30 feet.

Approximately 150,000 acre-feet of water is in storage in the Painted Woods Creek aquifer. The aquifer is under water-table conditions and the water table is generally between 5 and 15 feet below the land surface.

The major recharge to the aquifer is derived from precipitation infiltrating through surficial materials and leakage from adjacent drift deposits. During periods of above average precipitation, Painted Woods Creek discharges large quantities of water into the underlying aquifer. Probably large quantities of water move west through the aquifer as stream underflow.

Generally the aquifer can be expected to yield a sodium bicarbonate type water containing about 600 ppm dissolved solids.

Several small yield domestic and stock wells are developed in the aquifer at the present time (1965). The aquifer is probably capable of sustaining moderate development, especially in years of above average precipitation.

Dune Deposits

Dune deposits in south-central Burleigh County are generally 1 to 30 feet thick. They yield very little water to wells, but they act as good collection and transmission conduits for adjacent and underlying aquifers. The deposits overlie bedrock adjacent to the meltwater channels.

Lacustrine Deposits

The upper portions of the McKenzie, Long Lake, and Glencoe Channel aquifers consist of lacustrine deposits (figs. 6 and 7). Although the porosity is relatively high, the permeability is so low that these deposits yield only small quantities of water to wells. If water levels are lowered in the underlying aquifers, considerable recharge as downward leakage from these deposits will undoubtedly occur.

Moraine Deposits

Moraine deposits are found along the eastern and northern boundaries of the counties (fig. 6). These are composed chiefly of till, but contain local deposits of glaciofluvial sand and gravel. The till is relatively impermeable; however, a well in a sand and gravel deposit in the till usually yields small to moderate supplies, depending upon the distance to and degree of connection with a source of recharge.

UTILIZATION AND AVAILABILITY OF GROUND WATER IN BURLEIGH COUNTY

During the course of this study, information was obtained on approximately 1,200 wells in Burleigh County (Randich, 1965). The principal uses of ground water in the county are for domestic, stock, irrigation, and municipal supplies. In the past, one well per farm served to supply both the domestic and stock needs. However, the present trend seems to be for farms to use two or more wells in supplying their needs. In such cases usually a shallow well supplies hard water from Quaternary deposits for stock needs, and a deeper well drilled into the upper sandy or fractured zone of a bedrock formation supplies softer water for domestic purposes.

Nearly three-fourths of the domestic wells and approximately one-half of the stock wells in the county produce water from bedrock formations. An estimate of the amount of water pumped daily from domestic and stock wells in Burleigh County is given in table 9.

Fourteen irrigation wells had been drilled in the county at the time of this study (1964). They ranged in depth from about 70 to 140 feet, and produced from 200 to more than 2,000 gpm. All of these wells are believed to penetrate the entire aquifer thickness at each site. The primary use of irrigation water at this time is for feed crops such as corn and alfalfa. Irrigation has also been used successfully on five sugar beet test plots.

There are several irrigation developments in the Missouri River valley pumping water from the river for irrigation of crops in the bottom lands. The Apple Creek Country Club is the only present user of irrigation water from Apple Creek, because of the small amount

Use	Individual requirements gpd	Population or number	Total pumpage gpd
Domestic (not including towns having municipal supplies	150	7,000	1,050,000
Cattle	15	a/67,000	1,010,000
Hogs	2	a/ 6,800	13,600
Horses	10	400	4,000
Poultry	0.04	a/51,000	2,000
Sheep	1.5	a/13,500	20,000
Total			2,099,600

a/ North Dakota Livestock Statistics, Annual Summary, 1960.

Table 9.—Estimate of water pumped daily from domestic and stock wells in Burleigh County, North Dakota

of flow in the creek. The city of Bismarck uses Missouri River water for its water supply.

A comparison of specific capacities is useful for estimating the relative efficiency of wells and the field of permeability of aquifers. The drawdown is inversely proportional to the permeability of the water-bearing material, and is generally small in wells that tap well-sorted gravel and coarse sand. It is much greater (for the same pumping rate) in wells that tap less permeable materials, such as those that are poorly sorted or that contain fine sand, silt, or clay.

The "specific capacity" of a well is its rate of yield per unit of drawdown, and generally is determined by dividing the yield (gpm) by the drawdown (feet). High specific capacities generally indicate aquifers of high transmissibility; low specific capacities indicate aquifers of low transmissibility. The yield of a well per foot of drawdown is a function also of factors other than transmissibility, such as the diameter of the well (this effects T), the effectiveness of the casing perforations or well screens, and the effectiveness of well development. Screen efficiency tests were conducted on the two wells used for pumping tests in the McKenzie aquifer. The tests showed only a 1-foot difference in water levels between the pumping well and an observation well developed 10 feet from the production well, which indicates good development and high screen efficiency for the wells.

Under water-table condiitons the coefficient of storage is practically equal to the specific yield, which is defined as the ratio of the volume of water a saturated material will yield to gravity in proportion to its own volume.

The coefficients of transmissibility obtained from the aquifer tests were reduced to the field coefficients of permeability ($P = T/m$). The value used for m is the aggregate of the effective thickness of the sand and (or) gravel beds in the formation based on the interpretations of the well logs.

All aquifer tests were made on existing irrigation wells. The results are summarized in table 10. The analyses of data in table 10 show that aquifers near the Missuri River have the best water-bearing characteristics to support large sustained yields. However, yields vary considerably elsewhere in the aquifer system, as shown on figure 7.

Estimated potential yields of the Burleigh County aquifers are shown graphically on figure 7. Table 11 shows potential yields that can be expected from aquifers having a certain range of transmissibilities.

Present and potential areas of recharge were delineated by hydrofacies maps (figs. 28-32, in pocket). These show that the most extensive continuous area of permeable material with a surface exposure is found in the area outlined by the ratio lines 1 and 2 on figure 32 in

Well location	Owner	Aquifer	Depth of well (feet)	Depth to bedrock (feet)	Saturated thickness (feet)	Static water level used for test (feet) below lsd	Duration of pumping (minutes)	Pumping rate (gpm)	Water level after approximate equilibrium was reached (feet)	Coefficient of storage	Specific capacity (gpm per foot of drawdown)	Coefficient of transmissibility (gpd per foot)	Field coefficients permeability (gpd per foot^2)
138-77-23ddbl	R. Baeth	McKenzie	105	105	33	31.2	4,200	970	71.5	4.6×10^{-4}	24	32,000	960
138-77-25bbdl	G. D. Adams	McKenzie	78	80	25	32.7	4,260	380	47.7	7.3×10^{-4}	25	25,000	1,000
138-80-17acbl	J. Peterson	Bismarck	90	88	31	19.1	3,120	900	32.8	4.4×10^{-4}	69	340,000	11,000
138-80-22aac	D. McDonald	Bismarck	131	131	41	44.1	3,200	760	53.4	6.4×10^{-4}	85	150,000	3,600
138-80-24cacl	C. P. Yegen	Apple Creek	80	82	15	7.5	3,000	360	53.3	1.6×10^{-4}	8	10,000	670
138-80-25dac	C. P. Yegen	Soo Channel	155	155	50	54.3	1,400	200	80.9	----------	7	10,000	200

Table 10.—Summary of the results of aquifer tests.

the Glencoe Channel aquifer (fig. 7). The maps, when used in an overlay sequence, define more clearly the lithology of the aquifers. Areas of aquifers showing a good potential for recharge are: (1) the center of the McKenzie aquifer, especially in the vicinity of McKenzie Slough; (2) northwestern loop of the Long Lake aquifer; (3) along the eastern boundary of the Bismarck aquifer; and (4) the northeastern part of the Soo Channel aquifer (figs. 28-32).

The entire sequence of hydrofacies maps (figs. 28-32) when used as a series of overlays indicates the general configuration of the aquifers and the most desirable areas for development. The area enclosed by the ratio lines 4 and 8 on the hydrofacies maps generally contain materials having a high permeability. These areas will yield water readily to wells for irrigation, industrial, and municipal use if adequate recharge is available to the area for development. Also, these areas are potentials for artificial recharge sites.

The bedrock highs restrict the flow of water through an aquifer, whereas the former channels indicate areas of large ground-water reservoirs. These features are shown on the hydrofacies maps. South of Bismarck the 1,500-1,550 interval (fig. 28) shows a buried meander of the former Missouri River channel within the 1 ratio line bounded by bedrock highs shown by the ¼-ratio lines. Two additional bedrock highs are shown in the McKenzie aquifer (fig. 28) and can be traced upward (fig. 29) until they are masked with glaciofluvial material.

Recharge or discharge due to lateral movement of ground water between aquifers is also important in determining the long-term availability of ground water in the area. The amount of such ground-water discharge is variable and dependent upon three factors; (1) the

Transmissibility (gpd per foot)	Yield (gpm)
< 5,000	< 50
5,000 - 10,000	50 - 150
10,000 - 50,000	150 - 500
50,000 - 200,000	500 - 1,000
> 200,000	> 1,000

Table 11.—Classification of aquifers as related to estimated potential yields for Burleigh County

Discharge from (aquifer)	Recharge to (aquifer or stream)	Assumed coefficient of transmissibility "T" gpd/foot	Hydraulic gradient "I" (feet/foot)	Width of discharge sections "L" (feet)	Daily discharge gpd
Bismarck	Missouri River	$2.5x10^5$	$1.1x10^{-3}$	$2.6x10^4$	$7.2x10^6$
Lower Apple Creek	Bismarck aquifer	$2.4x10^4$	$2.0x10^{-3}$	$6.0x10^3$	$2.9x10^5$
Soo Channel	Lower Apple Creek aquifer	$1.2x10^4$	$1.3x10^{-3}$	$3.0x10^3$	$4.7x10^4$
McKenzie	Lower Apple Creek aquifer	$3.0x10^4$	$2.5x10^{-4}$	$1.5x10^4$	$1.1x10^5$
Upper Apple Creek	Lower Apple Creek aquifer	a/ $1.2x10^4$	$1.0x10^{-3}$	$1.4x10^3$	$1.7x10^4$
Upper Apple Creek	McKenzie aquifer	a/ $1.2x10^4$	$1.0x10^{-3}$	$2.5x10^4$	$3.0x10^5$
McKenzie	Glencoe Channel aquifer	$3.0x10^4$	$2.5x10^{-4}$	$1.2x10^4$	$9.0x10^4$
Glencoe Channel	Missouri River	a/ $3.0x10^4$	$1.3x10^{-3}$	$7.5x10^3$	$2.9x10^5$
Soo Channel	Missouri River	$1.2x10^4$	$1.3x10^{-3}$	$3.0x10^3$	$4.7x10^4$
Random Creek	McKenzie aquifer	a/ $1.8x10^4$	$3.0x10^{-3}$	$6.4x10^3$	$3.5x10^5$
Long Lake	McKenzie aquifer	a/ $3.0x10^4$	$2.7x10^{-5}$	$2.1x10^4$	$1.7x10^4$
Long Lake	McKenzie aquifer (in Emmons County)	a/ $3.0x10^4$	$2.7x10^{-5}$	$5.3x10^3$	$4.3x10^3$
Sibley Channel	Lower Apple Creek aquifer	a/ $3.0x10^4$	$2.0x10^{-3}$	$5.0x10^3$	$3.0x10^5$

a/ Estimated from comparison with adjacent aquifers of similar characteristics.

Table 12.—Ground-water discharge through selected sections

hydraulic gradient; (2) coefficient of transmissibility; and (3) the width of the section through which discharge occurs. Computations of ground-water discharge across selected sections in Burleigh County were made using Darcy's Law. Darcy's Law of the flow of water through porous mtaerial is:

$Qd = TIL$

where Qd = discharge in gallons per day

I = hydraulic gradient in feet per foot

T = coefficient of transmissibility in gallons per day per foot

L = the width in feet of the cross section through which discharge occurs.

Some of the computations of ground-water discharge in Burleigh County are shown in table 12. Approximately 7.5 million gallons per day of ground water moves into the Missouri River valley from the Bismarck and Lower Apple Creek aquifers. Sufficient data are not available to show the volume of ground-water movement for the other aquifers in Burleigh County.

SUMMARY AND CONCLUSIONS

Water is one of the most valuable resources of Burleigh County. Surface- and ground-water supplies are available in large quantities at places within the county. The increasing importance of water makes imperative the collection, analysis, and presentation of data that is understood and utilized by water-supply managers at all levels. Adequate and long-term data are essential for the proper use of water resources. Agriculture, municipalities, industry, and recreational facilities all depend on vast quantities of water of various standards of quality for their operations.

Additional test drilling is necessary to pinpoint areas of maximum permeability and saturated thickness within each aquifer. Complete penetration of the aquifer by a well is necessary for maximum yield and minimum drawdown. If the water decline regionally or local overdevelopment occurs, the saturated thickness will also decrease and well yields will be reduced. Proper spacing of wells for a well field development generally should be at least twice the thickness of the aquifer — or at least 250 feet between wells. Production wells should be arranged parallel to and as far away as possible from barrier boundaries, and as near to the center of a channel aquifer as possible. Where induced recharge is possible, wells should be arranged along a line parallel to and as close to the source of recharge as possible. These criteria are important to present and future developers if they are to gain maximum long-range benefits from ground-water resources in Burleigh County.

Deposits of Quaternary age comprise the major aquifers in Burleigh County. Seven major aquifers in terms of largest yield are located in preglacial stream channels. The aquifers are composed of glaciofluvial deposits of gravel and sand that average about 30 feet thick. The water-bearing characteristics indicate that the largest yields are obtained along the central axis and northeastern flanks of these channels. Ground-water movement through the channels is west and southwestward.

Alluvial deposits consisting of silt, clay, sand, and gravel are found in most stream valleys in Burleigh County. The intermittent stream valleys generally contain from 1 to 20 feet of alluvium. These deposits are generally less than 100 feet thick in the Missouri River valley where they contain 4 major aquifers. The aquifers adjacent to

Aquifer (for location see fig. 5)	Approximate areal extent (sq miles)	Water in storage (acre-feet)[a/]
McKenzie	36	2,700,000
Long Lake	32	810,000
Glencoe Channel	26	1,000,000
Bismarck	25	510,000
Lower Apple Creek	21	620,000
Painted Woods Creek	20	150,000
Upper Apple Creek	19	3,000
North Burleigh	19	600,000
Wing Channel	10	160,000
Random Creek	8	100,000
Burnt Creek	6	20,000
Glenview	5	80,000
Wagonsport	4	60,000
Sibley Channel	3	340,000
Totals	233	7,153,000

a/ 1 acre-foot of water equals 325,851 gallons.

Table 13.—Quantity of water in storage in major Quaternary aquifers...

the Missouri River are the most productive and yield the best quality water.

Outwash deposits consisting of sand and gravel form surficial aquifers in extensive plains and narrow valleys. These deposits are generally less than 20 feet thick, but they comprise important aquifers in the county.

Table 13 shows a total of approximately 7 million acre-feet of water is stored in ground-water reservoirs of Quaternary age (glacial and alluvial deposits) in Burleigh County. These aquifers, as outlined on figure 7, underlie approximately 150,000 acres. The total water in storage in Quaternary aquifers is equivalent to about one-third of the capacity of Garrison reservoir. Although this indicates a large quantity of water in storage, probably only about one-half or slightly more is available for use through proper development and placement of wells.

Ground water moves from the Bismarck aquifer of Quaternary age to the Missouri River valley at the rate of about 7 million gallons per day.

Aquifer tests indicate that coefficients of transmissibility range from 10,000 to 350,000 gpd per foot, and coefficients of storage range from 0.016 to 0.0007.

Water levels in most aquifers in the area fluctuate in response to seasonal precipitation, but also are influenced by streamflow and discharge from wells. Largest flows occur in perennial streams during June and in intermittent streams during March and April. Some of these intermittent streams flow only short distances in areas having sandy surface materials before the water is absorbed into the ground. In outwash areas in northern Burleigh County many small lakes have water levels at about the same elevation as the water table. Some of the larger water-table lakes and ponds are McKenzie Slough and Long Lake in southern Burleigh County, and Bunce, Florence, Salt, and Harriet Lakes in the northeastern part of the county. During periods of heavy runoff, water from the lakes percolates downward and laterally to form recharge mounds on the water table for short periods of time. During periods of high evapotranspiration the converse is true, and water-table depressions form under the lakes due to the loss of water from the lakes.

Most surficial outwash areas are hydrologically connected with deeper artesian aquifers, thus providing a ready source of recharge to the deeper aquifers. However, it appears that the recharge is very slow and is spread over extensive areas.

Discharge of water from the upper parts of the aquifers takes place through evaporation from shallow water-table ponds, marshes, and the soil surface; transpiration by plants; dischage from seeps and small springs in the stream valleys; and by downward percolation to deeper aquifers under less artesian heads.

The Tertiary and Cretaceous rocks yield water to about 70 percent of the domestic and stock wells in Burleigh County. The Dakota Sandstone underlies the county at a depth of about 3,000 feet, and will yield large quantities of sodium sulfate type water. The Pierre Shale yields small quantities of water from fractures in its upper zones. The Fox Hills Sandstone crops out in southeastern Burleigh County, and is buried progressively deeper by younger deposits towards the northwest. The permeable layers of sandstone in the Fox Hills generally yield large quantities of sodium bicarbonate chloride or sodium chloride bicarbonate type water. The Hell Creek Formation crops out extensively in southern Burleigh County, it is not known to yield large quantities of water to wells in the area. The Cannonball Formation is an extensive aquifer, but generally yields less than 50 gpm of sodium bicarbonate type water. The Tongue River Formation is one of the major sources of water for domestic and stock supplies and a minor source of municipal supplies. The yields are generally less than 20 gpm, and the water has a high salinity hazard if used for irrigation.

Although much of the ground water in the county has a dissolved solids concentratoin of more than 1,000 ppm, it has been used for most purposes including drinking water and apparently has caused no ill effects. More than 50 percent of the sampled waters were very hard (more than 180 ppm as $CaCO_3$).

The predominant dissolved constituents found in the ground water are sodium, bicarbonate, and sulfate. Iron is present in amounts that are objectionable if the water is used for domestic and many industrial purposes. However, the iron can be removed to increase the acceptability of the water.

The high salinity hazard and the marginal to unsuitable residual sodium carbonate classification of most of the water will require a careful evaluation of its effects on land and crops if it is to be used successfully for irrigation. Water in the glacial drift and alluvium generally has a boron concentration of less than 1 ppm; but in the bedrock aquifers the concentration is greater than 1 ppm and is as much as 4 ppm.

Hydrographs of water-level fluctuations in wells show that highest levels were observed during April and May in areas of irrigation development, and during July in most other areas. The recovery rate varies in different aquifers, and at times varies from place to place within the same aquifer. Most wells recover during the year to the level of the previous year. However, in some areas water levels are progressively declining from the same amount of pumping during successive years of irrigation. This indicates that all water removed from storage is not being replenished annually, and may result in subsidence or reorientation of materials causing a reduction in yields.

Efficient utilization and management of the ground-water resources in Burleigh County will require the permanent maintenance of water-level records and related hydrologic data.

DEFINITION OF TERMS

The following is a list of definitions of technical terms commonly used in this report. The hydrologic terms are adopted chiefly from Meinzer (1923b), and the geologic terms from the American Geological Institute "Glossary of Geology," 1962.

Aquiclude — a material which, although sometimes porous and capable of absorbing water slowly, will not transmit it fast enough to furnish an appreciable supply for a well or spring.

Aquifer — a formation, group of formations, or part of a formation that is water bearing.

Aquifer properties — the properties of an aquifer that control the occurence and movement of ground water.

Aquitard — a deposit that restricts the movement of water laterally through an area.

Area of influence — the area encompassed by the periphery of the "cone of depression" commonly caused by a discharging well.

Artesian water — ground water that is under sufficient pressure to rise above the zone of saturation.

Bedrock — the consolidated rock underlying the glacial and alluvium deposits of Pleistocene and Recent age.

Capillary fringe — the zone directly above the water table in which water is held in the pore spaces by capillary action.

Clastic — a textural term applied to rocks composed of fragmental material derived from other rocks.

Coarse-fine ratio — a statistical relationship of the percentage of coarse-fine rocks contained in a given geologic section.

Cone of depression — the depression, roughly conical in shape, produced in a water table or piezometric surface by pumping (or artesian flow).

Confined surface water — the water on the surface of the ground confined to a given area such as a lake.

Continuous stream (perennial) — a stream that flows year around.

Depletion — the act of emptying, reducing, exhausting; as the depletion of natural resources.

Discharge — in this report generally refers to ground-water discharge, the removal of water from the zone of saturation. Also applies to stream flow.

Drawdown — decline of the water level in a well or in nearby wells during pumping.

Effluent stream — a stream is generally said to be effluent if it receives water from ground-water reservoirs.

Evapotranspiration — a term embracing that portion of the precipitation returned to the air through direct evaporation from water or land surface and by transpiration of vegetation, no attempt being made to distinguish between the two.

Flowing well — an artesian well having sufficient head to discharge water above the land surface.

Gaging station — point at which stream discharge measurements are made and records of daily fluctuations of stage are kept to determine the daily flow.

Glaciofluvial — deposits formed by streams flowing from a glacier.

Ground water (as used in this report) — water in the zone of saturation, or below the water table.

Ground-water divide — a line on a water table on each side of which the water-table slopes downward in a direction away from the line.

Ground-water movement — the movement of ground water in or through an aquifer.

Hydraulic gradient — gradient of the water table measured in direction of greatest slope, generally expressed in feet per mile. The hydraulic gradient of an artesian aquifer is called the pressure gradient and is measured on the piezometric surface.

Hydrograph — a graph showing stage, flow, water level, precipitation or other property of water with respect to time.

Hydrologic system — a series of interconnected aquifers usually related to surface source.

Infiltration — the process whereby water enters the surface soil and moves downward toward the water table.

Inflow — movement of ground water into an area in response to a hydraulic gradient.

Influent stream — a stream that contributes water to the ground-water reservoir.

Intake area (of an aquifer) — an area where water is absorbed, which eventually reaches a part of an aquifer that is in the zone of saturation.

Intermittent stream — a stream that flows only at certain times following precipitation or when it receives water from springs, ground-water seepage or melting snow.

Irrigation — the controlled application of water to arable lands to supply water for crop demands not satisfied by rainfall.

Kettle — a depression in drift, made by the wasting away of a detached mass of glacier ice that had been either wholly or partly buried in the drift.

Lacustrine — formed by, or deposited in a lake environment.

Logarithm (log) — the exponent of the power to which a fixed number (the base and usually 10) must be raised in order to produce a given number. Logarithmic scale enables large numbers to be plotted on a graph within a short distance.

Molecular attraction — the cohesion of the molecules of water and by their adhesion to associated particles.

Observation well — a well from which water-level data are measured and recorded.

Orifice — a restricted opening of a given size at the end of a tube used to measure a quantity of water passing through it per unit of time.

Percolation — the movement, under hydrostatic pressure, of water through the interstices of a rock or soil.

Permeability — the capacity of rock to transmit water. The field coefficient of permeability of an aquifer may be expressed as the rate of flow of water at the prevailing temperatures, in gallons per day, through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot (vertical) per foot (horizontal).

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

Piezometric surface — as generally used, the pressure indicating surface of an artesian aquifer.

Porosity — the property of a rock containing openings or voids. Quantitatively, the porosity of a rock is the ratio (expressed as a percentage) of the volume of openings in the rock to the total volume of the rock.

Radius of influence — the distance to a point on the periphery of the "cone of depression" commonly caused by a discharging well.

Recharge — the process by which water is absorbed and added to the zone of saturation. Also used to designate the quantity of water added to a ground-water reservoir.

Runoff—the discharge of water through surface streams. It includes both surface-water runoff and ground-water runoff.

Specific capacity — the yield of a well generally expressed in gallons a minute per foot of drawdown after a specified time of pumping.

Stage — the elevation of water surface above or below any arbitrary datum plane.

Static water level — that level which for a given point in an aquifer passes through the top of a column of water that can be supported by the hydrostatic pressure of the water at equilibrium.

Storage — water stored in openings in the zone of saturation is said to be in storage. Discharge of water not replaced by recharge from an aquifer is said to be water from storage.

Storage coefficient — the volume of water released from storage in each vertical column of the aquifer having a base of 1 foot square when the water table or piezometric surface declines 1 foot.

Till — serves both as a genetic and descriptive term, and indicates an unsorted, unstratified, cohesive, moderately calcareous agglomeration of particles ranging from clay to boulder size.

Transmissibility — the transmissibility of a rock is its capacity to transmit water under pressure.

Transmissibility coefficient — the number of gallons of water which will move in one day through a vertical strip of aquifer 1 foot wide and having the height of the aquifer when the hydraulic gradient is unity.

Underflow or subsurface movement — as referred to in this report. The downstream movement of ground water through the permeable deposits that underlie a stream and that are more or less limited by rocks of low permeability.

Water table — the water table is the upper surface of the zone of saturation where the surface is not formed by an impermeable rock. The water table is not a plane surface, but has irregularities much like the land surface.

Zone of saturation — the zone in which the permeable rocks are saturated with water under hydrostatic pressure.

SELECTED REFERENCES

Abbott, G. A., and Voedisch, F. W., 1938, The municipal ground water supplies of North Dakota: North Dakota Geol. Survey Bull. 11, 99 p.

American Geological Institute, 1960, Glossary of geology and related sciences, 2nd ed., 325 p. and suppl.

Bennett, G. D., and Patten, E. P., Jr., 1962, Constant-head pumping test of a multiaquifer well to determine characteristics of individual aquifers: U. S. Geol. Survey Water-Supply Paper 1536-G, p. 181-203.

Bentall, Ray, et. al., 1963a, Methods of determining permeability, transmissibility and drawdown: U. S. Geol. Survey Water Supply Paper 1536-I, p. 243-341.

——————1963b, Shortcuts and special problems in aquifer tests: U. S. Geol. Survey Water-Supply Paper 1545-C, 115 p.

Bradley, Edward, Petri, L. R., and Adolphson, D. G., 1963, Geology and ground water resources of Kidder County, North Dakota; Part III, Ground water and chemical quality of water: North Dakota Geol. Survey Bull. 36 and North Dakota State Water Comm. County Ground Water Studies 1, 38 p.

Brown, R. H., 1953, Selected procedures for analyzing aquifer test data: Am. Water Works Assoc. Jour., v. 45, no. 8, p. 844-866.

Darton, N. H., 1896, Preliminary report on artesian waters of a portion of the Dakotas: U. S. Geol. Survey 7th Ann. Rept., pt. 2, p. 661-670.

Durfor, C. N., and Becker, Edith, 1964, Selected data on public supplies of the 100 largest cities in the United States, 1962: Am. Water Works Assoc. Jour., v. 56, no. 3, p. 237-246.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U. S. Geol. Survey Water-Supply Paper 1536-E, p. 69-174.

Fisher, S. P., 1952, The Geology of Emmons County, North Dakota: North Dakota Geol. Survey Bull. 26, 47 p.

Greenman, D. W., 1953, Reconnaissance of the Missouri River pumping units between Garrison Dam and Bismarck, North Dakota: U. S. Geol. Survey open-file report, 65 p.

Hainer, J. L., 1956, The geology of North Dakota: North Dakota Geol. Survey Bull. 31, 46 p.

Hansen, Miller, 1956, Geologic map of North Dakota: North Dakota Geol. Survey.

Hemm, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U. S. Geol. Survey Water-Supply Paper 1473, 269 p.

——————1963, Chemical equilibria and rates of manganese oxidation: U. S. Geol. Survey Water-Supply Paper 1667-A, 64 p.

Jacob, C. E., 1940, On the flow of water in an elastic artesian aquifer: Am. Geophys. Union Trans., pt. 2, p. 574-586.

Johnson, A. E., 1962, Methods of measuring soil moisture in the field: U. S. Geol. Survey Water-Supply Paper 1619-U, 25 p.

King, H. W., 1954, Handbook of hydraulics: New York, McGraw-Hill Book Co., Inc., 4th ed., 556 p.

Koberg, G. E. Cruse, R. R., and Shrewsbury, C. L., 1963, Evaporation control research, 1959-60: U. S. Geol. Survey Water-Supply Paper 1692, 53 p.

Krumbein, W. D., and Sloss, L. L., 1953, Stratigraphy and sedimentation: San Francisco, California, W. H. Freeman and Co., p. 269-276, 395-415.

Kume, Jack, and Hansen, D. E., 1965, Geology and ground water resources of Burleigh County, North Dakota; Part I, Geology: North Dakota Geol. Survey Bull. 42 and North Dakota State Water Comm. County Ground Water Studies 3, 111 p.

Laird, W. M., 1942, The geology of the southern part of Morton County, North Dakota: North Dakota Geol. Survey Bull. 14, 42 p.

Lang, S. M., 1961, Methods for determining the proper spacing of wells in artesian aquifers: U. S. Geol. Survey Water-Supply Paper 1545-B, 16 p.

Langbein, W. B., and Iseri, K. T., 1960, General introduction and hydrologic definitions: U. S. Geol. Survey Water-Supply Paper 1541-A, 29 p.

Meinzer, O. E., 1923a, The occurrence of ground water in the United States: U. S. Geol. Survey Water-Supply Paper 489, 314 p.

——————1923b, Outline of ground-water hydrology: U. S. Geol. Survey Water-Supply Paper 494, 68 p.

——————1932, Outline of methods for estimating ground-water supplies: U. S. Geol. Survey Water-Supply Paper 638-C, p. 99-144.

Meinzer, O. E., and others, 1942, Hydrology: Dover Publications, Inc., 704 p.

Moore, E. E., 1940, Progress report of the committee on quality tolerances of waters for industrial uses: New England Water Works Assoc. Jour., v. 54, p. 263.

North Dakota Livestock Statistics, 1960, Annual summary: North Dakota State University of Agriculture, Dept. of Economics.

Paulson, Q. F., 1962, Ground water — a vital North Dakota resource: North Dakota Geol. Survey Misc. Series Bull. 1, 26 p.

Patten, E. P., Jr., and Bennett, G. D., 1963, Application of electrical and radioactive well logging to ground-water hydrology: U. S. Geol. Survey Water-Supply Paper 1544-D, 58 p.

Pettijohn, F. J., 1957, Sedimentary rocks: New York, Harper and Brothers, 2nd ed., p. 611-644.

Rainwater, F. H., and Thatcher, L. L., 1960, Methods for collection and analysis of water samples: U. S. Geoel. Survey Water-Supply Paper 1454, 297 p.

Ramsahoye, L. E., and Long, S. M., 1961, A simple method for determining specific yield from pumping tests: U. S. Geol. Survey Water-Supply Paper 1536-C, p. 41-46.

Randich, P. G., 1963, Geology and ground-water resources of the Linton-Strasburg area, Emmons County, North Dakota: North Dakota Ground-Water Studies no. 50, 53 p.

———1965, Geology and ground water resources of Burleigh County, North Dakota; Part II, Ground water basic data: North Dakota Geol. Survey Bull. 42 and North Dakota State Water Comm. County Ground Water Studies 3, 273 p.

Randich, P. G., Petri, L. R., and Adolphson, D. G., 1962, Geology and ground water resources of Kidder County, North Dakota; Part II, Ground water basic data: North Dakota Geol. Survey Bull. 36 and North Dakota State Water Comm. County Ground Water Studies 1, 134 p.

Rau, J. L., and others, 1962, Geology and ground water resources of Kidder County, North Dakota; Part I, Geology: North Dakota Geol. Survey Bull. 36 and North Dakota State Water Comm. County Ground Water Studies 1, 70 p.

Remson, Irwin, McNeary, S. S., and Randolph, J. R., 1961, Water levels near a well discharging from an unconfined aquifer: U. S. Geol. Survey Water-Supply Paper 1536-B, 39 p.

Robinove, C. J., Langford, R. H., and Brookhart, J. W., 1958, Saline-water resources of North Dakota: U. S. Geol. Survey Water-Supply Paper 1428, 72 p.

Robinson, G. M., and Skibitzke, H E., 1962, A formula for computing transmissibility causing maximum possible drawdown due to pumping: U. S. Geol. Survey Water-Supply Paper 1536-F, p. 175-180.

Simons, D. B., and Richardson, E. V., 1962, The effect of bed roughness on depth-discharge relations in alluvial channels: U. S. Geol. Survey Water-Supply Paper 1498-E, 26 p.

Simpson, H. E., 1929, Geology and Ground-water resources of North Dakota: U. S. Geol. Survey Water-Supply Paper 598, p. 94-97.

Sniegocki, R. T., Bayley, F. H., 3rd, and Engler, Kyle, 1963, Equipment and controls used in studies of artificial recharge in the Grand Prairie region Arkansas: U. S. Geol. Survey Water-Supply Paper 1615-C, 39 p.

Stallman, R. W., 1963a, Electric analog of three dimensional flow to wells and its application to unconfined aquifers: U. S. Geol. Survey Water-Supply Paper 1536-H, p. 205-242.

——1963b, Calculation of resistance and error in an electric analog of steady flow through nonhomogeneous aquifers: U. S. Geol. Survey Water-Supply Paper 1544-G, 20 p.

Theis, C. V., 1935, Relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., 16th Ann. Meeting, pt. 2, p. 519-524.

Thomas, H. E., 1951, The conservation of ground water: New York, McGraw-Hill Book Co., 327 p.

Thwaites, F. T., 1959, Outline of glacial geology: Ann Arbor, Michigan, Edward Bros., 133 p.

Todd, J. E., 1896, The moraines of the Missouri Coteau and their attendant deposits: U. S. Geol. Survey Bull. 144, p. 13-59.

——1914, The Pleistocene history of the Missouri River: Science, v. 39, p. 263-274.

——1923, Is the channel of the Missouri River through North Dakota of Tertiary origin: Geol. Soc. America Bull., v. 34, p. 469-494.

Tolman, C. F., 1937, Ground Water: New York, McGraw-Hill Book Co., 593 p.

Towse, Donald, 1952, Subsurface geology of south-central North Dakota: North Dakota Geol. Survey Bull. 27, 23 p.

U. S. Bureau of Census, 1960, North Dakota census of population, 14 p.

U. S. Department of Agriculture, 1932, Climatic survey of the United States: Sec. 34-western North Dakota climatic data from the establishment of stations to 1930, inclusive.

U. S. Geological Survey, 1961, Surface water records of North Dakota and South Dakota: p. 101-102, 115.

——1962, Surface water records of North Dakota and South Dakota: p. 107-108, 121.

——1963, Surface water records of North Dakota and South Dakota: p. 111-112, 125.

U. S. Public Health Service, 1962, Public health drinking water standards: U. S. Public Health Service Pub. no. 956, 61 p.

U. S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U. S. Dept. of Agriculture, Agriculture Handb. 60.

U. S. Weather Bureau, 1955, Climatic summary of the United States: Suppl. for 1931 through 1952. North Dakota no. 28.

———1953-1964, Climatological data, North Dakota, Ann. Summ., 1952-1963, v. 61-72, no. 13.

Wells, J. V. B., 1959, Compilation of records of surface waters of the United States through Sept. 1950: U. S. Geol. Survey Water-Supply Paper 1309, p. 533-534, and 543.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials, with special reference to discharging-well methods: U. S. Geol. Survey Water-Supply Paper 887, 192 p.

Wilcox, L. V., 1955, Classification and use of irrigation waters: U. S. Dept. of Agriculture Circ. no. 969, 19 p.