GROUND-WATER RESOURCES

of

BURKE AND MOUNTRAIL COUNTIES

by
C. A. Armstrong
Geological Survey
United States Department of the Interior
1971

BULLETIN 55 - PART III
North Dakota Geological Survey
Edwin A. Noble, *State Geologist*

COUNTY GROUND WATER STUDIES 14 - PART III
North Dakota State Water Commission
Milo W. Hoisveen, *State Engineer*

Prepared by the United States Geological Survey
in cooperation with the North Dakota State
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This is one of a series of county reports published cooperatively by the North Dakota Geological Survey and the North Dakota State Water Commission. The reports are in three parts; Part I describes the geology, Part II presents the ground water basic data, and Part III describes the ground water resources. Part I will be published later.

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GROUND-WATER RESOURCES OF BURKE AND MOUNTRAIL COUNTIES, NORTH DAKOTA

By C. A. Armstrong

ABSTRACT

Ground water in Burke and Mountrail Counties is obtained from aquifers in the glacial drift of Quaternary age, the Sentinel Butte and Tongue River Formations in the Fort Union Group of Tertiary age, and the Fox Hills Formation, Hell Creek Formation, and the Dakota Group of Cretaceous age. Aquifers with the greatest potential for development are the sand and gravel deposits that form the New Town aquifer and the Shell Creek aquifer system in Mountrail County and the Columbus aquifer in Burke County. Properly constructed wells in the New Town aquifer will yield as much as 500 gallons per minute and may yield as much as 1,000 gallons per minute. The more permeable parts of the Shell Creek aquifer system and the Columbus aquifer will yield about 300 and 200 gallons per minute, respectively.

Yields of 10 to 350 gallons per minute are possible from some outwash, glaciofluvial, and valley-fill deposits that are scattered throughout the two counties.

Water from the glacial-drift aquifers differs greatly in chemical quality. Water low in dissolved solids generally is of a very hard calcium bicarbonate type. Water high in dissolved solids generally is of a very hard sodium sulfate type, and generally is too saline to be recommended for human consumption.

Yields from the Fort Union aquifers generally are only a few gallons per minute, but may be as great as 100 gallons per minute. The Sentinel Butte Formation and upper part of the Tongue River Formation generally yield water of a sodium bicarbonate type, but sulfate concentrations are high. The lower part of the Tongue River Formation yields a sodium bicarbonate water. The Fox Hills and Hell Creek Formations probably would yield small quantities of sodium bicarbonate water that has relatively high fluoride concentrations. Water from the Dakota Group is used for pressure maintenance in oil fields and is pumped at rates as great as 320 gallons per minute. The water from the Dakota Group is too saline for most other uses. Ground

water from the bedrock aquifers in the two-county area generally is too saline to be recommended for human consumption or irrigation.

INTRODUCTION

Burke County, an area of 1,121 square miles, and Mountrail County, an area of 1,817 square miles are in the northwestern part of North Dakota (fig.1).

The study of the geology and ground-water resources of Burke and Mountrail Counties has been a cooperative investigation by the U.S. Geological Survey, the North Dakota State Water Commission, the North Dakota Geological Survey, and the Burke and Mountrail Counties Water Management Districts. The North Dakota Geological Survey mapped the geology of the counties and will publish the results as Part I of this series. The data used in this report, unless otherwise referenced, were published in Part II of this series (Armstrong, 1969a).

The geologic nomenclature used in this report is that of the North Dakota Geological Survey and, in some instances, differs from that of the U.S. Geological Survey.

Selected terms commonly used in the report are defined in the "Definition of Terms" section.

Purpose and Scope

The purpose of the investigation was to determine the quantity and quality of ground water available in Burke and Mountrail Counties, N. Dak. for municipal, domestic, livestock, industrial, and irrigation uses. Specifically, the objectives within the limits of financing and time available were to: (1) determine the location, extent, and nature of the major aquifers; (2) evaluate the occurrence and movement of ground water, including the sources of recharge and discharge; (3) estimate the quantities of water stored in the aquifers; (4) estimate the potential yields to wells tapping the major aquifers; and (5) determine the chemical quality of the ground water.

The investigation was begun in July 1966 under the leadership of J. L. Hatchett. In September 1967 the author assumed project leadership, and the field investigation was completed in June 1968. Most wells and springs in the county were inventoried in order to

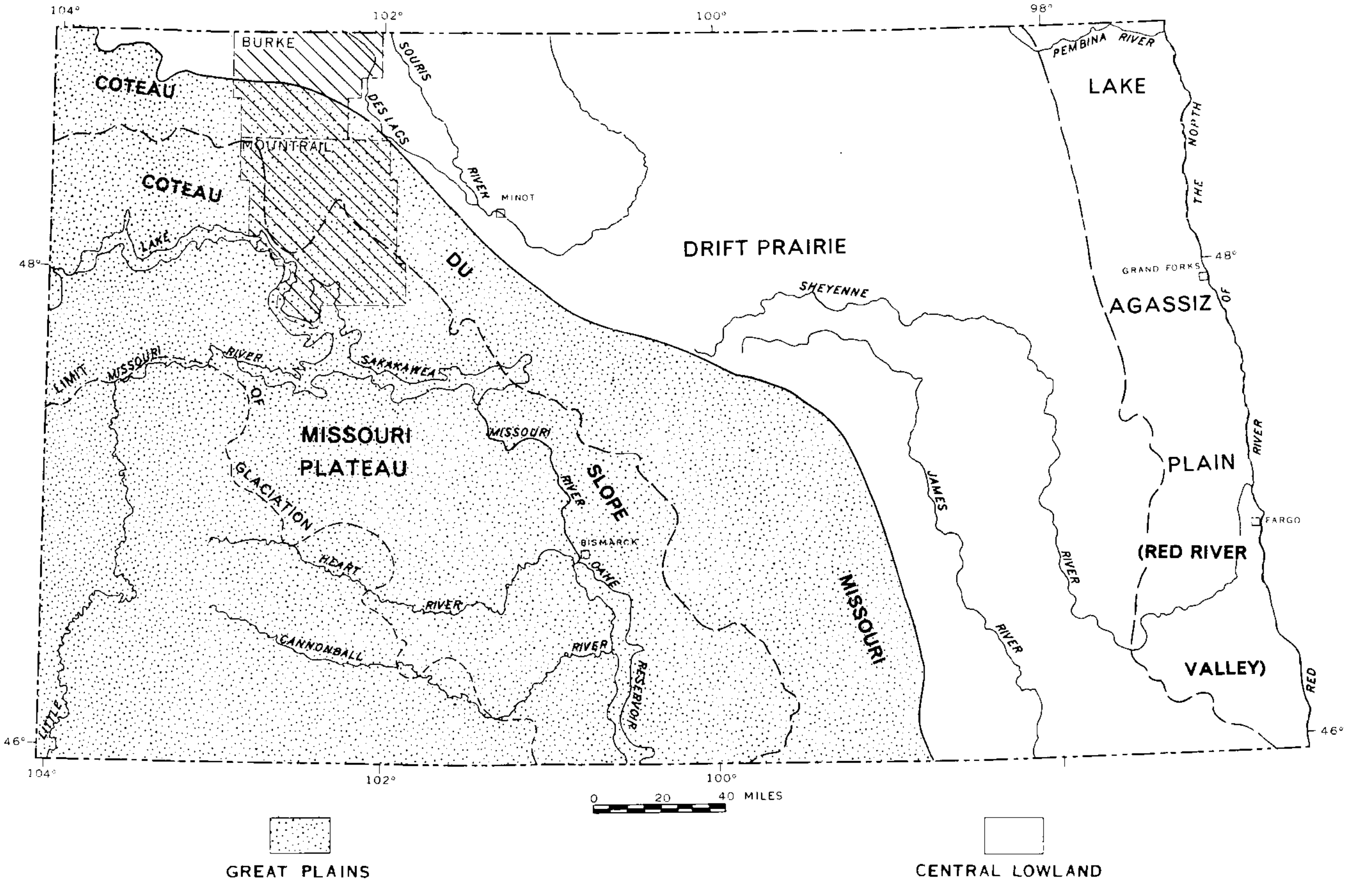

FIGURE 1. Physiographic divisions in North Dakota and location of report area.

obtain information about existing water supplies. Test holes were drilled by the North Dakota State Water Commission and by private drillers under contract to supplement the information gathered during the inventory. Water levels were measured periodically in selected wells to evaluate recharge to and discharge from the aquifers. Three aquifer tests were made to determine the transmissivities and storage coefficients, and to establish a basis for estimating transmissivities elsewhere in the two-county area. Water samples were obtained from selected wells to determine the chemical characteristics of water in the counties.

Well-Numbering System

The well-numbering system used in this report (fig. 2) is based on the federal system of rectangular surveys of the public lands. The first numeral denotes the township, the second denotes the range, and the third denotes the section in which the well, spring, or test hole is located. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). Thus, well 157-90-15DAA would be located in the NE¼NE¼SE¼ sec. 15, T. 157 N., R. 90 W. One row of sections, those numbered 25 through 30, T. 164N., Rs. 88-94 W., extend only about a quarter of a mile from the south to north side; these sections are considered as though they are only the southern part of normal square-mile sections. The numbering system also is used in this report for the location of small areas.

Previous Investigations

Ground-water data for Burke and Mountrail Counties were included by Simpson (1929) in a report on the ground-water resources of North Dakota. Abbott and Voedisch (1938) discussed the municipal ground-water supplies of Burke and Mountrail Counties and tabulated chemical analyses of water from the cities and villages using ground water. Dingman and Gordon (1954) described the geology and ground-water resources of the Fort Berthold Indian Reservation. LaRocque, Swenson, and Greenman (1963) studied the ground-water

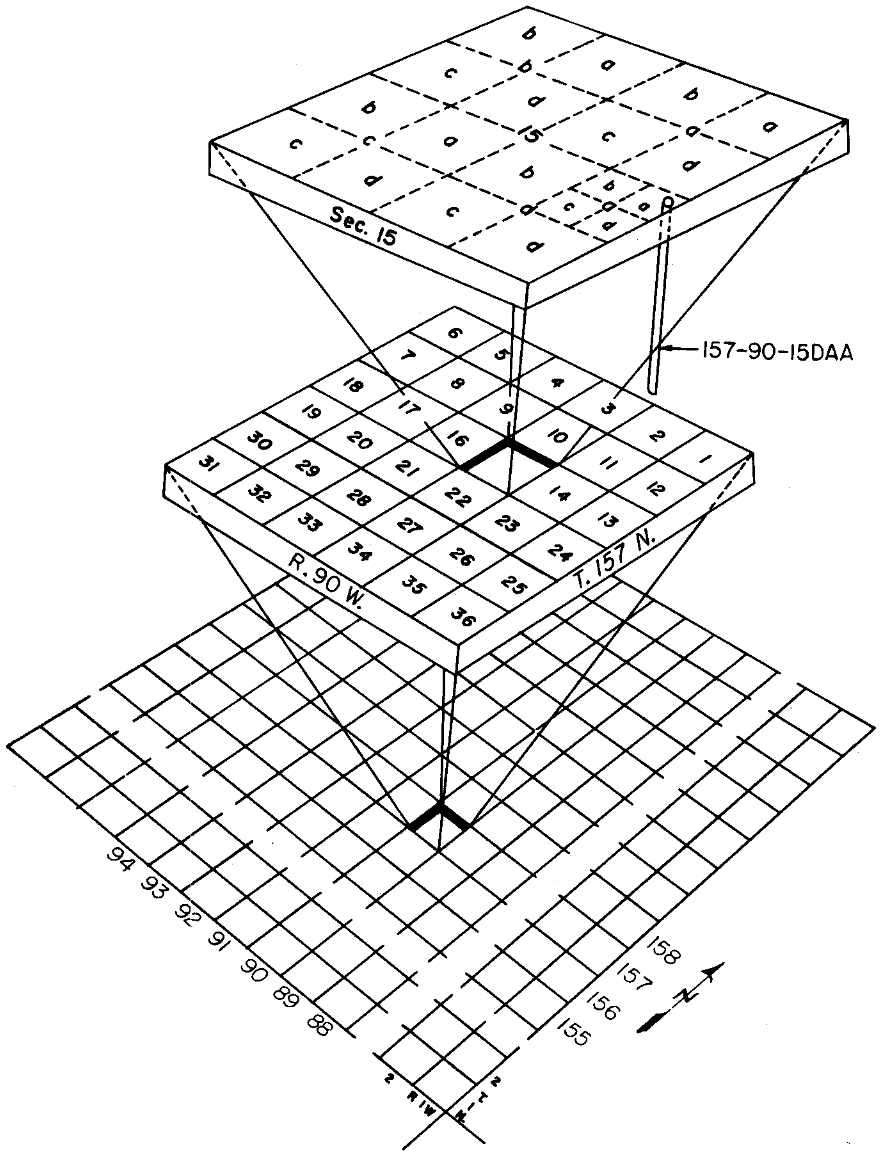

FIGURE 2. System of numbering wells, springs, and test holes.

conditions in northern Burke County as part of a larger study that included parts of Divide, Burke, Renville, and Ward Counties. Paulson (1954) described the geology and occurrence of ground water in the vicinity of Stanley, Mountrail County; Jensen (1962) reported on the geology and occurrence of ground water near Bowbells, Burke and Ward Counties; Schmid (1962) investigated the ground-water conditions in the vicinity of Parshall, Mountrail County; and Paulson and Powell (1962) made an investigation of the ground-water resources of the Tioga and Hofflund Flat areas, Williams and Mountrail Counties. The North Dakota State Department of Health (1964) published chemical analyses of water used in Burke and Mountrail Counties municipal supplies. Naplin (1969) made a detailed ground-water study of a small area near Columbus, Burke County. Several geologic and special mineral investigations have included at least parts of Burke and Mountrail Counties. Publications concerning these investigations will be listed in Part I of this series.

Acknowledgments

Appreciation is expressed to the Burke and Mountrail County Commissioners, water management board members, other county officials, and the various city officials and water-plant operators for assistance that made it possible to complete the field investigation without unnecessary delays. Particular recognition is due M. O. Lindvig and R. W. Schmid of the North Dakota State Water Commission for their aid during aquifer tests, and L. L. Froelich and C. E. Naplin for the logging of the test holes. Appreciation also is expressed to the well drillers who furnished well logs, and to the farmers and ranchers of Burke and Mountrail Counties for allowing access to their lands and for providing records of wells.

Population and Economy

The population of Burke and Mountrail Counties in 1960 was 5,886 and 10,077, respectively (U.S. Bureau of the Census, 1960). The largest cities in Burke County are Bowbells (county seat), Columbus, and Powers Lake, with populations of 687, 672, and 633, respectively. The largest cities in Mountrail County are Stanley (county seat), New

Town, and Parshall, which have populations of 1,795, 1,586, and 1,216, respectively. All other cities in Mountrail County have populations of less than 400 each.

The two-county area is served by the Great Northern Railway and the Soo Line Railroad, which connect all the cities and villages. U.S. highway 2, in Mountrail County, and North Dakota State Highways 5 and 50, in Burke County, cross the counties in an east-west direction; North Dakota State Highway 8 crosses in a north-south direction. Many State and county roads generally make all parts of the counties accessible by motor vehicles.

The economy of the counties is based largely on agriculture. Small grains, flax, and hay are the principal crops. Cattle and sheep are other important sources of farm income. Petroleum and lignite production, and services connected with these industries also make up a significant part of the economy.

Climate

The climate of Burke and Mountrail Counties is normally semiarid. U.S. Weather Bureau (1952-70) records show that the mean annual precipitation ranges from 13.49 inches at Columbus to 14.69 inches at Parshall. About 75 percent of the precipitation falls during the growing season from May to September. Most of the summer precipitation is extremely variable from month to month and from place to place within the counties. It is not uncommon for a part of a county to receive more than an inch of rain during a single thunderstorm while another part receives very little or none.

The minimum temperature in the two-county area since 1951 was -45°F at Lostwood on January 1, 1969. The summer daytime temperatures are usually warm, generally ranging from 76° to 84°F. However, temperatures exceeding 90°F commonly occur each summer. The maximum recorded temperature in the area since 1951 was 106°F at Powers Lake on July 20, 1960. The annual average temperature ranges from 37.7°F at Portal to 39.5°F at New Town.

Physiography and Drainage

Burke and Mountrail Counties lie within two physiographic provinces, which are the Central Lowland and the Great Plains (fig. 1). Northern Burke County is in the Drift Prairie section of the Central Lowland, which is characterized by a northward-sloping plain with low hills and shallow depressions. The southern part of Burke County and all of Mountrail County are in the glaciated Missouri Plateau section of the Great Plains. The Missouri Plateau section has been further divided by Clayton (1962, p. 14) into two districts--the Coteau du Missouri and the Coteau Slope. The Coteau du Missouri is an area of relatively youthful stagnation moraine and end moraine that is characterized by steep-sided hills and depressions. The northern edge of the Coteau is formed by a relatively steep escarpment that slopes 200 to 300 feet to the north and northeast in a distance of ½ to 2 miles. The Coteau Slope is an area of older ground moraine that is characterized by gently rolling topography dissected by stream valleys.

Maximum topographic relief in the two-county area is nearly 800 feet. The highest altitude is 2,572 (U.S. Army Map Service, 1957) feet at the summit of a hill at 157-93-25ADD in Mountrail County. The lowest altitude is a few feet lower than the 1,786-foot spillway level of Upper Des Lacs Lake in Burke County.

Drainage on the Coteau du Missouri generally is of the interior or nonintegrated type. Surface runoff is toward the undrained or poorly drained depressions commonly referred to as sloughs or prairie potholes. Many of the depressions represent small individual basins, but some fill up and overflow into lower ones, especially during spring thaws following winters of above normal snowfall. Many of the depressions contain water for only a few months during the spring and early summer, but others that have large drainage areas or are sustained by ground-water seepage may contain water throughout the year.

Drainage on the Coteau Slope is generally well developed, although there are locally a few poorly drained areas. Surface runoff on the Coteau Slope is toward the Missouri River. The four principal tributaries that drain the Coteau Slope in Mountrail County are: White Earth River, Little Knife River, Shell Creek, and East Fork Shell Creek.

Figure 3 is a hydrograph showing the flow in the White Earth River and in Shell Creek during the water year October 1966 through September 1967 (U.S. Geol. Survey, 1967). The large flows shown in March and early April are due to snowmelt during the spring thaws. The smaller peak flows that occur at other times of the year are due primarily to direct surface run-off from precipitation. The remainder of the flow is caused by ground-water discharge. The increases in

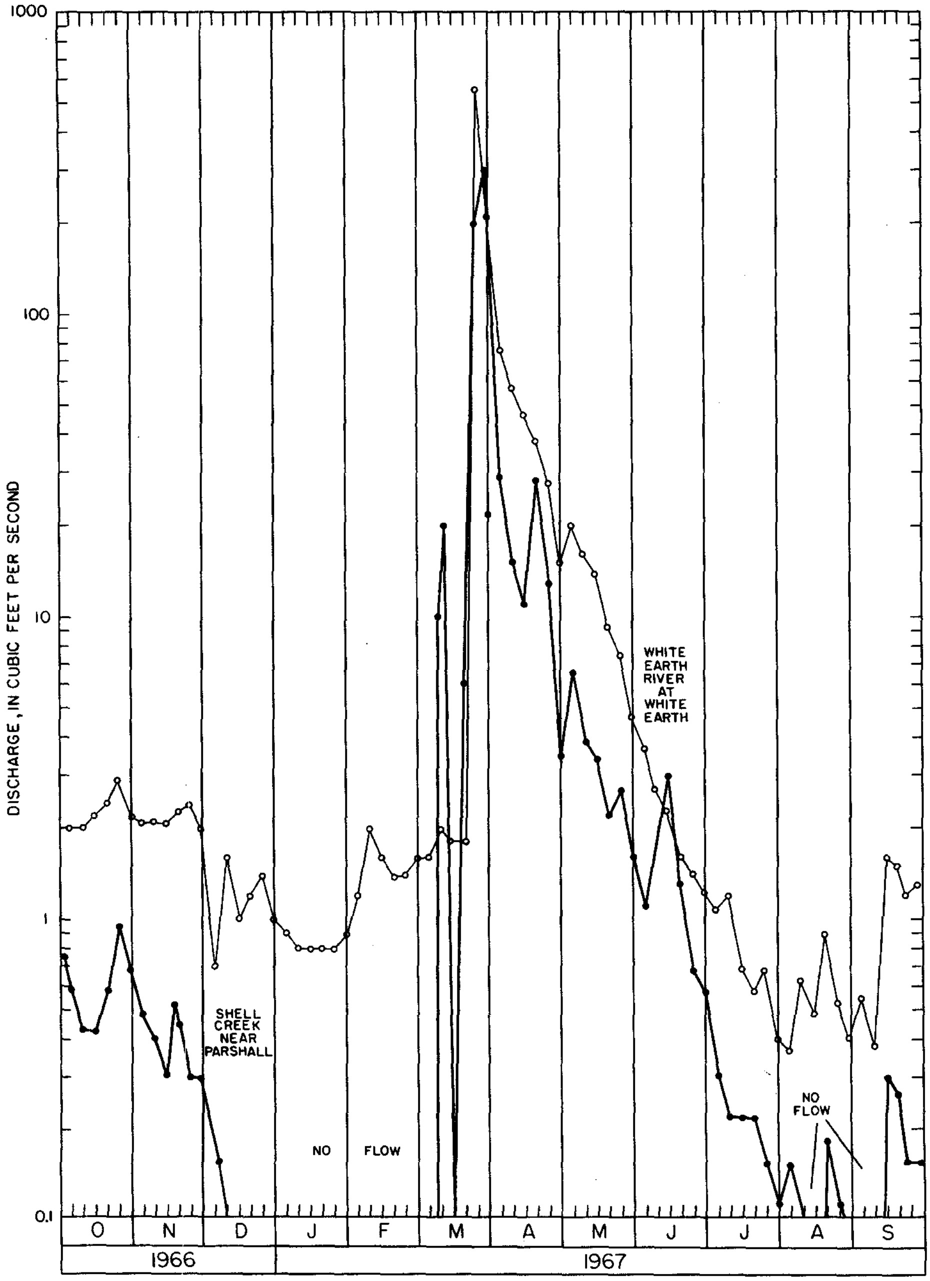

FIGURE 3. Flow in White Earth River and Shell Creek, October 1966-September 1967.

streamflow in late September, and probably October and November also, are due to killing frosts that decreased ground-water loss through transpiration. This water then became available to increase streamflow.

The Little Knife River and East Fork Shell Creek were not gaged.

Drainage in the Drift Prairie section is toward the Souris River or, its principal tributary, the Des Lacs River. The drainage system is poorly developed with generally shallow valleys and many shallow sloughs in the divide areas.

PRINCIPLES OF GROUND-WATER OCCURRENCE

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

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

The water level in a well fluctuates in response to recharge to and discharge from the aquifer. Atmospheric pressure changes and land surface loadings also cause minor water-level fluctuations in confined aquifers. When water is withdrawn from a well, the amount of drawdown is controlled by the transmissivity and storage properties of the aquifer, the physical characteristics of the well, and the rate and duration of pumping. During constant and uniform discharge from a well in an extensive aquifer, the water level declines rapidly at first and then continues to lower at a decreasing rate as the cone of depression expands. The area of influence of the cone of depression spreads directly with time and inversely with the storage coefficient. Under artesian conditions the storage coefficient is equal to a small fraction of the porosity, and the area of influence spreads rapidly. Under water-table conditions the storage coefficient, which is much larger than under artesian conditions, is practically equal to the specific yield, and the area of influence spreads slowly.

The theoretical shapes and rates of decline of cones of depression in buried-channel aquifers are distorted by the effects of relatively impermeable valley walls, and the rates of water-level decline are increased. The rates of decline in these narrow aquifers are not only functions of the transmissivity and storage, but also of the proximity of the valley walls. In very narrow valleys the rates of water-level decline may actually increase throughout a period of pumping.

The water level in a pumping well must decline in order that water may flow from the aquifer to the well. However, too great a decline may cause serious problems if (1) it causes water of undesirable quality to move into the aquifer, (2) the yield of the well decreases because of interference from other wells or from aquifer boundaries, (3) the pumping lift increases to the point where pumping becomes uneconomical, or (4) the water level declines below the top of the screen. When pumping is stopped, the water level recovers in the well and in its vicinity at a decreasing rate until the water level again is at or near the static level.

Under natural conditions, over a long period of time, the amount of discharge from an aquifer approximately equals the amount of recharge.

Withdrawal of water from an aquifer eventually causes one or a combination of the following: (1) a decrease in the rate of natural discharge, (2) an increase in the rate of recharge, or (3) a reduction in the volume of water in storage. The maximum rate of ground-water withdrawal that can be maintained indefinitely is related directly to the rate of recharge. However, recharge is regulated largely by climate and geologic controls and cannot be evaluated quantitatively without large amounts of data.

QUALITY OF WATER

All natural water contains dissolved minerals. Rainfall begins to dissolve mineral matter as it falls and continues to dissolve mineral matter as the water infiltrates through the soil. The amount and kind of dissolved mineral matter in water depends upon the solubility and types of rocks encountered, the length of time the water is in contact with the rocks, and the amount of carbon dioxide and soil acids in the water. Water that has been underground a long time, or has traveled a long distance from the recharge area, generally is more highly mineralized than water that has been in transit for only a short time and is withdrawn near the recharge area. Ground water usually contains more dissolved minerals than water from streams.

The dissolved mineral constituents in water are usually reported in parts per million (ppm), milligrams per liter (mg/1), or grains per U.S. gallon (gr/gal). A part per million is a unit weight of a constituent in a million unit weights of water. Milligrams per liter is practically equivalent to parts per million for water containing less than 7,000 ppm dissolved solids (Hem, 1959, p. 30). Parts per million can be converted to grains per gallon by dividing parts per million by 17.12.

The suitability of water for various uses is determined largely by the kind and amount of dissolved mineral matter. The chemical properties and constituents most likely to be of concern are: (1) dissolved solids and the related specific conductance, (2) sodium-adsorption ratio, (3) hardness, (4) iron, (5) sulfate, (6) nitrate, and (7) fluoride. The relative importance of the above properties and constituents of water depends primarily on the use of the water. For example, hardness has very little effect on the suitability of water for drinking, but it can make water undesirable for laundry use. Additional information may be found in "Drinking Water Standards" published by the U.S. Public Health Service (1962).

Table 1, modified from Durfor and Becker (1964, table 2), shows the major constituents normally found in water, their major sources, and their effects upon usability.

Dissolved Solids and Specific Conductance

The concentration of dissolved solids is a measure of the total mineralization of water. The dissolved solids concentration is significant because it may limit the use of water for many purposes. In general, the suitability of water decreases with an increase in dissolved solids. The limits shown in table 1 for drinking water were originally set for common carriers in interstate commerce. Residents in areas where dissolved solids are as high as 2,000 ppm have consumed the water with no noticeable ill effects. Livestock has been known to survive on water containing 15,000 ppm. However, growth and reproduction of livestock may be affected by water containing more than 3,000 ppm of dissolved solids.

The specific conductance of water is a measure of the water's ability to conduct an electrical current; it is a function of the amount and kind of dissolved mineral matter. Specific conductance usually is reported in micromhos at 25°C. An estimate of the total dissolved solids in parts per million can be obtained by multiplying specific conductance by 0.65. The conversion factor, however, may range from 0.5 to 1.0, but generally ranges from 0.55 to 0.75, depending upon the type and amount of dissolved minerals. The conversion factor should not be used for estimating dissolved solids of more than 50,000 ppm, nor should it be used if the specific conductance has not been adjusted to a standard temperature of 25°C.

Irrigation Indices

Two indices used to show the suitability of water for irrigation are SAR and specific conductance. SAR is related to the sodium hazard; the specific conductance is related to the salinity hazard. Figure 4 shows the classifications of water using SAR and specific conductance. Numerical values of 3 or 4 indicate that the water is of marginal or unsuitable quality for irrigation; however, high-sodium waters have been used successfully for selected crops with the addition of proper amendments, and high-salinity waters have been used where ideal soil conditions and drainage exist.

Another index used to evaluate irrigation water is the residual sodium carbonate (RSC). The RSC is determined by subtracting the equivalents per million (epm) of calcium and magnesium from the sum of equivalents per million of bicarbonate and carbonate. If the RSC is between 1.25 and 2.5 epm, the water is considered marginal for irrigation. An RSC of more than 2.5 epm indicates that the water is not suitable for irrigation purposes. Good management practices might make it possible to use successfully some of the marginal RSC water for irrigation. For further information, the reader is referred to "Diagnosis and Improvement of Saline and Alkali Soils" (U.S. Salinity Laboratory Staff, 1954).

Hardness

The hardness of water determines its usefulness for laundries and for some industries. The U.S. Geological Survey rates water having a hardness (as $CaCO_3$) of 0 to 60 ppm as soft, between 61 and 120 ppm

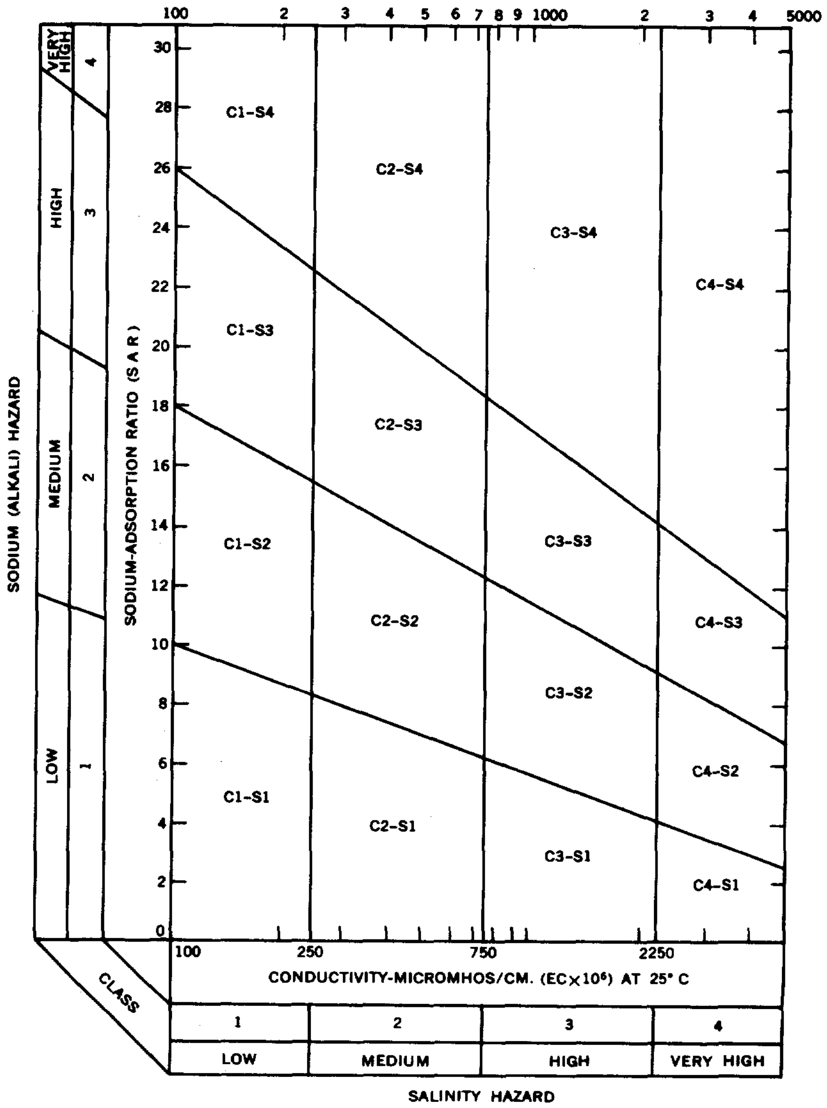

FIGURE 4. Salinity- and sodium-hazard classification diagram (from U. S. Salinity Laboratory Staff, 1954).

as moderately hard, between 121 and 180 ppm as hard, and more than 180 ppm as very hard. Hardness does not seriously interfere with the use of water for most purposes, but it does increase the consumption of soap. Its removal by a softening process can be profitable for domestic uses, for laundries, and for some industries.

AQUIFER CONSTANTS

Aquifer constants, especially transmissivity, storage coefficient, and hydraulic conductivity are used in evaluating the water-bearing properties of the aquifer. These constants, together with head factors, determine the quantity of water available in an aquifer and the rate the water will move through an aquifer.

Theis (1935), Jacob (1940), Stallman (1963), and others developed methods whereby transmissivity and storage coefficient could be determined from pumping tests. Their methods were used to analyze the pumping-test data obtained during this project.

Hydraulic conductivities of glacial aquifer materials were estimated from lithologic logs based on the following values:

Material	Hydraulic conductivity (gpd per ft^2)
Gravel	2,500-4,000
Sand and gravel	2,000-2,500
Coarse sand	1,500
Medium sand	1,000
Fine sand	500
Very fine sand	50
Silt	5

Generally the lower value is used unless a high degree of sorting is indicated on the log. The transmissivity of an aquifer is obtained by multiplying the hydraulic conductivity by the thickness of each aquifer increment. Generally very fine sand and silt units are omitted from estimates if they do not contribute more than 5 percent of the total transmissivity.

The above values are not applicable in bedrock aquifers because of greater compaction and cementation in the bedrock.

A method of estimating transmissivity from specific capacities of wells was derived from a graph devised by Meyer (1963, p. 339). The graph indicates that a well in an artesian aquifer with a transmissivity of 2,000 gpd (gallons per day) per foot will have a specific capacity of 1 gpm (gallons per minute) per foot of drawdown. Theis (1963, p. 334) showed the factor is about 1,200 gpd per foot in water-table aquifers. Thus, the specific capacity of a small-capacity well can be multiplied either by 2,000 or 1,200 to obtain an approximate transmissivity (the factor may be as much as 30 percent larger for large-capacity wells). These methods assume that a well is 100 percent efficient, fully penetrates the aquifer, and that the specific capacity is calculated at the end of 1 day of pumping. Specific capacities calculated on less than a day's pumping will result in estimated transmissivities that are too high. Specific capacities of partially penetrating wells will result in estimated transmissivities that are too low.

THE ROCKS AND THEIR WATER-BEARING PROPERTIES

The sedimentary rocks of Burke and Mountrail Counties that form aquifers are divided into the following units: (1) rocks of pre-Cretaceous age, (2) Dakota Group of Cretaceous age, (3) Fox Hills and Hell Creek Formations of Cretaceous age, (4) Fort Union Group of Tertiary age, and (5) glacial drift of Quaternary age. The Dakota Group, Fox Hills Formation, Hell Creek Formation, Fort Union Group, and the glacial drift contain the only aquifers that are presently of economic importance. Consequently, these units are described in the greatest detail. The Hell Creek Formation is included as an aquifer even though there is a scarcity of data concerning its water-bearing properties. It probably will yield sufficient quantities of water to be of economic value as it does in west-central North Dakota (M. G. Croft, written commun., 1969).

Burke and Mountrail Counties are located over the northeast flank of the Williston basin; consequently, the pre-Quaternary rocks generally dip to the west or southwest. However, in northwestern Mountrail County and western Burke County the rocks dip eastward because of the effects of the Nesson anticline, a north-northeast-trending fold. The sediments are about 14,500 feet thick in southwestern Mountrail County and only about 10,000 feet thick in northeastern Burke County (C. G. Carlson, written commun., 1969).

The following discussion concerning the pre-Cretaceous rocks is based on information obtained from petroleum exploration.

Rocks of Pre-Cretaceous Age

Pre-Cretaceous rocks generally are more than 3,900 feet below land surface in northeastern Burke County and more than 5,600 feet below land surface in southwestern Mountrail County. The rocks are composed mainly of limestone and dolomite with lesser amounts of sandstone, shale, and evaporites. Some of the limestone is porous or cavernous and would yield very large supplies of water. The sandstones are reported to be either fine or very fine grained and probably would yield small but dependable supplies of water. A sample of water from oil test 163-92-34BA, which taps an aquifer in the Madison Group of Mississippian age, contained 271,000 ppm dissolved solids, 86,000 ppm sodium, 4,300 ppm potassium, 150,000 ppm chloride, and 17,600 ppm sulfate. The quality of water elsewhere in the Madison Group and in the other pre-Cretaceous rocks of the area probably differs considerably, as it does in Divide County where the analyzed water contained from 205,100 to 328,800 ppm dissolved solids (Armstrong, 1967a, p. 16). Some of the shallower pre-Cretaceous rocks may contain water of better quality than that of the sample from oil test 163-92-34BA; nevertheless, the water would be too saline for most purposes.

Cretaceous System

Dakota Group

The Dakota Group in North Dakota consists of the Lakota, Fall River, Skull Creek, Newcastle, and Mowry Formations. Sandstone beds in the Fall River and Lakota Formations form the only important aquifer in the group and are herein referred to as the Dakota aquifer.

The top of the aquifer ranges in depth from 3,505 feet in oil test 163-89-6AA in northeastern Burke County to 5,210 feet in oil test 151-93-10AA near the deepest part of the Williston basin in southwestern Mountrail County. The altitude of the top of the aquifer at these two locations is 1,620 and 3,066 feet below msl (mean sea level), respectively (C. G. Carlson, written commun., 1969).

The interval containing the Dakota aquifer in Burke and Mountrail Counties generally ranges from 330 to 460 feet in thickness and averages about 375 feet. It is composed of hydrologically connected beds of very fine to medium-grained sandstone and interbedded gray shale. Electric logs of many oil tests in Burke and Mountrail Counties indicate that sandstone comprises approximately 25 to 45 percent of the total interval thickness. The remainder is predominantly shale and siltstone.

The Newcastle Formation in Burke and Mountrail Counties is lithologically similar to the rocks of the Dakota aquifer, but the sediments are somewhat finer grained and the formation is much thinner. The depth and limited thickness of the Newcastle preclude the possibility of its being a major aquifer, though it probably would yield small quantities of water. The Skull Creek and Mowry Formations are predominantly shale and would not yield significant quantities of water.

Yield–In 1966, seven wells in Williams County, which is adjacent to Mountrail County on the west, were producing water from the Dakota aquifer (Armstrong, 1969b). Six of the wells were pumped at approximately 290 gpm each, and the other well was pumped at 156 gpm. It was estimated that the specific capacities of the wells ranged between 0.4 and 3 gpm per foot of drawdown.

Six wells produce water from the Dakota aquifer in the report area. The water is pumped into oil-producing horizons to maintain oil-field pressures. Data for these wells are shown in the following table.

Location	Total depth (feet below land surface)	Perforated interval (feet below land surface)	Yield (gpm)
158-94-31AA	5,325	......	....
159-94-20BA	4,420	4,330-4,390	....
160-94-29CC	....	5,093-5,120 5,143-5,164	320
163-90-29CC	4,230	4,090-4,100 4,120-4,140	130
163-92-22CB	....	......	....
163-92-34AA	....	......	....

Even though the data in the table are not sufficient to make estimates of transmissivity and specific capacity, they are sufficient to indicate a similarity between the water-yielding properties of the Dakota aquifer in Williams County and in the report area. Electric logs also indicate considerable uniformity in the Dakota aquifer throughout most of the report area and in Williams County. Therefore, pumping rates and specific capacities in most parts of Burke and Mountrail Counties can be expected to be similar to those obtained in Williams County.

Quality of water–Water from the Dakota aquifer in Burke and Mountrail Counties, as classified by Robinove and others (1958), is too saline for most uses. A water sample from the Anschutz Oil Company's Bakken-C well in 161-92-3, Burke County, was a sodium chloride type that contained 12,300 ppm dissolved solids, 4,480 ppm sodium, 5,850 ppm chloride, and 110 ppm sulfate (Earlougher Engineering, Tulsa, Okla., written commun., 1963). The analyses of water from the Dakota aquifer in Divide County (Armstrong, 1965, table 5) and in Williams County (Armstrong, 1967b, table 4) indicate that the water is similar throughout northwestern North Dakota.

Fox Hills and Hell Creek Formations

The Fox Hills and Hell Creek Formations are composed of similar lithologies. The hydrologic boundaries do not correlate with the formation boundaries; consequently, the formations have not been differentiated in this report. The lower part of the Fox Hills Formation is composed principally of siltstone and claystone that probably would not yield significant quantities of water to wells.

The upper part of the Fox Hills Formation and the lower part of the Hell Creek Formation contain about 100 feet of sandstone in an interbedded sandstone, siltstone, and shale zone. The sandstone beds in the zone apparently are hydrologically connected and herein are referred to as the Fox Hills-Hell Creek aquifer.

The top of the Fox Hills-Hell Creek aquifer generally ranges from 1,550 to 2,100 feet below land surface (altitude about 300 feet above msl) in the south-central and southwestern parts of Mountrail County. The top of the aquifer is about 1,450 to 2,100 feet below land surface (altitude about 550 feet above msl) in the southeastern part of the county. Although correlations are somewhat tenuous, the top of the aquifer in north-central Burke County generally ranges from 1,100 to 1,300 feet below land surface (altitude of about 700 feet above msl), and may be about 800 feet in depth (altitude about 1,000 feet above msl) in northeastern Burke County.

Electric logs of oil tests indicate that the interbedded zone that forms the aquifer generally is about 125 to 200 feet thick throughout most of the two-county area. Locally, however, the electric logs indicate that the sandstone beds contain large quantities of interstitial clay or silt.

Electric logs of oil-test holes in the southern half of Mountrail County indicate a few thin beds of sandstone are interbedded with siltstone or claystone in the upper part of the Hell Creek Formation. These sandstone beds generally occupy less than 25 percent of the total interbedded section and are generally separated from the lower Fox Hills-Hell Creek aquifer by more than 80 feet of relatively impermeable sediments. No data are available on the quantity and quality of water in the upper Hell Creek sands, but yields probably would be less than from the lower Fox Hills-Hell Creek aquifer.

Yield–The Fox Hills-Hell Creek aquifer probably would yield small quantities of water to wells in most of Burke and Mountrail Counties. Only one well, 152-93-26BCC, however, is presently producing water from this aquifer. This well flows approximately 2 gpm at an altitude of 2,100 feet above msl. The well owner, M. D. Pennington, reported that the static water level was 5 to 6 feet above land surface when the well was first drilled in 1967, but 7 months later the water level had declined to about 3 feet above land surface.

Data are not sufficient to determine the transmissivity of the aquifer in Burke and Mountrail Counties, but Croft (1970, p. B194) reported that the average transmissivity of the aquifer in Mercer County is about 1,400 gpd per foot and the specific capacities of wells range from less than 0.1 to 0.6 gpm per foot of drawdown. Similar transmissivities and specific capacities can be expected in Burke and Mountrail Counties. Therefore, yields as high as 60 gpm with about 100 feet of drawdown should be obtainable.

Quality of water–A water sample from well 152-93-26BCC was a very soft sodium bicarbonate type and had a 1,530 ppm total dissolved solids content. The water contained 5.1ppm fluoride, which exceeds the U.S. Public Health Service (1962) standards for human consumption. Samples of water from Hettinger, Mercer, Oliver, and McKenzie Counties (North Dakota State Laboratories, written commun., 1968) indicate that the water from the Fox Hills-Hell Creek aquifer is of similar quality throughout much of western North Dakota.

Tertiary System

Fort Union Group

The Fort Union Group crops out in bluffs along the Missouri River and its tributaries and in a few small areas elsewhere in Mountrail County. Outcrops in Burke County occur in small areas along the Des Lacs River, along the lower reaches of Short Creek, and in several lignite strip mines. The Fort Union Group generally underlies the glacial drift at depths of less than 100 feet throughout much of the Coteau Slope and the Drift Prairie, except in the larger ancient buried valleys. Depths to the Fort Union are commonly more than 100 feet in the Coteau du Missouri area, but many exceptions do exist.

The group is subdivided into four formations in some parts of North Dakota: the basal Ludlow Formation (continental); the Cannonball Formation (marine), which interfingers with and is the time equivalent to the Ludlow; the intermediate Tongue River Formation (continental); and the upper Sentinel Butte Formation (continental). These formations are present in Burke and Mountrail Counties, but key beds and contacts between the formations are generally not recognizable in the subsurface.

Plates 1 and 2 (in pocket) show the configuration of the preglacial surface of the Fort Union Group or the overlying Golden Valley Formation (areas higher than about 2,300 feet altitude) as it would appear if the glacial drift and alluvial material were removed. Many small bedrock irregularities such as valleys and hills probably exist, but are not shown because of inadequate data. The preglacial topography of Burke and Mountrail Counties probably was similar to that of the present unglaciated areas of southwestern North Dakota. Buttes, mesas, and possibly some badland-type topography may have existed locally, but the area for the most part was too far from major streams to have extensive badlands develop.

Ludlow and Cannonball Formations

The Ludlow and Cannonball Formations are not exposed and, with possible exceptions in northeastern Burke County, do not directly underlie the glacial drift or alluvium in the report area. Information from oil tests is limited, and definite identification of either the Ludlow or the Cannonball has not been made in these tests. However, the top of the rock sequence tentatively assigned to these formations was picked by the author at a depth of 822 feet (altitude, 1,500 feet above msl) in oil test 156-92-14BD and at a depth of 990 feet (altitude, 1,337 feet above msl) in oil test 160-91-10CC. Lithologic logs of oil tests

(North Dakota Geol. Survey, written commun., 1969) indicate that the Ludlow and Cannonball Formations are composed of interbedded very fine to fine-grained sandstone with minor amounts of medium-grained sandstone, claystone, siltstone, and some lignite. Electric logs indicate that the formations are composed of 250 to 350 feet of interbedded sandstone, siltstone, and claystone with the sandstone occupying about 20 to 45 percent of the total interval.

The areal extent of the formations is not known, but the presence of the Cannonball Formation in northwestern Divide County (Armstrong, 1967a), in southern Williams County (Armstrong, 1969b), in western Renville County (LaRocque and others, 1963, p. 17), and in Ward County (Lemke, 1960, p. 28-29) indicates that the Cannonball Formation, or its Ludlow equivalent, underlies all of Burke and Mountrail Counties.

Yield–The sand thicknesses shown by electric logs indicate that the Ludlow Formation or its Cannonball equivalent will yield at least a few gallons per minute to wells in most of Burke and Mountrail Counties. However, data are not sufficient to estimate maximum possible yields.

Quality of water–Water samples were not obtained from known Ludlow or Cannonball aquifers in either Burke or Mountrail counties. However, a sample from well 163-90-32CBC in Burke County contained a sodium bicarbonate type water with 2,240 ppm dissolved solids and 491 ppm chloride. The high chloride content, which is much higher than is generally found in the Tongue River aquifer, may indicate a mixture of water from either the Cannonball or the Ludlow Formations and the Tongue River Formation. LaRocque, Swenson, and Greenman's (1963, p. 37) description of Cannonball and undifferentiated Ludlow and Tongue River water in Burke and adjacent Renville and Ward Counties indicates that the Ludlow and Cannonball water in Burke County generally would contain from 2,000 to 4,000 ppm dissolved solids. Also, the chloride content probably would be excessive for many uses.

Tongue River and Sentinel Butte Formations

The Tongue River and Sentinel Butte Formations either crop out or immediately underlie the glacial drift in the report area, except in some of the deeper valleys in northern Burke County. These units are distinguishable only on the surface in Mountrail County. The two formations are lithologically and hydrologically similar in the subsurface; consequently, they generally are not differentiated in this report. A sand section commonly occurs at or near the base of the Sentinel Butte Formation, but locally it is absent. Wherever the altitudes of this section were known or could be projected reasonably from known outcrops, the Sentinel Butte Formation was identified in the logs (Armstrong, 1969a, table 4). The Tongue River Formation was also identified on test-hole logs when possible.

These formations are composed of a series of nearly horizontal, lenticular beds of lignite, shale, silt or siltstone, and very fine to medium sand or semi-indurated sandstone. Outcrops in the bluffs along the Missouri River and its tributaries indicate that some lignite beds have an areal extent of as much as 10 square miles. The other exposed sediment types generally are much more limited in extent, and some cannot be traced for more than a few hundred yards. Shale and silt lenses are more common than sand and also appear to have a somewhat greater lateral extent. However, in the subsurface, the sandy zone at the base of the Sentinel Butte Formation and probably another at the base of the underlying Tongue River Formation are of much greater extent than any other units in the formations.

Individual sand beds in the Tongue River-Sentinel Butte Formations vary greatly in thickness. Most sand beds are less than 10 feet thick, but thicknesses exceeding 100 feet, such as in test hole 156-91-28BAC2, do occur. The sands generally are very fine to fine with medium sand reported locally. The sands also are commonly reported to be clayey.

Yield–The water yield from the Tongue River and Sentinel Butte Formations depends to a great extent on the thickness, sorting, and grain size of the sand unit, and the quantity of interstitial or interbedded clay in the vicinity of the well. Sand units that are as thick as 100 feet may have transmissivities as high as 5,000 gpd per foot, and properly constructed wells finished in these aquifers would have specific capacities as high as 2.5 gpm per foot of drawdown, as in well 156-91-28BAC2. Well yields, with 20 feet of drawdown, should be as much as 50 gpm.

Most sand lenses in the Tongue River and Sentinel Butte Formations are thin, and the transmissivity of each lens is low. Therefore, wells developed in these sand lenses will have low specific capacities. The three lowest water-level measurements in well 151-90-36DDA (fig. 5) were taken 3 to 15 minutes after pumping had stopped. These water levels, coupled with known pumping rates of approximately 8 gpm, indicate that the specific capacity of the well is less than 0.5 gpm per foot and the transmissivity is less than 1,000 gpd per foot. The large fluctuations of the water level in well 163-93-32BDD (fig. 6) are due to pumping about 13 gpm from a well about 300 feet away, and indicate that the aquifer transmissivity is less than 700 gpd per foot. Therefore, the specific capacity of wells in this aquifer would be less than 0.35 gpm per foot of drawdown.

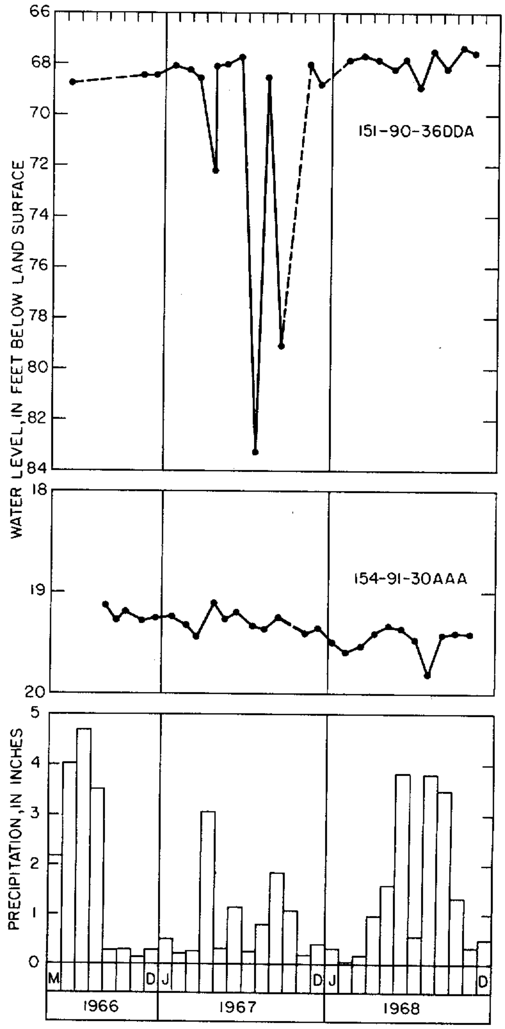

FIGURE 5. **Water-level fluctuations in wells 151-90-36DDA and 154-91-30AAA, and precipitation at Parshall.**

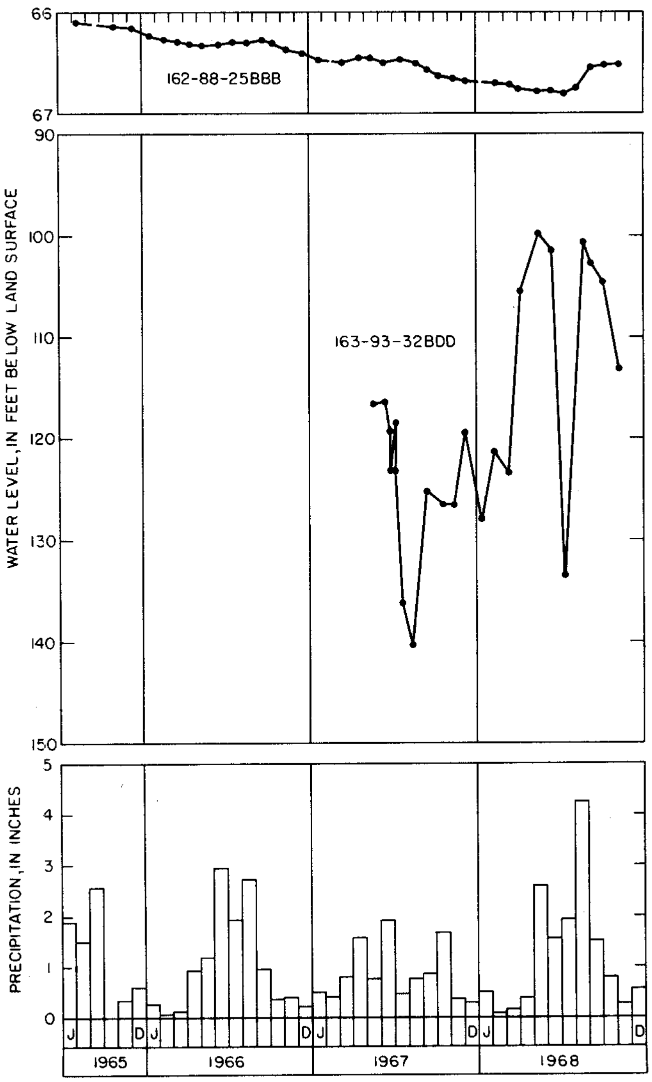

FIGURE 6. Water-level fluctuations in wells 162-88-25BBB and 163-93-32BDD, and precipitation at Columbus.

C. A. Simpson (written commun., 1959) ran a 12-hour pumping test on a well finished in the Sentinel Butte aquifer at Plaza. Although there were only eight measurements, the drawdown-time relationship (fig. 7) appears reasonable and indicates that the coefficient of transmissivity is about 3,000 gpd per foot. Paulson (1954, p. 26) ran a pumping test on a Fort Union (probably Tongue River) aquifer at Stanley. The well, 156-91-28BAC1, was pumped at 100 gpm for 24 hours and had a drawdown of 38 feet. The transmissivity and specific capacity calculated from this test were 6,000 gpd per foot and 2.6 gpm per foot of drawdown.

The results of the test at Stanley substantiate the estimates of transmissivity of the aquifer at test hole 156-91-28BAC2.

Most farm wells that pump from the Tongue River and Sentinel Butte aquifers are completed in the uppermost saturated sand lens. The wells commonly are equipped with cylinder pumps generally with capacities of only 2 to 4 gpm. Some of the lenses are only a foot or two thick and of limited areal extent. Therefore, the wells are not capable of yielding more than the capacity of the pump and the water levels draw down to near the level of the pump intake when pumping.

Lignite beds in the Tongue River and Sentinel Butte Formations also yield water. The quantity depends on the size and extent of the fractures in the lignite and on the transmissivity of the overlying or underlying rocks. Yields from lignite beds are variable from place to place, but are commonly more than 1 gpm. Most wells completed in lignite seams apparently have higher specific capacities than those finished in comparable thicknesses of sand.

Recharge and water-level fluctuations--Recharge to the Tongue River and Sentinel Butte Formations occurs in small quantities in most areas where water stands at the surface for a considerable time. This allows some water to infiltrate to the zone of saturation. The quantity of recharge is not known, but it differs considerably from place to place and time to time. The variations in recharge and discharge cause most of the smaller fluctuations that are illustrated in figures 5 and 6. Wells 154-91-30AAA (fig. 5) and 162-88-25BBB (fig. 6) are in areas where there is no pumping from the aquifers within a mile of the observation wells, and the hydrographs generally show fluctuations due to natural recharge and discharge. The hydrographs of wells 151-90-36DDA (fig. 5) and 163-93-32BDD (fig. 6) likewise show the effects of natural recharge and discharge; however, pumping effects are the major cause of the fluctuations shown.

Well 151-90-36DDA generally is pumped from 1 to 2 hours daily for livestock and domestic purposes. Well 163-93-32BDD is within the area of influence of three wells, at least one of which was pumping

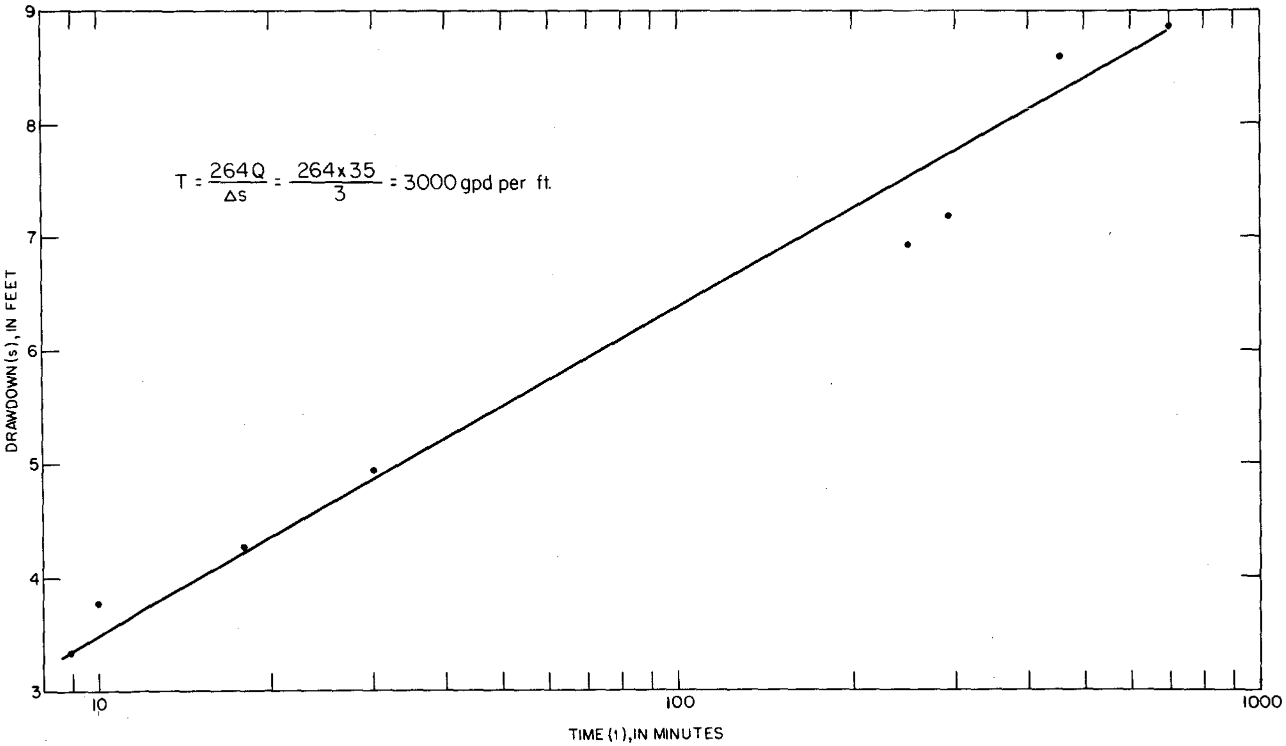

FIGURE 7. Semilogarithmic plot of drawdown (s) versus time (t) during a pumping test on a Sentinel Butte aquifer at Plaza.

most of the time. The higher water levels (fig. 5 and 6) may, therefore, contain some small increments of drawdown and may only approximate the static water level.

Quality of water--The lower part of the Tongue River Formation generally contains a sodium bicarbonate type water. Locally, however, chloride or sulfate may be present in moderately large quantities. The upper part of the Tongue River Formation and most of the Sentinel Butte Formation also generally contain a sodium bicarbonate type water, but sulfate concentrations commonly are high and may exceed the bicarbonate. Locally calcium may exceed sodium in shallow wells tapping the Sentinel Butte Formation. Chloride is generally low in the upper Tongue River and Sentinel Butte Formations.

Chemical analyses were made of water samples from 40 wells that are believed to tap aquifers in the Tongue River and Sentinel Butte Formations. The sodium-ion concentration ranged from 8 to 99 percent; however, only five of the samples contained less than 56 percent. Sulfate exceeded the U.S. Public Health Service (1962) recommended limit of 250 ppm in 25 samples. Dissolved solids ranged from 494 to 3,870 ppm, and exceeded 1,000 ppm in 35 of the samples.

The water from the Tongue River and Sentinel Butte Formations generally is not recommended for either human consumption or irrigation use. However, water from these formations has been used for many years by residents of the area without any noticeable ill effects.

Springs--There are many springs discharging from the Tongue River and Sentinel Butte Formations in Burke and Mountrail Counties. Most of them occur on the lower slopes or near the base of valley walls of the larger tributaries of the Missouri and Des Lacs Rivers. Springs and seeps, many of which are seasonal, also occur along shorter tributary valleys and gulleys that have formed in the Missouri River bluffs and along the northern edge of the Coteau du Missouri. Only a few of these smaller springs were visited or recorded during this investigation.

Most of the springs discharge from sandstone or lignite beds that are underlain by relatively impermeable clay or silt beds. A few have developed at the contact between the formations and the overlying glacial drift, and a few originate in the glacial drift. The smaller springs commonly have only one outlet, but some of the larger springs may have several closely spaced separate outlets, or may form seepage areas of several hundred square feet.

Discharge rates ranged from less than 1 gpm to about 160 gpm. The flow rates generally vary from season to season and depend on the amount of recharge that is available.

Golden Valley Formation

The Golden Valley Formation overlies the Tongue River Formation in a few areas in western Mountrail County. The formation generally occurs at altitudes above 2,300 feet, but small slump blocks containing the formation do occur in the White Earth River valley at lower altitudes.

The Golden Valley Formation is composed of sandy siltstone, siltstone, and shale. In the report area the formation is not known to exist below the water table, therefore the formation is not an aquifer.

Quaternary System

Glacial Drift

Burke and Mountrail Counties are, for the most part, covered by glacial drift that generally is less than 200 feet thick. Locally, however, in buried bedrock valleys the drift thickness exceeds 500 feet; on the Coteau du Missouri the drift thickness may exceed 300 feet. The various types of drift deposits were mapped and described in detail in Mountrail County by Clayton (written commun., 1969), and in Burke County by Freers (written commun., 1969). Generally the topographically higher areas in the Coteau du Missouri consist of stagnation moraine and end moraine with many sloughs, referred to by some as prairie potholes. The sloughs together with the outwash and alluvial deposits are principal areas of ground-water recharge. Conversely, deep stream valleys and lake depressions in topographically low areas commonly are areas of ground-water discharge.

The glacial drift is composed principally of till--a relatively impermeable mixture of clay, silt, sand, gravel, and boulders--that yields little or no water to wells. Some drift, however, consists of stratified glaciofluvial deposits of sand and gravel. The ability of these deposits to yield water depends on their transmissivity, size, and the amount and rate of recharge they receive. If a sand or gravel deposit is small and enclosed in till, it receives recharge slowly; consequently, such a deposit will not yield large quantities of water for sustained periods.

Plates 3 and 4 (in pocket), which show the availability of water from glacial-drift aquifers in Burke and Mountrail Counties, respectively, are based primarily on test-drilling records and on information about private wells. The bedrock topography maps (pls. 1 and 2), Clayton's (written commun., 1969) geologic map of Mountrail County, and Freers' (written commun., 1969) geologic map of Burke

County also aided in determining the extent of the various aquifers. Yields were determined by methods described under aquifer constants.

The central part of the New Town aquifer in southwestern Mountrail County is the only aquifer in the two counties that can provide sustained well yields of more than 500 gpm.

The principal aquifers that can yield from 100 to 500 gpm to wells are: the Columbus, Lignite City, and Kenmare(?) aquifers in Burke County; the peripheral segments of the New Town aquifer, the Shell Creek aquifer system, the aquifers in the East Fork Shell Creek, White Earth, and Little Knife River valleys, and the aquifer near the vicinity of Clearwater Lake in Mountrail County. These aquifers generally are in areas that contain moderately thick glaciofluvial deposits in buried valleys. Some of the thicker aquifers in the buried-valley deposits shown as yielding 100 to 500 gpm may yield more than 500 gpm for limited periods. The length of time these aquifers might yield more than 500 gpm depends on the distance from the well to the adjacent valley walls and the transmissivity of the aquifer.

The 25 to 100 gpm areas show where the aquifers are located that will yield moderately small quantities of water. Locally, more than 100 gpm can be obtained from these aquifers for periods of as much as a few days before recovery is necessary.

The 0-25 gpm areas cover most of each county and indicate where glaciofluvial deposits are of limited extent or nonexistent.

If sufficient water for livestock or domestic purposes cannot be obtained from the glaciofluvial deposits in the drift in the two-county area, a well finished in the underlying Sentinel Butte or Tongue River Formations probably will furnish a sufficient supply, but the quality probably will be inferior.

Water from the glacial drift aquifers differs greatly in quality, but is generally too saline to be recommended for human consumption. Generally water low in dissolved solids is a very hard calcium bicarbonate type, and water high in dissolved solids is a very hard sodium sulfate type.

Columbus aquifer

The Columbus aquifer is in a buried, generally east-west-trending valley (referred to as the Columbus valley in this report) in northern Burke County (pls. 1 and 3). The valley apparently was formed when the ancestral Yellowstone River, which flowed northward into Canada about 20 miles west of Columbus, N. Dak., was dammed by ice and glacial drift. A lake formed behind the dam and filled the ancient Yellowstone River valley. When the lake spilled over the divide it carved the valley now occupied by the Columbus aquifer. The path taken was indicated by Armstrong (1967a, fig. 5) as a tributary of the

Yellowstone, but subsequent drilling has shown it to be a principal diversion channel. The depth and narrowness of the Columbus valley indicate that erosion was rapid. The sequence and distribution of the sediments in the valley, as shown in logs of test holes drilled north of Columbus, some of which are shown on Figure 8, suggest that at least two and possibly three cycles of erosion occurred. Each erosion cycle was followed by the deposition of glacial drift, principally till. The first erosion cycle apparently was terminated by a glacial advance before any appreciable amount of stream deposition could occur. The second cycle of erosion removed some of the glacial drift that had been deposited between the first two erosion cycles. The newly eroded valley was then filled with fluvial deposits, principally sand and gravel. The uppermost part of this latter sequence of deposits contains some finer grained materials that were identified as fluvial deposits, but probably are lake deposits. These, in turn, are overlain by till and some glaciofluvial deposits, which completely filled the older valley. At the present time there is no surface indication of the old valley.

The Columbus aquifer is divided into two zones that are separated by till and (or) silt. The lower zone, which generally is more than 225 feet below land surface, is composed of lenticular bodies of sand and gravel deposited during and after the second cycle of erosion. The upper zone, which may represent a third cycle, also is composed of lenticular sand and gravel deposits, but these deposits apparently are not as thick nor as extensive as those in the lower zone. A 100-hour aquifer test indicated that the sand and gravel lenses within the lower zone are hydraulically interconnected in the Columbus area. The test did not indicate a hydraulic connection with the upper zone, although a longer pumping period probably would show some degree of connection.

The thickness of individual sand and gravel lenses in the lower zone ranges from 1 to 100 feet, and the largest known aggregate thickness is 146 feet. The irregular distribution and thickness of individual sand beds and the fact that only two test holes penetrated the deeper parts of the valley make it impossible to determine an accurate average thickness of the aquifer from the logs.

Test holes drilled into the aquifer in the eastern part of Burke County penetrated fewer sand and gravel lenses than were penetrated in the Columbus area. However, there were fewer test holes drilled in the eastern part of the county and thicker lenses may be present but were not penetrated in the test drilling. It is also possible that the coarser materials were deposited in the Columbus area while the finer grained materials were carried downstream and deposited farther east.

Yield--A 100-hour pumping and 83-hour recovery test was made in August 1968 on the lower zone of the Columbus aquifer to determine

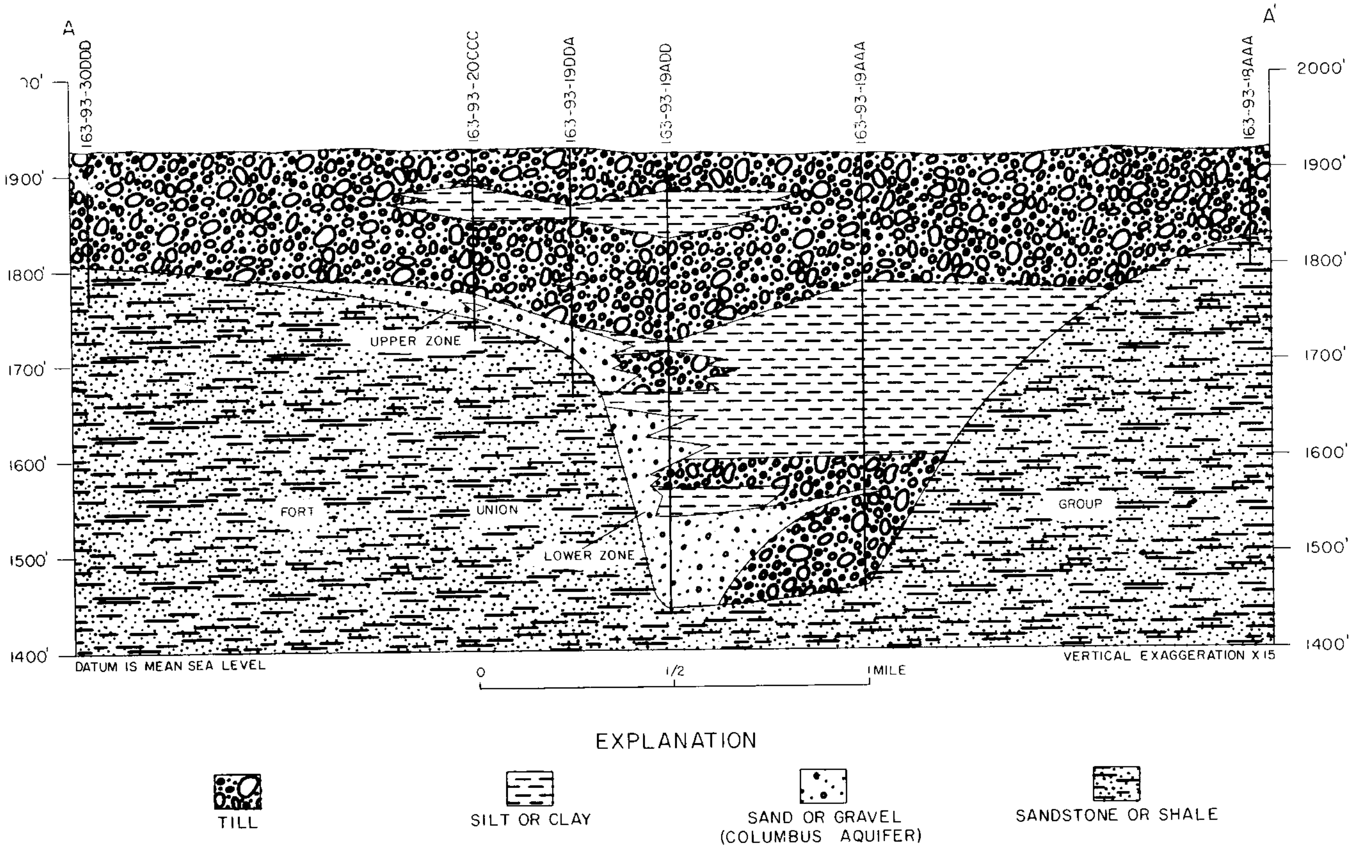

FIGURE 8. Geologic section (A-A') through the Columbus aquifer. (Location of section shown on pl. 3.)

the aquifer constants and to verify the yield estimates shown on plate 3. The test was made using the newly drilled well (163-93-30BBB1) in the city of Columbus, which is 305 feet deep, has an 8-inch-diameter steel casing, and is finished with a 30-foot screen. The discharge of 400 gpm was measured by a flowmeter coupled to a recorder. The rate of flow was regulated by adjusting a 4-inch valve at the end of the discharge pipe.

Water samples were collected for chemical analyses after 7 minutes, and 25, 50, 75, and 99 hours of pumping. Complete analyses were made on the first and last samples.

Water levels in 10 observation wells were measured throughout the test, either continuously with recorders or intermittently with steel tapes. Observation wells 1 (163-93-19CCC2), 6 (163-93-19CCC1), 2 (163-93-30BBB2), 3 (163-93-30BBB3), and 4 (163-94-25AAB), and 163-93-20AAA were equipped with recorders. Observation wells measured intermittently were 163-93-19ADD, 19DDA, 21CBB, and 163-94-22CBB2. The pumped well was measured intermittently at predetermined intervals.

Hydrographs of drawdown and recovery in the pumped well and observation wells 1, 2, 3, 4, and 163-93-20AAA are shown in figure 9. Observation wells 1, 2, and 3 are all 500 feet from the pumped well and theoretically should display equal rates of drawdown. Observation well 2, however, was finished in a deeper gravel lens than the others and the water levels (head changes) reacted as though the well were a few thousand feet away from the pumped well instead of only 500 feet. Observation well 4 is at a distance of 1,000 feet and observation well 163-93-20AAA is at a distance of about 11,600 feet from the production well.

The aquifer-test data were analyzed using methods developed by Theis (1935) and Stallman (1963). Figure 10 is a logarithmic plot of the early data from observation well 3 and the match with the Theis type curve. Only the first three points, representing the first 3 minutes of the test, match before the two curves depart. This first departure is caused by a relatively impermeable boundary, in this case the south side of the buried valley. A second departure occurs at about 7 minutes after the start of the test and probably is caused by the boundary on the north side of the valley. Using a method developed by Stallman (1963, p. 45-47) and matching the test data with his curves, it was determined that the southern boundary is about 400 to 600 feet south of the pumped well. The match of the curves used to determine the northern boundary was poor and the actual distance could be between 750 and 1,350 feet. The best match point, however, indicates that the boundary is about 900 feet to the north of the pumped well.

The analysis of the test, although somewhat inconclusive because

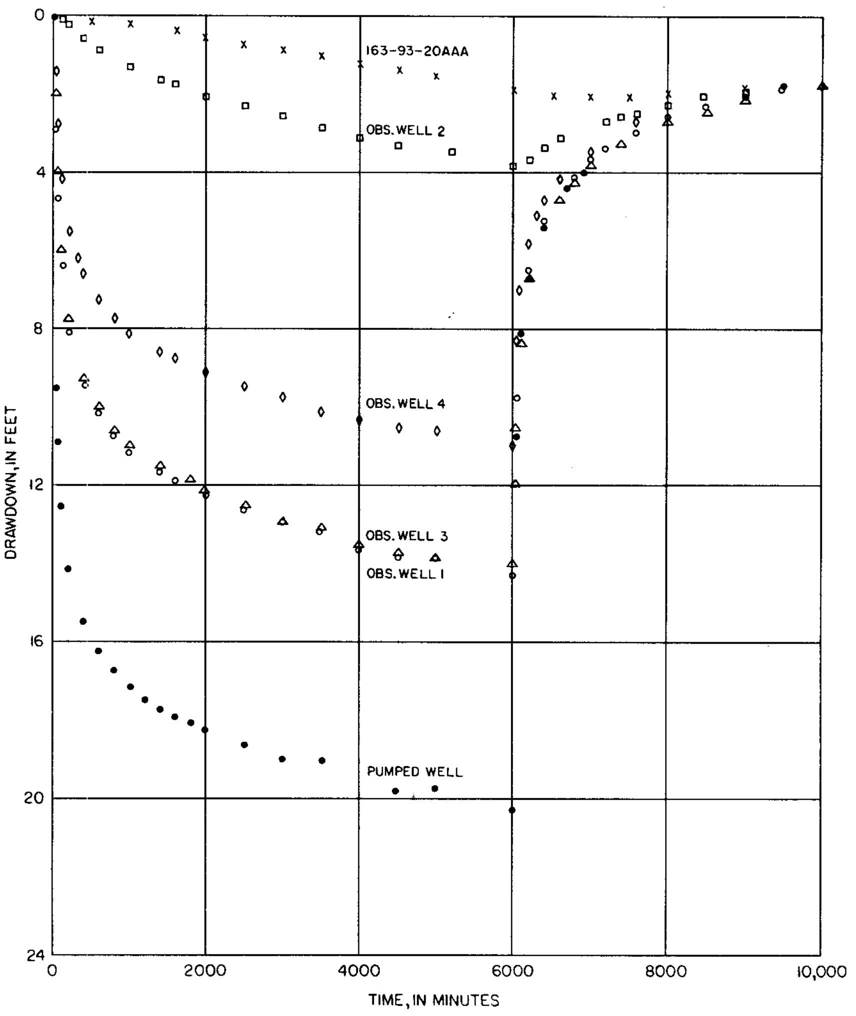

FIGURE 9. **Water-level drawdown and recovery in observation wells during the Columbus aquifer test.**

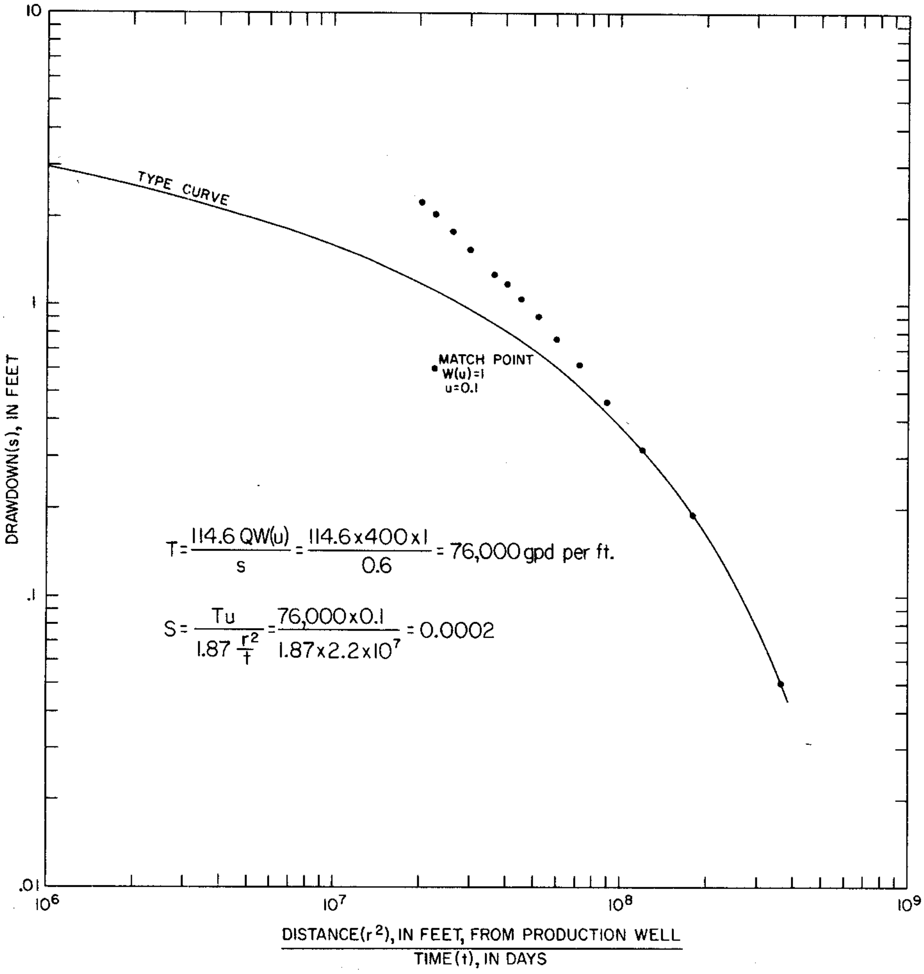

FIGURE 10. Logarithmic plot of Columbus aquifer test data (observation well 3).

of early boundary conditions, indicates that the transmissivity of the aquifer ranges from about 76,000 gpd per foot at observation well 3 to 88,000 gpd per foot at observation well 1. The storage coefficient of the aquifer ranges from 0.0002 to 0.0005. The specific capacity of the pumped well after 24 hours was 22.4 gpm per foot of drawdown. Because of partial penetration and boundary effects, this specific capacity is only about 60 percent of that estimated using the Meyer method (Meyer, 1963, p. 339). At 100 hours the specific capacity was about 19.5 gpm per foot of drawdown, or nearly 3 gpm per foot less than at 24 hours. The data indicate that more than 500 gpm could be pumped from the aquifer. However, the decrease in specific capacity and the short distance to the known boundaries make such a high rate impractical for long time periods. Not more than 200 gpm would be a more practical rate if sustained pumping is to be maintained. Figure 11 shows the projected loss of specific capacity with time in well 163-93-30BBB1. This graph is based on a pumping rate of 400 gpm and considers the boundary effects only for the duration of the aquifer test. The effects of boundaries increase with time until the cone of depression spreads up and down the channel far enough for the effects of the lateral boundaries to be nullified. Therefore, the loss of specific capacity under actual pumping conditions might differ to some extent from the projected line on figure 11.

Generally yields from the upper zone should be similar but somewhat less than yields from the lower zone. Well yields locally, such as at well 163-94-22BBC, generally should be 100 to 500 gpm; however, yields in excess of 500 gpm could be obtained for periods of at least a few days.

Recharge and water-level fluctuations--Recharge to the Columbus aquifer is principally by underflow from adjacent rocks in the undifferentiated Fort Union Group. Direct infiltration of precipitation on the outwash or alluvial deposits that overlie the aquifer also contributes to recharge. The quantity or proportion of recharge from each source is not known; however, the high sodium and dissolved solids indicate that most of the recharge is from the Fort Union Group. The decrease of sulfate in the water with depth in the aquifer as well as higher water levels in the shallower deposits also indicates that water is moving downward from the higher parts of the aquifer where there is more sulfate.

The hydrograph (fig. 12) of well 163-93-20AAA shows the water level on about every fifth day during the period of record. Only small fluctuations occurred before the Columbus city well was drilled in early August 1968. Most of these fluctuations probably were caused by barometric pressure changes. The near-uniform water-level depth of

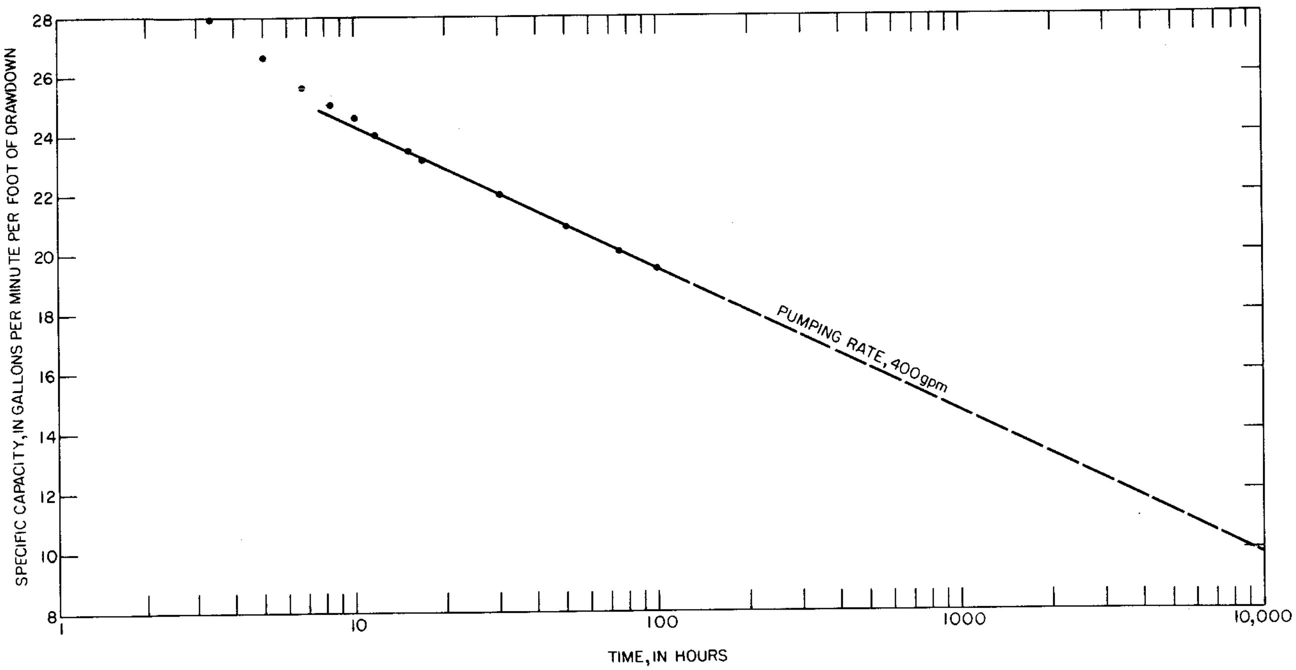

FIGURE 11. Projected loss of specific capacity with time in well 163-93-30BBB1.

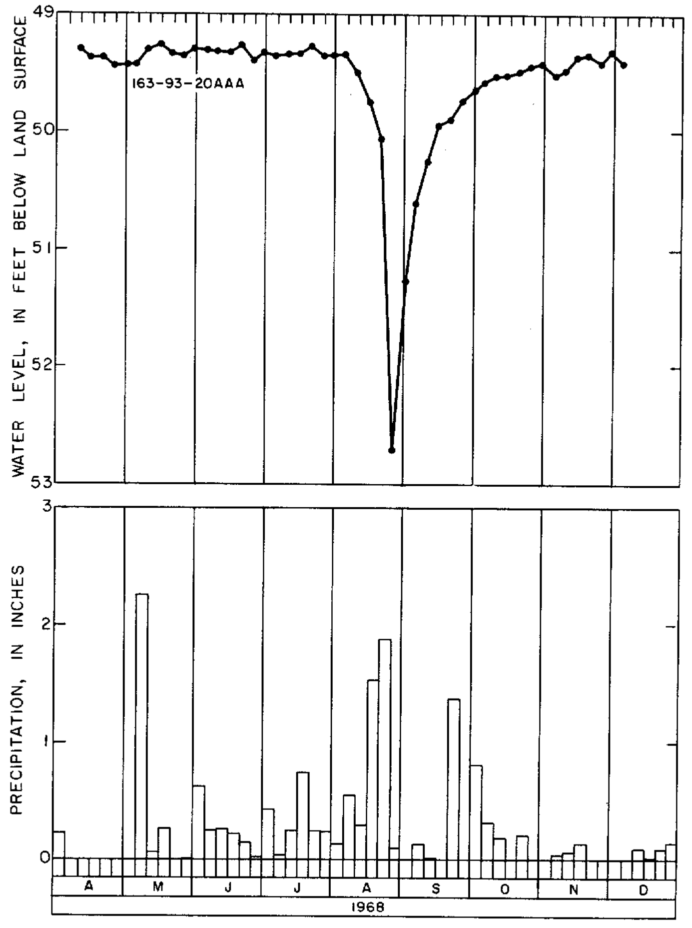

FIGURE 12. Water-level fluctuations in the Columbus aquifer, April to December 1968, and precipitation at Columbus.

TABLE 1.—Major chemical constituents in water—their sources, concentrations, and effects upon usability

(Concentrations are in parts per million)

(Modified after Durfor and Becker, 1964, table 2)

Constituents	Major source	Effects upon usability	U. S. Public Health Service recommended limits for drinking water[1]
Silica (SiO_2)	Feldspars, ferromagnesium, and clay minerals.	In presence of calcium and magnesium, silica forms a scale in boilers and on steam turbines that retards heat transfer.	
Iron (Fe)	Natural sources: Amphiboles, ferromagnesium minerals, ferrous and ferric sulfides, oxides, and carbonates, and clay minerals. Man-made sources: well casings, pump parts, storage tanks.	If more than 0.1 ppm iron is present, it will precipitate when exposed to air; causing turbidity, staining plumbing fixtures, laundry and cooking utensils, and imparting tastes and colors to food and drinks. More than 0.2 ppm is objectionable for most industrial uses.	0.3 ppm
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, calcite, aragonite, dolomite, and clay minerals.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate, and silica to form scale in heating equipment.	
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, dolomite, magnesite, and clay minerals.	Calcium and magnesium retard the suds-forming action of soap. High concentrations of magnesium have a laxative ef-	
Sodium (Na)	Feldspars, clay minerals, and evaporites.	More than 50 ppm sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers.	
Potassium (K)	Feldspars, feldspathoids, some micas, and clay minerals.		
Boron (B)	Tourmaline, biotite, and amphiboles.	Many plants are damaged by concentrations of 2.0 ppm.	
Bicarbonate (HCO_3)	Limestone and dolomite	Upon heating, bicarbonate is changed to steam, carbonate, and carbon dioxide.	
Carbonate (CO_3)		Carbonate combines with alkaline earth (principally clacium and magnesium) to form scale.	
Sulfate (SO_4)	Gypsum, anhydrite, and oxidation of sulfide minerals.	Combines with calcium to form scale. More than 500 ppm tastes bitter and may be a laxative.	250 ppm
Chloride (Cl)	Halite and sylvite.	In excess of 250 ppm may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 ppm.	250 ppm
Fluoride (F)	Amphiboles, apatite, fluorite, and mica.	Optimum concentration in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. Concentrations in excess of optimum may cause mottling of children's teeth.	Recommended limits depend on average of maximum daily temperature. Limits range from 0.6 ppm at 90.5°F to 1.7 ppm at 50°F.
Nitrate (NO_3)	Nitrogenous fertilizers, animal excrement, legumes, and plant debris.	More than 100 ppm may cause a bitter taste and may cause physiological distress. Concentrations greatly in excess of 45 ppm have been reported to cause methemoglobinemia in infants.	45 ppm
Dissolved solids	Anything that is soluble.	More than 500 ppm is not desirable if better water is available. Less than 300 ppm is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	500 ppm

[1] U. S. Public Health Service, 1962.

about 49.5 feet and a measured water-level depth of 49.6 feet on June 27, 1967, indicate that near equilibrium conditions existed in the aquifer prior to August 1968.

The decline during August and recovery in September are due primarily to pumping effects of the new city well. The record is too short to determine how much of the pumpage is coming from either recharge or storage.

Storage--Test drilling in the Columbus valley has not been sufficient to delineate the water-bearing materials throughout its 47-mile length in Burke County. However, by extrapolating all of the data from both the test holes and the pumping test in the Columbus area, an estimate of ground-water storage has been made. The average thickness of the coarser materials in the aquifer appears to be about 55 feet. The pumping-test data indicate that near Columbus the aquifer is between 1,150 and 1,950 feet wide and an average width of 1,500 feet has been assumed for purposes of estimation. On the basis of these data, the aquifer underlies approximately 8,500 acres in Burke County. Wenzel (1942, p. 13, 143) reported that materials of the type in the aquifer have a porosity of about 32 percent. Therefore, in Burke County there should be about 150,000 acre-feet of water in the coarser materials of the aquifer. Much of the better aquifer material described in test-hole logs ranges from medium sand to coarse gravel, which have a hydraulic conductivity of 1,000 to 2,500 gpd per square foot. Materials with this high hydraulic conductivity would drain rapidly, so as much as 60 to 70 percent, or 90,000 to 105,000 acre-feet of water would be recoverable. If the sands and silts in the upper zone and the intervening fluvial sediments, which would drain much more slowly, are included in the estimate, the total storage would be about 300,000 acre-feet; however, probably not more than 150,000 acre-feet of this total storage could be recovered. In addition, considerable recharge would occur if large-scale pumping removed water from the aquifer.

Quality of water--Water samples from eight wells in the Columbus aquifer indicated that the water quality differs both laterally and vertically. The deeper water in the lower zone was a hard to very hard sodium bicarbonate type with total dissolved solids ranging from 1,760 ppm in well 163-93-19ADD to 1,950 ppm in well 163-93-30BBB1. Sulfate ranged from 315 to 536 ppm and iron ranged from 0.1 to 2.9 ppm. Chloride was generally less than 120 ppm, and the percent sodium was greater than 75. The water in the higher parts of the lower zone generally contained the greatest quantities of sulfate. The water in the upper zone was either a very hard sodium sulfate or a very hard calcium sulfate type with sodium ranging from 44 percent in well 163-93-19DDA to 77 percent in well 163-93-22CAB. Sulfate ranged from 693 ppm in well 163-94-22CBB2 to 1,500 ppm in well

163-93-22CAB. Dissolved solids in these wells ranged from 1,750 ppm to 2,800 ppm. An increase in sulfate and dissolved solids occurred in 163-93-30BBB1 (lower zone) during the previously described pumping test. This may indicate a local connection between the upper and lower zones. If so, an increase in sulfate and dissolved solids may be expected in the Columbus water supply with continued pumping of the city well. This increase may be limited by reducing the pumping rates. The irrigation classification of water in the Columbus aquifer ranged from C4-S2 to C4-S4.

Lignite City aquifer

The Lignite City aquifer, in northwestern Burke County (pl. 1), is named after the city of Lignite, which overlies a small part of the aquifer. The water-bearing materials consist principally of surficial outwash deposits, but may include some underlying buried-valley deposits.

During the time the Columbus buried valley was being eroded, a small tributary valley was formed near what is now the city of Lignite. This valley was nearly filled with glacial drift, principally till with some sand and gravel deposits. After the valley was nearly filled with drift, as much as 93 feet of outwash sand and gravel was deposited over the valley and nearby uplands--covering an area of about 1 mile wide and at least 2 miles long. The average thickness of the deposit, as determined from four test holes, is about 35 feet. However, water levels indicate that the contained aquifer averages about 25 feet thick over an area about half a mile wide and 2 miles long (640 acres). Where the aquifer is thickest, the lower part of the aquifer apparently contains finer sands. The outwash deposits are buried beneath from 12 to 27 feet of glacial drift, mostly till.

Yield--Water levels in the Lignite City aquifer generally are from 15 to 40 feet below land surface. Most of the wells in the aquifer are limited in their yield by the capacities of the pumps--generally only a few gallons per minute. The only large-capacity well is the Lignite city well, 162-92-12BBB, which normally is pumped at 125 gpm, but has been pumped at 250 gpm for as long as 18 hours. The pump intake is set at 40 feet below land surface so the pumping level could not have been lower than this depth. If the static water level at the time the well was pumped at the 250 gpm pumping rate was the same as the 35 feet reported in 1967, then the drawdown would have been less than 5 feet and the specific capacity of the well would have been more than 50 gpm per foot of drawdown. The specific capacity of the well at the present time (1969) is not known, but it has to be greater than 25 gpm per foot of drawdown. Using the method developed by Theis (1963) for estimating transmissivities, it was determined that the transmissivity should be at least 50,000 gpd per foot at the city well. An incomplete log of the city well indicates the transmissivity may be as high as 85,000 gpd per foot. Using the logs as a basis for estimating the transmissivity at test holes 162-92-1BCC, 2CBB, and 2CDD1, it should be about 14,000, 57,000, and 28,000 gpd per foot, respectively, at these sites.

The transmissivities indicate that fully penetrating, properly developed wells should yield from about 50 gpm at test hole 162-92-1BCC to at least 500 gpm at the city well. However, the larger yields at the city well probably could not be maintained because of the nearness to the boundaries of the aquifer.

Recharge and water-level fluctuations–Recharge to the Lignite City aquifer is principally from direct infiltration of precipitation and inflow from the adjacent undifferentiated Fort Union Group. The quantity of recharge from each source is not known, but the quality of water indicates that much of the recharge is from infiltrating precipitation.

Water-level records for observation wells 162-92-2CBB and 2CDD2 (fig. 13) show a slight downward trend and indicate that there has been more discharge from the aquifer than recharge to the aquifer during the period of record. The city of Lignite is the only large user of water, and it uses about 39 acre-feet per year. The other users combined probably do not pump more than 1 to 2 acre-feet per year, so the total known discharge due to pumping averages about 40 acre-feet per year. This quantity is about what would be expected from the aquifer with the declines shown if the aquifer had a specific yield of 20 percent and all of the water was obtained from storage. This in turn indicates that pumping had very little effect on natural recharge to or discharge from the aquifer during the period of record.

Storage–If the porosity is about 32 percent, the total quantity of water in storage would be about 5,100 acre-feet; however, only 60 percent, or 3,100 acre-feet would be available for pumping.

Quality of water–Only one sample of water was obtained from the Lignite City aquifer. It was a very hard calcium bicarbonate sulfate type that contained 0.08 ppm iron and 915 ppm dissolved solids. The irrigation classification was C3-S1. The water from the aquifer probably could be used successfully for irrigating most soils that overlie the aquifer.

Kenmare(?) aquifer

The Kenmare(?) aquifer is composed of buried sand and gravel deposits in a valley that extends from the vicinity of Upper Lostwood Lake in southeast Burke County, beneath Thompson Lake, and northeastward to the Ward county line east of Bowbells. W. A.

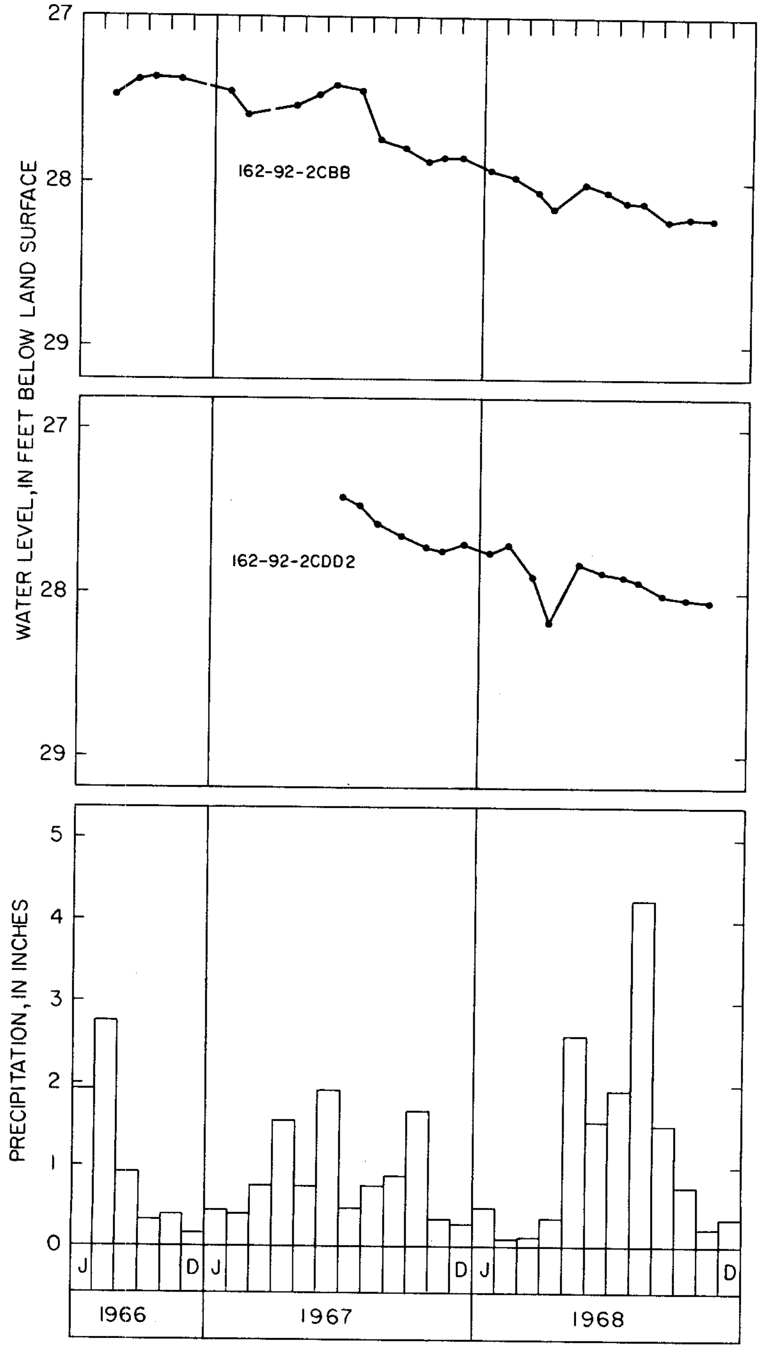

FIGURE 13. Water-level fluctuations in observation wells in the Lignite City aquifer, and precipitation at Columbus.

Pettyjohn (written commun., 1969) has shown that the valley trends southeastward from the county line to the city of Kenmare in Ward County where it is a tributary to the valley containing the Kenmare aquifer. The valley containing the Kenmare(?) aquifer is slightly more than a mile wide in the vicinity of Thompson Lake; however, the aquifer is only about half a mile wide. The valley and probably the aquifer also widens to the north (fig. 14).

Yield–The only wells penetrating the Kenmare(?) aquifer in Burke County are of small capacity and produce only a few gallons per minute. The logs of test holes 160-91-13ACD1 and 161-90-13DDD show several sand lenses that are composed of medium to coarse sand or gravel and range from 2 to 47 feet in thickness. Wells tapping these sand and gravel lenses should have specific capacities of as much as 10 gpm per foot of drawdown, and short-term yields as great as 200 gpm with about 20 feet of drawdown probably could be obtained. Wells in the vicinity of test hole 159-91-34BCA, where there is 284 feet of gravel and sand, should yield more than 500 gpm; however, the aquifer is believed to be narrow and the high rates probably could not be maintained for more than a few weeks. Sustained yields elsewhere in the aquifer in excess of 100 gpm would have excessive drawdowns and probably are only locally obtainable.

Recharge and water-level fluctuations--Recharge to the Kenmare(?) aquifer is derived from direct precipitation, infiltration from the sloughs overlying the aquifer, and inflow from the adjacent undifferentiated Fort Union sediments.

Water levels in two observation wells, 160-91-13ACD1 and 13ACD2, which were installed in test hole 160-91-13ACD, show that the head is greater in the lower part of the aquifer than in the higher part. This indicates an upward ground-water movement and a discharging aquifer in the vicinity of the observation wells. The discharge may be into the lakes to the south of the observation wells and through small seeps in the lower elevations of the valley.

The hydrographs (fig. 15) of the observation wells show a general decline of water levels during most of the record. There is no appreciable pumping in the area of the observation wells, so the declines probably are the result of below normal precipitation during the period 1966, 1967, and the first part of 1968.

Storage--No estimates of storage were made because the aquifer dimensions are in doubt.

Quality of water–The quality of water in the Kenmare(?) aquifer is known only from three water samples from observation wells 160-91-13ACD1, 13ACD2, and 159-91-34BCA. The samples indicated that the water from 160-91-13ACD1 and 159-91-34BCA were very hard calcium sodium sulfate types with 1.8 and 0.2 ppm iron, 510 and

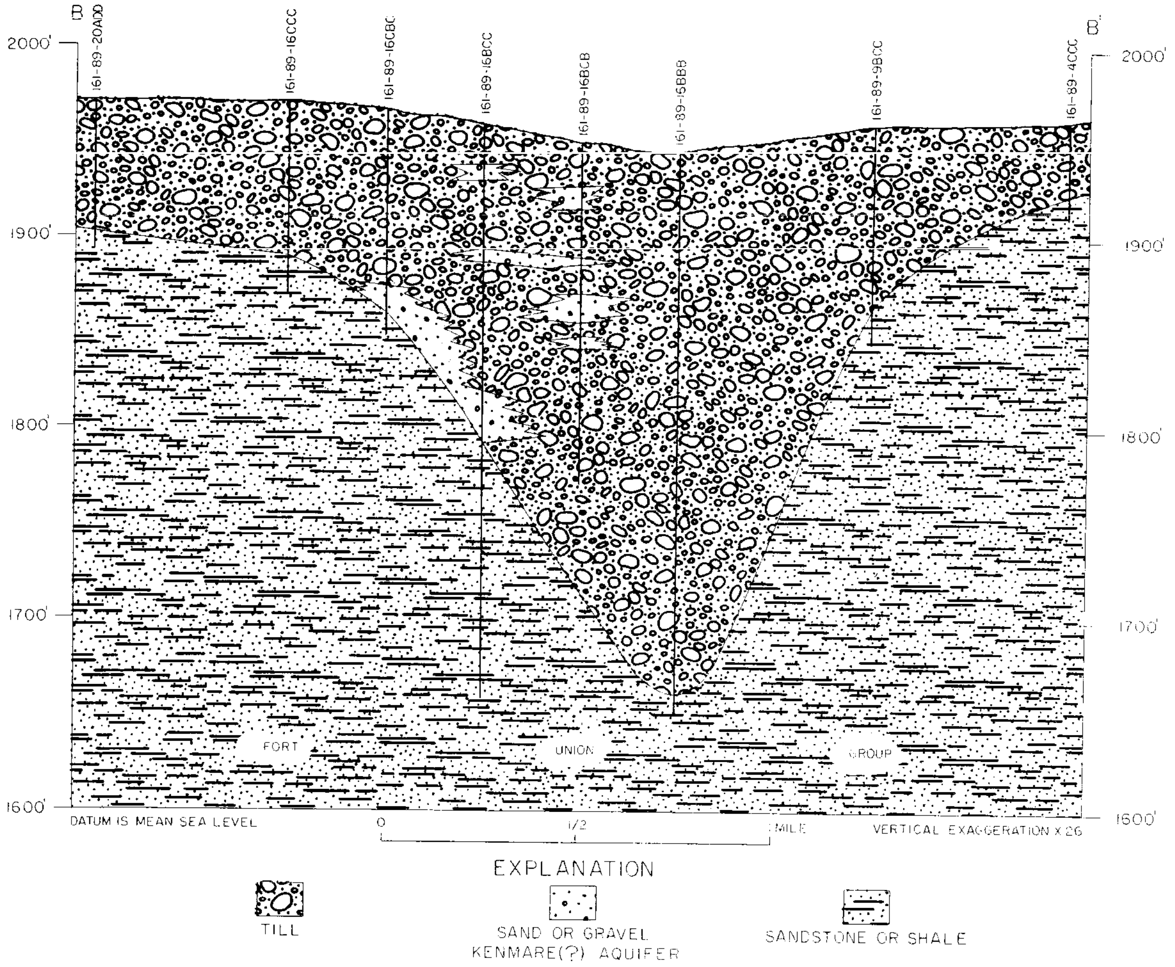

FIGURE 14. Geologic section (B-B') through the Kenmare (?) aquifer. (Location of section shown on pl. 3.)

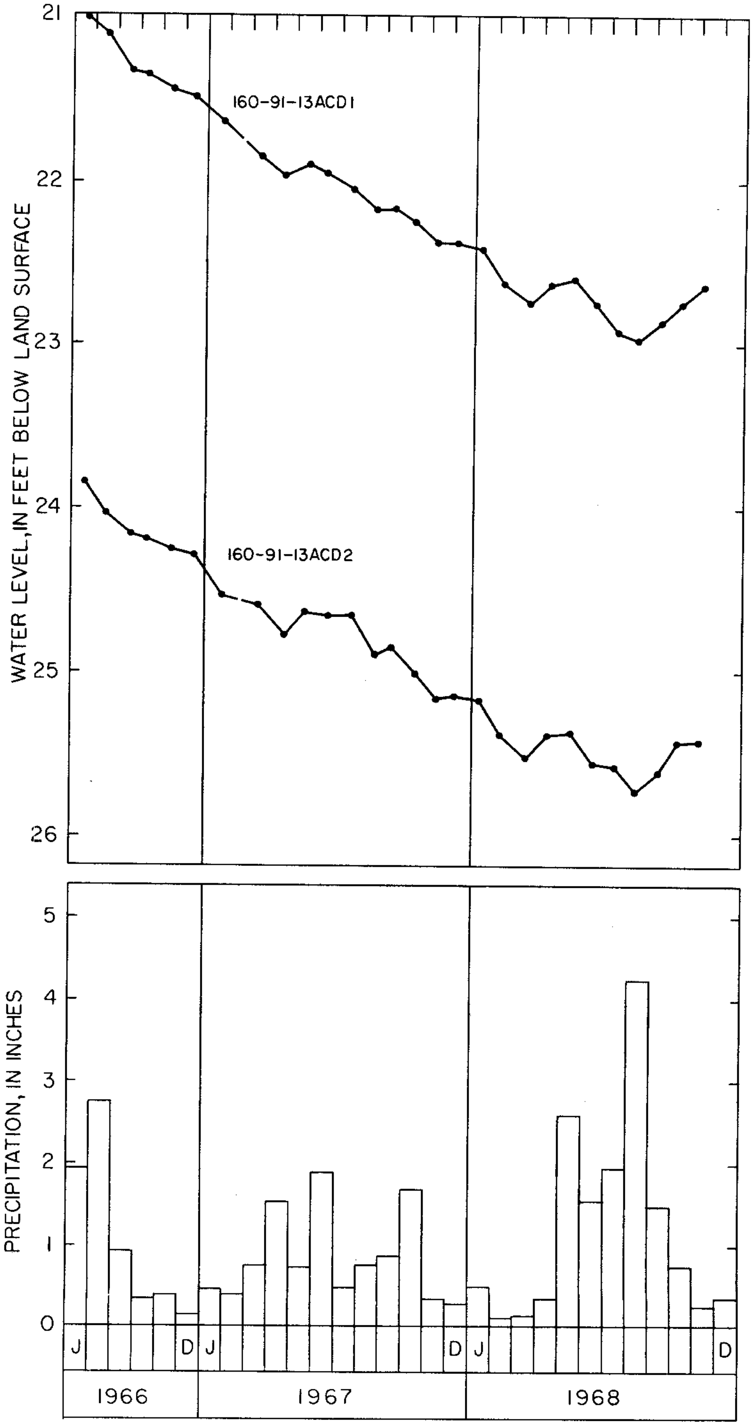

FIGURE 15. Water-level fluctuations in the Kenmare (?) aquifer, and precipitation at Columbus.

469 ppm sulfate, and 1,180 and 1,100 ppm dissolved solids, respectively. The water from 160-91-13ACD2 was a very hard calcium bicarbonate type with 0.2 ppm iron, 188 ppm sulfate, and 616 ppm dissolved solids. All three samples had sodium-adsorption ratios less than 2, less than 30 percent sodium, and no residual sodium carbonate. The water was classified as C3-S1 for irrigation.

New Town aquifer

The New Town aquifer, in southwestern Mountrail County, consists of sand and gravel deposited in a 2-mile wide buried valley that was one of the early valleys cut by the Missouri River. It underlies a 6-mile isthmus near New Town and extends under the east side of the peninsula to the south, and Lake Sakakawea (pl. 4).

The time of erosion of the ancient Missouri River valley and the subsequent deposition is not known, but it apparently occurred early in the Wisconsin glaciation; perhaps as early as the first advance or retreat of Wisconsin ice. The fact that the lower gravel deposits contain a large percentage of reworked glacially transported limestone pebbles suggests that deposition occurred after the initial advance of the Wisconsin ice.

The thickness of the drift in the valley ranges from 0 at the edges to a known maximum of 307 feet in test hole 152-92-20ADD. The principal part of the New Town aquifer consists of sand and gravel deposits that are more than 100 feet below land surface and range in thickness from 19 feet in test hole 152-92-29DDD to 95 feet in test holes 152-92-20BBA and 152-92-20BBB2. The average thickness is about 50 feet. The sand and gravel deposits apparently are lenticular with coarsest material being near the base.

Yield--The only large-capacity wells that tapped the New Town aquifer in 1967 were those used for the New Town city supply. These wells, 152-92-19AAA1 (city well 1), 152-92-19AAA2 (city well 2), and 152-92-20BBB1 (city well 3), yield 150, 150, and 450 gpm, respectively. The capacities of city wells 2 and 3 apparently are limited by the length and condition of the screens and the size of the pumps.

In September 1967, a 1,685-minute pumping and a 145-minute recovery test was made on the New Town aquifer to determine the aquifer constants and to verify the estimated yields shown on plate 4. The test, which was prematurely ended by a power failure, was made by pumping city well 3 at a rate of about 485 gpm. Water-level fluctuations were measured in the pumped well, observation well 1 (152-92-20BBB2, 150 feet east of the pumped well), observation well 2 (152-92-19AAA3, 300 feet southwest of the pumped well), observation well 3 (152-92-20BBA, 600 feet east of the pumped well), city well 2 (152-92-19AAA2, 230 feet west of the pumped well), and observation well 4 (152-92-19AAB, 980 feet west of the pumped well). No other wells were pumping in the area. Observation well 2 did not show any drawdown during the test and apparently is finished in a sand lens that is, at least locally, isolated from the main aquifer.

Analysis of the test using the Theis (1935) formula shows that the transmissivity of the aquifer near New Town ranges from about 140,000 gpd per foot at city well 3 to about 260,000 gpd per foot at observation well 3. The transmissivity increases are due to an increase in the aquifer thickness toward the center of the buried valley. The storage coefficient ranges from 0.0001 to 0.0007. The logarithmic plot of data from observation well 1 is shown in figure 16. These data show a transmissivity of 180,000 gpd per foot. The departure of the plotted points below the type curve indicates a recharge source in the area. There is no apparent source of recharge within 1,000 feet of observation well 1, as the data indicate, so the recharge probably is due to leakage either from adjacent sand and gravel lenses or from the finer grained material that overlies the principal part of the aquifer.

The specific capacity of city well 3 during the pumping test was approximately 18 gpm per foot of drawdown, which indicates that sustained yields of more than 500 gpm could not be obtained from the aquifer without having drawdowns larger than about 28 feet. However, the transmissivity values obtained during the test indicate that higher yields should be available and that there probably is considerable entrance loss in the city well. Most of the well loss probably can be attributed to partial penetration, but some may be caused by encrustation or plugging of the screen. The theoretical specific capacity of a fully penetrating, efficiently developed well at the site of city well 3 should be about 50 gpm per foot of drawdown. Yields of as much as 1,000 gpm, therefore, should be obtainable for periods of at least several days length.

Recharge and water-level fluctuations–Recharge to the New Town aquifer probably is from inflow from the undifferentiated Fort Union sediments and from Lake Sakakawea. The quantity of recharge from each source is not known, but water-level fluctuations indicate that Lake Sakakawea has been an important source. The water level in the fall of 1951 (prior to filling of the lake) in New Town city well 1 was reported to be at 110.5 feet below land surface, or at an altitude of about 1,787 feet above msl. The water level December 17, 1960, was reported to be at 82 feet below land surface, or at an altitude of 1,816 feet above msl. The water level in the city well has not been measured since 1960, but the water level in observation well 152-92-19AAA3, which is completed at a similar depth and is about 250 feet from the city well, was 55 feet below land surface and at an altitude of 1,844 feet above msl in September 1967. These rising water levels, coupled with the lake level and ground-water fluctuations shown in figures 17

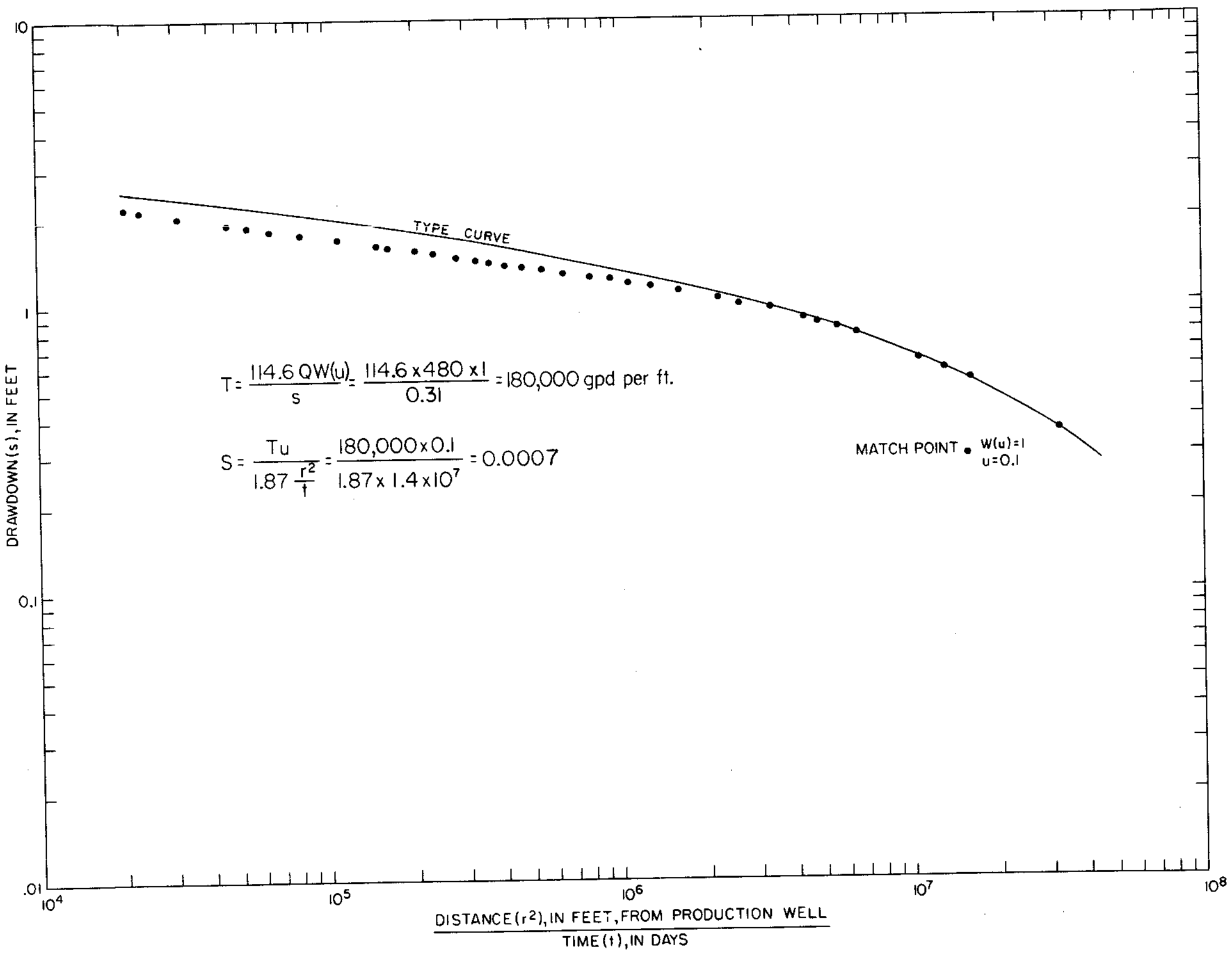

FIGURE 16. Logarithmic plot of the New Town aquifer test data (observation well 1).

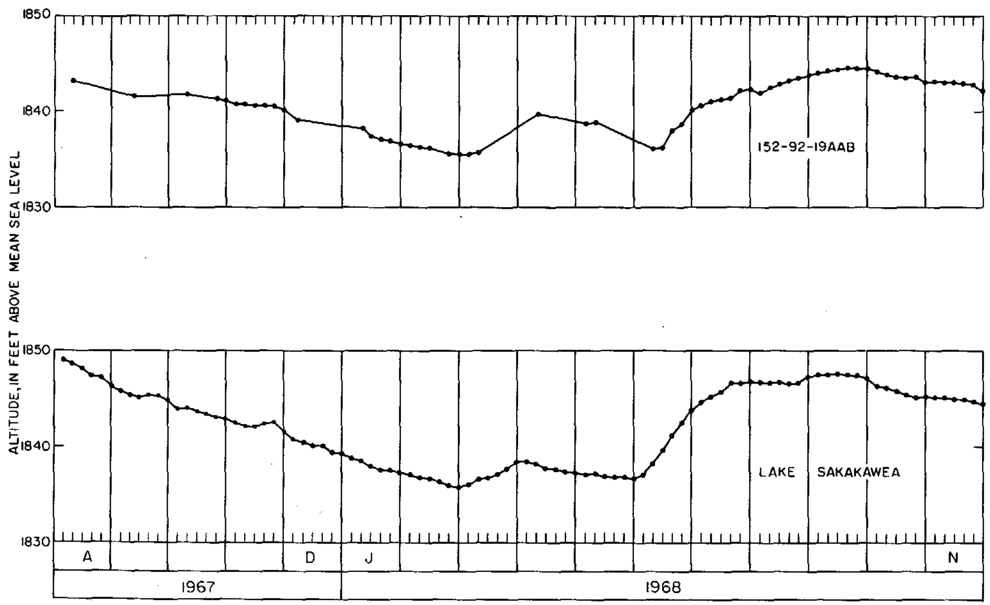

FIGURE 17. Water-level fluctuations in well 152-92-19AAB and Lake Sakakawea.

and 18, indicate a direct connection between the lake and the aquifer. Pumping from the city wells causes a temporary cone of depression to form, but the water level in the aquifer recovers to within a few feet of the lake level soon after the pumps are shut off. In the winter when the pumps are off for longer periods than in the summer, the water levels in the wells recover to within less than a foot of the lake level.

During the time that the lake was filling, there probably was considerable recharge from the lake into the aquifer; but since the lake has become nearly filled, the water-level fluctuations are due primarily to pressure pulses caused by fluctuating lake stages rather than ground-water recharge or discharge. However, large-scale pumping from the aquifer would increase the gradient from the lake to the aquifer, and consequently, would induce recharge from the lake.

The data indicate that the aquifer has good recharge capabilities and has a large potential for future development.

Storage–Only an approximation can be made of the quantity of water in storage in the New Town aquifer because of the uncertainty of the width of the aquifer. Assuming an average aquifer width of 1 3/4 miles, a length of 6 miles (6,700 acres), a thickness of 50 feet, and a porosity of 32 percent, the aquifer would contain about 110,000 acre-feet of water in storage. Probably as much as 65,000 acre-feet of this could be recovered. The 6-mile length includes only that part of the aquifer that underlies the isthmus and does not include any of the aquifer that underlies either the lake or the east edge of the peninsula.

Quality of water–Water samples from wells tapping the central part of the New Town aquifer indicated a very hard sodium bicarbonate or sodium sulfate type with total dissolved solids ranging from 982 to 1,380 ppm. Sulfate ranged from 338 to 523 ppm, which is higher than the recommended limits set by the U.S. Public Health Service (1962). Iron content ranged from 0.22 to 4.9 ppm and generally was great enough to cause staining. Three samples of water taken from well 152-92-20BBB1 over a period of 5 months (two were taken during the pumping test), indicated a slight improvement in quality during the period. Dissolved solids decreased from 1,170 to 1,100 ppm, sulfate from 454 to 441 ppm, and iron from 4.2 to 0.74 ppm. Large-scale pumping from the aquifer may further improve the quality of the water. The sharp reduction in iron content suggests that the well pipe was the source of much of the iron.

The water in the central part of the aquifer had an irrigation classification that ranged from C3-S1 to C3-S2. Residual sodium carbonate locally exceeded 2.5 epm and the water may not be suitable for irrigation. Generally, however, the water from the central part of the New Town aquifer could be used successfully on well-drained soils if proper amendments were added.

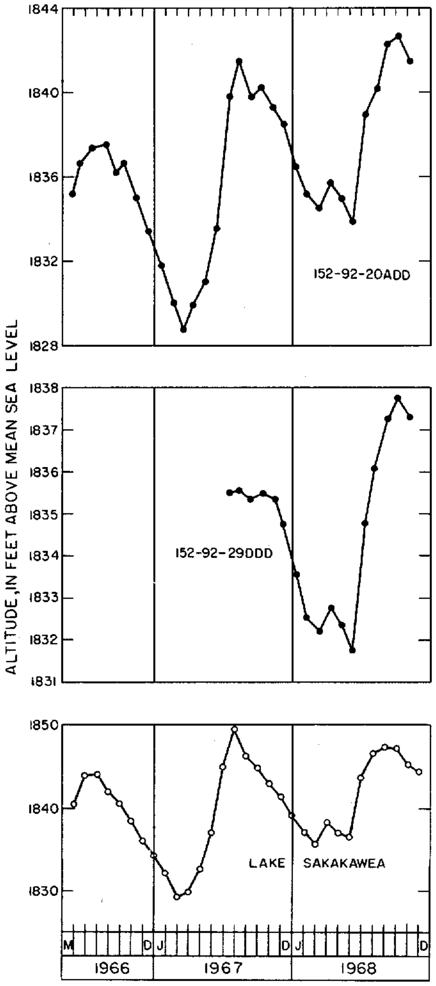

FIGURE 18. **Water-level fluctuations in the New Town aquifer and Lake Sakakawea.**

A sample from observation well 152-92-29DDD, near the edge of the aquifer, indicated a sodium bicarbonate type and contained 814 ppm sulfate and 2,500 ppm dissolved solids. The water contained 95 percent sodium and had a sodium-adsorption ratio of 39. Water analyses were not available from elsewhere along the edges of the aquifer, but the water probably is of poorer quality than in the central part.

Shell Creek aquifer system

The Shell Creek aquifer system consists of saturated sand and gravel deposited in the outwash-alluvium complex in the Shell Creek valley and the buried or partly buried deposits in the ancient White Lake branch, central branch, and east branch valleys (pls. 3 and 4).

The valley containing the White Lake branch of the system extends from the Burke county line west of Battleview eastward to Powers Lake, then southward to Cottonwood Lake in Mountrail County, thence southeastward to Shell Creek. The valley, which was referred to as the White Lake depression by Paulson (1954, p. 24), was dammed someplace between Cottonwood Lake and the southeastern part of White Lake during part of its history. Although there are sand and gravel lenses northwest of the "dam," data are scarce and these lenses may not be hydrologically connected with the rest of the Shell Creek aquifer system. Therefore, this isolated part of the aquifer is not discussed further in this report.

The part of the White Lake branch that extends from the vicinity of White Lake to a junction with the east branch is about half a mile wide (fig. 19; Paulson, 1954, pl. 2) and 22 miles long. The thicker deposits generally are 12 to 37 feet thick. Water levels in observation wells that penetrate the aquifer north of Stanley indicate that the sand and gravel lenses are separated by relatively impermeable material and have poor hydraulic connection.

The central branch of the Shell Creek aquifer extends from the vicinity of sec. 1, T. 158 N., R. 90 W., southward to its junction with Shell Creek. Only a few test holes were drilled into the central branch of the Shell Creek aquifer and the course is not as well defined as the White Lake branch. North of U.S. Highway 2, the valley is only partly buried beneath the glacial drift, and is fairly well defined. South of U.S. Highway 2 the valley is completely buried and the trend is not known, but the most probable course is shown by dashed lines on plate 4. The width of the central branch of the Shell Creek aquifer system is not known. Individual sand and gravel deposits in the central branch are as much as 128 feet thick, and appear to have considerable continuity.

The east branch of the Shell Creek aquifer trends southwestward from the Mountrail-Ward county border about 3 miles south of Tagus

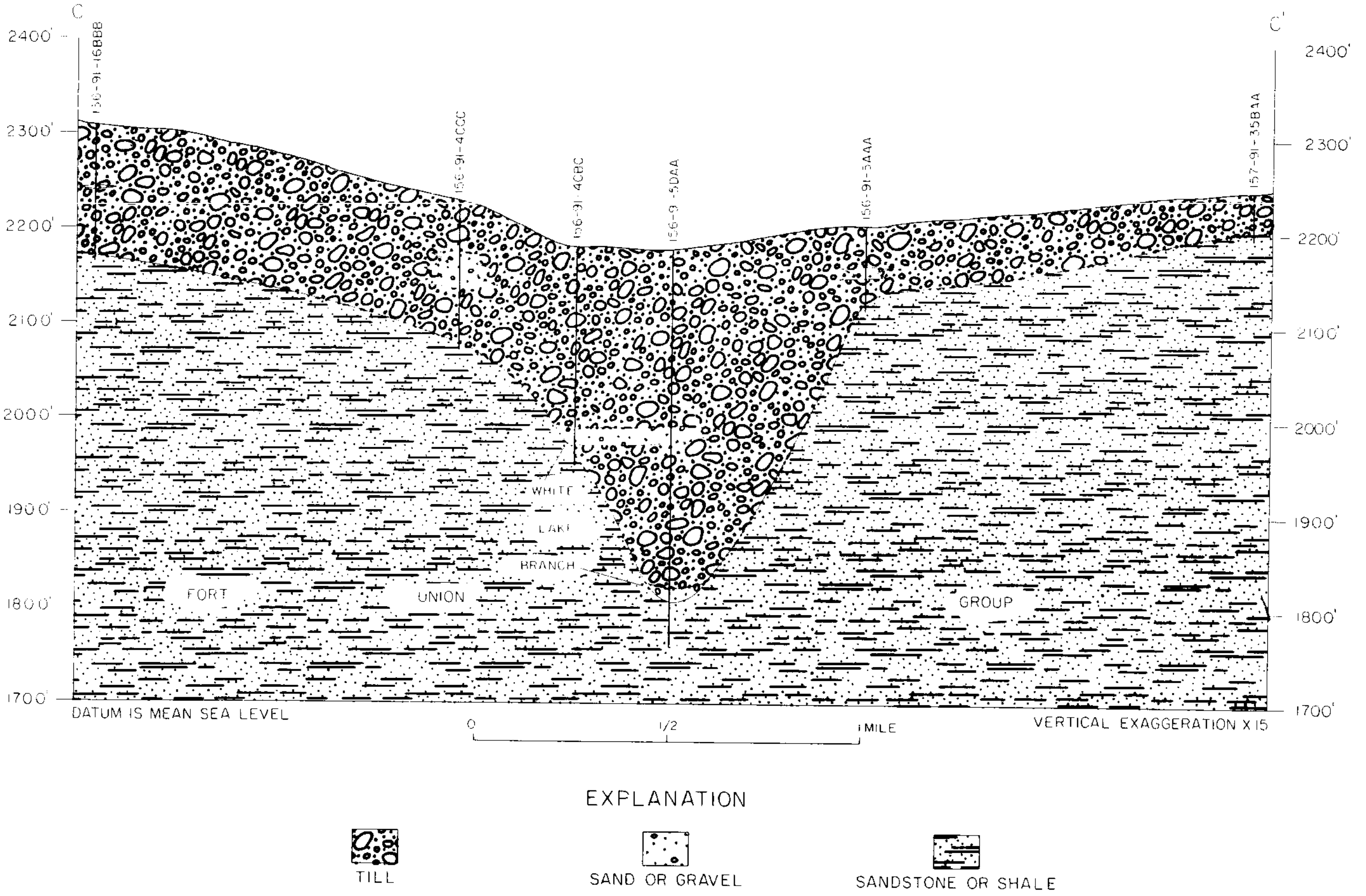

FIGURE 19. Geologic section (C-C') through the White Lake branch of the Shell Creek aquifer system. (Location of section shown on pl. 4.)

to a confluence with Shell Creek in the northern part of T. 154 N., R. 89 W. Individual sand and gravel deposits in this valley are as much as 51 feet thick. A secondary south-southwesterly-trending tributary joins the main branch at sec. 25, T. 155 N., R. 89 W. Test hole 155-88-6DDD was drilled into this secondary tributary and penetrated 68 feet of sand and gravel, but only 45 feet was saturated.

Pettyjohn (written commun., 1969) described an aquifer at Carpenter Lake in Ward County. This aquifer apparently is another tributary to the Shell Creek aquifer system. It trends from Carpenter Lake in Ward County to a junction with the east branch of the Shell Creek aquifer in the vicinity of sec. 28, T. 155 N., R. 88 W.

The lower reach of the Shell Creek aquifer system is confined to the Shell Creek valley. Locally there are higher sand and gravel deposits along the sides of the valley, but they contain only thin zones of saturation. The greatest thickness of saturated sand and gravel penetrated by test drilling in the Shell Creek valley was 55 feet in testhole 154-89-15DDD.

Gradients of the ancient buried valleys cannot be determined accurately because the deepest part of the valleys at any particular cross section is not known. However, by projecting the gradient of the top of the bedrock from 156-89-6AAB and 155-88-2ADD, respectively, to 153-89-31CBC, the apparent gradients appear to be slightly less than 2 feet per mile toward the south.

Yield--Only a few wells tap the Shell Creek aquifer system. All but two of these wells are used for domestic or livestock purposes and their yields are generally limited by the capacities of the pumps. Estimated specific capacities of wells in the White Lake branch of the aquifer probably would be about 9 gpm per foot of drawdown and, for a few days, pumping rates as high as 180 gpm should be obtainable with only about 20 feet of drawdown. However, because of boundary conditions, pumping rates higher than 100 gpm probably could not be maintained for periods of more than several weeks.

The greater thickness of sand and gravel lenses in the central branch of the aquifer indicates that rates of somewhat more than 100 gpm probably could be maintained. However, data are insufficient for accurate estimates.

Two irrigation wells are located in the east branch of the aquifer in sec. 25, T. 155 N., R. 89 W. Well 155-89-25BCD, an 8-inch diameter well, was drilled in 1968 to a depth of 60 feet and had a static water level of 5 feet below land surface. The well is equipped with a submersible pump that is set at 45 feet, and the well yields about 400 gpm. This well was pumped continuously for nearly 5 weeks in 1968 before the water level reached the pump intake. Well 155-89-25ACB1 was drilled and a pumping test was made in 1966. The test data were analyzed by the Theis method and indicated a transmissivity of about 90,000 gpd per foot at the pumped well and about 138,000 gpd per foot at observation well 1 (fig. 20), which is about 100 feet from the pumped well. The storage coefficient was 0.0004. The difference in transmissivity may have been caused by incomplete removal of drilling mud from the aquifer in the vicinity of the pumped well, or by leaky aquifer conditions at the observation well.

The data plot on figure 20 trends below the respective type curve and indicates a source of recharge. The analyses of all the test data showed that the source of recharge was about 1,000 to 1,500 feet west-southwest of the pumped well. The aquifer in the indicated area is locally unconfined and it is possible that some of the water from the pumped well was the source of recharge.

The last three to five plotted points (left side fig. 20) and the latter parts of the curves for the other wells (not shown) show a rising trend that indicates a relatively impermeable boundary. The data are not of sufficient quality to determine the direction or distance to the boundary, but it probably is one of the valley walls.

The results of the pumping test and the data from well 155-89-25BCD indicate that pumpage rates of about 300 gpm probably can be maintained for at least as long as an irrigation season, but rates of 400 gpm would be excessive. The pumping-test site is near the confluence of two tributary valleys, so the aquifer here probably is larger and more productive than in most other parts of the system.

Recharge–Recharge to the Shell Creek aquifer system is from direct precipitation, underflow through adjoining outwash, and inflow from the adjacent undifferentiated Fort Union sediments. It is not known how much recharge is obtained from any of the sources, but the quality of the water indicates that the Fort Union Group may be the chief source of recharge.

Storage–The quantity of water in storage in the Shell Creek aquifer system cannot be calculated with a great degree of accuracy because of the lack of data. However, the available data indicate that the average width is about half a mile. By assuming a conservative average of 20 feet of saturated thickness and 32 percent porosity, it is estimated that there is at least 2,000 acre-feet of water per mile length of the aquifer.

Quality of water–The quality of water in the Shell Creek aquifer system differs from place to place and apparently with depth. Water from well 156-91-2CCC, 214 feet deep, in the deeper part of the White Lake branch of the aquifer north of Stanley was a sodium sulfate type. Water from well 156-91-5DAA, 196 feet deep, also from the deeper part of the aquifer, was a sodium sulfate bicarbonate type. At 156-91-10BBB, 128 feet deep, the water was a calcium sulfate type.

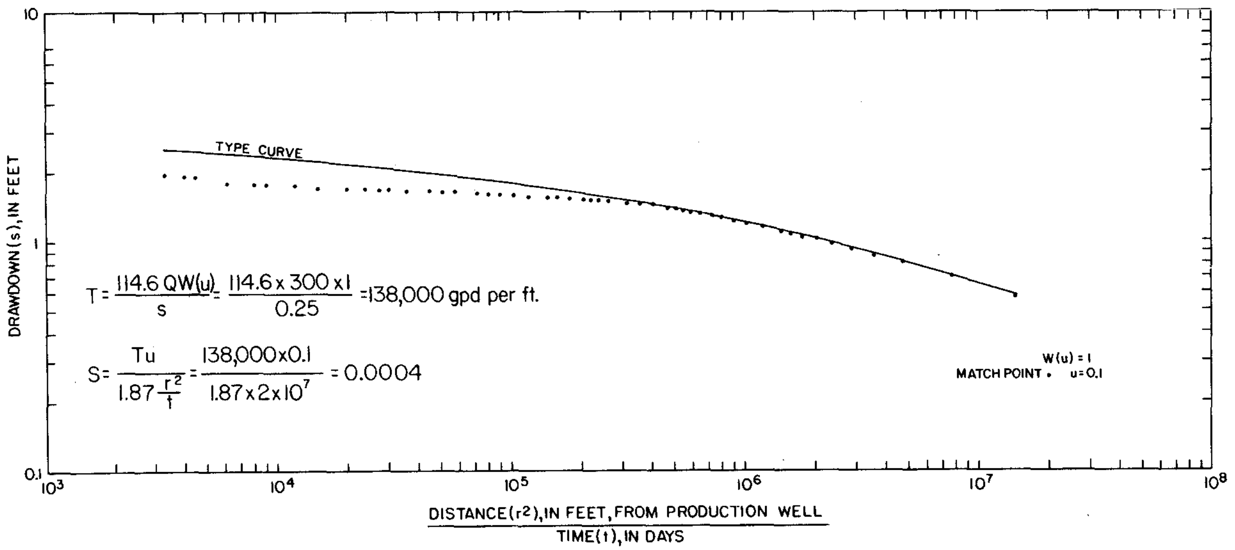

FIGURE 20. Logarithmic plot of the Shell Creek aquifer test data (observation well 1).

The water from these three wells, respectively, contained 82, 18, and 201 ppm calcium; 684, 596, and 25 ppm sodium; 845, 844, and 356 ppm bicarbonate; 1,060, 676, and 524 ppm sulfate; and 2,290, 1,690, and 1,080 ppm dissolved solids. The sodium-adsorption ratios were 18, 26, and 0.4, and the specific conductances were 3,190, 2,560, and 1,380 micromhos. A water sample from well 155-90-12DDD, 178 feet deep, in the southeastern part of the White Lake branch indicated a sodium sulfate type, but of poorer quality than in the northwestern part. The water contained 1,120 ppm sulfate, 2,430 ppm dissolved solids, had a sodium-adsorption ratio of 26, and a specific conductance of 3,400 micromhos. All of the water sampled had a sodium- and salinity-hazard classification of C4-S4, except the water from 156-91-10BBB, which had a sodium- and salinity-hazard classification of C3-S1.

A water sample from well 156-89-6AAB, 179 feet deep, in the central branch of the aquifer indicated that the water was a very hard (371 ppm) sodium sulfate type. The sample contained 780 ppm sulfate, 1,710 ppm dissolved solids, and had a specific conductance of 2,420 micromhos. The sodium-adsorption ratio was 11 and the percent sodium was 73. The water had an irrigation classification of C4-S3, and contained 4.1 epm residual sodium carbonate.

Water from well 155-88-2ADD, 119 feet deep, in the northeastern reach of the east branch of the Shell Creek aquifer was a very hard (2,060 ppm) calcium sulfate type that contained 4.5 ppm iron, 2,020 ppm sulfate, and 3,270 ppm dissolved solids. The water had a sodium-adsorption ratio of 1.4, a specific conductance of 3,160 micromhos, and an irrigation classification of C4-S1.

Well 155-89-35AAA, 38 feet deep, was drilled away from the center of the valley in the east branch of the aquifer. The water from this well was a very hard (318 ppm) calcium magnesium bicarbonate type that contained 3.5 ppm iron, 523 ppm dissolved solids, and no residual sodium carbonate. It had a sodium-adsorption ratio of 1.2 and a specific conductance of 782 micromhos. The irrigation classification was C3-S1. Water of this kind probably could be used successfully to irrigate the sandier soils in the area.

Well 155-89-25ACB1, an 80-foot irrigation well, was drilled near the central part of the east branch of the Shell Creek aquifer. Four analyses taken at various times before and during a pumping test showed that the quality of water varied only slightly with pumping. The water was a very hard (472 to 487 ppm) sodium sulfate type that contained 634 to 657 ppm sulfate, 1,530 to 1,560 ppm dissolved solids, and 2.3 epm residual sodium carbonate. The sodium-adsorption ratio was 6.9 to 7.4 and the specific conductance was 2,170 to 2,240 micromhos. The water had an irrigation classification of C3-S2. Water of this kind should be considered of marginal quality for irrigation.

An analysis of water from well 155-89-25BCC, 89 feet deep, showed that the water was a hard (154 ppm) sodium sulfate type that contained 0.89 ppm iron, 882 ppm sulfate, 2,060 ppm dissolved solids, and 10.9 epm residual sodium carbonate. The sodium-adsorption ratio was 24 and the specific conductance was 2,080 micromhos. The water had an irrigation classification of C4-S4.

Well 154-89-15DDD was finished at a depth of 58 feet in the lower part of the Shell Creek valley. An analysis of water from this well showed a very hard (243 ppm) sodium sulfate type water that contained 0.96 ppm iron, 1,080 ppm sulfate, 2,410 ppm dissolved solids, and 10.8 epm residual sodium carbonate. The sodium-adsorption ratio was 22 and the specific conductance was 3,390 micromhos. The water had an irrigation classification of C4-S4.

Little Knife River valley

The Little Knife River valley extends from a few miles east of Stanley southward to Lake Sakakawea northwest of New Town (pl. 4). The valley is wide in relation to its depth near Stanley, and much deeper in relation to its width beginning a few miles south of Stanley. The deeper parts of the valley are partly filled with outwash and alluvium, which are as much as 92 feet thick. The deposits that form the aquifer generally are coarsest near the central part of the valley and finer, with only small quantities of sand and gravel, near the edges.

Test holes 154-91-30AAA and 154-92-25BBB contain 92 and 80 feet, respectively, of alluvium and glacial drift. Both of these test holes were drilled near the valley edge where Fort Union sediments are exposed in the nearby valley walls. The materials in the test holes are predominantly silt and clay. Test holes 153-92-17BBB and 156-91-33BDA2 were more centrally located and penetrated a much higher proportion of sand and gravel. Most of the gravel and sand in these latter test holes was derived from glacial drift.

Yield–Yields of wells in the Little Knife River valley probably will differ considerably from place to place. Near the edges of the valley, the yields probably would be only a few gallons per minute. Near the central part, however, yields should be much greater. As of 1968, there was only one moderately large capacity well (156-91-33ACC) tapping the valley fill. This well is near the edge of a reservoir and has been pumped at rates as high as 200 gpm, but is generally pumped at rates between 80 and 100 gpm. It is not known how long the higher rate could be maintained, but the lower rates probably could be maintained as long as there was a significant amount of water in the adjacent reservoir. When the water level in the adjacent reservoir is low, as it commonly is in the late fall, the water level in the well would be low also and a rate of 100 gpm probably could not be maintained for more than a few months.

Estimates of the transmissivities of the valley fill near Stanley, based on thickness and grain size, range from about 4,000 gpd per foot at 156-91-33CAB to about 25,000 gpd per foot at 156-91-33BDA2. Paulson (1954, p. 23) ran a pumping test at 156-91-33BDA2 and determined that the transmissivity was 24,000 gpd per foot. The storage coefficient was 0.02. Specific capacities of properly constructed wells should range from 2 to about 15 gpm per foot of drawdown in this area.

The transmissivity of the valley fill at 153-92-17BBB, where there is 36 feet of sandy gravel, should be about 70,000 gpd per foot. Theoretically the specific capacity of a well at this location should be about 40 to 50 gpm per foot of drawdown, and yields of from 800 to 1,000 gpm should be obtainable. However, the actual specific capacity of a well would be much less because of the narrowness of the valley. Maximum yields with continuous pumping probably would be about 300 gpm.

Storage–By using a water-table gradient of 12 feet per mile and assuming that the average transmissivity of the valley fill is 35,000 gpd per foot, the quantity of water moving down the valley through a cross section having a width of a quarter of a mile would be about 105,000 gpd, or 70 gpm. This is approximately the quantity of water that could be pumped continuously from the aquifer without depleting water in storage. Assuming an average porosity of 32 percent, there should be about 900 acre-feet of water in storage per mile length of the valley. Pumping for about 3 years at 200 gpm more than the recharge rate would essentially dewater the equivalent of 1 mile of the valley. However, the recharge rate would be increased to some extent during the dewatering process.

Recharge–Recharge to the Little Knife River valley fill is from three sources: (1) the undifferentiated Fort Union Group, either through direct percolation or runoff from springs along the valley walls; (2) direct precipitation on the surface of the fill materials; and (3) streamflow in the Little Knife River and its tributaries. This last source is relatively unimportant except in the upper reaches near Stanley and in other short reaches where water is ponded behind dams. Elsewhere the stream generally is a gaining stream and receives discharge from the aquifer. The stream loses water during flood periods, but most of this goes into temporary bank storage and is soon returned to the stream.

Quality of water–Two analyses of water from well 156-91-33ACC, near Stanley, indicated a very hard sodium sulfate bicarbonate type that had 1,970 ppm dissolved solids. The sulfate content was 687 to

795 ppm, which exceeds that recommended by the U.S. Public Health Service (1962). The sodium-adsorption ratio was 8.9 and 8.6 and the specific conductance 2,620 and 2,820 micromhos. The water had an irrigation classification of C4-S3. Residual sodium carbonate exceeded 2.5 epm. Because of the hazards, the water may not be suitable for irrigation.

A sample of water from test hole 153-92-17BBB (North Dakota State Laboratory, written commun., 1967) showed that the water was a moderately hard sodium sulfate type that contained excessive quantities of sulfate (902 ppm), iron (0.44 ppm) and dissolved solids (2,050 ppm). The water had a sodium-adsorption ratio of 37, a specific conductance of 3,000 micromhos, and an irrigation classification of C4-S4. The water also contained more than 12 epm of residual sodium carbonate.

White Earth River valley

The White Earth River valley extends from Smisheck Lake in Burke County (pl. 3) to Lake Sakakawea in Mountrail County (pl. 4). In Burke County the valley generally is eroded only into older drift. It is wide in relation to its depth, and the edges of the valley fill are not well defined. In Mountrail County the valley is more deeply incised, and bedrock commonly is exposed on each side of the valley. The deposits in the valley fill generally have not been differentiated, but are predominantly outwash overlain by thin alluvium. The sand and gravel lenses in these deposits range in thickness from 0 to 57 feet. Logs of test holes 154-94-3BBA, 156-94-16DBA, and 157-94-25DBA indicate that the valley fill in the White Earth River valley is very similar to that in the Little Knife River valley. The gravels were glacially derived and much of the silt and clay was derived from the nearby bedrock.

Yield--There are no large-capacity wells in the White Earth River valley, so yields can only be estimated by the thickness of saturated materials. At test hole 154-94-3BBA there is about 46 feet of saturated gravel, which should have a transmissivity ranging from 90,000 to 120,000 gpd per foot. A fully penetrating, properly constructed well at this site should have a specific capacity of from 50 to 70 gpm per foot of drawdown, and pumping rates of more than about 1,000 gpm may be obtained for short periods. Continuous pumping rates of more than about 350 gpm could not be maintained.

Storage--By assuming a water-table gradient of 8 feet per mile, and a width of a quarter of a mile, the quantity of water moving down the valley was computed to be about 200,000 gpd, or about 140 gpm; approximately this amount could be pumped without depleting the water in storage. Assuming an average saturated thickness of 25 feet and a porosity of 32 percent, there would be about 1,300 acre-feet of water per mile of valley in storage.

Recharge–Recharge to the White Earth River valley fill is from: (1) the undifferentiated Fort Union Group, either through direct percolation or from springs along the valley walls (principally the west side); and (2) direct precipitation on the surface of the fill materials. Minor quantities of recharge also are derived from streamflow down the small tributary valleys. The quality of water in the aquifers associated with the fill indicates that water from the Fort Union sediments is the chief source of recharge.

Discharge is mainly by seepage into the White Earth River and by evapotranspiration. There are a few wells that discharge water from the aquifer, but the total quantity of discharge from all of these would not average more than a few hundred gallons per day.

Quality of water–The quality of water in the White Earth River valley fill generally is poor near the central part of the valley where the larger quantities of water can be obtained. The analysis of a sample of water from test hole 156-94-16DBA showed that the water was a very hard sodium sulfate type that contained 2,870 ppm dissolved solids, 1,330 ppm sulfate, and 1.2 ppm iron. These constituents in the water greatly exceeded the U.S. Public Health Service (1962) standards. The water had 84 percent sodium and a sodium-adsorption ratio of 20. The irrigation classification was C4-S4. The residual sodium carbonate was 9.4 epm.

A sample of water from well 157-94-36BCC, which is located on the west side of the valley fill, was a hard sodium bicarbonate type that contained 923 ppm dissolved solids and 1.3 ppm iron. This sample indicates that locally, along the edges, water of relatively good quality does exist in the valley fill.

East Fork Shell Creek valley

The East Fork Shell Creek valley (pl. 4) is a wide, shallow valley that extends from the Ward-Mountrail county line through Parshall to Lake Sakakawea. Previous to the filling of Lake Sakakawea, this valley was a tributary of the Shell Creek valley, and the contained aquifer apparently was part of the Shell Creek aquifer system. The lake, however, has effectively isolated the East Fork Shell Creek valley. The East Fork Shell Creek valley has had a complex history with at least two cycles of fluvial deposition that were interrupted by the deposition of glacial till. The fluvial deposits consist of sand and gravel, are lenticular, and are relatively thin. They range from 0 to 34 feet in thickness and average about 10 feet. However, the average saturated thickness is less than 10 feet.

Yield–The city of Parshall has the only large-capacity well (152-90-25DBC2) in the valley fill. It has been pumped at 110 gpm for a period of 10 hours with a drawdown of 8 feet. The projected drawdown at the end of 24 hours (assuming no boundary effects) would be about 10 feet. Thus, the specific capacity of the well would be about 11 gpm per foot of drawdown and indicates a transmissivity of about 22,000 gpd per foot. This compares reasonably well with an estimated transmissivity of 25,000 for the water-bearing materials penetrated in test hole 152-90-25DBC1.

Inasmuch as there are no other large-capacity wells in the East Fork Shell Creek valley, maximum yields can only be estimated. Estimated transmissivities based on grain size and thickness are as high as 30,000 gpd per foot, but generally are less than 10,000 gpd per foot. These transmissivities indicate that locally yields as large as 150 gpm could be obtained for short periods of time, but generally yields will be less than 50 gpm. The indicated pumping rates could not be maintained for long periods, probably not more than a few days because of boundary effects.

Recharge–Recharge is from direct precipitation, seepage from streamflow in times of maximum runoff in the East Fork Shell Creek, and from inflow from the Sentinel Butte Formation. The quality of the water indicates the principal source of recharge is inflow from the Sentinel Butte Formation.

Quality of water–The quality of water as determined from complete and partial analyses of water samples obtained from the valley fill near Parshall generally was poor. The water was either a very hard sodium bicarbonate or a very hard sodium sulfate type with more than the recommended quantity of sulfate, iron, and dissolved solids. Sulfate ranged from 730 to 1,200 ppm, iron ranged from 0.25 to 8.4 ppm, and dissolved solids ranged from 1,870 to 3,020 ppm. Only the analysis from well 152-90-25DBC2 was complete enough to obtain irrigation indices. On the basis of this analysis, the water was classified as C4-S4. The residual sodium carbonate was 12.12.

Surficial outwash aquifers

The surficial outwash and alluvial deposits in Burke and Mountrail Counties are not differentiated in this report. In the few areas where alluvial deposits can be identified as a separate unit, they are too thin to be significant aquifers. The outwash deposits, which underlie the alluvial deposits, are also thin, but they locally contain enough saturated sand and gravel to furnish sufficient water for most domestic and livestock uses. The surficial deposits generally are shown on plates 3 and 4; however, they are not identified where they overlie buried aquifers of known yields.

The outwash deposits generally were deposited in small diversion valleys, such as are common in the northern half of Burke County. The deposits are composed principally of sand, gravel, silt, and minor amounts of clay. Data from test holes and reports from well owners indicate that the water-saturated portions of the outwash deposits generally are thickest and coarsest near the centers of the valleys. The outwash deposits range from 0 to 44 feet in thickness, but generally contain less than 10 feet of saturation--except in the lower parts of the larger stream valleys and near Lake Sakakawea. Other exceptions probably exist; however, water levels are not known where observation wells were not installed, and saturated thicknesses were estimated by projecting water levels from private wells or by assuming that water levels are at the base of the oxidized sand or gravel zones. Thus, the saturated thickness shown may be somewhat in error.

Although the surficial outwash deposits generally are thin and only partly saturated, they may overlie other buried glaciofluvial deposits that are saturated, such as at 161-92-35CCC, and considerable water may be available at these locations.

Outwash materials have been deposited in a generally north-south-trending valley that extends from about the Burke-Mountrail county boundary (158-90) to Clearwater Lake, thence to about a mile south of Palermo. The relationship of this valley to either the ancient Little Knife River or the Shell Creek drainages is not known. Locally, near the center of the valley, such as at test holes 156-90-4ABB, 157-90-15BBB, and 158-90-17BBA, clay or till separates the sand and gravel into two units. The surficial unit generally contains little or no water; the lower unit may be either completely or partly saturated. At other localities, such as from about 2 to 4 miles northward from Clearwater Lake and near the edges of the north-south valley (156-90-4BAB and 156-90-15BBB), the outwash sand and gravel is topographically high and only a few inches to a few feet at the base of the deposits is saturated.

Several Pleistocene lake deposits were mapped by Freers (written commun., 1969) in Burke County and Clayton (written commun., 1969) and Paulson (1954, pl. 2) in Mountrail County. Many of these deposits are nearly surrounded by sand and gravel that apparently was deposited along the beaches or in contact with surrounding ice. Other types of ice-contact deposits of sand and gravel have been mapped also. All of these deposits, together with most of the outwash deposits, are shown on plates 3 and 4 as surficial deposits.

Yield--Wells tapping the surficial outwash deposits commonly yield only a few gallons per minute. The yields generally are limited by the capacities of the pumps. Most are less than 10 gpm, but are sufficient for domestic or small stock needs. Hydrologically, the ice-contact deposits resemble the higher outwash deposits. They rarely contain more than a few feet of saturated material at their base, and they generally will yield only small quantities of water to wells. Locally, however, where these deposits are in topographically low areas, yields in excess of 25 gpm may be obtainable. Where buried glaciofluvial deposits are present beneath the outwash or ice-contact deposits, such as at 156-90-4ABB, 158-90-17BBA, 159-91-34BCA, and 159-94-23DDC, yields from the combined deposits may be greater than 50 gpm.

Test hole 156-90-4ABB penetrated 22 feet of saturated sand and gravel that should have a transmissivity of about 42,000 gpd per foot. The specific capacity of a properly constructed well at this site should be about 30 gpm per foot of drawdown, and pumping rates as high as 300 gpm should be obtainable for short periods. Boundaries, which have not been precisely located, are probably less than a quarter of a mile from the test hole and would cause large drawdowns during long periods of pumping.

Recharge–Recharge to the topographically high outwash and ice-contact aquifers is principally from precipitation that infiltrates rapidly to the water table. Topographically low aquifers may receive some recharge from underlying or laterally adjacent deposits also.

Quality of water–The quality of water in the surficial outwash deposits varies considerably with topographic position and drainage. Those deposits that are topographically high have good drainage. They generally receive recharge directly from precipitation, and the water quality is good for many purposes. The analyses of water from wells 156-90-4ABB and 159-94-23CD are typical examples of water from high and well-drained areas. The waters were, respectively, very hard calcium bicarbonate types with 490 and 850 ppm dissolved solids, low sodium-adsorption ratios, and only 17 and 23 percent sodium. The deposits that are in topographic lows have poor drainage, commonly they receive recharge from upward percolating water as well as from precipitation and from the higher adjacent deposits. The total effect is a shallow water table accompanied by high rates of evaporation and transpiration, which result in a concentration of dissolved solids and a poor quality of water. Well 163-94-31DCC1 is in a topographically low area; the water was a very hard sodium sulfate type that had 2,040 ppm dissolved solids, a high sodium-adsorption ratio, and 66 percent sodium.

Undifferentiated drift aquifers

Small deposits of glaciofluvial sand and gravel commonly are interspersed with the till throughout much of Burke and Mountrail Counties. These were formed wherever there was sufficient glacial melt water to cause sorting. Many of the deposits probably are in comparatively long, narrow channels, but are shown on plates 3 and 4 as isolated circular deposits because of insufficient data to determine the exact boundaries. An exception is in the vicinity of Flaxton and Woburn in Burke County. The depth to bedrock in the Flaxton city wells and in test hole 162-91-24AAA probably indicates a tributary to the Columbus valley.

Many small saturated glaciofluvial deposits of sand and gravel within the till have been discovered in the two-county area. Many others probably exist, but were not located. Generally the greater the thickness of drift at any particular location, the greater the chance that sand or gravel beds might be present.

The areas most likely to contain buried saturated sand or gravel deposits are those in long, narrow depressions or where several sloughs are in a chainlike arrangement. Many of these areas are mantled with thin surficial outwash deposits that also may be saturated. Hence, these low areas are the most likely places to prospect for water.

Neither the Ryder Ridge nor the Hiddenwood Lake aquifers, which Pettyjohn (written commun., 1969) shows to underlie areas in Ward County adjacent to the eastern edge of Mountrail County, were located during this investigation. The aquifers were described as being about 250 yards wide in Ward County. If they extend into Mountrail County, they would be about a mile south of State Highway 23. The Vang aquifer, which Pettyjohn (written commun., 1969) also shows to be present at the Mountrail-Ward county boundary, extends into the headwaters of the East Fork Shell Creek. Test hole 152-88-11BBB penetrated 5 feet of near-surface, fine-grained sand, but only about 2 feet of the deposit was saturated. Therefore, the Vang aquifer is not considered to be significant in Mountrail County.

Yield--The small size of most of the undifferentiated drift aquifers severely restricts their capacity to yield water to wells. Many of these aquifers probably could not sustain yields of as much as 10 gpm. The small colored circles surrounding some of the test holes on plates 3 and 4 show the areas where sand or gravel thicknesses indicate that specific capacities would be greater than 5 gpm per foot of drawdown, and yields of 25 gpm should be obtainable. However, because the estimated specific capacities are based on lithology and thickness and do not consider the volume of the aquifer, the estimates may be larger than might be determined in actual tests.

Recharge and water-level fluctuations--Recharge to the undifferentiated drift aquifers is principally from sloughs, seepage from surficial sand or gravel deposits, and from adjacent deposits of glacial till. Most of the sloughs contain water during the spring and early summer months. Even though many of these are underlain by materials having very low permeabilities, the water is available for a period long enough for some recharge to occur. The quantity of recharge from any one slough probably is small, but the total amount of recharge is significant and it probably is sufficient to replace most of the water presently being discharged from the aquifers.

Figure 21 shows the monthly water-level fluctuations in two shallow observation wells (151-89-12ADD and 161-92-35CCC); each taps a small undifferentiated drift aquifer. The hydrographs show comparatively large water-level fluctuations. Water-level trends in well 151-89-12ADD during periods of no measurements probably approximated the trends shown by the dashed lines. Because there was no appreciable pumping near the wells, the water levels appear to reflect the seasonal variations of precipitation and depth of water in nearby sloughs or lakes. The release of water from the frost zone also may be a major cause of the spring water-level rises. Water levels in the deeper drift aquifers, as shown by the hydrographs of observation wells 158-94-16BBB, 159-90-4BCC, and 160-94-7DDD (fig. 22), generally do not fluctuate as much as the shallow water levels unless they are affected by pumping. These deeper aquifers show little effect of short-term recharge or discharge.

Quality of water–Ground water in the undifferentiated drift aquifers differs considerably in quality, as was shown by the wide range of various chemical properties in the sampled water. Water low in dissolved solids generally was a calcium bicarbonate type, and water high in dissolved solids generally was a sodium sulfate type. The total dissolved solids in the samples analyzed ranged from 287 ppm in well 161-92-35CCC (38 feet deep) to 3,590 ppm in test hole 163-93-17DDD (76 feet deep). Hardness ranged from 18 ppm in well 157-89-20ADC (141 feet deep) to 2,140 ppm in well 163-93-17DDD. Sulfate ranged from 2 ppm in well 160-94-29BBB (112 feet deep) to 2,140 ppm in well 163-93-17DDD. The sodium-adsorption ratio ranged from 0.1 in 155-90-12CAA (12 feet deep) and 161-92-35CCC to 69 in 157-89-20ADC. The water had a low to very high sodium hazard and a medium to very high salinity hazard for irrigation.

UTILIZATION OF GROUND WATER

The principal uses of ground water in the two-county area are for domestic and livestock supplies, public supplies, industrial supplies, and irrigation.

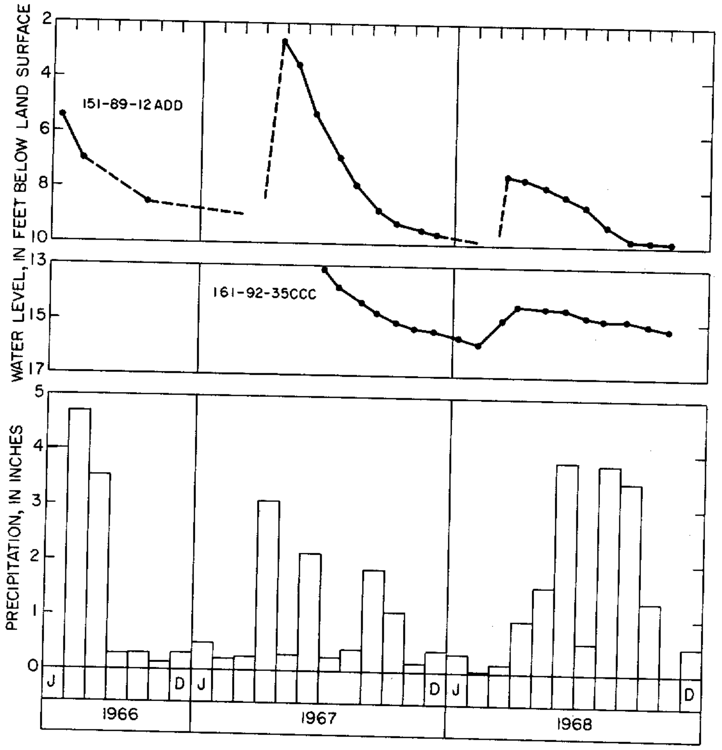

FIGURE 21. Water-level fluctuations in shallow undifferentiated glacial drift aquifers, and precipitation at Parshall.

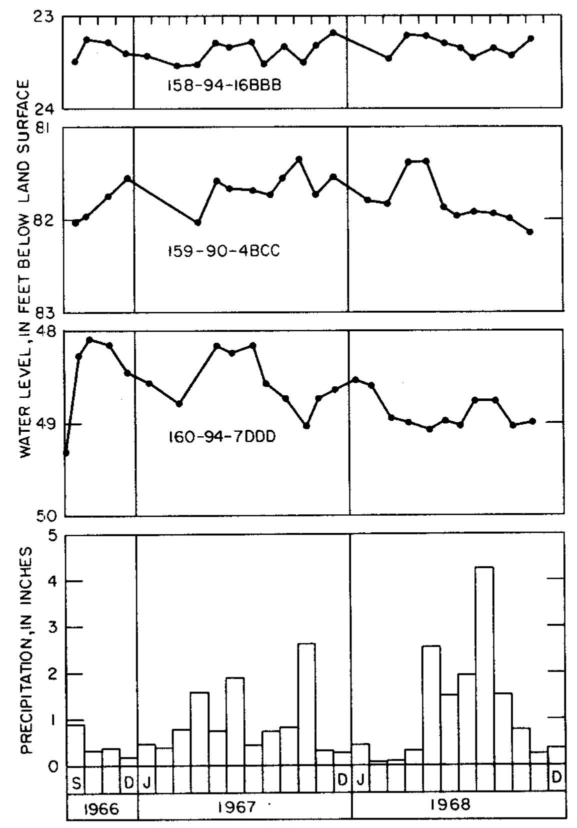

FIGURE 22. Water-level fluctuations in deep undifferentiated glacial drift aquifers, and precipitation at Columbus.

Domestic and Livestock Supplies

Most farm units in the two-county area have at least one well for their domestic and livestock uses, but no records are available to accurately determine the quantity of water used. The following table shows an approximation of the quantity of water used in 1967.

Use	Individual Requirements (gpd)	Population	Pumpage (gpd)
Domestic (not including cities having public supplies)	a/70	7,909	554,000
Cattle	15	b/62,000	930,000
Hogs	2	b/ 1,700	3,400
Poultry	.04	b/29,000	1,160
Sheep	1.5	b/96,000	144,000
Total			c/1,632,560 gpd

a/ Average per person use in cities in Burke and Mountrail Counties.

b/ North Dakota State University, 1968.

c/ 1,820 acre-feet per year.

The quantities in the table probably are somewhat higher than the amount of ground water used because some farms are vacant during the winter and some cattle get part of their water from stock ponds or sloughs.

Public Supplies

The cities and villages in Burke and Mountrail Counties all depend on ground water for their water supplies. The cities of Bowbells, Columbus, Flaxton, Lignite, New Town, Parshall, Plaza, Portal, and Powers Lake have distribution systems that furnish water to individual residences. The city of Tagus has a distribution system that supplies water to hydrants that are spaced at regular intervals along the main street. The city of Battleview has a public supply, but no distribution system. None of the other communities in the two-county area have public supplies.

Bowbells

The city of Bowbells, Burke County, obtains its water supply from four wells (161-89-5AC1, 5AC2, 5ACD, and 5ADC), which are finished in the Tongue River Formation and are capable of yielding a total of 150,000 gpd (U.S. Public Health Service, 1964, p. 120). In 1963, the average use of water was approximately 40,000 gpd, which was approximately 67 gpd per person. The water is chlorinated before delivery to the city mains.

The quality of the municipal water supply depends on the wells in production. Water from wells 161-89-5AC1 and 5AC2 is a soft sodium bicarbonate type. Dissolved solids were 1,990 and 2,350 ppm, respectively. Water from well 161-89-5ACD was a very hard sodium calcium sulfate type that contained 1,280 ppm sulfate, 2,400 ppm dissolved solids, and 954 ppm hardness. Water from 161-89-5ADC was a moderately hard sodium bicarbonate type that contained 416 ppm sulfate, 1,680 ppm dissolved solids, and 104 ppm hardness. The water from the Bowbells' wells does not meet U.S. Public Health Service (1962) drinking water standards and is not recommended for irrigation.

Columbus

Prior to 1969, the city of Columbus, Burke County, obtained its water supply from three wells, which are finished in the Tongue River Formation. These wells were capable of yielding 65,000 gpd (U.S. Public Health Service 1964, p. 120). By 1968, the maximum yield was reported to have declined to about 56,000 gpd and it is doubtful that this yield could have been sustained for more than a few days at a time.

The average use was about 18,000 gpd, or 30 gpd per person, in 1963. Approximately the same quantity was used in 1967. This supply is available on a standby basis.

In late 1968, city well 163-93-30BBB1 was added to the city's distribution system. The new well is equipped with a pump that is rated at 100 gpm. Precise records have not been kept, but Norbert Kihle, Mayor of Columbus, reported that the well generally has been pumped for about 3 hours per day during the first half of 1969.

Water samples taken from the new city well at 163-93-30BBB1 on August 22, 1968, and August 26, 1968, showed that the water was a very hard sodium bicarbonate type that changed quality slightly with heavy pumpage. The dissolved solids increased from 1,890 ppm to 1,950 ppm, sulfate increased from 447 to 536 ppm, and iron increased from 0.07 to 0.1 ppm. The water was classified as C4-S4 for irrigation and had about 15 epm residual sodium carbonate.

Flaxton

The city of Flaxton, Burke County, obtains its water supply from two wells. Well 163-90-32CBC is 715 feet deep and is finished in the lower part of the Tongue River Formation; well 163-90-31DAA is finished in either the Tongue River Formation or in a tributary to the Columbus aquifer. These wells are reported (U.S. Public Health Service, 1964, p. 121) to have a maximum capacity of 70,000 gpd. The average daily use during 1963 was reported to be 25,000 gallons, or about 71 gpd per person. Well 163-90-31DAA supplies most of the water used by the city.

Analyses of samples from the two wells show that there is considerable difference in the water quality. The water from well 163-90-31DAA was a very hard sodium bicarbonate type that contained 661 ppm sulfate, 31 ppm chloride, 0.18 ppm iron, and 1,670 ppm dissolved solids. This water had 81 percent sodium, a sodium-adsorption ratio of 14, and a residual sodium carbonate of 9.2 epm. The water from well 163-90-32CBC was a soft sodium bicarbonate type that contained 2.6 ppm sulfate, 491 ppm chloride, 0.14 ppm iron, and 2,240 ppm dissolved solids. This water had 99 percent sodium, a sodium-adsorption ratio of 87, and a residual sodium carbonate of 25 epm. This well also is reported to yield some methane gas.

Lignite

The city of Lignite, Burke County, obtains its water supply from well 162-92-12BBB, which is finished in the Lignite City aquifer. The well as presently equipped yields 125 gpm. In 1966, the average daily use was 35,000 gallons, with a peak use of 120,000 gallons per day. Approximately 1,600,000 gallons was used in the period January through March 1967.

An analysis of a sample from the city well shows that the water was a very hard calcium bicarbonate sulfate type. The water contained 297 ppm sulfate and 915 ppm dissolved solids, but otherwise did not contain any ions in excess of the U. S. Public Health Service (1962) standards. The water was classified as C3-S1 (fig. 4) for irrigation and contained no residual sodium carbonate.

New Town

The city of New Town, Mountrail County, obtains its water from three wells (152-92-19AAA1, 19AAA2, and 152-92-20BBB1) finished in the New Town aquifer. These wells are capable of yielding a total of 1,080,000 gpd, but usually average about 205,000 gpd, or approximately 124 gpd per person. The average daily use by the city in 1966, the peak year of record, was 227,000 or 138 gpd per person. The water is softened, filtered, and chlorinated before delivery to the city mains.

Analyses of samples (North Dakota State Dept. of Health, 1964, p. 16-17) from two of the wells (152-92-19AAA1 and 20BBB2) show that the water was a sodium sulfate type that contained excessive quantities of iron (1.6 and 3.5 ppm), sulfate (420 and 400 ppm), and dissolved solids (1,077 and 972 ppm). The hardness of the water as calcium carbonate was 278 and 225 ppm. After treatment of the combined waters, the dissolved solids were reduced to 883 ppm, the hardness was reduced to 115 ppm, iron was reduced to 0.0, and the sulfate was increased to 470 ppm. Samples of water obtained in 1967 from well 152-92-20BBB1 indicated that the water varied in quality to some extent both with the time of year and the period of pumping. The dissolved solids content of the water was 1,170 ppm on April 26, 1,110 ppm on September 21, and 1,100 ppm on September 22. The water was classified as C3-S1 for irrigation and had an average of 0.2 epm residual sodium carbonate.

Parshall

The city of Parshall, Mountrail County, obtains its water supply from four wells that are finished in the East Fork Shell Creek deposits. The wells have a maximum capacity of 280,000 gpd. In 1963, the average use of water was 72,000 gpd (U.S. Public Health Service, 1964, p. 124), or about 41 gpd per person. Most of this water is obtained from city well 4, 152-90-25DBC2, which is rated at 110 gpm and generally is the well in use. The other three wells are used principally as needed in times of peak demand or well repair.

The quality of the city's supply depends on the wells in use, but city well 4, which is in use most often, has the greatest effect on the total supply. A 1967 analysis shows that the water from well 4 was a very hard (230 ppm) sodium bicarbonate type that contained 0.25 ppm iron, 730 ppm sulfate, and 1,870 ppm dissolved solids. Analysis of a sample collected in 1962 or 1963 (North Dakota State Dept. of Health, 1964, p. 18-19) shows that the water at that time contained 1.3 ppm iron, 600 ppm sulfate, and 2,156 ppm dissolved solids. The cause of the apparent change has not been determined. The 1964 publication also shows analyses from wells 1, 2, and 3. The waters from these wells were very hard sodium sulfate types that contained 1.5 ppm iron, and, respectively, contained 750, 725, and 800 ppm sulfate and 2,415, 2,317, and 2,504 ppm dissolved solids. The water at Parshall contained more than 85 percent sodium, had a sodium-adsorption ratio greater than 18 and was classified as C4-S4 for irrigation purposes.

Plaza

The city of Plaza, Mountrail County, obtains its water supply from two wells finished in the Sentinel Butte Formation. These wells as presently adjusted (1968) are capable of yielding about 72,000 gpd, but the valves can be adjusted so that yields as high as 100,000 gpd can be obtained. The average use in 1968 was about 22,000 gpd, or about 58 gpd per person. City well 3, 152-88-4BBB, supplies most of the water for the city and is the only well used when the demand is less than 36,000 gpd.

The quality of water used by the city generally is that of city well 3. Water from this well was a very hard (295 ppm) sodium bicarbonate type that contained 1.1 ppm iron, 522 ppm sulfate, and 1,560 ppm dissolved solids. The water contained 76 percent sodium, had a residual sodium carbonate of 9.1 epm, and a sodium-adsorption ratio of 12. The irrigation classification was C4-S3. The water is not suitable for irrigation.

Portal

The city of Portal, Burke County, obtains its water from a well, 164-92-36AAB, finished in the Tongue River Formation. The well can supply 140,000 gpd, but there are no supply records available.

An analysis of the water from the Portal well shows that the water was a soft sodium bicarbonate type that contained 0.16 ppm iron, 1.7 ppm fluoride, and 1,700 ppm dissolved solids. Fluoride and dissolved solids were the only constituents present that exceeded the U.S. Public Health Service (1962) standards.

Powers Lake

The city of Powers Lake, Burke County, obtains its water supply from two wells that apparently are finished in the northwest continuation of the White Lake branch of the Shell Creek aquifer system. A combined yield of 140,000 gpd is obtainable from the two wells. In 1962 (U.S. Public Health Service, 1964, p. 124) an average of about 36,000 gpd, or an average of about 57 gallons per person, was used. Well 2, 159-93-35AAA, is the city's principal source of supply; well 1, 159-93-25CDA, is used for a supplemental water supply when needed.

The quality of the Powers Lake water supply varies with the well or wells in use. The water from well 1, in 1967, was a very hard (198 ppm) sodium sulfate type that had 2.3 ppm iron, 527 ppm sulfate, and 1,400 ppm dissolved solids. The 1963 analysis (North Dakota State Dept. of Health, 1964, p. 18-19) showed an iron content of 0.9 ppm and a sulfate content of 460 ppm. The increase in sulfate is probably due to the migration of water with a higher sulfate content. Most of the increase in iron probably is due to iron scale from the pipes.

Water from well 2 was also a very hard (215 ppm) sodium sulfate type that in 1963 contained 1.0 ppm iron, 470 ppm sulfate, and 1,063 ppm dissolved solids. A partial analysis of water from well 2 in 1967 showed an iron content of 7.4 ppm and a sulfate content of 460 ppm. The small change in sulfate content indicates that there has been very little change in water quality in the approximately 4 years between samples. The high iron in the latter sample probably indicates some pipe corrosion.

The water from well 1 contained 81 percent sodium and had a sodium-adsorption ratio of 13. The water was classified as C3-S3 for irrigation. The water from well 2 was somewhat better, but also had a classification of C3-S3. The water is not recommended for irrigation, but probably could be used for supplemental watering in some of the sandy soils in Powers Lake.

Tagus

The city of Tagus, Mountrail County, obtains its water supply from well 156-88-12DCB, which is believed to be finished in an undifferentiated drift deposit of sand. No records are available as to how much water can be pumped. However, with the equipment on the well, it is not likely that as much as 25 gpm could be obtained.

An analysis of water from the Tagus well shows that the water was a very hard (465 ppm) calcium sodium bicarbonate type that contained 4.3 ppm iron, 314 ppm sulfate, and 822 ppm dissolved solids. Other constituents were present in smaller quantities than the recommended limits.

The water contained 33 percent sodium and had a sodium-adsorption ratio of 2.2. There was no residual sodium carbonate.

Battleview

The city of Battleview has a well 17 feet deep that is finished in outwash deposits. The well, 159-94-23CD, is equipped with a hand pump. An analysis of water obtained from the well in 1968 shows that it was a very hard (525 ppm) calcium bicarbonate type that contained 0.38 ppm iron, 306 ppm sulfate, and 850 ppm dissolved solids.

Industrial Supplies

Practically all of the water used for industrial purposes in Burke and Mountrail Counties is either used in connection with the production of petroleum or is obtained from public supplies and no records are kept.

The largest use of ground water in the two-county area is for pressure maintenance. The North Dakota Geological Survey records (oral commun., 1969) show that from July 1, 1968 to June 30, 1969, there was approximately 560 acre-feet of brines produced with oil that was returned to the oil-producing formations. In addition, a total of about 1,200 acre-feet of water was pumped from the Dakota aquifer. The water was pumped into the oil-bearing beds to maintain the formation pressure as the oil was being produced.

Accurate records of water use at the various booster pumping plants and liquid-petroleum separation plants are not available. However, reports from the Hunt Oil Company's plant near Battleview indicate that a total of about 25 acre-feet was used in 1968. This estimate does not include the use of water by Texaco's petroleum storage plant, which uses the Lignite municipal supply.

Irrigation

Two irrigation wells were in use in 1968 in Mountrail County. Although the wells are capable of yielding a total of 700 gpm if both are pumped, generally only one well is pumped at a time. The average pumping rate was about 400 gpm for a total of about 40 days. Thus, about 70 acre-feet of water was pumped for irrigation.

SUMMARY

The glacial drift aquifers in Burke and Mountrail Counties with the greatest potential for ground-water development are: the New Town aquifer, the Shell Creek aquifer system, and the Columbus aquifer. The New Town aquifer is in a buried valley in southwest Mountrail County. It averages about 50 feet in thickness under an area about 1 3/4 miles wide and 6 miles long. The aquifer contains approximately 65,000 acre-feet of water in storage and can be pumped at rates exceeding 500 gpm. The aquifer receives recharge from Lake Sakakawea and has a good potential for future development. The water from the New Town aquifer was either a sodium bicarbonate or sodium sulfate type with dissolved solids ranging from 982 to 2,500 ppm.

The Shell Creek aquifer system in Mountrail County is composed of three principal branches and a main stem. The White Lake branch consists of a series of poorly connected sand and gravel lenses that generally range from 12 to 37 feet in thickness. Sustained yields in most parts of the White Lake branch probably would not exceed 100 gpm. The central and east branches of the Shell Creek aquifer system are similar to the White Lake branch, but contain somewhat thicker and better connected sand lenses. Pumping rates somewhat in excess of 100 gpm possibly could be maintained. Locally, at the junction of two or more tributaries, pumping rates of about 300 gpm can be obtained for at least as long as an irrigation season. The water from the Shell Creek aquifer system was variable in quality. The deeper, more centrally located water generally was a very hard sodium sulfate type that contained from 1,080 to 3,270 ppm dissolved solids. Locally calcium may be the dominant cation and bicarbonate the dominant anion. Water from wells away from the central part of the aquifer or finished in shallower sand and gravel deposits may be a calcium magnesium bicarbonate type containing as few as 523 ppm dissolved solids. Generally water from the Shell Creek aquifer should be considered marginal to unsuitable for irrigation.

The Columbus aquifer is in a buried, generally east-west-trending valley in northern Burke County. The aquifer has a length of about 47 miles and an average thickness of about 55 feet. It apparently contains about 150,000 acre-feet of water that can be pumped for short periods at rates greater than 500 gpm; but long-term pumping rates should not exceed 200 gpm. The water from the Columbus aquifer ranged from a sodium bicarbonate type in the lower zone to a sodium sulfate or calcium sulfate type in the upper zone. Dissolved solids ranged from 1,760 ppm to 1,950 ppm in the lower zone and from 1,750 ppm to 2,800 ppm in the upper zone.

The Lignite City aquifer in Burke County averages about 25 feet in thickness under an area about half a mile wide and 2 miles long, and contains about 5,100 acre-feet of water in storage. Approximately 3,100 acre-feet of this water should be available to wells at rates of from 50 to at least 500 gpm. The water in the Lignite City aquifer was a very hard calcium bicarbonate sulfate type with 915 ppm dissolved solids.

The Kenmare(?) aquifer, which is in a buried valley that crosses southeast Burke County, apparently is about half a mile wide. Locally yields of as much as 500 gpm may be obtained for short periods of time, but generally continuous yields in excess of 100 gpm probably would cause excessive drawdowns. The water from the Kenmare(?) aquifer was either a calcium sodium sulfate or a calcium bicarbonate type with less than 1,200 ppm dissolved solids.

The outwash and alluvial deposits in the Little Knife River and White Earth River valleys are the most important minor aquifers in the report area. Short-term pumping rates of as much as 800 to 1,000 gpm probably could be obtained from the central parts of these valleys where the saturated thicknesses are greatest. Continuous pumping at rates in excess of about 300 gpm in the Little Knife River valley and 350 gpm in the White Earth River valley probably could not be maintained. Pumping rates of about 70 gpm in the Little Knife River valley and 140 gpm in the White Earth River valley can be maintained without depleting the quantity of water in storage. The quantity of water in the valleys is about 900 and 1,300 acre-feet per mile in the Little Knife and White Earth River valleys, respectively. The water from the central parts of both of the valleys was a very hard sodium sulfate or sodium sulfate bicarbonate type with from 1,970 to 2,870 ppm dissolved solids.

The East Fork Shell Creek valley contains sand and gravel deposits that are as much as 34 feet thick, and the average saturated thickness is less than 10 feet. Well yields locally may be as large as 150 gpm, but generally will be less than 50 gpm. The water in the aquifer was very hard, and was either a sodium bicarbonate or sodium sulfate type with more than the recommended quantity of sulfate, iron, and dissolved solids.

Outwash deposits not included in the previously described aquifers generally contain less than 10 feet of saturated thickness and may yield sufficient water for domestic and livestock supplies. Locally, where the saturated thicknesses are greater than 10 feet or the outwash overlies buried glaciofluvial deposits, yields greater than 50 gpm may be obtained. The quality of the water from the outwash deposits was variable with topographic position and drainage. The higher deposits contained a very hard calcium bicarbonate type water that had as little as 490 ppm dissolved solids. Water from the topographic low areas generally was a sodium sulfate type with as much as 2,040 ppm dissolved solids.

Undifferentiated glacial drift aquifers are scattered throughout both counties, and some of these deposits will yield sufficient water for domestic or livestock supplies. The water in these aquifers generally was very hard and had a wide range of dissolved solids. Water containing low total dissolved solids usually was a calcium bicarbonate type. Water containing high total dissolved solids usually was a sodium sulfate type.

The Dakota aquifer, which is in the lower part of the Dakota Group, underlies all of Burke and Mountrail Counties at depths ranging from about 3,505 to 5,210 feet. The aquifer averages about 375 feet thick and will yield water at rates as high as 320 gpm. The water is too saline for most uses.

The upper part of the Fox Hills and lower part of the Hell Creek Formations contain an aquifer that is about 125 to 200 feet thick in the report area. Depths to the aquifer apparently range from 800 feet in northeast Burke County to 2,100 feet in southwest Mountrail County. Only one well, which flowed at about 2 gpm in 1967, exists in the report area; however, yields of as much as 60 gpm with about 100 feet of drawdown should be obtainable. The water from the flowing well is a very soft sodium bicarbonate type that contained 1,530 ppm dissolved solids and 5.1 ppm fluoride. The water quality is too poor to be recommended for either human consumption or irrigation uses.

The Tongue River and Sentinel Butte Formations of the Fort Union Group either outcrop or immediately underlie the glacial drift in the report area. These formations contain lenticular beds of lignite and very fine to medium sand or semi-indurated sandstone that generally will yield only small quantities of water, but locally yields as great as 100 gpm are obtainable. The water in the Tongue River and Sentinel Butte Formations generally is a sodium bicarbonate type, but sulfate concentrations commonly are high. The water generally is not recommended for either human consumption or irrigation use. However, water from these formations has been used by residents of the area without any noticeable ill effects.

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DEFINITION OF TERMS

Amendment – a substance that aids plant growth by improving the condition of the soil.

Aquifer – permeable saturated deposits that will yield water to wells.

Area of influence – the area within the cone of depression commonly caused by a discharging well.

Artesian water – ground water that is under sufficient pressure to rise above the top of the aquifer.

Bedrock – consolidated rocks underlying glacial and alluvial deposits of Pleistocene and Holocene age.

Cone of depression – the conical low produced in a water table or piezometric surface by pumping (or artesian flow).

Discharge – the removal or loss of water from an aquifer or the flow of water in a stream.

Drawdown – decline of the water level in a well or cone of depression caused by pumpage or artesian flow.

Evapotranspiration – water returned to the air through direct evaporation from water or land surface and by transpiration of vegetation.

Flowing well – a well in an artesian aquifer having sufficient head to discharge water at the land surface.

Fluvial deposits – sediments deposited by streams.

Glaciofluvial deposits – sediments deposited by streams that flowed from a glacier.

Ground water – water in the zone of saturation.

Ground-water divide – a line on a water table on each side of which the water table slopes downward and away from the line.

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

Head – the hydraulic pressure of water in a well or aquifer measured in a vertical direction with reference to some datum.

Hydraulic conductivity – the capacity of a rock to transmit water--usually expressed as the rate of flow in gallons per day through 1 square foot of the aquifer under unit hydraulic gradient, at the prevailing ground-water temperature.

Hydraulic gradient – slope of the water table or potentiometric surface generally expressed in either feet per foot or in feet per mile.

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 and streams.

Infiltration – the movement of water from the surface toward the water table.

Inflow -- movement of ground water into an area in response to the hydraulic gradient.

Irrigation – the controlled application of water for crops.

Lacustrine deposits – sediments formed in a lake environment.

Logarithm (log) – the exponent indicating the power to which it is necessary to raise the base number (usually 10) to equal a given number. Logarithmic scale enables large numbers to be plotted on a graph within a short distance.

Observation well – a well from which hydrologic data are measured and recorded.

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

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

Porosity – the ratio of the volume of voids in the rock to the total volume of the rock; expressed either as a percentage or a decimal.

Potentiometric surface – the water table in an unconfined aquifer or the horizon to which water will rise in an artesian aquifer.

Radius of influence – the horizontal distance between a discharging well and the edge of the cone of depression.

Recharge – the addition of water to the zone of saturation.

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

Specific yield – the quantity of water that an aquifer will yield under the force of gravity compared to the total volume of the aquifer that is drained; usually the ratio is expressed as a percentage.

Static water level – the water level in a well that is outside the area of influence of any pumping.

Storage – the quantity of water in openings in the zone of saturation.

Storage coefficient – the volume of water released from or taken into storage in a vertical column of the aquifer having a base of 1 foot square when the potentiometric surface changes 1 foot.

Surface runoff – the discharge by streams of precipitation that is not evaporated or infiltrated into the soil.

Till – an unsorted, unstratified glacial deposit composed of particles ranging in size from clay to boulders.

Transmissivity – the capacity of a rock to transmit water under pressure, usually expressed as the number of gallons of water that will move in 1 day under a unit hydraulic gradient through a vertical strip of aquifer 1 foot thick extending the height of the aquifer.

Underflow – the downstream movement of ground water through the permeable deposits beneath a stream.

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

Zone of saturation – the zone below the water table.