GROUND-WATER RESOURCES

of

DUNN COUNTY, NORTH DAKOTA

by
Robert L. Klausing
U.S. Geological Survey

COUNTY GROUND-WATER STUDIES 25 — PART III
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

BULLETIN 68 — PART III
North Dakota Geological Survey
Lee Gerhard, *State Geologist*

Prepared by the U.S. Geological Survey
in cooperation with the North Dakota Geological Survey,
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BISMARCK, NORTH DAKOTA

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A dual system of measurements — U.S. customary units and the International System (SI) of metric units — is given in this report. SI is an organized system of units adopted by the 11th General Conference of Weights and Measures in 1960. Selected factors for converting U.S. customary units to SI units are given below.

Multiply U.S. customary units	By	To obtain SI units
Acre	0.4047	hectare (ha)
Acre-foot	.001233	cubic hectometer (hm^3)
Cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
Foot	.3048	meter (m)
Foot per day (ft/d)	.3048	meter per day (m/d)
Foot squared per day (ft^2/d)	.0929	meter squared per day (m^2/d)
Foot per mile (ft/mi)	.18943	meter per kilometer (m/km)
Gallon	3.785	liter (L)
Gallon per minute (gal/min)	.06309	liter per second (L/s)
Gallon per minute per foot [(gal/min)/ft]	.207	liter per second per meter [(L/s)/m]
Inch	25.4	millimeter (mm)
Million gallons (Mgal)	3,785	cubic meter (m^3)
	3.785×10^{-3}	cubic hectometer (hm^3)
Mile	1.609	kilometer (km)
Square mile (mi^2)	2.590	square kilometer (km^2)

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By

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ABSTRACT

Ground water in Dunn County is obtainable from aquifers in the preglacial rocks and from aquifers in the glacial drift. Aquifers in the preglacial rocks have a greater areal distribution than those in the glacial drift, but those in the drift provide higher yields to individual wells.

Sandstone aquifers in the preglacial rocks occur in the Fox Hills and Hell Creek Formations of Cretaceous age and in the undifferentiated Cannonball-Ludlow, Tongue River, and Sentinel Butte Formations of Tertiary age. Potential yields to wells tapping these aquifers range from 1 to as much as 200 gallons per minute (0.06 to 13 liters per second). The water from these aquifers is predominantly soft and is a sodium bicarbonate type. However, the water from the Sentinel Butte sandstone aquifers is predominantly hard to very hard.

Numerous fractured lignite aquifers are present in the Sentinel Butte Formation. These aquifers will yield from 1 to 200 gallons per minute (0.06 to 13 liters per second) to wells. Water from the lignite aquifers is predominantly a sodium bicarbonate type and is hard to very hard.

The Killdeer, Horse Nose Butte, Knife River, and Goodman Creek aquifers are composed of sand and gravel and are contained in glacial melt-water channels. These aquifers underlie an area of about 99 square miles (256 square kilometers) and contain approximately 700,000 acre-feet (860 cubic hectometers) of available ground water. Yields of as much as 1,000 gallons per minute (64 liters per second) are available from all of these aquifers except Horse Nose Butte, which will yield as much as 500 gallons per minute (32 liters per second). The water from these aquifers is hard to very hard and predominantly a sodium bicarbonate type.

INTRODUCTION

This investigation was made cooperatively by the U.S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and the Dunn County Water Management District. The results of the investigation will be published in three parts. Part I is an interpretive report describing the geology of the county; part II is a compilation of the data collected during the study; and part III, this report, is an interpretive report describing the ground-water resources of the county. The data used in this report are from part II (Klausing, 1976), unless otherwise referenced.

Purpose and Objectives

The purpose of this investigation was to determine the availability and quality of ground water in Dunn County. The primary objectives were to: (1) determine the location and extent of major aquifers; (2) evaluate the occurrence and movement of water in the aquifers, including the sources of recharge and discharge; (3) estimate the quantity of water stored in the aquifers; (4) estimate the potential yield of the aquifers; and (5) determine the chemical quality of the water in the aquifers.

Geography

Dunn County encompasses an area of 2,081 mi^2 (5,390 km^2) in west-central North Dakota. The county lies within the Great Plains physiographic province of Fenneman (1946; fig. 1), and all of the county except the extreme western part is glaciated.

The principal streams in the county are Spring Creek and the Little Missouri, Knife, and Green Rivers. Most of the drainage is integrated; however, in the north-central and southeastern parts of the county there are areas that have internal drainage to small potholes and sloughs.

The topography of the county, which is primarily the result of erosion, varies from gently rolling to highly dissected. The highest point is 3,314 feet (1,010 m) above msl (mean sea level) in the NE¼NW¼ sec. 29, T. 146 N., R. 96 W., and the lowest point is 1,840 feet (560 m) above msl in the valley of the Little Missouri River east of State Highway 22.

The population of Dunn County was 4,895 in 1970 (U.S. Bureau of the Census, 1971). Killdeer, which is the largest city in the county, had a population of 615. Halliday, Dodge, Dunn Center, and Werner had populations of 413, 121, 107, and 21, respectively. The population of Manning, the county seat, is included in the rural population because Manning is not incorporated.

The economy of the area is based on agriculture. Agricultural products include small grains (predominantly wheat), cattle, and hay.

The climate of the county is cool and semiarid. The mean annual temperature at Dunn Center is about 40°F (4.5°C; National Weather Service, 1948-75). August is generally the hottest month and January is usually the coldest. The mean annual growing season, when the temperature is above 32°F (0°C), is 116 days. The mean annual precipitation is about 16.5 inches (419 mm; National Weather Service, 1948-75). Data from the National Weather Service station at Dunn Center show that about 75 percent of the annual precipitation occurs during the 6-month period extending from April through September.

Location-Numbering System

The location-numbering system used in this report is based on the public land classification system used by the U.S. Bureau of Land Management. The system is illustrated in figure 2. The first numeral denotes the township north of a base

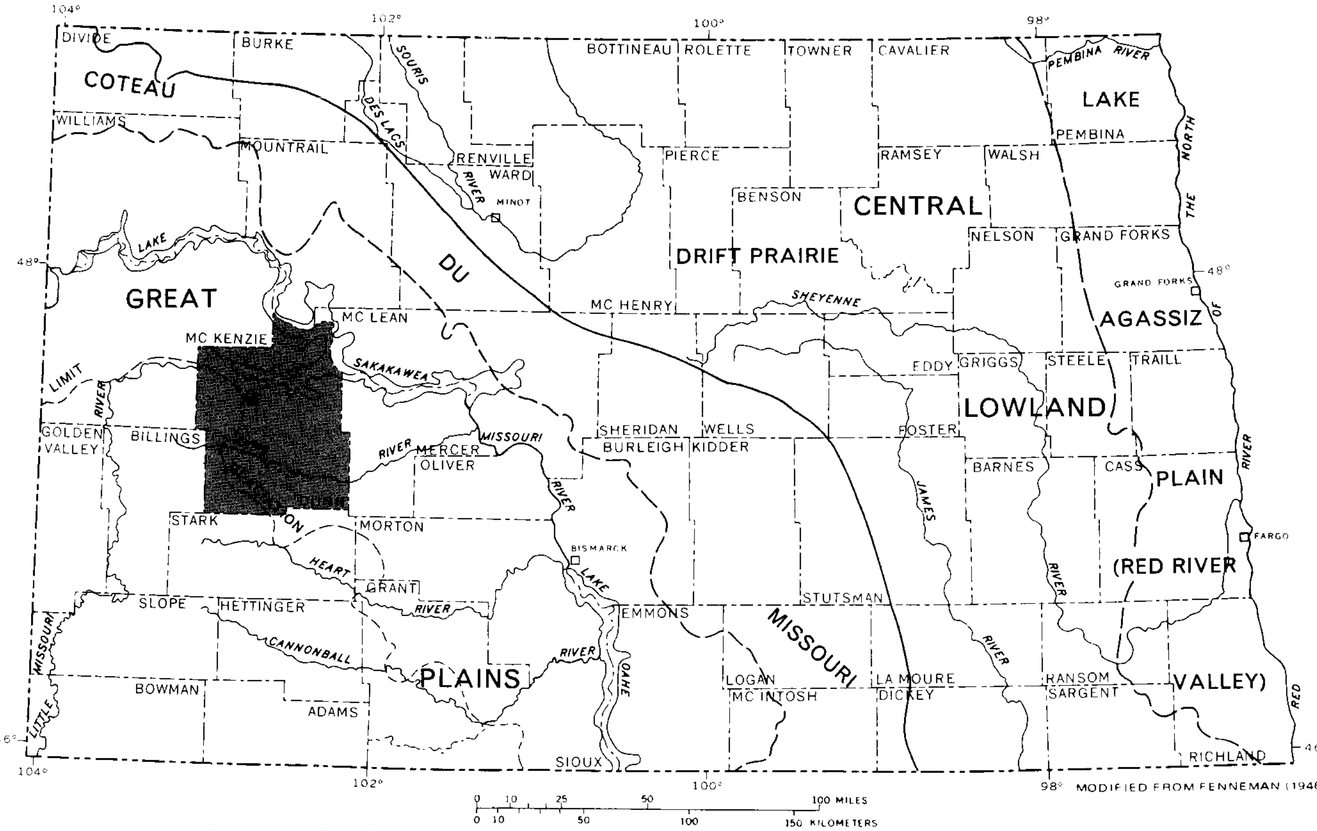


FIGURE 1.— Physiographic divisions in North Dakota and location of study area.

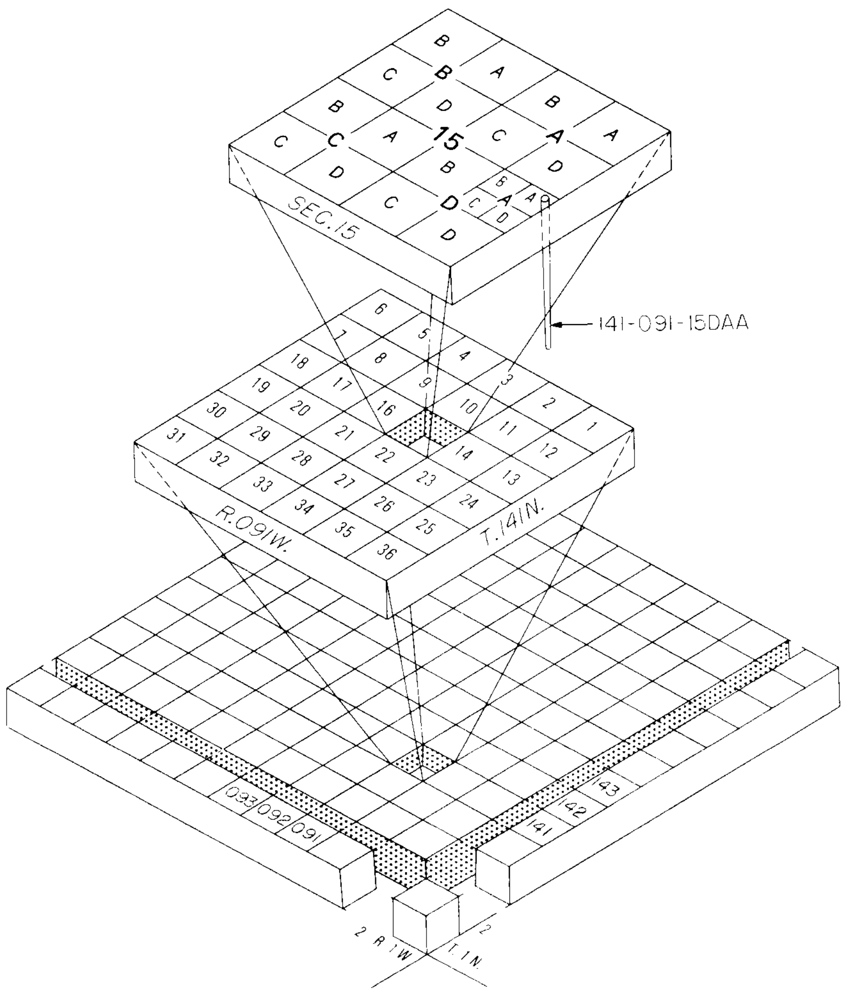


FIGURE 2.— Location-numbering system.

line, the second numeral and range west of the fifth principal meridian, and the third numeral indicates 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 or 4-ha tract). For example, well 141-091-15DAA is in the NE¼NE¼SE¼ sec. 15, T. 141 N., R. 91 W. Consecutive terminal numbers are added if more than one well, spring, or test hole is recorded within a 10-acre (4-ha) tract. This numbering system also is used in this report for the location of small areas.

Acknowledgments

The collection of data for this report was made possible by the cooperation of the Dunn County Water Management District and residents of the county. K. J. Thompson, Mann Drilling Co., Kruger Drilling Co., and Ralph Wold furnished well logs. L. L. Froelich and C. E. Naplin, ground-water geologists with the North Dakota State Water Commission, prepared lithologic logs and ran geophysical logs of most of the test holes. Recognition is due M. O. Lindvig, ground-water engineer, and R. W. Schmid, ground-water hydrologist with the North Dakota State Water Commission for making aquifer tests.

Previous Investigations

Quirke (1918, p. 255-271), described the geology and geomorphology of the Killdeer Mountains. Simpson (1929, p. 124-127) briefly described the occurrence of ground water in the Sentinel Butte Formation. Logs of wells and chemical analyses from selected wells in Dunn County were included in Simpson's report. Dingman and Gordon (1954) reported on the geology and ground-water resources of the Fort Berthold Indian Reservation. Their report contains well and test-hole logs, chemical analyses of water from different aquifers, and records of numerous springs. Denson and Gill (1965) briefly described the geology of the Killdeer Mountains in relation to uranium-bearing lignite and carbonaceous shale in the southwestern part of the Williston basin. Clayton (1971) prepared a preliminary geologic map of Dunn County, which shows the distribution of post-Paleocene rocks in the county. Naplin (1974) described the geology and ground-water resources in the vicinity of Halliday.

AVAILABILITY AND QUALITY OF GROUND WATER

General Concepts

All ground water of economic importance in Dunn County is derived from precipitation. After precipitation falls on the earth's surface, part is returned to the atmosphere by evaporation, part runs off into streams, and the remainder infiltrates into the soil. A large quantity of water that enters the soil is held temporarily and then is returned to the atmosphere by evaporation or by transpiration. After soil and plant requirements have been satisfied, the excess water, if any, percolates downward until it reaches the zone of saturation, at which time it becomes available to wells.

Ground water moves by gravity from areas of recharge to areas of discharge. Ground-water movement generally is very slow; it may be only a few feet per year. The rate of movement is governed by the hydraulic conductivity of the material through which the water moves and by the hydraulic gradient. Gravel and sand generally are highly conductive, and deposits of these materials commonly form aquifers. Fine-grained materials such as silt, clay, and shale usually have low conductivity.

The water level in an aquifer fluctuates in response to recharge to and discharge from the aquifer. Aquifers exposed at land surface are recharged by direct infiltration of precipitation. Recharge to these aquifers usually is sufficient to replace losses caused by natural processes and by pumping of wells. Aquifers that are confined by thick deposits of fine-grained materials also are recharged by infiltration of precipitation, but at a much slower rate. Recharge rates may increase as water levels in the aquifers are lowered by pumping, but water levels may decline for several years before sufficient recharge is induced to balance the rate of withdrawal. In some cases this balance may never be achieved without curtailment of withdrawals.

In parts of Dunn County, surface-water sources are in hydraulic connection with the aquifers. The aquifers either receive recharge from these sources or discharge into them, depending on head relationships.

Ground water contains variable amounts of dissolved minerals. Rain begins to dissolve minerals from particles of dust in the air as it falls, and continues this process as it percolates through the soil. The amount and kind of dissolved minerals in water depends upon many factors, including the solubility and types of rocks encountered, temperature, pressure, the length of time the water is in contact with the rocks, and the pH of the water.

The suitability of water for various uses is determined largely by the kind and amount of dissolved minerals it contains. The chemical constituents and physical properties most likely to be of concern are iron, sulfate, nitrate, fluoride, dissolved solids, hardness, temperature, odor, specific conductance, sodium-adsorption ratio (SAR), trace elements, and percent sodium. The relative importance of the above constituents and properties of water depends primarily on the use of the water. Table 1, modified from Durfor and Becker (1964, table 2), shows the major constituents usually found in water, their major sources, and their effects upon usability. Additional information regarding drinking-water standards may be found in the publication "Water Quality Criteria, 1972" (National Academy of Sciences — National Academy of Engineering, 1973).

The concentration of dissolved solids is a measure of the mineralization of the water. The dissolved-solids concentration is important 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 established for common carriers in interstate commerce.

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

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

Constituents	Major source	Effects upon usability	National Academy of Sciences — National Academy of Engineering (1973) recommended limits for drinking water
Silica (SiO_2)	Feldspars, ferromagnesian, and clay minerals.	In presence of calcium and magnesium, silica forms a scale that retards heat transfer in boilers and on steam turbines.	
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. Calcium and magnesium retard the suds-forming action of soap. High concentrations of magnesium have a laxative effect.	
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, dolomite, magnesite, and clay minerals.		
Sodium (Na)	Feldspars, clay minerals, evaporites, and cation exchange with calcium and magnesium on clay minerals.	More than 50 mg/L (milligrams per liter) sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers.	
Potassium (K)	Feldspars, feldspathoids, some micas, and minerals.		
Bicarbonate (HCO_3)	Limestone, dolomite, and anaerobic processes.	Upon heating of water to the boiling point, bicarbonate is changed to steam, carbonate, and carbon dioxide. Carbonate combines with alkaline earths (principally calcium and magnesium) to form scale.	
Carbonate (CO_3)			
Sulfate (SO_4)	Gypsum, anhydrite, and oxidation or weathering of sulfide minerals in lignite.	Combines with calcium to form scale. More than 500 mg/L tastes bitter and may be a laxative.	250 mg/L
Chloride (Cl)	Halite and sylvite.	In excess of 250 mg/L may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 mg/L.	250 mg/L
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 maximum limits depend on average of maximum daily temperatures. Maximum limits range from 1.4 mg/L at 32°C to 2.4 mg/L at 10°C.
Nitrate (NO_3)	Nitrogenous fertilizers, animal excrement, legumes, and plant debris.	More than 100 mg/L may cause a bitter taste and may cause physiological distress. Concentrations greatly in excess of 45 mg/L have been reported to cause methemoglobinemia in infants.	45 mg/L
Iron (Fe)	Natural sources: Amphiboles, ferromagnesian minerals, ferrous and ferric sulfides, oxides, carbonates, and clay minerals. Manmade sources: well casings, pump parts, and storage tanks.	If more than 100 ug/L (micrograms per liter) 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 200 ug/L iron is objectionable for most industrial uses. High concentrations of manganese cause difficulty in water-quality control.	300 ug/L
Manganese (Mn)			50 ug/L
Boron (B)	Tourmaline, biotite, and amphiboles.	Many plants are damaged by concentrations of 2,000 ug/L.	
Dissolved solids	Anything that is soluble.	Less than 300 mg/L is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	Because of the wide range of mineralization, it is not possible to establish a limiting value.

The hardness of water determines its usefulness for some industries. Hardness does not seriously affect the use of water for most purposes, but it does increase the consumption of soap. Hardness removal by a softening process increases suitability for domestic, laundry, and industrial purposes. The classifications of hardness used in this report are listed below:

Calcium and magnesium hardness, as $CaCO_3$ (milligrams per liter)	Hardness description
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

Two indices of the suitability of water for irrigation are SAR and specific conductance. SAR is related to the sodium hazard, and the specific conductance is related to the salinity hazard. The hazards increase as the numerical values of the indices increase. Figure 3 shows 16 classifications of water as determined by the SAR and specific conductance. For further information the reader is referred to "Diagnosis and Improvement of Saline and Alkali Soils" (U.S. Salinity Laboratory Staff, 1954).

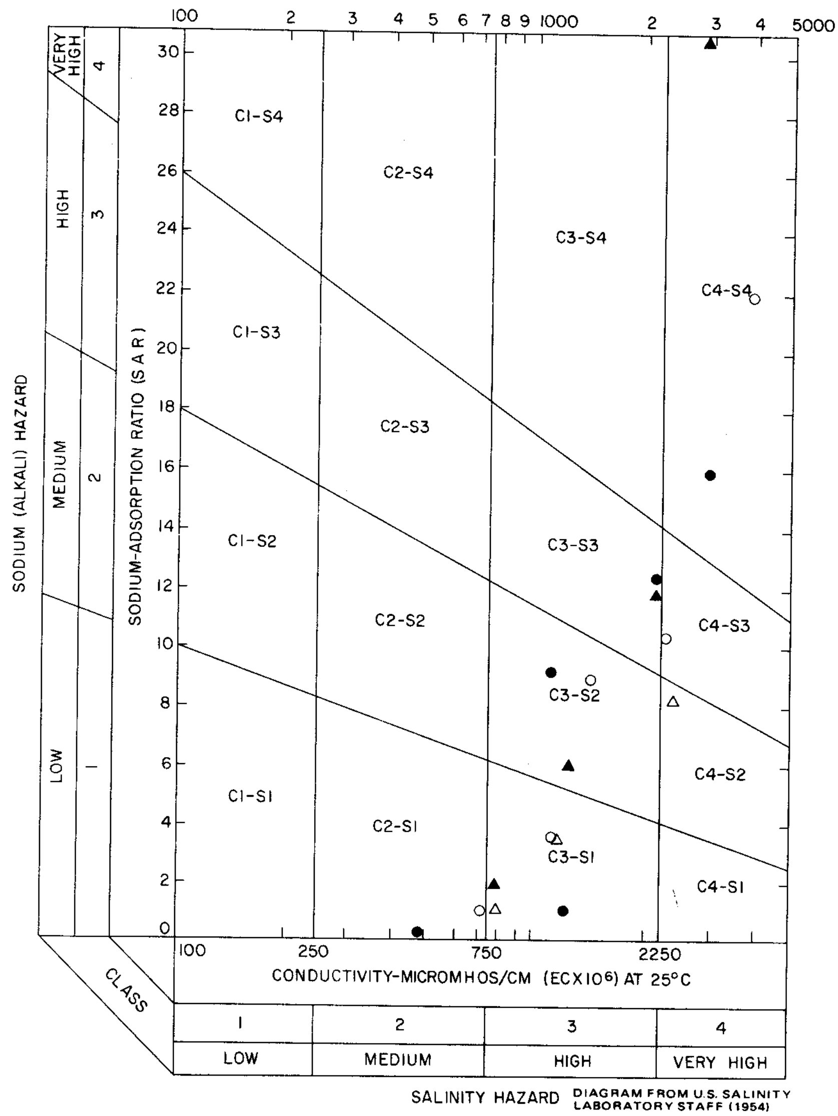
Elsewhere in this report numerous references are made to ground-water types, such as sodium bicarbonate, sodium sulfate, etc. These types are determined from inspection of the chemical analyses and represent the predominant cation (calcium, magnesium, or sodium) and anion (bicarbonate, chloride, or sulfate) present in the water.

Aquifers in the Preglacial Rocks

The preglacial sedimentary rocks in Dunn County were deposited in the intermittently subsiding Williston basin. The rocks have a maximum thickness of about 15,000 feet (4,600 m) in the deepest part of the basin (Hainer, 1956), which is located in northwestern Dunn County. The approximate thicknesses and predominant lithologies of the stratigraphic units[1], down to and including the Pierre Formation are shown in table 2.

The preglacial rocks contain thick sections of water-bearing material, but only those aquifers at relatively shallow depths are of economic importance at the present time (1977). Preglacial aquifers described in this report occur in the Upper Cretaceous Fox Hills and Hell Creek Formations and in the Tertiary Cannonball, Ludlow, Tongue River, and Sentinel Butte Formations.

[1]The stratigraphic nomenclature used in this report is that of the North Dakota Geological Survey and does not necessarily conform to that of the U.S. Geological Survey.



EXPLANATION

○ KILLDEER AQUIFER

● HORSE NOSE BUTTE AQUIFER

▲ KNIFE RIVER AQUIFER

△ GOODMAN CREEK AQUIFER

FIGURE 3.— Irrigation classifications of selected water samples from glacial-drift aquifers.

TABLE 2.—Generalized geologic section and water-yielding characteristics of geologic units in Dunn County, North Dakota

System	Series	Lithologic unit, group, or formation		Maximum thickness (feet)	Lithology	Water-yielding characteristics
Quaternary	Holocene	Alluvium		40	Silt, sand, and gravel.	Maximum yield of 50 gal/min to individual wells from thicker and more permeable sand and gravel deposits.
	Pleistocene	Glacial drift		310	Till, silt, sand, and gravel.	Yields as much as 1,000 gal/min to individual wells from thicker and more permeable sand and gravel deposits.
Tertiary	Eocene	Golden Valley Formation		375	Sandstone, silt, clay, claystone, lignite, and carbonaceous shale.	Yields 1 to 20 gal/min from springs.
	Paleocene	Fort Union Group	Sentinel Butte Formation	670	Clay, claystone, shale, sandstone, siltstone, and lignite.	Individual wells in sandstone will yield 5 to 100 gal/min. Individual wells in lignite will yield 1 to 200 gal/min.
			Tongue River Formation	490	Clay, claystone, shale, sandstone, siltstone, and lignite.	Yields to individual wells in sandstone generally less than 100 gal/min.
			Cannonball and Ludlow Formations, undifferentiated	660	Cannonball — marine sandstone, clay, shale, and siltstone. Ludlow — continental siltstone, sandstone, shale, clay, and lignite.	Yields to individual wells in sandstone generally less than 50 gal/min.
Upper Cretaceous		Hell Creek Formation		300	Siltstone, sandstone, shale, claystone, and lignite.	Yields from 5 to 100 gal/min to individual wells in sandstone.
		Montana Group	Fox Hills Formation	300	Sandstone, shale, and siltstone.	Yields to individual wells generally less than 200 gal/min from thicker sandstone beds. Locally, yields to individual wells may be as much as 400 gal/min.
			Pierre Formation	2,300	Shale and silt.	Not known to yield water to wells.

Fox Hills Aquifer

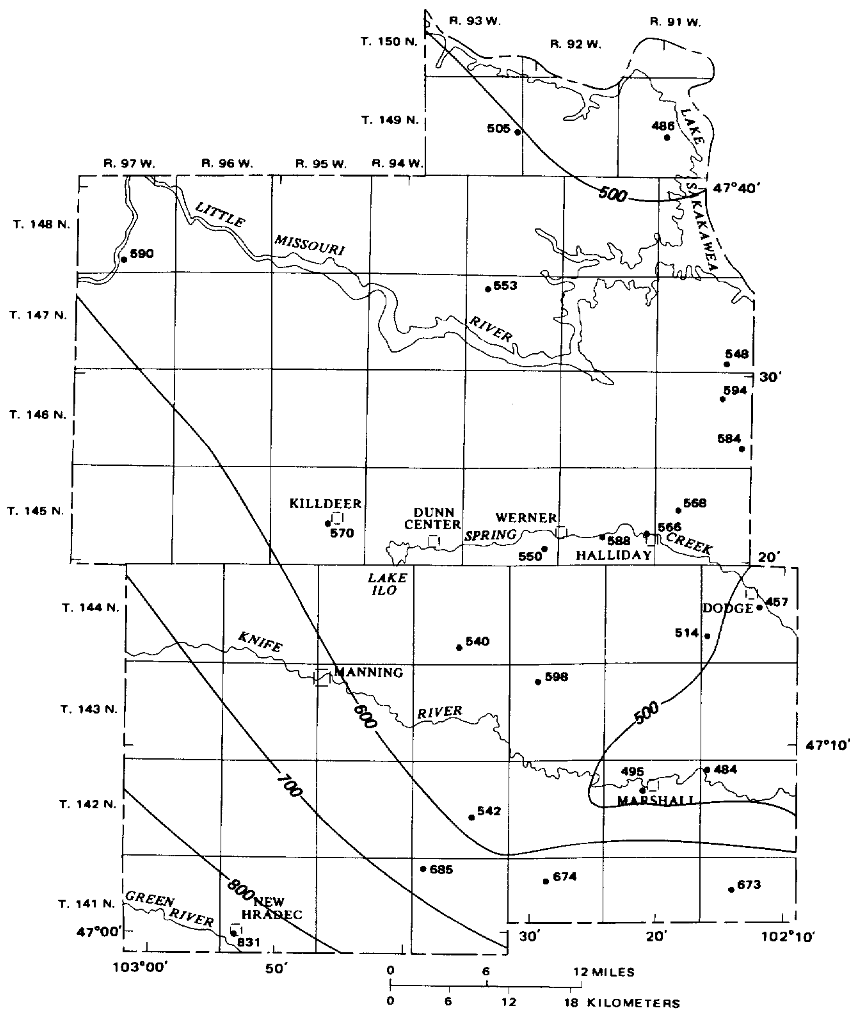
The Fox Hills Formation, which is marine in origin, underlies all of Dunn County. The depth to the top of the formation ranges from 1,330 feet (405 m) in the valley of the Little Missouri River in the northwestern part of the county to about 1,960 feet (597 m) in sec. 14, T. 146 N., R. 96 W., also in the northwestern part of the county. The formation ranges in thickness from about 80 to 300 feet (24 to 90 m) and is composed of interbedded sandstone, shale, and siltstone. It is underlain by the Pierre Formation and overlain by the Hell Creek Formation (pl. 1, in pocket). The basal contact is usually gradational but the upper contact may be either gradational or erosional (Feldmann, 1972). Structure contours drawn on top of the formation (fig. 4) show that it dips to the northeast. The sandstone beds in the Fox Hills Formation comprise the Fox Hills aquifer.

The Fox Hills aquifer is composed predominantly of very fine to medium-grained sandstone. Mechanical and hydrometer analyses of 11 sidewall cores indicate that the sandstone contains 2 to 37 percent interstitial clay and silt. The sandstone beds range in thickness from about 6 to 92 feet (2 to 28 m) and have a maximum aggregate thickness of about 158 feet (48 m).

Hydraulic-conductivity values for the Fox Hills and other preglacial aquifers listed in this report were obtained from drill-stem tests, recovery tests on flowing wells, slug tests, laboratory analyses of sidewall cores, and resistivity curves of calibrated electrical logs. The drill-stem tests were made by Johnston Division of Schlumberger Corp., (written commun., 1972-73), the recovery tests on flowing wells and the slug tests were analyzed using methods described by Lohman (1972), the sidewall cores were analyzed by Core Laboratories, Inc. (written commun., 1972-73), and the values from resistivity curves of electrical logs were determined using a method described by Croft (1971). Tests used to determine the hydraulic conductivity of the Fox Hills aquifer were made at different locations and at different depths, consequently the following values show the range in conductivities and indicate that the aquifer is not homogeneous.

Method	Hydraulic conductivity (ft/d)
Drill-stem test	0.5
Recovery tests	<1 - 1.9
Sidewall cores	<1 - 3.4
Resistivity curves	<1 - 13.4

The transmissivity determined from the drill-stem test was 38 ft^2/d (3.5 m^2/d). Transmissivity values obtained from the recovery tests ranged from 5 to 235 ft^2/d (0.5 to 22 m^2/d) with a mean of 49 ft^2/d (4.6 m^2/d). Values determined from electrical logs for individual sandstone beds ranged from less than 1 to



EXPLANATION

—700— STRUCTURE CONTOUR—Shows altitude of top of Fox Hills Formation. Contour interval 100 feet (30 meters). Datum is mean sea level

•673 TEST HOLE—Number is altitude, in feet above mean sea level

FIGURE 4.— Structure contours on top of the Fox Hills Formation.

about 670 ft^2/d (0.1 to 62 m^2/d), and transmissivities computed for the aggregate thicknesses of the sandstone beds ranged from 69 to about 1,200 ft^2/d (6.4 to 110 m^2/d). The transmissivity values obtained from the drill-stem and recovery tests generally are less than those obtained from the electrical logs because they were made on partially penetrating wells.

Specific capacities determined from the recovery tests ranged from 0.15 to 6.6 (gal/min)/ft [0.03 to 1.4 (L/s)/m] of drawdown with a mean of 1.5 (gal/min)/ft [0.31 (L/s)/m] of drawdown.

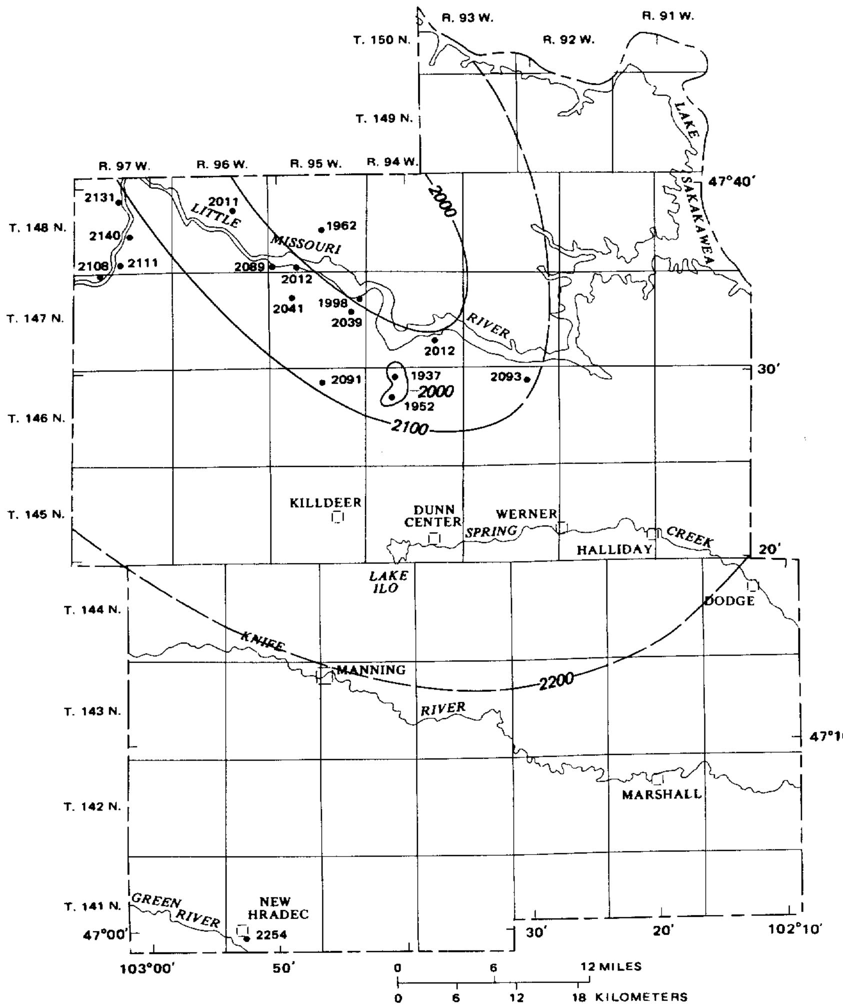
Potential yields from the Fox Hills aquifer will vary depending on the thickness and hydraulic conductivity of the sandstone penetrated. Yields from properly developed wells may be as much as 200 gal/min (13 L/s); however, in the extreme northwest corner of the county, test well 148-097-33ABB flowed an estimated 400 gal/min (25 L/s) before casing was installed.

Recharge to the Fox Hills aquifer probably occurs where the formation crops out in the extreme southwestern part of North Dakota and in eastern Montana. Discharge from the aquifer occurs as well discharge and lateral movement into adjacent areas.

The potentiometric contours shown in figure 5 indicate that water in the aquifer moves northeastward. The hydraulic gradient is about 6 ft/mi (1 m/km), except near the Little Missouri River where it increases to about 20 ft/mi (4 m/km). The increase in gradient is caused by the discharge of approximately 168 Mgal (636,000 m^3) of water annually from numerous flowing wells located in or adjacent to the river valley.

Water samples were collected from 25 wells tapping the Fox Hills aquifer. Chemical analyses of the samples indicate that the water in the aquifer is soft and of a sodium bicarbonate type. The minimum, maximum, and mean concentrations of selected constituents and properties are listed in the following table.

Constituent or property	Minimum	Maximum	Mean
Dissolved solids (mg/L)	1,180	2,300	1,486
Sodium, Na (mg/L)	494	913	604
Bircarbonate, HCO_3 (mg/L)	897	1,980	1,292
Sulfate, SO_4 (mg/L)	0	260	28
Chloride, Cl (mg/L)	82	292	170
Fluoride, F (mg/L)	.6	6.8	4.7
Iron, Fe (ug/L)	0	1,200	136
Nitrate, NO_3 (mg/L)	.3	3.9	1.2
Boron, B (ug/L)	71	2,700	1,639
Percent sodium	94	99	98.7
Sodium-adsorption ratio	29	95	86



EXPLANATION

—2200— — POTENTIOMETRIC CONTOUR—Shows altitude at which water level would have stood in tightly cased wells, 1972. Dashed where approximately located. Contour interval 100 feet (30 meters). Datum is mean sea level

• 2111 WELL—Number is altitude of water level, in feet above mean sea level

FIGURE 5.— Potentiometric surface of the Fox Hills aquifer, 1972.

Aquifers in the Hell Creek Formation

The Hell Creek Formation, which is continental in origin, underlies the study area at depths ranging from about 1,150 feet (350 m) in the southeastern part of the area to about 1,730 feet (527 m) in the northwestern part. The formation ranges in thickness from about 150 to 300 feet (46 to 90 m) and is composed of interbedded siltstone, shale or claystone, poorly consolidated sandstone, and a few thin lignite beds. Structure contours drawn on the top of the formation show that it dips generally northeastward (fig. 6).

Croft (1973, p. 25) stated that sandstone beds in the upper part of the Fox Hills Formation and in the lower part of the Hell Creek Formation form a major aquifer system in adjacent Mercer County. This aquifer system appears to extend throughout most of Dunn County, but it is absent in the northwestern part of the county owing to nondeposition of the basal Hell Creek sandstone. Consequently, the terminology used by Croft in Mercer County is not used in this report.

The aquifers in the Hell Creek Formation consist of fine-grained sandstone beds that range in thickness from about 10 to 60 feet (3 to 20 m) and have a maximum aggregate thickness of about 106 feet (32 m). Because there is no evidence of a hydraulic connection between the beds, each of the sandstone beds is considered to be a separate aquifer. The aquifers underlie most of the county, but, as shown on plate 1, they pinch out to the northwest and bifurcate to the southeast.

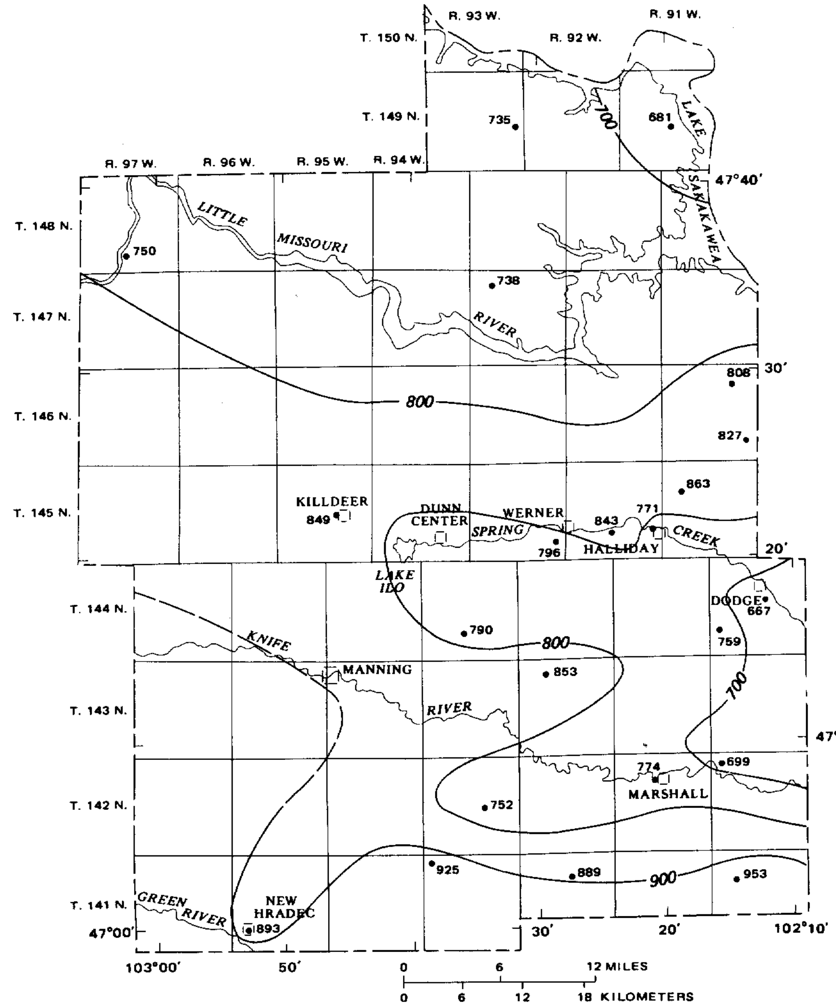
Hydraulic-conductivity values for aquifers in the Hell Creek Formation were determined from sidewall-core analyses, recovery tests on three flowing wells, and resistivity curves of electrical logs. The values obtained from sidewall cores ranged from 0.06 to 1.2 ft/d (0.02 to 0.37 m/d); analysis of recovery tests on the flowing wells indicated hydraulic conductivity values of 1.1, 0.4, and 0.5 ft/d (0.34, 0.1, and 0.2 m/d); values calculated from resistivity curves of electrical logs were less than 0.9 ft/d (0.3 m/d).

Transmissivity values obtained from the recovery tests were 67, 26, and 14 ft^2/d (6.2, 2.4, and 1.3 m^2/d). Transmissivity values determined from the resistivity curves for individual sandstone beds ranged from 4 to 71 ft^2/d (0.4 to 6.6 m^2/d). Specific capacities obtained from the recovery tests ranged from 0.4 to 1.0 (gal/min)/ft [0.1 to 0.2 (L/s)/m].

Depending on the thickness and hydraulic conductivity of the aquifer penetrated, properly developed wells should yield as much as 100 gal/min (6 L/s).

Recharge to the aquifers in the Hell Creek Formation occurs outside the study area. Discharge from the aquifers occurs as well discharge and lateral movement into adjacent areas. Annual discharge from three flowing wells known to tap aquifers in the Hell Creek Formation is about 4.5 Mgal (17,000 m^3). Inadequate water-level data prevent determination of the hydraulic gradient.

Water from aquifers in the Hell Creek Formation is soft and is a sodium bicarbonate type. The minimum, maximum, and mean concentrations of selected constituents and properties of water samples collected from the aquifers are listed in the following table.



EXPLANATION

—900— — STRUCTURE CONTOUR–Shows altitude of top of Hell Creek Formation. Dashed where approximately located. Contour interval 100 feet (30 meters). Datum is mean sea level

•750 TEST HOLE—Number is altitude, in feet above mean sea level

FIGURE 6.— Structure contours on top of the Hell Creek Formation.

Constituent or property	Minimum	Maximum	Mean
Dissolved solids (mg/L)	1,360	2,080	1,588
Sodium, Na (mg/L)	584	837	656
Bicarbonate, HCO_3 (mg/L)	1,350	1,730	1,554
Sulfate, SO_4 (mg/L)	13	20	17
Chloride, Cl (mg/L)	.3	323	119
Fluoride, F (mg/L)	1	5.7	2.8
Iron, Fe (ug/L)	0	580	230
Nitrate, NO_3 (mg/L)	1	1.5	1.1
Boron, B (ug/L)	1,100	2,200	1,560
Percent sodium	96	99	98
Sodium-adsorption ratio	35	86	65

Aquifers in the Undifferentiated Cannonball-Ludlow Formations

The Cannonball Formation, which is marine in origin, and the Ludlow Formation, which is continental in origin, are interfingered throughout Dunn County. The undifferentiated Cannonball-Ludlow Formations underlie the county at depths ranging from about 570 feet (174 m) in the southeastern corner of the county to about 1,130 feet (344 m) in the northwestern quarter of the county. The formations, which range in thickness from 495 to 660 feet (151 to 200 m), consist of interbedded siltstone, poorly consolidated sandstone, shale or clay, and lignite.

Croft (1973, p. 35) indicated that sandstone beds in the upper part of the Hell Creek Formation and in the lower part of the undifferentiated Cannonball-Ludlow Formations were hydraulically connected and formed a major aquifer system in adjacent Mercer County. This aquifer system has not been extended into Dunn County because the upper Hell Creek sandstone is absent.

The aquifers in the undifferentiated Cannonball-Ludlow Formations consist predominantly of fine to very fine silty sandstone beds that range in thickness from about 10 to 125 feet (3 to 38 m). There is no evidence indicating a hydraulic connection between the beds, consequently each bed is considered to be a separate aquifer (pl. 1).

Hydraulic-conductivity values were derived from laboratory analyses of sidewall cores. The values obtained are listed in the following table.

Recovery tests made on two flowing wells indicated transmissivities of 4 and 3 ft^2/d (0.4 and 0.3 m^2/d). A slug test made in well 141-093-16AAA1 indicated a transmissivity of about 4 ft^2/d (0.4 m^2/d). Specific capacities obtained from the recovery tests were 0.12 and 0.09 (gal/min)/ft [0.02 (L/s)/m)] of drawdown.

Potential yields of wells developed in aquifers in the undifferentiated Cannonball-Ludlow Formations will vary depending on the extent, thickness,

Sidewall-core analyses

Location	Sampling depth (in feet)	Hydraulic conductivity (ft/d)
141-096-29CCC	980	0.06
141-096-29CCC	1,210	.23
141-096-29CCC	1,284	.11
142-092-09DAB	1,160	.02
145-092-25ABB	1,210	.45
145-095-22DAD1	920	.26
148-097-33ABB	725	.34

and hydraulic conductivity of the aquifers penetrated. Properly developed wells tapping the aquifers probably will yield from 1 to 50 gal/min (0.06 to 3 L/s).

Recharge to aquifers in the lower part of the undifferentiated Cannonball-Ludlow Formations occurs outside the study area. Aquifers in the upper part of the formations probably are recharged by downward movement of water from the Tongue River Formation. Discharge from the aquifers occurs as well discharge and lateral movement into adjacent areas. The discharge from four flowing wells known to tap aquifers in the undifferentiated Cannonball-Ludlow Formations ranged from about 0.7 to 4 gal/min (0.04 to 0.3 L/s). Total annual discharge from these wells is about 5.3 Mgal (20,100 m^3). Inadequate water-level data prevent determination of the hydraulic gradient.

Chemical analyses of water samples collected from four wells known to tap aquifers in the undifferentiated Cannonball-Ludlow Formations indicate that the water is soft and is a sodium bicarbonate type. The minimum, maximum, and mean concentrations of selected constituents and properties are as follow:

Constituent or property	Minimum	Maximum	Mean
Dissolved solids (mg/L)	1,680	1,940	1,855
Sodium, Na (mg/L)	700	803	760
Bicarbonate, HCO_3 (mg/L)	1,750	2,110	1,932
Sulfate, SO_4 (mg/L)	0	19	5.6
Chloride, Cl (mg/L)	25	148	66
Fluoride, F (mg/L)	1.3	2.7	2
Iron, Fe (ug/L)	0	80	25
Nitrate, NO_3 (mg/L)	1	1.3	1.1
Boron, B (ug/L)	380	3,000	1,305
Percent sodium	99	99	99
Sodium-adsorption ratio	74	97	86

Aquifers in the Tongue River Formation

The Tongue River Formation, which is continental in origin, underlies all of Dunn County. The depth to the top of the formation ranges from about 230 feet (70 m) in the valley of the Little Missouri River in the northwestern corner of the county to about 750 feet (229 m) in sec. 14, T. 146 N., R. 96 W. The formation ranges in thickness from about 290 to 490 feet (88 to 150 m), and consists of interbedded siltstone, claystone or shale, poorly consolidated sandstone, lignite, and occasional limestone lenses or concretions. The top of the formation generally consists of lignite or carbonaceous shale. The basal part of the formation generally consists of an extensive, poorly consolidated sandstone. Structure contours drawn on the base of the formation show that the formation generally dips to the northeast (fig. 7).

Aquifers in the Tongue River Formation consist of very fine to fine-grained sandstone beds. The sandstone beds, which range in thickness from about 10 to 100 feet (3 to 30 m), frequently pinch out or grade laterally into siltstone or sandy clay. Data are insufficient to determine if there is a hydraulic connection between the sandstone beds, consequently each bed is considered to be a separate aquifer.

Hydraulic conductivities determined from laboratory analyses of sidewall cores and from slug tests are as follow:

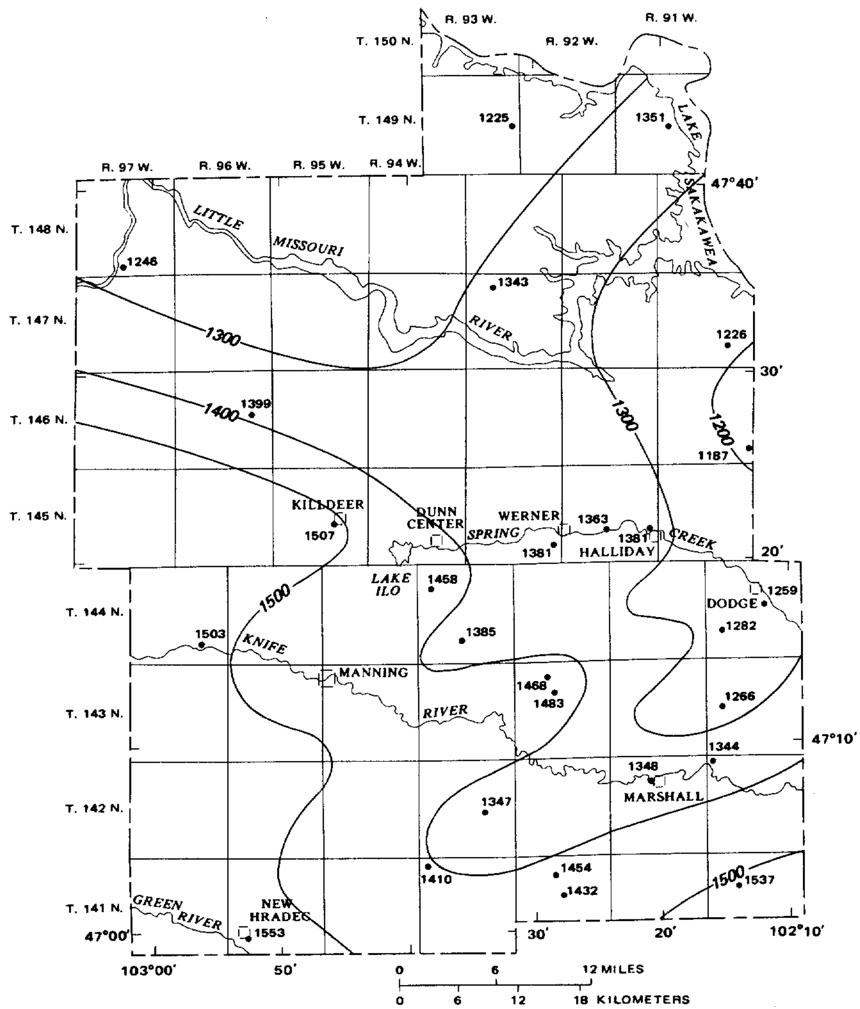
Sidewall-core analyses

Location	Sampling depth (feet)	Hydraulic conductivity (ft/d)
141-096-29CCC	675	0.95
141-096-29CCC	892	.088
142-092-09DAB	421	.173
142-092-09DAB	605	.010
148-097-33ABB	345	.176

Slug tests

Location	Screened interval (feet)	Hydraulic conductivity of screened interval (ft/d)
143-091-19AAA1	652-670	0.4
144-097-26CBD1	700-718	.9

The transmissivity values obtained from slug tests and from recovery tests on flowing wells ranged from 7 to 96 ft^2/d (0.7 to 8.9 m^2/d). Specific capacities of



EXPLANATION

—*1300*— STRUCTURE CONTOUR—Shows altitude of base of Tongue River Formation. Contour interval 100 feet (30 meters). Datum is mean sea level

•1246 TEST HOLE—Number is altitude, in feet above mean sea level

FIGURE 7.— Structure contours on base of the Tongue River Formation.

the flowing wells ranged from 0.15 to 2.3 (gal/min)/ft [0.03 to 0.48 (L/s)/m] of drawdown.

Potential yields of wells developed in the aquifers will vary depending on the extent, thickness, and hydraulic conductivity of the aquifer penetrated. Properly developed wells tapping the aquifers should yield from 10 to as much as 200 gal/min (0.6 to 13 L/s).

Aquifers in the Tongue River Formation are recharged by leakage from aquifers in the overlying Sentinel Butte Formation. Discharge from the aquifers occurs as well discharge and lateral movement into adjacent areas. Measured discharge rates of flowing wells tapping aquifers in the Tongue River Formation ranged from less than 1 gal/min (0.06 L/s) to 6 gal/min (0.4 L/s). Total annual discharge from wells is about 32.8 Mgal (124,000 m^3).

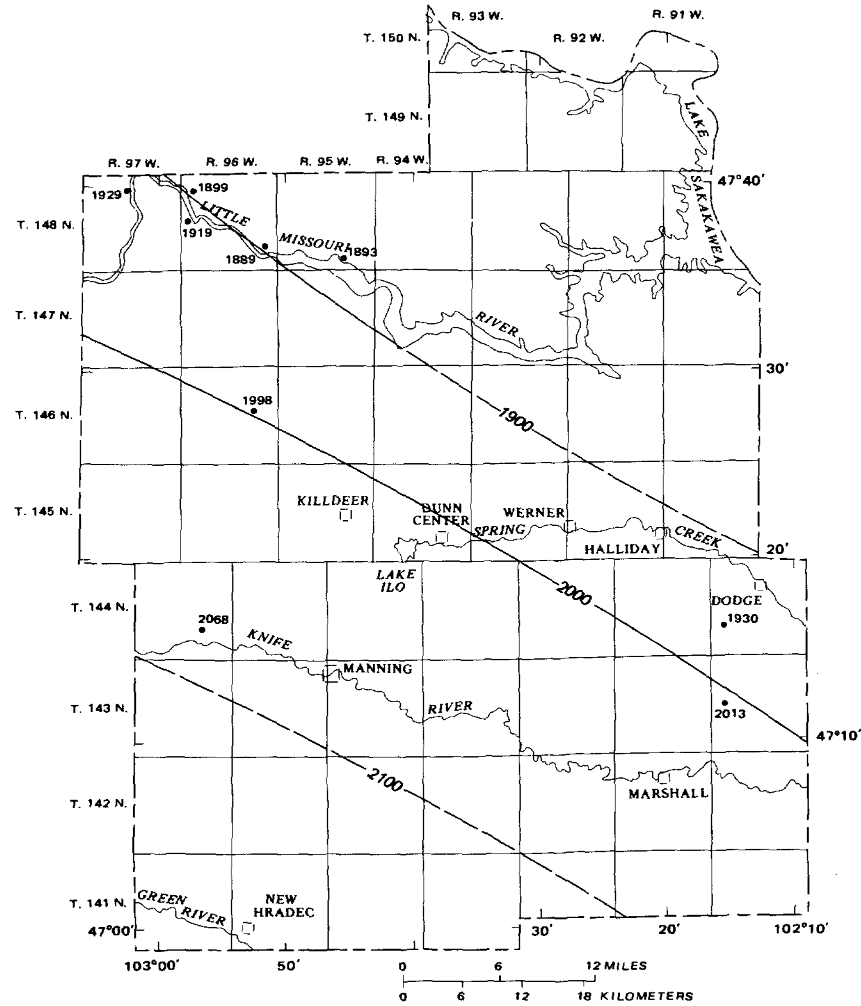
Potentiometric contours (fig. 8), which were drawn by using static water levels measured in October 1974, indicate that the water in the basal Tongue River aquifer moves northeastward under a hydraulic gradient of about 6 ft/mi (1 m/km).

Chemical analyses of 20 water samples indicate that the water in the Tongue River aquifers is predominantly soft and is a sodium bicarbonate type. Minimum, maximum, and mean concentrations of selected constituents and properties are shown in the following table.

Constituent or property	Minimum	Maximum	Mean
Dissolved solids (mg/L)	1,730	2,610	2,043
Sodium, Na (mg/L)	229	973	808
Bicarbonate, HCO_3 (mg/L)	746	2,480	2,112
Sulfate, SO_4 (mg/L)	0	1,290	89
Chloride, Cl (mg/L)	10	159	32
Fluoride, F (mg/L)	.1	4.6	2.6
Iron, Fe (ug/L)	0	570	105
Nitrate, NO_3 (mg/L)	1	26	2.3
Boron, B (ug/L)	0	770	288
Percent sodium	26	99	86
Sodium-adsorption ratio	25	93	78

Aquifers in the Sentinel Butte Formation

The Sentinel Butte Formation, which is continental in origin, occurs throughout Dunn County, except where glacial melt-water channels have been eroded below the base of the formation. It is exposed except where overlain by outliers of the Golden Valley Formation, isolated deposits of till, and(or) glaciofluvial and alluvial deposits (fig. 9).



EXPLANATION

—*2000*— — POTENTIOMETRIC CONTOUR—Shows altitude at which water level would have stood in tightly cased wells, 1974. Dashed where approximately located. Contour interval 100 feet (30 meters). Datum is mean sea level

•1998 WELL—Number is altitude of water level, in feet above mean sea level

FIGURE 8.— Potentiometric surface of basal Tongue River aquifer, 1974.

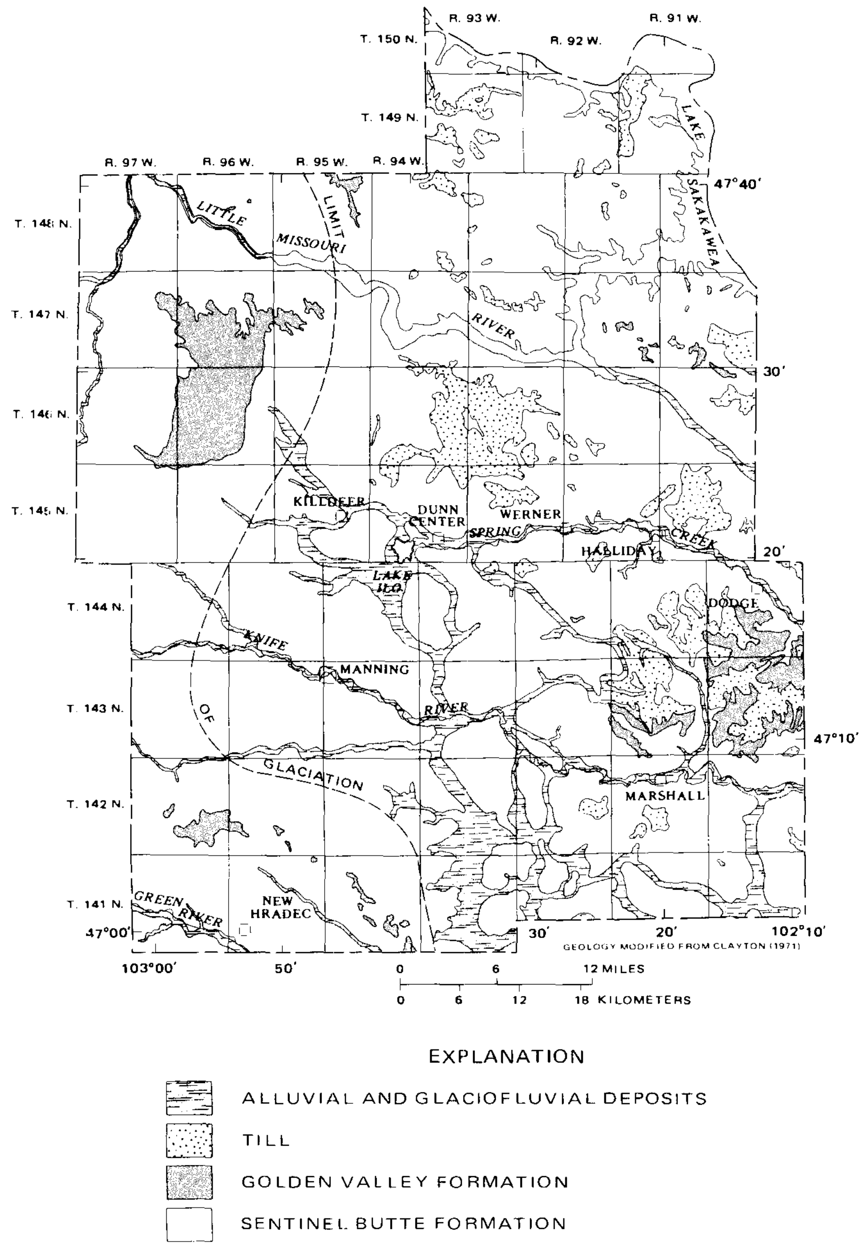


FIGURE 9.— Surficial geologic units in Dunn County.

The formation consists of interbedded clay, shale, claystone, siltstone, poorly consolidated sandstone, and lignite. It has a maximum thickness of about 670 feet (200 m).

The aquifers in the Sentinel Butte Formation consist of poorly consolidated sandstone and fractured lignite. Most of the wells in Dunn County tap sandstone or lignite aquifers in the upper part of the Sentinel Butte Formation.

Sandstone aquifers — The sandstone aquifers are composed predominantly of fine sand enclosed in a matrix of 20 to 40 percent clay and silt. The aquifers range in thickness from a few feet to a maximum of about 119 feet (36 m) and occur at depths ranging from about 16 to 700 feet (4.9 to 210 m). The most extensive aquifer occurs near the base of the formation. This basal sandstone aquifer, which has a maximum thickness of about 80 feet (24 m; pl. 1), underlies much of the county, but is absent in the central and southeastern parts.

Hydraulic conductivity and transmissivity values were obtained from laboratory analyses of sidewall cores and from slug tests. These values, along with other pertinent data, are as follow:

Sidewall-core analyses

Location	Sampling depth (feet)	Hydraulic conductivity (ft/d)
141-096-29CCC	223	0.18
148-097-33ABB	215	.057

Slug tests

Location	Screened interval (feet)	Hydraulic conductivity of screened interval (ft/d)	Transmissivity of screened interval (ft²/d)
141-093-16AAA2	378-384	0.5	3
143-091-19AAA3	147-153	.5	3
144-094-07DAA1	114-130	.2	4
145-091-05DDD2	567-585	.2	3
145-092-25AAC	68-74	.5	3
148-093-04CBD	462-480	.06	1

Potential yields of wells developed in the sandstone aquifers will vary depending on the extent, thickness, and hydraulic conductivity of the aquifer penetrated. Yields of properly developed wells probably will range from 1 to about 100 gal/min (0.06 to 6 L/s).

Water from the sandstone aquifers is predominantly a sodium bicarbonate type. Analyses of samples collected from 81 wells tapping the sandstone aquifers show that the water is predominantly hard to very hard. Minimum, maximum, and mean concentrations of selected constituents and properties are listed in the following table.

Constituent or property	Minimum	Maximum	Mean
Dissolved solids (mg/L)	123	7,060	1,742
Sodium, Na (mg/L)	9.2	1,410	466
Bicarbonate, HCO_3 (mg/L)	53	2,360	841
Sulfate, SO_4 (mg/L)	6.2	4,290	586
Chloride, Cl (mg/L)	0	130	12.5
Fluoride, F (mg/L)	.1	6.7	1.3
Iron, Fe (ug/L)	0	14,000	1,186
Nitrate, NO_3 (mg/L)	0	424	20
Boron, B (ug/L)	0	2,300	380
Percent sodium	9	99	66
Sodium-adsorption ratio	.2	98	27

Lignite aquifers – Lignite beds are randomly spaced throughout the entire thickness of the Sentinel Butte Formation. They range in thickness from 1 to about 20 feet (0.3 to 6 m) and occur at depths ranging from about 15 to 600 feet (5 to 180 m). Available data indicate that the upper part of the formation generally contains thicker and more numerous lignite beds than the lower part. Geologic section B-B′ (pl. 2, in pocket) shows the extent and thickness of lignite beds in the upper part of the Sentinel Butte Formation between the cities of Killdeer and Halliday.

Data obtained from test drilling and drillers logs indicate that not all lignite beds will yield water. Also, a lignite bed may yield water at one location, but will yield little or no water at other locations. The amount of water yielded is related to the size and extent of the fractures in the lignite and to the transmissivity of the adjacent rocks.

Hydraulic properties of some of the lignite aquifers were determined from recovery tests on three flowing wells and two pumping tests. The recovery tests indicated transmissivities of 920, 51, and 49 ft^2/d (85, 4.7, and 4.6 m^2/d).

Pumping tests were made by the North Dakota State Water Commission (R. W. Schmid, written commun., 1975) on two superimposed lignite aquifers at a site about half a mile (0.8 km) northeast of Dunn Center. Test hole 145-094-26AAA1 penetrated saturated lignite from 12 to 28 feet (3.7 to 8.5 m) and 62 to 70 feet (19 to 21 m) below lsd.

The test on the lower aquifer was made using a production well constructed by the State Water Commission. The production well extended through the entire thickness of lignite, but was cased (6-inch or 152-mm plastic pipe) only to the top of the lignite. Three 1¼-inch (31.8-mm) screened and gravel-packed observation wells were spaced at distances of 50, 100, and 200 feet (15, 30, and

41 m) from the production well to monitor the effects of pumping. The production well was pumped at a constant rate of 28 gal/min (8.5 L/s) for 50 hours. The discharge rate was regulated by a gate valve in the discharge pipe and was measured with a 5-gallon (19-L) bucket and a stopwatch.

Analyses of the data indicated that the lower aquifer had a transmissivity of 750 ft^2/d (70 m^2/d) and a storage coefficient of 0.0002. The drawdown in the production well after 3,000 minutes was 29.65 feet (9 m) and the specific capacity was 0.9 (gal/min)/ft [0.2 (L/s)/m].

The test on the upper aquifer also was made by using a production well constructed by the State Water Commission. The production well also extended through the entire thickness of the lignite but was cased (6-inch or 152-mm plastic pipe) only to the top of the lignite. Three 1¼-inch screened and gravel-packed observation wells were spaced at distances of 40, 70, and 100 feet (12, 21, and 30 m) from the production well to monitor the effects of pumping. The production well was pumped at a constant rate of 128 gal/min (8 L/s) for 22 hours. The discharge rate was measured using a manometer and an orifice.

Analyses of the data for the upper lignite aquifer gave a transmissivity of 19,500 ft^2/d (1,810 m^2/d) and a storage coefficient of 0.007. The drawdown in the production well after 1,320 minutes was 1.89 feet (0.58 m) and the specific capacity was 68 (gal/min)/ft [14 (L/s)/m] of drawdown.

Depending on the thickness and the degree of fracturing of the lignite and the transmissivity of the adjacent rocks, potential yields of wells developed in the lignite aquifers will range from about 1 to as much as 200 gal/min (0.06 to 13 L/s).

Water from the lignite aquifers is predominantly a sodium bicarbonate or sodium bicarbonate-sulfate type. Analyses of samples collected from 63 wells tapping the lignite aquifers show that water is predominantly hard to very hard. The following table shows minimum, maximum, and mean concentrations of selected constituents and properties in water from the lignite aquifers.

Constituent or property	Minimum	Maximum	Mean
Dissolved solids (mg/L)	250	9,090	1,526
Sodium, Na (mg/L)	15	1,820	416
Bicarbonate, HCO_3 (mg/L)	192	1,320	714
Sulfate, SO_4 (mg/L)	26	5,210	572
Chloride, Cl (mg/L)	0	309	14
Fluoride, F (mg/L)	.2	5.7	1.3
Iron, Fe (ug/L)	0	21,000	1,185
Nitrate, NO_3 (mg/L)	.7	450	9.99
Boron, B (ug/L)	0	1,600	389
Percent sodium	7	99	72
Sodium-adsorption ratio	.4	91	21

Four of the samples had nitrate concentrations exceeding the 45 mg/L maximum limit recommended for public use. The origin of the high nitrate concentrations in the four samples is not known specifically. However, because the samples were collected from wells located in feedlots or holding pens, it is suspected that the nitrate is derived from the infiltration of water contaminated by animal wastes.

Water from the lignite aquifers frequently is colored. The color, which varies from a slight yellowish tint to the color of well-brewed coffee, appears to be related to the amount of dissolved organic carbon in the water. The following comparisons seems to verify this assumption. The water from well 145-094-26AAA3 had a slight yellowish tint; the chemical analysis indicated a color value of 70 and a dissolved organic carbon concentration of 24 mg/L. The water from well 145-094-26AAA4 was very dark; the chemical analysis indicated a color value of 800 and a dissolved organic carbon concentration of 97 mg/L.

Recharge, discharge, and movement. — The sandstone and lignite aquifers in the Sentinel Butte Formation are recharged by infiltration of precipitation.

Ground water is discharged from the aquifers by wells, by springs, by seepage into streams, and by movement into adjacent areas. Most wells have to be pumped; however, there are some flowing wells located in or adjacent to Spring Creek valley between Halliday and Killdeer and in the Knife River valley in the vicinity of Marshall. The flowing wells are developed in lignite aquifers and have discharge rates ranging from two-thirds to about 10 gal/min (0.04 to 0.6 L/s). Annual discharge from the flowing wells is about 18.3 Mgal (69,000 m^3).

The springs commonly emerge from lignite, or less commonly from sandstone, outcropping on the sides of buttes, hills, and valley walls. Discharge rates of these springs range from about 1 to 80 gal/min (0.06 to 5 L/s), but generally are less than 6 gal/min (0.4 L/s).

Discharge of ground water into streams was verified by low-flow measurements made in Spring Creek and the Knife River on October 22 and 23, 1974. Precipitation recorded prior to the measurements was 0.07 inch (1.8 mm) on October 14. The low-flow measurements made in Spring Creek show that the cumulative discharge of the creek over a distance of 54 miles (87 km) was 4.1 ft^3/s (116 L/s; fig. 10). Most of this water was derived from ground-water seepage from the adjacent sandstone and lignite aquifers in the Sentinel Butte Formation. However, water-level measurements indicate that a glacial sand and gravel aquifer probably contributes some water to the creek in the vicinity of Killdeer. The increase in discharge downstream from measuring site 145-094-36AB is attributed to an increase in the ground-water seepage and to the waste water derived from the flowing wells.

Low-flow measurements made in the Knife River in October 1974 show that the cumulative discharge in the river increased 3.6 ft^3/s (102 L/s; fig. 11) over a distance of 88 miles (424 km). The water in the stream is derived mainly from the ground-water seepage from sandstone and lignite aquifers in the adjacent Sentinel Butte Formation and from the discharge of springs emanating from the

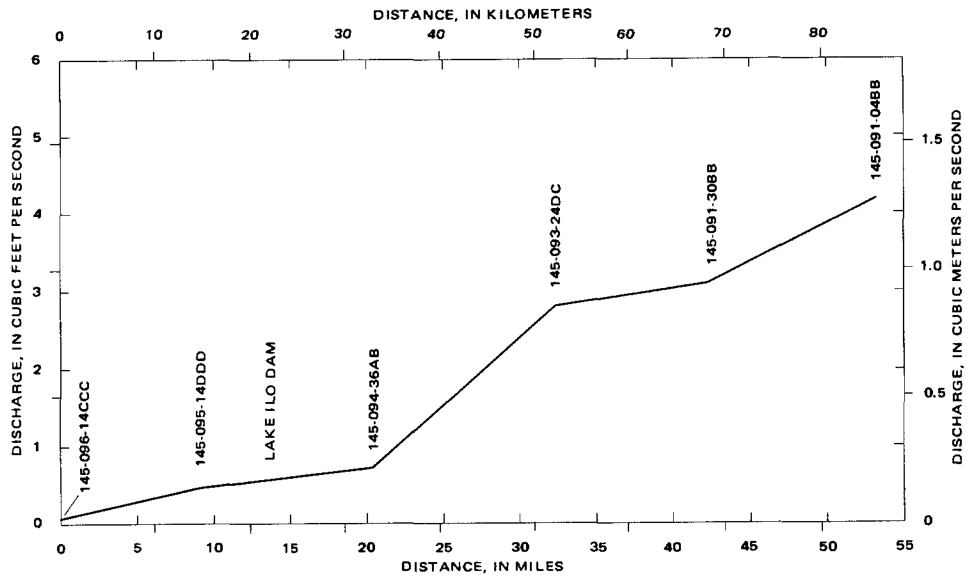


FIGURE 10.— Cumulative discharge of Spring Creek, October 1974.

valley walls. East of measuring site 143-094-19DAA some of the discharge may be derived from glacial-drift aquifers.

Data are inadequate to determine the direction of ground-water movement in all of the sandstone and lignite aquifers in the Sentinel Butte Formation. Water-level measurements made in five wells tapping the basal sandstone aquifer indicate that the ground water is moving in a northeasterly direction. Head measurements made in four flowing wells developed in the relatively extensive basal lignite bed shown on geologic section B-B′ (pl. 2) indicate that ground water is moving in an eastward direction.

Generalized geohydrology of the Sentinel Butte Formation. —Water-level measurements made in observation wells developed in the sandstone and lignite aquifers in the upper part of the Sentinel Butte Formation show that the hydraulic head in these aquifers is higher than in the basal sandstone aquifer. Water levels in the basal sandstone aquifer, at least locally, are only 1 to 2 feet (0.3 to 0.6 m) higher than those in the basal Tongue River aquifer. These differences in head indicate that ground water is moving downward into the Tongue River aquifers and probably into aquifers in the upper part of the undifferentiated Cannonball-Ludlow Formations. The approximate equality of the hydraulic heads in the basal Sentinel Butte aquifer and the basal Tongue River aquifer suggests a relatively high transmissivity and transition from vertical to horizontal flow near the base of the Tongue River aquifer.

Within the major flow system, there are local flow systems in which the movement of ground water is upward. The existence of these systems is indicated by the presence of relatively shallow flowing wells in the valley of Spring Creek and in the valley of the Knife River.

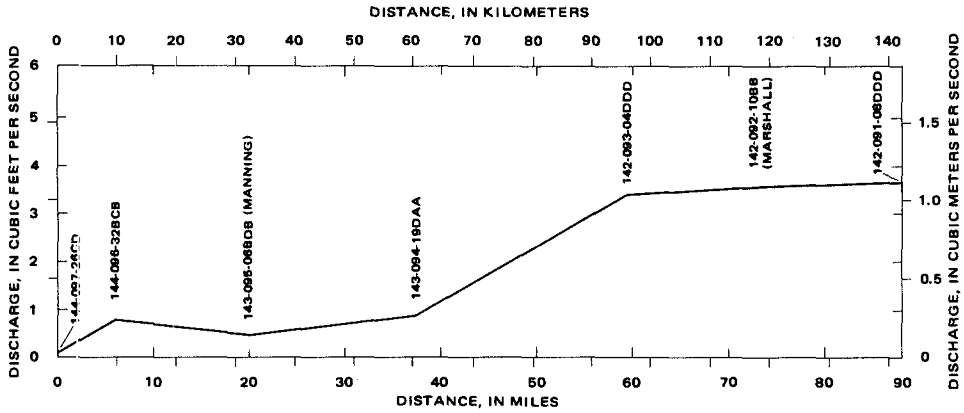


FIGURE 11.— Cumulative discharge of the Knife River, October 1974.

Aquifers in the Golden Valley Formation

The Golden Valley Formation, which is continental in origin, occurs as outliers overlying the Sentinel Butte Formation. The formation has a maximum thickness of about 375 feet (114 m) in sec. 26, T. 147 N., R. 96 W. (C. G. Carlson, written commun., 1975). At this location, the formation consists of fine-grained sandstone that is underlain by beds of silt, clay or claystone, lignite, and carbonaceous shale. Exposures of the formation occurring in other parts of the county consist predominantly of silt and clay.

The available data indicate that aquifers in the Golden Valley Formation consist predominantly of fractured lignite. The aquifers are small in areal extent and occur only in the southeastern parts of Tps. 146 and 147 N., R. 96 W.

No wells are known to tap the lignite aquifers; however, four springs, reported to be discharging from lignite aquifers, yield from 1 to 20 gal/min (0.06 to 1.3 L/s). Specific conductances of the water samples from the springs ranged from about 500 to 2,950 umho/cm (micromho per centimeter).

Aquifers in the Glacial Drift

The glacial drift in Dunn County consists of till and glaciofluvial sand and gravel deposits. The till, which occurs as isolated remnants overlying the Sentinel Butte Formation, is not known to yield water to wells in the county. The glaciofluvial sand and gravel deposits, which are confined in glacial melt-water channels, contain large quantities of ground water.

The availability of ground water from the glacial-drift aquifers is shown on plate 3 (in pocket). For convenience of discussion and identification in this report and for future reference, the aquifers are named after nearby cities, streams, or prominent landmarks. However, if an aquifer has been formally named in an adjacent county and the aquifer extends into Dunn County the name applied in the adjacent county takes precedence. The order of discussion is generally from the most productive aquifer to the least productive.

Where sufficient test drilling, hydrologic and geologic data are available, an estimate of ground-water availability from storage is given for each aquifer. The estimates are in acre-feet and are products of areal extent, thickness, and specific yield. The storage estimates are provided for comparison purposes only and are based on static conditions. They do not take into account recharge, discharge, or ground-water movement between adjacent aquifers. The quantitative evaluation of these factors is beyond the scope of this study.

The yield values shown on the availability map (pl. 3) are based on transmissivities derived from a method described by Keech (1964). Because the aquifers generally are lenticular in cross section, the largest yields usually are obtainable from the central and thickest parts.

The ground-water availability map should be used with the understanding that the estimated yields are for fully penetrating, properly screened and developed wells of adequate diameter. The map is intended as a general guide for use in developing ground water and not as a map to locate specific wells. Few if any aquifers are so uniform in areal extent, thickness, and hydrologic properties that production wells can be drilled without preliminary test drilling.

Killdeer Aquifer

The Killdeer aquifer underlies an area of about 74 mi^2 (190 km^2) in Dunn County. It extends southward from T. 146 N., Rs. 95 and 96 W., to the Stark County line in the southeast corner of T. 141 N., R. 94 W. From this point the aquifer extends east along the northern edge of Stark County. The tributary channels extending northward from the Stark County line in T. 141 N., Rs. 92 and 93 W. are hydraulically connected to the aquifer in Stark County and are therefore considered to be part of the Killdeer aquifer.

The aquifer is composed predominantly of fine to medium sand, but several test holes penetrated fine to coarse gravel near the base. It has a maximum thickness of 233 feet (71 m) and a mean thickness of about 80 feet (24 m). As shown in sections C-C′, D-D′, and E-E′ on plate 4 (in pocket), the aquifer generally is overlain by and interbedded with clay and silt.

One pumping test was made in the Killdeer aquifer in May 1973 by the North Dakota State Water Commission (R. W. Schmid, written commun.). The production well (145-095-29ADD3) was screened from 60 to 110 feet (18 to 34 m) in sand. Eight observation wells, spaced at distances ranging from 100 to 980 feet (30 to 300 m) from the production well, were equipped with continuous water-level recorders and electrical sensing devices to monitor water-level changes. The production well was pumped for 7,200 minutes at a rate of 266 gal/min (17 L/s). Analyses of the test data indicated a transmissivity of about 10,000 ft^2/d (930 m^2/d) and a storage coefficient of 0.02.

Depending on the thickness and hydraulic conductivity of the material penetrated, properly developed wells in the aquifer should yield from 50 to as much as 1,000 gal/min (3 to 63 L/s; pl. 3).

The aquifer is recharged by infiltration of precipitation through the overlying silt and clay. Water is discharged from the aquifer by base flow into Spring Creek and the Knife River, by evapotranspiration, and by pumping.

Water levels in the aquifer range from about 0.3 feet (0.09 m) above lsd to about 37 feet (11 m) below lsd. Seasonal fluctuations range from about 1 foot

(0.3 m) to a maximum of about 7 feet (2 m). The minimum seasonal fluctuations (fig. 12) occur in a confined part of the aquifer, whereas the maximum fluctuations (fig. 12A) occur in an unconfined part. In addition to the seasonal fluctuations, the hydrographs also show a gradual decline of the water level. This gradual decline, which is shown on all of the hydrographs of wells in the drift, is attributed to above-normal precipitation prior to 1973 and below-normal precipitation in 1973 and 1974.

Water in the Killdeer aquifer is very hard and of either a sodium bicarbonate or sodium sulfate type. Minimum, maximum, and mean concentrations of selected constituents and properties of water collected from 53 wells tapping the aquifer in Dunn County are listed in the following table.

Constituent or property	Minimum	Maximum	Mean
Dissolved solids (mg/L)	234	5,030	1,531
Sodium, Na (mg/L)	50	1,350	413
Bicarbonate, HCO_3 (mg/L)	374	1,250	713
Sulfate, SO_4 (mg/L)	33	3,000	626
Chloride, Cl (mg/L)	0	25	4.5
Fluoride, F (mg/L)	.1	1.6	.66
Iron, Fe (ug/L)	0	5,500	1,029
Nitrate, NO_3 (mg/L)	.3	6.7	1.2
Boron, B (ug/L)	0	3,700	534
Percent sodium	27	91	71
Sodium-adsorption ratio	1.3	28	10.8

With few exceptions, the water in the aquifer north of T. 143 N. is of better quality than that south of T. 143 N. The dissolved-solids concentration of the water north of T. 143 N. rarely exceeds 1,100 mg/L; however, south of T. 143 N., the concentration of dissolved solids in the water commonly exceeds 2,000 mg/L. The samples had irrigation classifications that ranged from C2-S1 to C4-S4 (fig. 3).

Based on an areal extent of 74 mi^2 (192 km^2), an average thickness of 80 feet (24 m), and an assumed specific yield of 15 percent, about 568,000 acre-feet (701 hm^3) of water would be available from storage in the Killdeer aquifer.

Horse Nose Butte Aquifer

The Horse Nose Butte aquifer underlies an area of about 10 mi^2 (26 km^2) in Dunn County. It extends from sec. 36, T. 145 N., R. 94 W. southeasterly to sec. 33, T. 143 N., R. 93 W. The aquifer generally is composed of very fine to very coarse sand, but beds of fine to coarse gravel occur locally. It ranges in thickness from 3 to 85 feet (0.9 to 26 m) and has a mean thickness of about 40

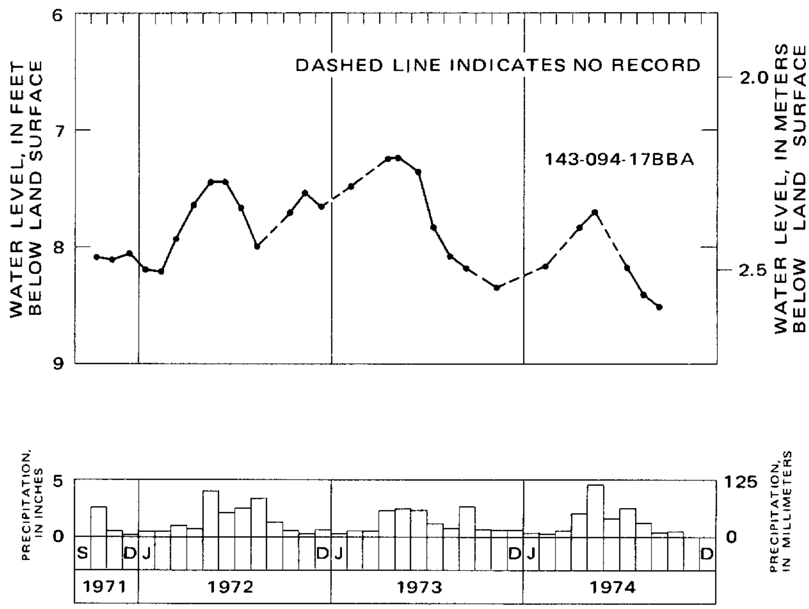


FIGURE 12.— Water-level fluctuations in the Killdeer aquifer and precipitation at Dunn Center.

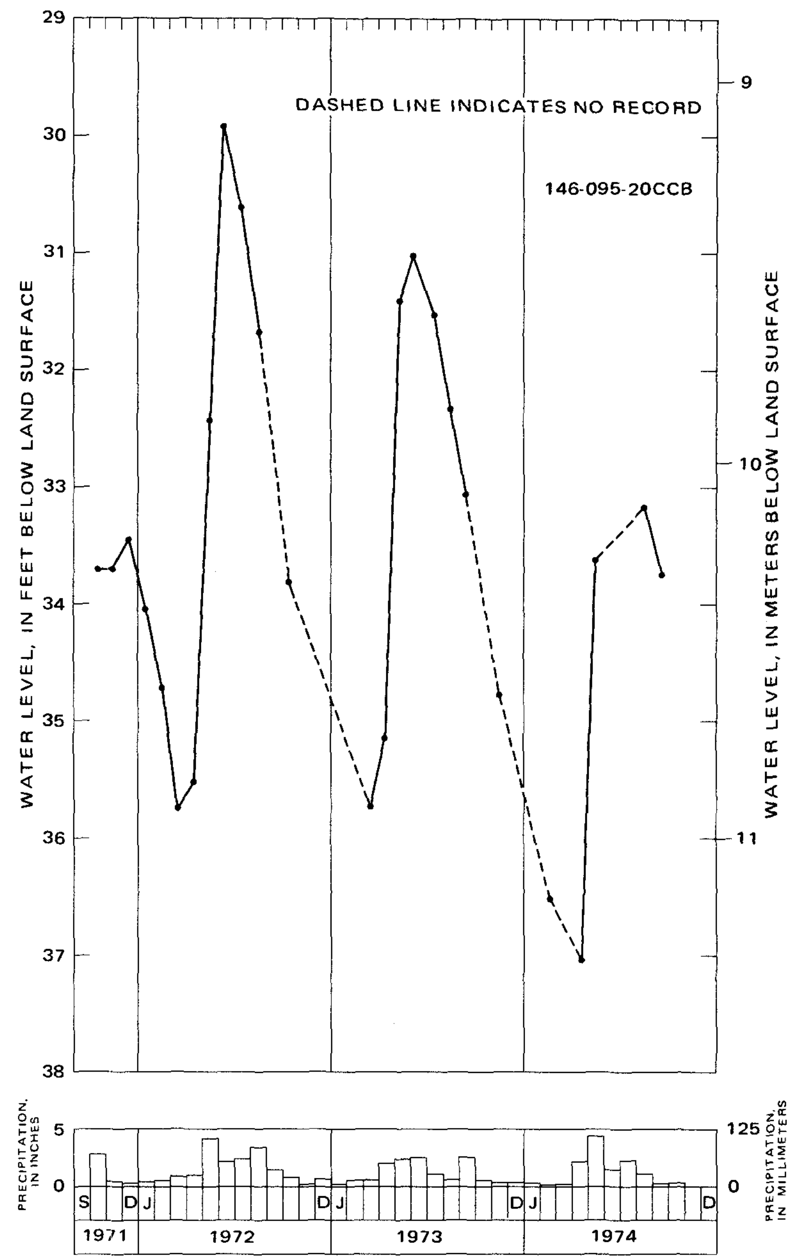


FIGURE 12A.— Water-level fluctuations in the Killdeer aquifer and precipitation at Dunn Center.

feet (12 m). As shown on plate 4, section F-F′, the Horse Nose Butte aquifer is overlain by and interbedded with clay and silt.

Depending on the saturated thickness and hydraulic conductivity of the material penetrated, properly developed wells should yield from 50 to as much as 500 gal/min (3 to 32 L/s; pl. 3).

The aquifer is recharged by infiltration of precipitation through the overlying clay and silt and probably by movement of ground water from the adjacent bedrock. Water is discharged from the aquifer by a few domestic and stock wells, by evapotranspiration, and be seepage into the Knife River. Available data indicate that ground water in the aquifer moves toward the Knife River.

Water levels in the aquifer range from about 1 to 128 feet (0.3 to 39 m) below lsd. The water-level fluctuations shown in figure 13 reflect seasonal variations in storage — the highest water levels generally occur between the middle of April and the middle of June when recharge from precipitation is greatest. The high and low water levels shown in figure 13 occur in both wells at about the same time. However, the water-level fluctuations are greater in well 143-092-07DDD (25 feet or 8 m) because recharge to and discharge from this part of the aquifer are more rapid than in the part penetrated by well 143-093-14AAD, which is 133 feet (40 m) deep.

Water in the Horse Nose Butte aquifer is very hard and is predominantly of a sodium bicarbonate type. The minimum, maximum, and mean concentrations of selected constituents and properties of 13 water samples collected from wells tapping the aquifer are shown in the following table.

Constituent or property	Minimum	Maximum	Mean
Dissolved solids (mg/L)	272	1,900	1,173
Sodium, Na (mg/L)	4.9	540	258
Bicarbonate, HCO_3 (mg/L)	275	870	613
Sulfate, SO_4 (mg/L)	33	808	380
Chloride, Cl (mg/L)	1.3	11	4
Fluoride, F (mg/L)	.1	1.3	.8
Iron, Fe (ug/L)	0	4,500	852
Nitrate, NO_3 (mg/L)	.2	1	.9
Boron, B (ug/L)	40	1,100	381
Percent sodium	4	84	57
Sodium-adsorption ratio	.1	16	7

The irrigation classifications ranged from C2-S1 to C4-S4 (fig. 3); however, most of the samples were classified as C2-S1 or C3-S2.

Based on an areal extent of 10 mi^2 (26 km^2), an average thickness of 40 feet (12 m), and an assumed specific yield of 15 percent, approximately 38,400 acre-feet (47.4 hm^3) of water would be available from storage in the Horse Nose Butte aquifer.

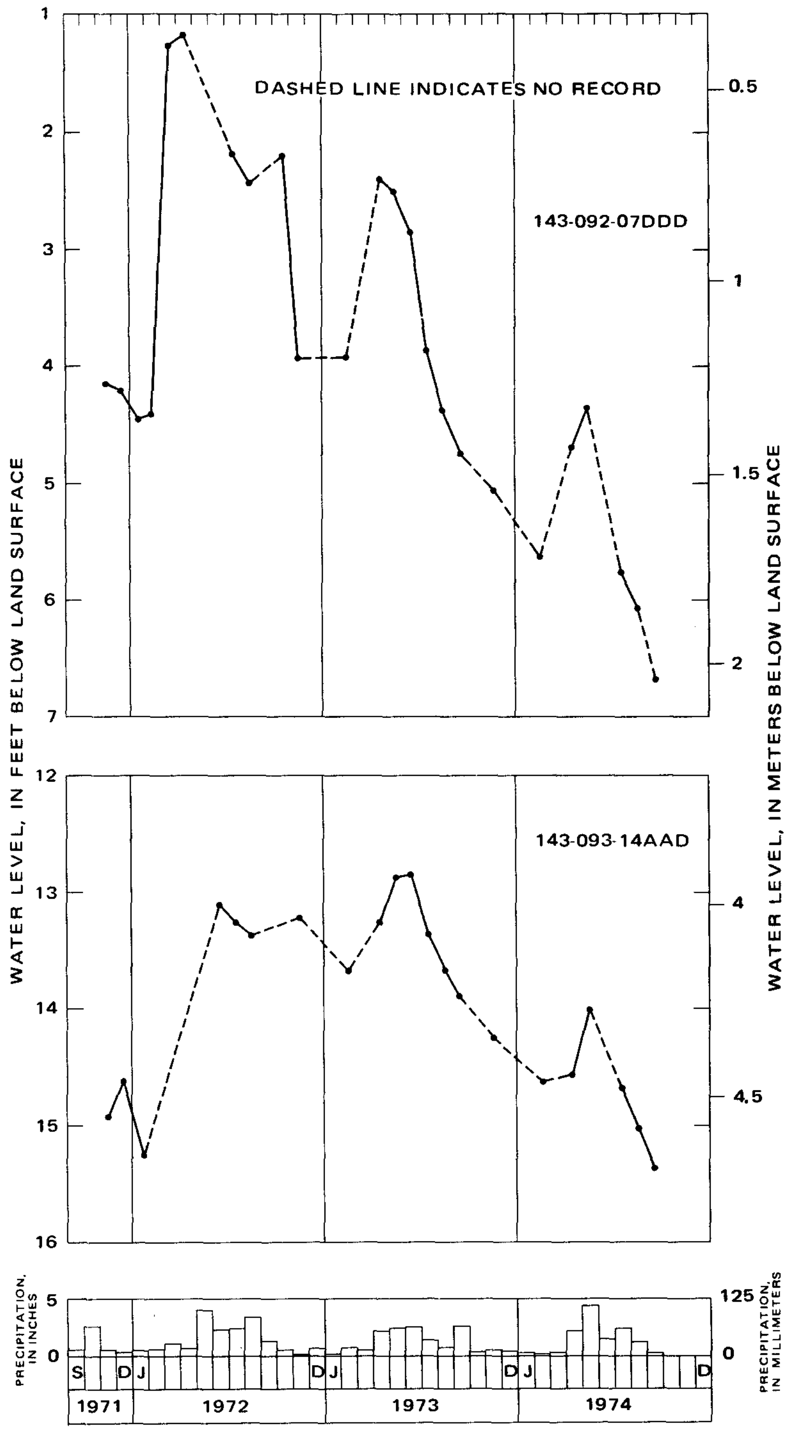


FIGURE 13.— Water-level fluctuations in the Horse Nose Butte aquifer and precipitation at Dunn Center.

Knife River Aquifer

The Knife River aquifer, located in southeastern Dunn County, has an areal extent of about 9 mi^2 (23 km^2). It underlies the valley of a branch of the Knife River in Tps. 141-142 N., R. 91 W., and a small part of the Knife River valley in the NE¼ T. 142 N., R. 91 W. The aquifer is composed of very fine to very coarse sand interbedded or lensed with clay and silt. Locally the aquifer contains thin lenses of gravel. In secs. 3 and 9, T. 141 N., R. 91 W., the aquifer consists of thin sand beds that are interbedded with till. The Knife River aquifer has a maximum thickness of about 140 feet (43 m) and a mean thickness of 66 feet (20 m). The aquifer is overlain by clay and silt.

Depending on the saturated thickness and hydraulic conductivity of the material penetrated, properly developed wells should yield from 50 to as much as 1,000 gal/min (3 to 63 L/s; pl. 3).

The aquifer is recharged by infiltration of precipitation through the overlying clay and silt deposits. Water is discharged from the aquifer by a few domestic and stock wells, by evapotranspiration, and by seepage into the river. Available data indicate that the water in the aquifer moves to the north.

Water levels in the aquifer range from about 3 to 19 feet (0.9 to 5.8 m) below lsd. Seasonal water-level fluctuations range from about 1 foot (0.3 m) to as much as 5 feet (2 m). The fluctuations shown in figure 14 reflect, for the most part, seasonal variations of storage within the aquifer. However, spring runoff in the Knife River and its tributaries was unusually high during March 1972 and the coinciding gage-height and water-level peaks suggest that the March water-level rise was caused by water-loading and consequent compression of the aquifer.

Water in the Knife River aquifer is hard to very hard and predominantly of a sodium bicarbonate type. Minimum, maximum, and mean concentrations of selected constituents and properties of eight water samples collected from wells tapping the aquifer are shown in the following table.

Constituent or property	Minimum	Maximum	Mean
Dissolved solids (mg/L)	502	1,750	1,196
Sodium, Na (mg/L)	91	670	379
Bicarbonate, HCO_3 (mg/L)	435	1,740	931
Sulfate, SO_4 (mg/L)	41	820	257
Chloride, Cl (mg/L)	.6	10	4.7
Fluoride, F (mg/L)	.4	1.5	.9
Iron, Fe (ug/L)	80	5,800	1,301
Nitrate, NO_3 (mg/L)	1	1	1
Boron, B (ug/L)	130	530	315
Percent sodium	43	94	73
Sodium-adsorption ratio	2.5	32	13

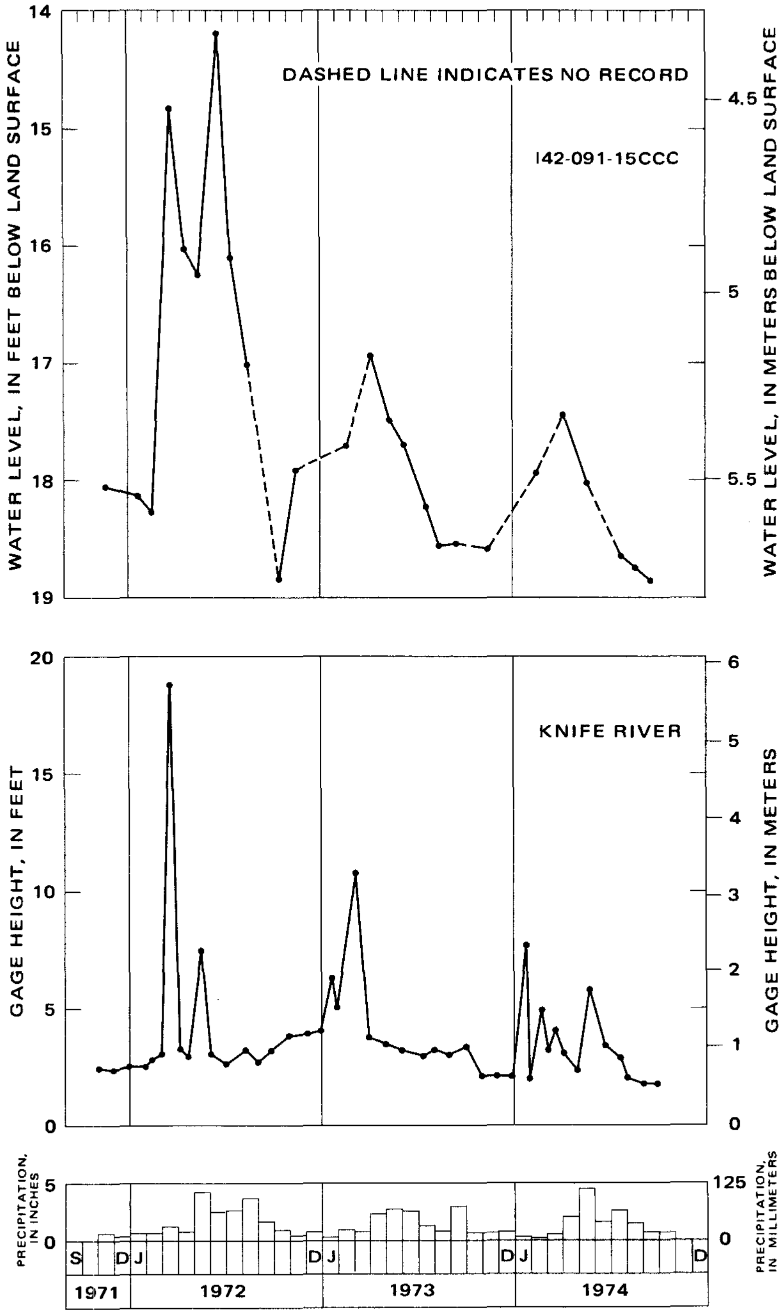


FIGURE 14.— Water-level fluctuations in the Knife River aquifer, gage height of the Knife River at Marshall, and precipitation at Dunn Center.

Irrigation classifications of the samples ranged from C3-S1 to C4-S4 (fig. 3).

Based on an areal extent of about 9 mi^2 (23 km^2), an average thickness of 66 feet (20 m), and an assumed specific yield of 15 percent, approximately 57,000 acre-feet (70 hm^3) of ground water would be available from storage in the Knife River aquifer.

Goodman Creek Aquifer

The Goodman Creek aquifer underlies an area of about 6 mi^2 (16 km^2) in northwestern Dunn County. It extends northwestward from the northeast corner of T. 145 N., R. 91 W. and intersects an embayment of Lake Sakakawea in sec. 4, T. 146 N., R. 92 W. The aquifer consists of an upper and lower unit (sec. G-G′, pl. 2B). The upper unit is composed of very fine to coarse gravelly sand and is separated from the lower unit by a silty and sandy clay bed that may be as much as 77 feet (23 m) thick. The lower unit consists of interbedded sand, gravel, and clayey gravel. The combined aquifer thickness ranges from 28 to 139 feet (6.7 to 42.4 m) and the mean is 66 feet (20 m). The aquifer is overlain by silt and clay.

Depending on the saturated thickness and hydraulic conductivity of the material penetrated, wells developed in both units of the aquifer should yield from 50 to as much as 1,000 gal/min (3 to 63 L/s; pl. 3).

The aquifer is recharged by infiltration of precipitation through the overlying clay and silt. Water is discharged from the aquifer by a few domestic and stock wells and by evapotranspiration. Available data indicate that the water in the aquifer moves northwesterly and discharges into Lake Sakakawea.

Water levels in the Goodman Creek aquifer range from 16 to about 40 feet (4.9 to 12 m) below lsd. Water-level fluctuations for wells 146-091-21CDD1 and 21CDD2, which are completed in the lower and upper units, respectively, are shown in figure 15. The greater fluctuations occurring in well 146-091-21CDD2 indicate that the upper unit is more readily recharged and discharges more rapidly than the lower unit.

Water from the Goodman Creek aquifer is very hard and of the following types: calcium bicarbonate, sodium bicarbonate, and sodium sulfate. The minimum, maximum, and mean concentrations of selected constituents and properties of six water samples collected from wells tapping the aquifer are given in the following table.

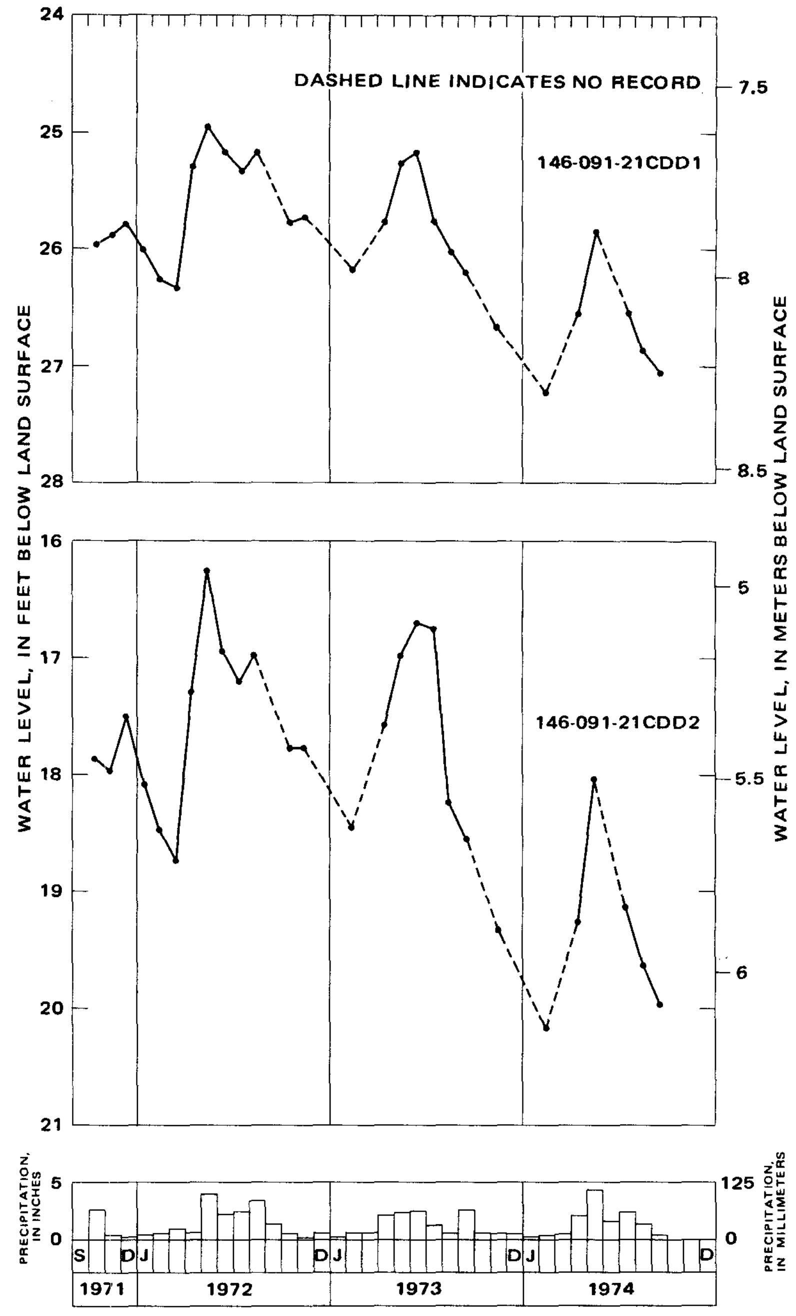


FIGURE 15.— Water-level fluctuations in the Goodman Creek aquifer and precipitation at Dunn Center.

Constituent or property	Minimum	Maximum	Mean
Dissolved solids (mg/L)	514	2,100	917
Sodium, Na (mg/L)	46	489	166
Bicarbonate, HCO_3 (mg/L)	420	630	478
Sulfate, SO_4 (mg/L)	130	1,190	382
Chloride, Cl (mg/L)	1.4	5.1	3
Fluoride, F (mg/L)	.7	.9	.8
Iron, Fe (ug/L)	0	2,700	933
Nitrate, NO_3 (mg/L)	0	1	.4
Boron, B (ug/L)	0	440	193
Percent sodium	21	59	40
Sodium-adsorption ratio	1	7.9	3.3

Five of the samples had a C3-S1 irrigation classification and the sixth sample had a C4-S2 irrigation classification.

Based on an areal extent of 6 mi^2 (16 km^2), an average thickness of 66 feet (20 m), and an assumed specific yield of 15 percent, approximately 38,000 acre-feet (47 hm^3) of water would be available to wells from storage.

Undifferentiated Sand and Gravel Aquifers

Undifferentiated sand and gravel aquifers are scattered throughout the county. Test holes and wells frequently penetrate one or more beds of sand and(or) gravel at depths ranging from 6 feet (2 m) to more than 100 feet (30 m) below lsd. The aquifers appear to be limited in areal extent and have a maximum thickness of about 45 feet (14 m). Most of the sand and gravel aquifers are of glaciofluvial origin; however, the terrace deposits occurring along the Green River in the vicinity of New Hradec (fig. 9) lie beyond the limit of glaciation and appear to be associated with fluvial deposition. The discontinuous sand and gravel aquifers occurring in the valleys of the Knife River and Spring Creek consist of reworked glacial deposits intermixed with alluvial deposits.

Wells developed in the undifferentiated sand and gravel aquifers generally will yield from 5 to 10 gal/min (0.3 to 0.6 L/s); however, the thickness and lithology of some of the aquifers suggest that greater yields may be obtainable locally. Any well development in the undifferentiated sand and gravel aquifers should be preceded by test drilling and aquifer testing. The amount of water available from storage in these aquifers is unknown.

The undifferentiated sand and gravel aquifers are recharged by infiltration of precipitation through the overlying deposits and from adjacent bedrock deposits. Water is discharged from these aquifers by pumping, evapotranspiration, seepage into streams, and by subsurface movement into adjacent rocks.

Water levels measured during this investigation in wells penetrating undifferentiated sand and gravel aquifers ranged from about 6 to 57 feet (2 to 17 m) below lsd.

Water from the undifferentiated sand and gravel aquifers is hard to very hard. The predominant cation is sodium and the predominant anion may be either bicarbonate or sulfate. The ranges of selected constituents occurring in the samples collected from 30 wells tapping undifferentiated sand and gravel aquifers are shown in the following table.

Constituent	Range
Dissolved solids (mg/L)	192-4,360
Sulfate, Na (mg/L)	0-1,660
Chloride, Cl (mg/L)	0-315
Fluoride F (mg/L)	0.3-3.4
Iron, Fe (ug/L)	0-1,300
Boron, B (ug/L)	0-900
Nitrate, NO_3 (mg/L)	0-681

Samples from two wells had nitrate concentrations of 62 and 129 mg/L. Both wells are relatively shallow and are located in or near dwellings, indicating that the ground water may be contaminated by effluent from septic tanks. Water from well 142-097-24CCB, which was reported to be used for watering livestock, had 681 mg/L nitrate, 89 mg/L potassium, and 315 mg/L chloride. The high concentrations of these constituents suggest that the water is probably being polluted by feedlot wastes.

UTILIZATION OF GROUND WATER

The rural population of Dunn County is dependent upon ground water for its domestic and livestock needs. In addition, the cities of Halliday and Killdeer obtain water for public supply from wells. At the completion of the fieldwork for this project (1975), there were no irrigation wells in the area.

Domestic and Livestock Use

Most of the wells that provide water for domestic and livestock use are drilled wells. These wells range in depth from 14 to as much as 1,980 feet (4.3 to 604 m); however, most wells are less than 200 feet (61 m) deep. Well yields will vary depending on the transmissivity of the aquifer, the type of well construction, and the capacity of the pump installed in the well. Most domestic and stock wells are equipped with small-capacity pumps; consequently, the yield of these wells usually ranges from 5 to 10 gal/min (0.3 to 0.6 L/s). Estimates of the quantity of water pumped daily for domestic and livestock use in Dunn County are listed in the following table.

Use	Individual requirements[1] (gal/d)	Population or number	Total pumpage (gal/d)
Domestic (not including communities having municipal supplies)	100	[2]3,861	386,100
Cattle	15	[3]112,000	1,680,000
Milk cows	35	[3]3,000	105,000
Sheep	1.5	[3]2,500	3,750
Chickens	.10	[3]13,000	1,300
Hogs	5	[3]5,700	28,500
Total pumpage			2,200,000 (rounded)

[1]Murray, 1965.
[2]U.S. Bureau of the Census, 1971.
[3]North Dakota State University, 1974.

Public Supplies

Halliday

Prior to June 1974, the city of Halliday obtained water for its municipal supply from a spring (145-092-24BCA) discharging from a lignite bed on the north bluff of Spring Creek valley. The yield from the spring was inadequate to meet the city's needs during the summer months. A study made by the North Dakota State Water Commission in 1971 (Naplin, 1974) indicated that the undifferentiated sand and gravel deposits occurring in Spring Creek valley in the vicinity of Halliday would not provide an adequate supply of water for the city. Consequently, the city completed a 1,555-foot (474-m) well in the Fox Hills aquifer. This well yields from 50 to 65 gal/min (3 to 4 L/s) of soft, sodium bicarbonate water with a dissolved-solids concentration of about 1,400 mg/L.

It is estimated that about 12 Mgal (45,000 m^3) of water was obtained annually from the spring; however, the annual use of ground water by the city of Halliday will probably increase now that the city has a more reliable source of water.

Killdeer

The city of Killdeer obtains its water supply from a 70-foot (21-m) well tapping sand and gravel deposits in the Killdeer aquifer. The water is very hard and is a sodium bicarbonate type containing 1,090 mg/l dissolved solids. Average annual production from this well from 1966 through 1973 was 21.9 Mgal (83,000 m^3).

SUMMARY

Ground water in Dunn County is obtained from sandstone aquifers in the preglacial rocks and from glaciofluvial sand and gravel deposits contained in glacial melt-water channels.

Aquifers in the preglacial rocks occur in the Fox Hills, Hell Creek, undifferentiated Cannonball-Ludlow, Tongue River, and Sentinel Butte Formations.

The Fox Hills aquifer underlies all of Dunn County, but the aquifers in the overlying formations are not as extensive because they pinch out, grade into silt and clay deposits, or are absent due to nondeposition.

Recharge to the Fox Hills aquifer and to aquifers in the overlying Hell Creek and the lower part of the undifferentiated Cannonball-Ludlow Formations occurs outside the study area. Aquifers in the upper part of the undifferentiated Cannonball-Ludlow, Tongue River, and Sentinel Butte Formations are recharged by the downward movement of precipitation.

Ground water is discharged from the aquifers by wells and by lateral movement into adjacent areas. In addition to well discharge and lateral movement into adjacent areas, ground water in the aquifers in the upper part of the Sentinel Butte Formation is discharged by springs and seepage into streams.

Ground water in the Fox Hills aquifer, the basal Tongue River aquifer, and the basal Sentinel Butte aquifer moves in a northeasterly direction. Inadequate water-level data prevent determination of the direction of movement in the other aquifers.

Maximum potential yields of these aquifers range from about 50 gal/min (3 L/s) in the undifferentiated Cannonball-Ludlow to as much as 200 gal/min (13 L/s) in the Tongue River and Fox Hills.

The water from aquifers in these formations generally is soft and is a sodium bicarbonate type. Dissolved-solids concentrations range from 1,200 to about 2,600 mg/L.

Most of the water used in Dunn County is obtained from wells tapping sandstone and lignite aquifers in the Sentinel Butte Formation. Potential yields of the sandstone aquifers range from 5 to 100 gal/min (0.3 to 6 L/s). Potential yields of the lignite aquifers range from about 1 to 200 gal/min (0.3 to 13 L/s). The water from these aquifers is generally hard to very hard and is predominantly a sodium bicarbonate type. The dissolved-solids concentrations ranged from 123 to 7,060 mg/L in water from the sandstone aquifers and from 250 to 9,090 mg/L from the lignite aquifers.

The aquifers with the greatest potential for development are the glaciofluvial sand and gravel deposits contained in the glacial melt-water channels. Hydrologic data relating to these aquifers are listed in table 3.

The rural population of Dunn County is dependent upon ground water for its domestic and livestock needs, and the cities of Halliday and Killdeer rely on ground water for municipal water supplies. At the present time ground water is not being used for irrigation.

TABLE 3.—Summary of data for aquifers in the glacial drift

Aquifer	Areal extent (square miles)	Average saturated thickness (feet)	Water available from storage (acre-feet)	General water type	General irrigation classification of water	Potential yield to wells (gal/min)
Killdeer	74	80	568,000	Sodium bicarbonate to sodium sulfate.	C2-S1 to C4-S4.	50 to 1,000.
Horse Nose Butte	10	40	38,400	Sodium bicarbonate.	C2-S1 to C4-S4.	50 to 500.
Knife River	9	66	57,000	Sodium bicarbonate.	C3-S1 to C4-S4.	50 to 1,000.
Goodman Creek	6	66	38,000	Calcium bicarbonate, sodium bicarbonate, and sodium sulfate.	C3-S1 to C4-S2.	50 to 1,000.

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DEFINITIONS OF TERMS

Aquifer – a formation, group of formations, or part of a formation that contains sufficient saturated conductive material to yield significant amounts of water to wells and springs.

Bedrock – consolidated rock underlying glacial and alluvial deposits of Pleistocene and(or) Holocene age.

Cone of depression – the conical low produced in a water table or potentiometric surface by a discharging well.

Drawdown – the decline of the water level in a well or aquifer caused by pumping or artesian flow.

Evapotranspiration – that portion of the precipitation returned to the atmosphere through direct evaporation or by transpiration of vegetation.

Gage height – the height of a water surface above an established datum. Stage is often used interchangeable with the term "gage height."

Glaciofluvial – pertaining to streams flowing from glaciers or the deposits made by such streams.

Ground water – water in the zone of saturation.

Head – pressure of a fluid upon a unit area due to the height at which the fluid stands above the point where the pressure is determined.

Hydraulic conductivity – the capacity of a rock to transmit water — usually described as the rate of flow in cubic feet per day through 1 ft^2 (0.09 m^2) of the aquifer under unit hydraulic gradient, at existing kinematic viscosity.

Hydraulic gradient – the change in head per unit of distance in a given direction.

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

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

Sodium-adsorption ratio – the sodium-adsorption ratio (SAR) of water is defined as:

$$SAR = \frac{(Na^{+2})}{\sqrt{\frac{(CA^{+2} + Mg^{+2})}{2}}}$$

where ion concentrations are expressed in milliequivalents per liter. Experiments cited by the U.S. Salinity Laboratory Staff (1954) show that SAR predicts reasonably well the degree to which irrigation water tends to enter into cation reactions in soil. High values of SAR imply a hazard of sodium replacing adsorbed calcium and magnesium. This replacement is damaging to soil structure.

Specific capacity – the rate of discharge of water from a well divided by the drawdown of the water level within the well.

Specific conductance – electrical conductance, or conductivity, is the ability of a substance to conduct an electrical current. The electrical conductivity of water is related to the concentration of ions in the water. Distilled water normally will have a conductance of about 1.0 micromhos per centimeter, whereas sea water may have a conductance of about 50,000 micromhos per centimeter. Standard laboratory measurements report the conductivity of water in micromhos per centimeter at 25° Celsius.

Storage coefficient – the volume of water an aquifer releases or takes into storage per unit surface area of the aquifer per unit change in head.

Transmissivity – the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths.

Zone, saturated – that part of the water-bearing material in which all voids, large and small, are filled with water under pressure of one atmosphere or greater.