GROUND-WATER RESOURCES

of

GRANT AND SIOUX COUNTIES NORTH DAKOTA

by

P. G. Randich

U.S. Geological Survey

COUNTY GROUND-WATER STUDIES 24 — PART III
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

BULLETIN 67 — 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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SELECTED FACTORS FOR CONVERTING U.S. CUSTOMARY UNITS TO THE INTERNATIONAL SYSTEM (SI) OF METRIC UNITS

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 (acre-ft)	.001233	cubic hectometer (hm^3)
Cubic foot per second (ft^3/s)	.02832	cubic meter per second (m^3/s)
Foot	.3048	meter (m)
Foot per day (ft/d)	.3048	meter per day (m/d)
Foot per mile (ft/mi)	.18943	meter per kilometer (m/km)
Foot squared per day (ft^2/d)	.0929	meter squared per day (m^2/d)
Gallon	3.785	liter (L)
Gallon per day (gal/d)	3.785×10^{-3}	cubic meter per day (m^3/d)
Gallon per minute (gal/min)	.06309	liter per second (L/s)
Inch	25.4	millimeter (mm)
Mile	1.609	kilometer (km)
Million gallons (Mgal)	3,785	cubic meter (m^3)
Square mile (mi^2)	2.590	square kilometer (km^2)

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ABSTRACT

Ground water in Grant and Sioux Counties is obtainable from aquifers of Late Cretaceous, Tertiary, Pleistocene, and Holocene age. Aquifers of Cretaceous and Tertiary age are larger in areal extent, but those of Pleistocene age provide larger yields of better quality water to individual wells.

The major bedrock aquifers in Grant and Sioux Counties are the Fox Hills and Hell Creek aquifers of Late Cretaceous age and the Cannonball and Ludlow, undifferentiated, and Tongue River aquifers of Tertiary age. Potential yields to individual wells range from about 5 to 150 gallons per minute (0.3 to 9.5 liters per second). Water in these aquifers becomes increasingly saline as it moves from topographically high recharge areas toward low-lying discharge areas. As the ground water moves downward through the aquifers it changes from sodium and calcium bicarbonate-sulfate types to a sodium bicarbonate-chloride type. The water generally is soft and high in dissolved solids.

Aquifers of Pleistocene age — the Shields, Elm Creek, St. James, Beaver Creek, and Battle Creek aquifers — underlie about 48 square miles (120 square kilometers) in Grant and Sioux Counties and contain approximately 355,000 acre-feet (438 cubic hectometers) of available ground water. Well yields of as much as 1,000 gallons per minute (63 liters per second) are obtainable in a few places along the central axes of these aquifers. The major dissolved constituents in water from these aquifers are calcium, magnesium, sodium, bicarbonate, and sulfate. Dissolved solids in samples collected from the aquifers ranged from 321 to 1,870 milligrams per liter.

Aquifers of Holocene age are located in the alluvial deposits in the Cannonball River, Heart River, and Cedar Creek valleys. These aquifers contain about 70,000 acre-feet (86 cubic hectometers) of available ground water in Grant and Sioux Counties. Potential well yields generally are less than 50 gallons per minute (3.2 liters per second).

INTRODUCTION

The investigation of the ground-water resources of Grant and Sioux Counties (fig. 1) was made cooperatively by the U.S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and Grant and Sioux Counties Water Management Districts. The results of the investigation are published in three parts. Part I is an interpretive report describing the geology of the study area. Part II (Randich, 1975) is a compilation of the

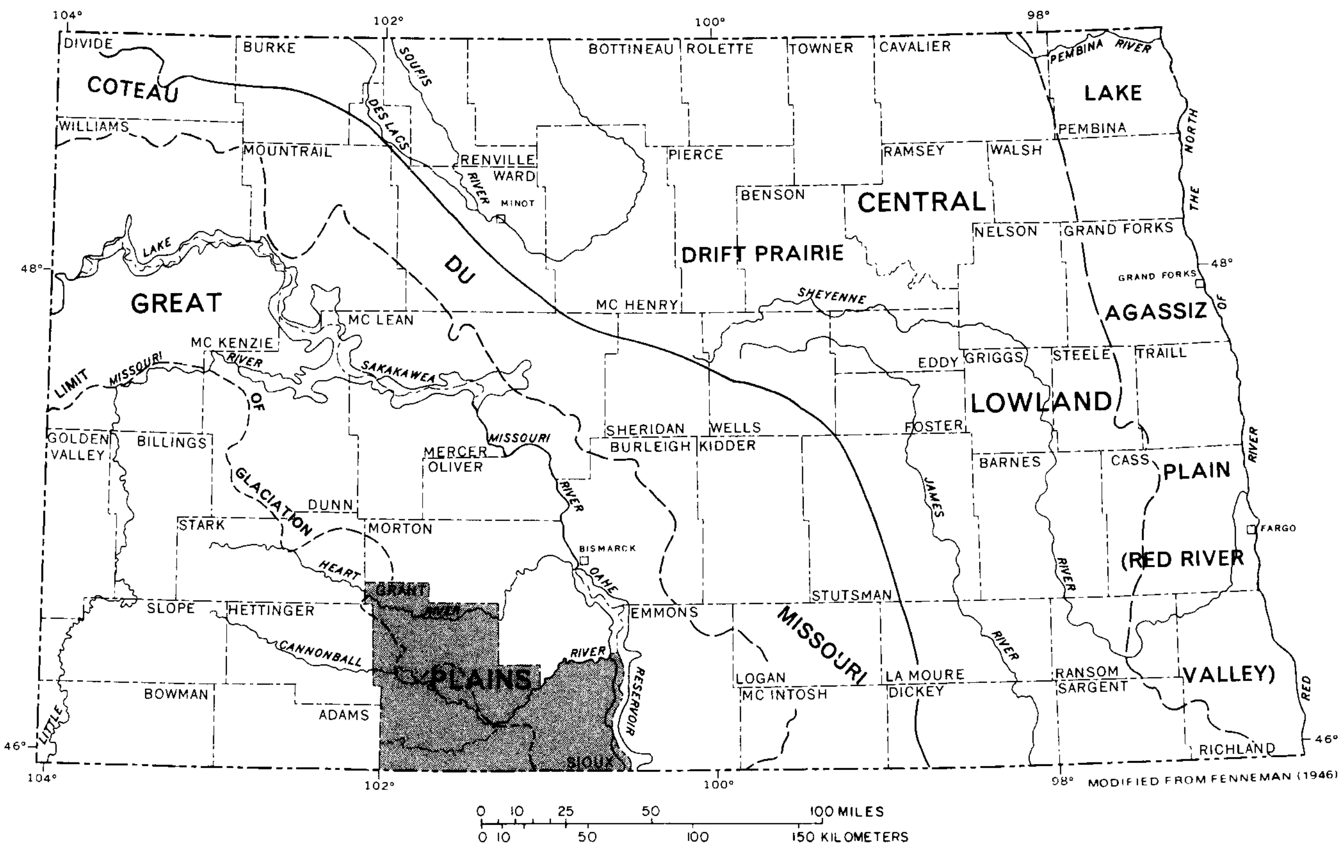


FIGURE 1.—Physiographic divisions in North Dakota and location of study area.

geologic and hydrologic data collected during the investigation, and is a reference for the other two parts. Part III is this interpretive report describing ground-water resources. The reports are prepared and written to assist State and County water managers, consultants to water users, and water users in the development of ground-water supplies for municipal, domestic, livestock, irrigation, industrial, and other uses.

Objectives and Scope

The objectives of the investigation in Grant and Sioux Counties were to: (1) determine the location, extent, and characteristics of the aquifers; (2) evaluate the occurrence, movement, recharge, and discharge of ground water; (3) estimate the quantities of water stored in the glacial and alluvial aquifers; (4) estimate potential yields to wells penetrating major aquifers; and (5) describe the chemical quality of the ground water.

Interpretations contained in this report are based on data from 1,610 wells and test holes. These data include lithologic and geophysical logs of 257 test holes and wells; water-level measurement in 77 observation wells; chemical analyses of 135 samples of ground water; 13 chemical analyses of minor elements in water from wells; 30 laboratory tests of core samples to determine hydrologic properties, particle sizes, and heavy minerals; and 24 flow- or slug-tests to determine aquifer characteristics. Also used were chemical analyses of 15 water samples from streams during periods of low flow and 15 stream discharge measurements during periods of low flow.

Previous Investigations

The first geologic or hydrologic studies that included Grant and Sioux Counties were made by Lloyd (1914), who investigated the lignite deposits in the Cannonball Formation, and by Calvert and others (1914), who investigated the geology of the Standing Rock and Cheyenne River Indian Reservations. Simpson (1929) included a brief description of the geology and ground-water resources of Grant and Sioux Counties in his report on the geology and ground-water resources of North Dakota. Denson (1950) studied the usable lignite deposits on the Cheyenne River and Standing Rock Reservations, and Maclay (1952) discussed the occurrence of ground water on the reservations. The geology in two topographic quadrangles in the Heart Butte area have been mapped by Stephens (1970).

Acknowledgments

Collection of the data on which this report is based was made possible by the cooperation of residents and officials of Grant and Sioux Counties, the U.S. Public Health Service, the U.S. Bureau of Indian Affairs, and council members of the Standing Rock Indian Reservation. M. O. Lindvig, L. L. Froelich, and C. E. Naplin of the North Dakota State Water Commission contributed to the

interpretation of the geohydrology of the area. Special recognition is given to C. G. Carlson of the North Dakota Geological Survey for his contribution to the understanding of the surface geology and subsurface stratigraphy.

Location-numbering System

The location-numbering system (fig. 2) used in this report is based on the system of land survey used by the U.S. Bureau of Land Management and the North Dakota district of the U.S. Geological Survey. The first numeral denotes the township north of a base line, the second numeral denotes the range west of the fifth principal meridian, and the third numeral denotes the section in which the well is located. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre or 4-ha tract). For example, well 129-090-15ADC is in the SW¼SE¼NE¼ sec 15, T. 129 N., R. 090 W. Consecutive final numerals are added if more than one well is recorded within a 10-acre (4-ha) tract.

Geography

Grant and Sioux Counties are in the glaciated and unglaciated section of the Great Plains physiographic province (fig. 1). The counties have an area of about 2,769 mi^2 (7,172 km^2) in south-central North Dakota — Grant County has an area of about 1,666 mi^2 (4,315 km^2) and Sioux County has an area of about 1,103 mi^2 (2,857 km^2). All of Sioux County lies within the Standing Rock Indian Reservation.

The counties are in the Missouri River drainage basin. The principal streams, Cedar Creek, the Cannonball River, and the Heart River, are east-flowing drainages to Lake Oahe. Lake Oahe, formed behind Oahe Dam, borders Sioux County on the east.

The topography ranges from rolling prairie in Grant County to large areas of badlands in Sioux County. The maximum relief is about 1,200 feet (370 m). The highest point (Pretty Rock Butte) is 2,823 feet (860 m) above sea level in southwestern Grant County.

The climate is semiarid; mean annual precipitation is 15 to 16 inches (381 to 406 mm). Most precipitation is received during the growing season, which is the period April through September. The mean annual temperature ranges from 41.4°F (5.2°C) at Carson to 43.2°F (6.2°C) at Fort Yates. The average number of days in the growing season (above 32°F or 0°C) ranges from 110 to 129 days per year.

Grant County has a population of 5,009 and Sioux County has a population of 3,632 (U.S. Bureau of the Census, 1971).

Dry-land farming and stock raising are the two primary industries. The principal crops are wheat, hay, oats, corn, and barley. Livestock production includes cattle, chickens, hogs, and sheep. In general, farming is carried on in the rolling uplands near the stream divides and in the stream valleys, and stock

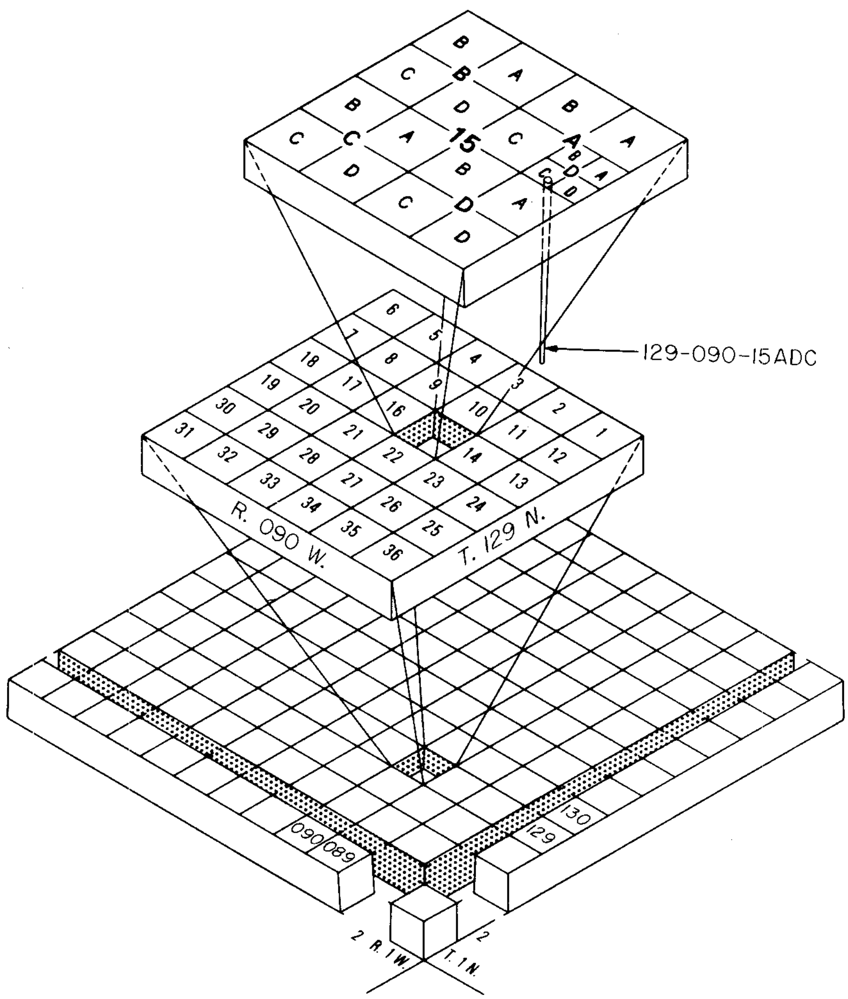


FIGURE 2.—Location-numbering system.

raising in the badlands and hilly terrain adjoining the main drainage courses. Some lignite is mined commercially in western Grant County.

Geohydrologic Setting

The generalized surficial geology of Grant and Sioux Counties is shown in figure 3. Rocks of Late Cretaceous and Tertiary age crop out across the two-county area. Most of the usable ground water in Grant and Sioux Counties is in these rocks and in unconsolidated deposits of Quaternary age; thus they are studied in detail with special reference to their water-bearing properties. Table 1 summarizes the stratigraphy of the geologic units overlying the Pierre Formation[1]. For practical purposes the Pierre Formation forms the base of the freshwater-bearing units in the study area, and test drilling stopped when this formation was reached. Water-bearing rocks older than the Pierre generally are at depths greater than 2,500 feet (760 m) and they contain brackish or saline water.

The structure-contour map (fig. 4) of the base of the Fox Hills Formation shows that the Fox Hills dips about 5 to 18 ft/mi (0.9 to 3.4 m/km) northwest toward the center of the Williston basin. The Cretaceous rocks exposed in the eastern part of the area lie several hundred feet below land surface in the northwestern part of the area.

About two-thirds of the area was glaciated during Pleistocene time. Most of the glacial drift (Coleharbor Formation) has been eroded away, leaving only isolated remnants randomly scattered in parts of the area (fig. 3). The thickest drift deposits are located in buried valleys, which at one time contained glacial ice-front streams. The buried valleys now contain the major glacial-drift aquifers in Grant and Sioux Counties (pl. 1, in pocket).

The flood plains of the major rivers and creeks contain alluvial deposits (Walsh Formation) of Holocene age. Saturated sand and gravel intervals in these deposits form productive aquifers in Grant and Sioux Counties (p. 1).

AVAILABILITY AND QUALITY OF GROUND WATER

General Concepts

All ground water 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 ground. Some of the water that enters the ground is held by capillarity and evaporates or is transpired. The water in excess of the moisture-holding capacity of the soil infiltrates downward to the water table and becomes available to wells.

Ground water moves under the influence of gravity from areas of recharge to areas of discharge. Ground-water movement generally is very slow and may be only a few feet per year. The rate of the ground-water movement is governed by the hydraulic conductivity of the material through which it moves and

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

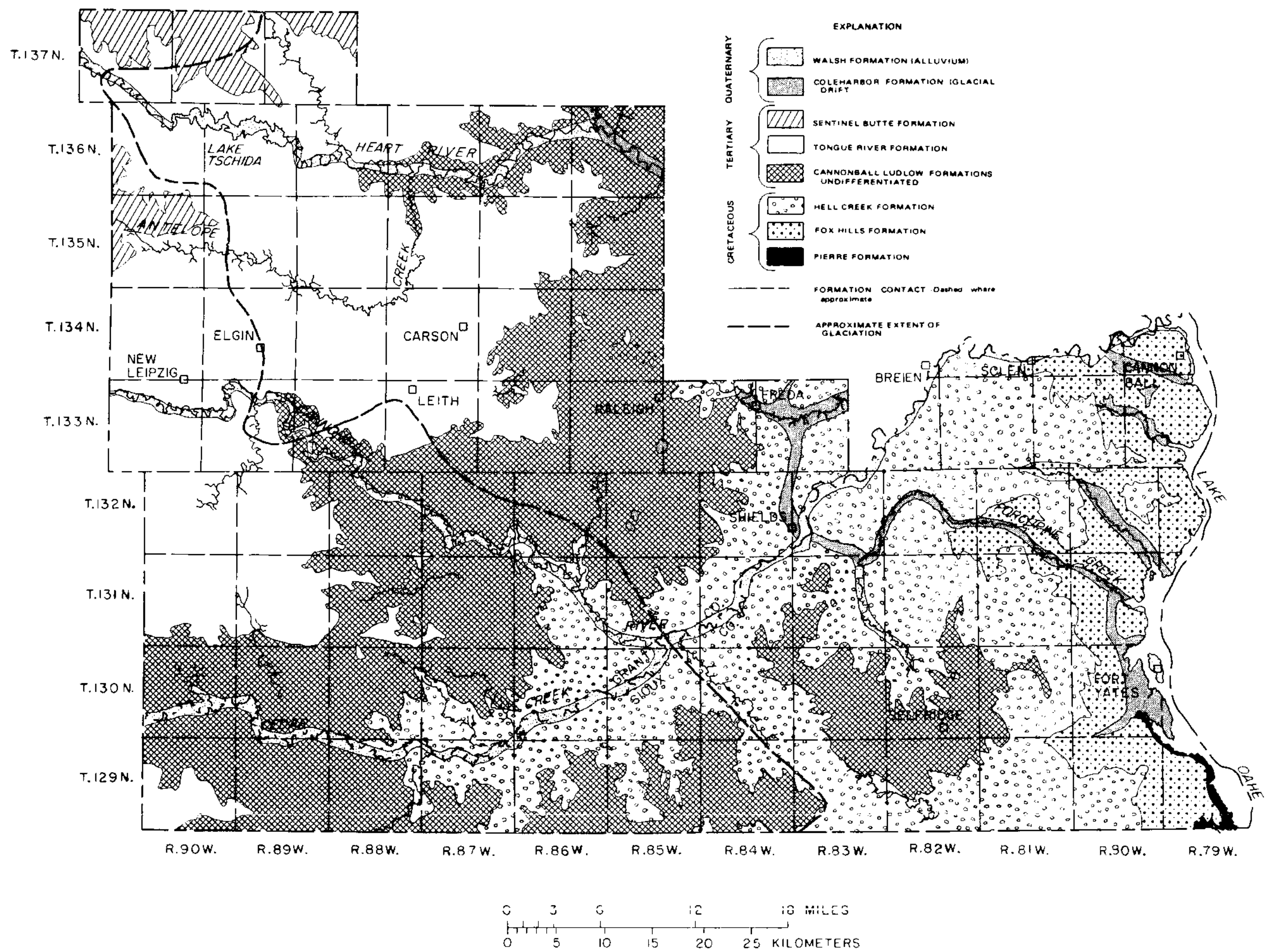


FIGURE 3.—Generalized surficial geology.

TABLE 1. — Stratigraphy of geologic formations that crop out in Grant and Sioux Counties

System	Series	Geologic formations	Average thickness (feet)	Range in thickness (feet)	Occurrence and lithology
Quaternary	Holocene	Walsh Formation (alluvium)	35	0-117	Occurs in the flood plains of the Heart and Cannonball Rivers, Cedar Creek, and their tributaries. It is composed of stratified gravel, sand, silt, and clay. The materials appear to be randomly interfingered and mixed. The thickest sections of sand and gravel occur in the channel terraces. The present channels contain mostly sand, silt, and clay. Origin of the materials varies from western siliceous rocks to redeposited glaciofluvial or bedrock material.
	Pleistocene	Coleharbor Formation (glacial drift)	220	0-338	Mantles parts of the surface in the northeastern and eastern parts of the area. It consists of till, clay, silt, sand, gravel, cobbles, and boulders. In many places the fine materials have been eroded so that only a boulder pavement remains. The thickest accumulation of drift is in buried valleys. The coarsest sand and gravel generally is located at the bottom and along the northern flanks of the buried valleys. About 90 percent of the drift in these valleys is a mixture of sand, silt, and clay.
Tertiary		Sentinel Butte Formation	100	0-185	Present in a small area in the northwestern part of Grant County. It consists of interbedded very fine to fine sandstone, siltstone, claystone, shale, and lignite. A sandstone interbedded with siltstone generally occurs near the base of the formation. The basal unit contains carbonaceous streaks. Interbedded siltstone, claystone, shale and lignite make up about 90 percent of the formation. Ironstone nodules and petrified wood fragments are often concentrated along bedding planes.
		Tongue River Formation	250	0-358	Well exposed in the northwestern one-third of the area in Grant County. It consists of interbedded very fine to medium sandstone, siltstone, claystone, shale, lignite, and limestone. Persistent sandstone beds generally occur at two stratigraphic horizons. The most extensive is the basal sandstone, which contains abundant petrified wood and, locally, carbonaceous plant fragments or seams of lignite. Interbedded shale, claystone, and siltstone make up about 70 percent of the formation. Extensive thick lignite beds are rare, but locally may be several feet thick. Thin lenses of limestone, usually less than 4 inches thick, occur in the siltstone and claystone beds.
		Cannonball and Ludlow Formations, undifferentiated	395	0-465	Widely exposed in the central part of the area. It consists of interbedded very fine to medium sandstone, siltstone, claystone, and shale. Persistent sandstone beds generally occur at three stratigraphic horizons. The most extensive is the middle bed, which contains large circular concretions. The sandstones are generally friable, glauconitic, and noncalcareous, except that the large concretions have a matrix of calcium carbonate cement. About two-thirds of the formation consists of siltstone, claystone, and shale. The siltstone and claystone are noncalcareous and contain abundant macerated plant and carbonaceous material, mica flakes, and iron concretions. The shales are carbonaceous and, locally, quite oily.
Cretaceous	Upper Cretaceous	Hell Creek Formation	294	0-325	Extensively exposed in the east-central part of the area. It consists of very fine to medium quartzose sandstone, siltstone, shale, and very thin beds of lignite. Lensing sandstone beds occur at about three stratigraphic horizons. The sandstone is characterized by a "salt and pepper" appearance because it contains many magnetite grains and manganese minerals. The most extensive is the upper bed, which contains thin lenses of bentonitic siltstone and siderite nodules. The basal sandstone is lignitic and grades into lignitic and bentonitic shale containing petrified wood.
		Fox Hills Formation	297	0-396	Exposed in the eastern part of Sioux County. It consists of very fine to medium sandstone, siltstone, and shale. A persistent sandstone bed occurs at or near the top of the formation. It is very fossiliferous in places, and often forms broad resistant benches or hilltops capped by resistant flaggy sandstone. This standstone is occasionally interbedded with thin lenses of siltstone and shale and comprises about one-third of the formation thickness in this area. The remaining two-thirds of the formation consists of interbedded siltstone and shale containing occasional fossil zones and limonitic concretions. In places, the basal part contains a volcanic ash bed associated with a very dense bentonitic shale.
		Pierre Formation	1,100		Exposed in a very small part of the area in southeastern Sioux County along Lake Oahe. The contact between the Pierre and the overlying Fox Hills is gradational for about 80 feet of the stratigraphic section in most places and consists of a bentonitic shale. The Pierre Formation consists predominantly of dark-grayish-black bentonitic shale with occasional fossils. Only the upper part of the formation was examined during this study.

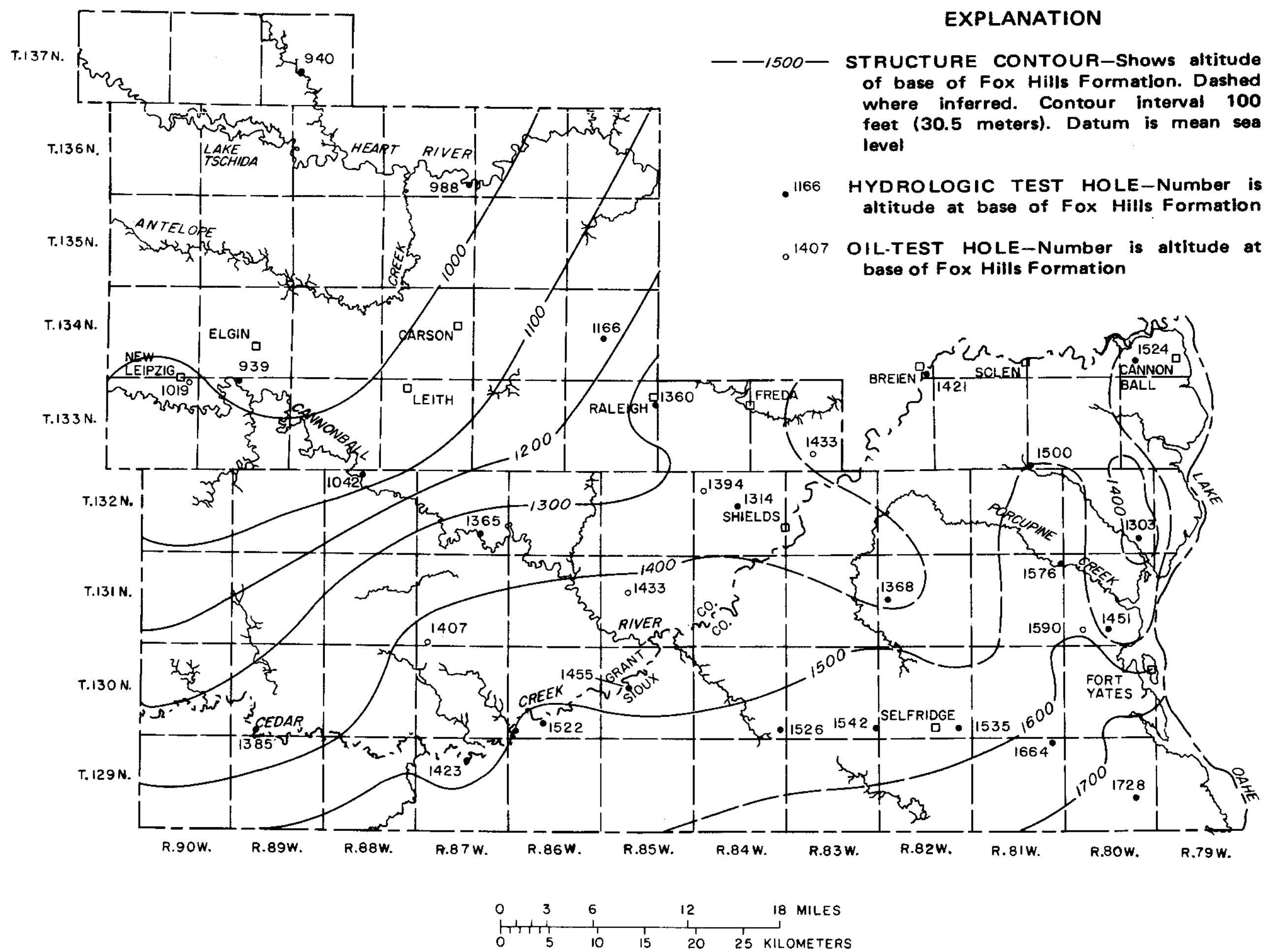


FIGURE 4.—Structure contours of the base of the Fox Hills Formation.

by the hydraulic gradient. Gravel, well-sorted sand, and fractured rocks generally are highly conductive. Deposits of these materials form aquifers. Cemented deposits and fine-grained materials such as silt, clay, and shale usually have a low conductivity and restrict ground-water movement.

The water level in an aquifer fluctuates in response to recharge to and discharge from the aquifer, usually indicating a change in the amount of water stored in the aquifer. In confined aquifers, however, changes in atmospheric pressure and in surface load also cause fluctuations in water level. In the report area, aquifers exposed at land surface are recharged each spring, summer, and early fall by direct infiltration of precipitation. Aquifers that are confined by thick deposits of fine-grained materials are recharged by seepage from the fine-grained materials or by lateral movement downgradient from a recharge area exposed at land surface. The rate of recharge may increase as water levels in the aquifer are lowered by pumping. However, water levels may decline for several years before sufficient recharge is induced to balance the rate of withdrawal. In some places this balance may never be achieved without curtailment of withdrawal.

In parts of Grant and Sioux Counties, surface-water sources, such as Lake Oahe, the Heart and Cannonball Rivers, and other smaller sources, are in hydraulic connection with aquifers. The aquifer may either receive recharge from the surface-water sources or discharge ground water into them, depending on head relationships, which generally vary both in time and space.

The ground water in Grant and Sioux Counties contains varying concentrations of dissolved mineral matter. 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 kinds and proportions of minerals that make up the soil and rocks, the pressure and temperature of the water and rock formations, and the concentration of carbon dioxide and soil acids in the water. Ground water that has been in transient storage a long time, or has moved a long distance from a recharge area, generally is more highly mineralized than water that has been in transit only a short time.

The suitability of water for various uses usually is determined by the kind and amount of dissolved mineral matter. The chemical constituents, physical properties, and indices most likely to be of concern are: iron, sulfate, nitrate, fluoride, boron, chloride, dissolved solids, hardness, temperature, odor, taste, specific conductance, sodium-adsorption ratio (SAR), and percent sodium. The sources of the major chemical constituents, their effects on usability, and the recommended limits are given in table 2. Additional information regarding drinking-water standards may be found in "Water-Quality Criteria, 1972," published by the U.S. Environmental Protection Agency (National Academy of Sciences-National Academy of Engineering, 1972).

In this report numerous references are made to ground-water types, such as sodium bicarbonate type and calcium bicarbonate type. These types are derived from inspection of the water analyses and represent the predominant cation (sodium, calcium, or magnesium) and anion (bicarbonate, sulfate, or chloride), as expressed in milliequivalents per liter.

TABLE 2.—Major chemical constituents in water — their sources, effects upon usability, and recommended concentration limits
(Modified from Durfor and Becker, 1964, table 2)

Constituents	Major source	Effects upon usability	National Academy of Sciences — National Academy of Engineering (1972) recommended limits for drinking water
Silica (SiO_2)	Feldspars, quartz, ferromagnesian 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, ferromagnesian minerals, ferrous and ferric sulfides, oxides, carbonates, and clay minerals. Manmade sources: well casings, pumps, and storage tanks.	If more than 0.1 mg/L[1] is present, it will precipitate when exposed to air; causes turbidity, stains plumbing fixtures, laundry, and cooking utensils, and imparts tastes and colors to food and drinks. More than 0.2 mg/L is objectionable for most industrial uses.	0.3 mg/L
Manganese (Mn)	Soils, micas, amphiboles, and hornblende.	More than 0.2 mg/L precipitates upon oxidation. Causes undesirable taste and dark-brown or black stains on fabrics and porcelain fixtures. Most industrial uses require water containing less than 0.2 mg/L.	0.05 mg/L
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, anhydrite, calcite, aragonite, limestone, 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 and detergent. High concentrations of magnesium have a laxative effect.	
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, magnesite, dolomite, and clay minerals.		
Sodium (Na)	Feldspars, clay minerals, and evaporites.	More than 50 mg/L 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.	Essential to plant nutrition. More than 2 mg/L may damage some plants.	
Bicarbonate (HCO_3)	Limestone and dolomite.	Heating water dissociates bicarbonate to carbonate and(or) carbon dioxide. The carbonate can combine with alkaline earths (principally calcium and magnesium) to form scale.	
Carbonate (CO_3)			
Sulfate (SO_4)	Gypsum, anhydrite, and oxidation of sulfide minerals.	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. Maximum limit for Grant and Sioux Counties is 2.4 mg/L.	Recommended maximum limits depend on average of maximum daily air temperatures. Maximum limits range from 1.4 mg/L at 32°C to 2.4 mg/L at 10°C.
Nitrate (NO_3)	Organic matter, fertilizers, and sewage.	More than 100 mg/L may cause a bitter taste and may cause physiological distress. Concentrations in excess of 45 mg/L have been reported to cause methemoglobinemia in infants.	45 mg/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.

[1]Milligrams per liter.

The quality of water used for irrigation is an important factor in productivity and in quality of the irrigated crops. Irrigation classifications were determined for selected water samples from aquifers in Grant and Sioux Counties (fig. 5), using a classification system developed by the U.S. Salinity Laboratory Staff (1954).

Ground Water in the Rocks of Late Cretaceous Age

Fox Hills aquifer

The Fox Hills Formation crops out in most of eastern Sioux County (fig. 3). Extensive beds of sandstone occur in the upper part of the formation. These sandstone beds form a major aquifer (pls. 2-4, in pocket), underlying all of Grant County and all but the extreme southeastern part of Sioux County.

The Fox Hills aquifer is the largest and most extensive aquifer studied in the two-county area. Depth to the top of the aquifer ranges from land surface in eastern Sioux County to about 900 feet (270 m) below land surface in northwestern Grant County. Thickness of the aquifer measured in 18 test holes ranged from 39 to 170 feet (12 to 52 m); mean thickness was about 100 feet (30 m).

Sediment-size classifications of six core samples show the aquifer materials consist predominantly of sand, but include 5 to 30 percent silt and 5 to 14 percent clay. Size analyses of material from the core samples show that the median particle diameter ranges from 0.08 to 0.15 mm, and the uniformity coefficient ranges from 9.9 to 150. The high values for the uniformity coefficient indicate that the sandstone is poorly sorted.

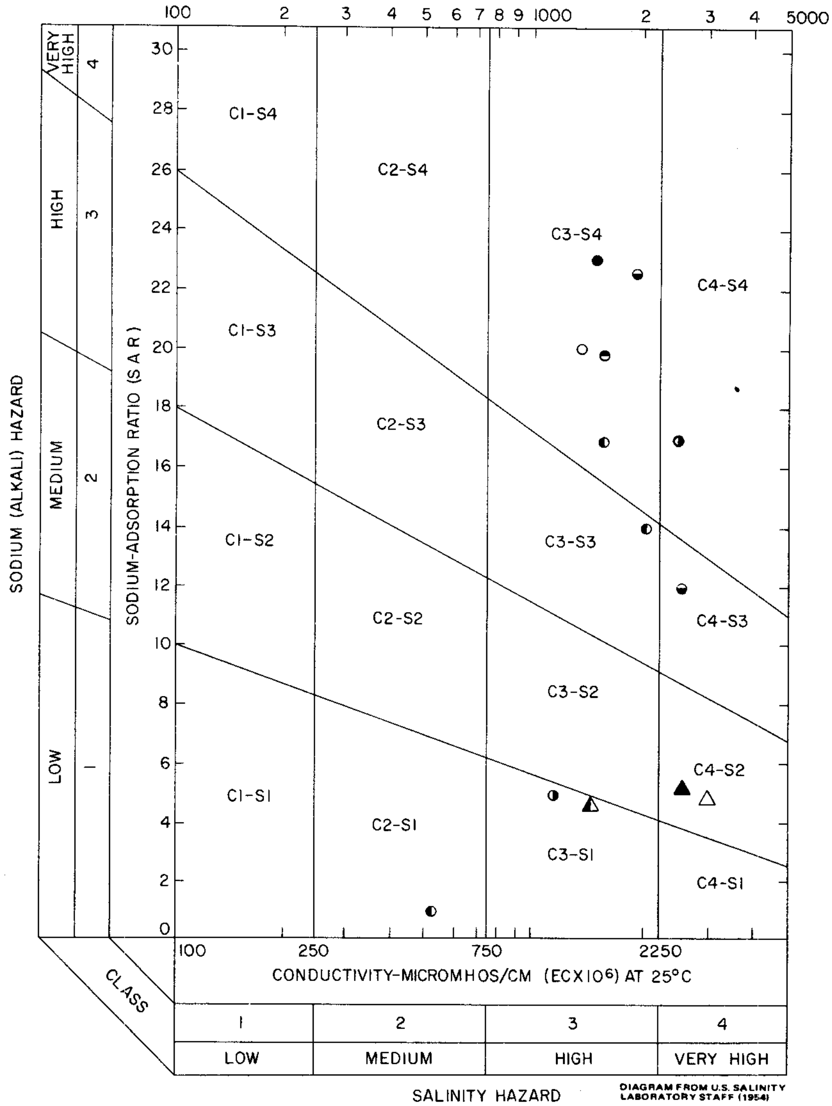
Laboratory tests on the core samples indicated that vertical hydraulic conductivities ranged from 11.8×10^{-5} ft/d (3.6×10^{-5} m/d) to 108 ft/d (33 m/d) and had a mean of 1.9 ft/d (5.7×10^{-1} m/d). Total porosity ranged from 39.3 to 53.2 percent and had a mean of 44.3 percent.

Slug tests were made on 15 observation wells. Transmissivities calculated from the slug tests ranged from 18 to 135 ft^2/d (1.7 to 12.5 m^2/d) and had a mean of 56 ft^2/d (5.2 m^2/d).

Potential yields of wells penetrating the aquifer range from 5 to 100 gal/min (0.3 to 6.3 L/s).

Water-level fluctuations shown in figure 6 reflect seasonal variations of water in storage and regional water-level trends in different parts of the Fox Hills aquifer. The seasonal variations are very small and are representative of conditions when withdrawal from the aquifer by wells is negligible. Figure 7 shows water-level fluctuations in well 134-082-36DCD, stage changes in the Cannonball River, and precipitation in an area where ground-water discharge is occurring. Water levels in this area fluctuate with stage changes in the river rather than with local precipitation. The hydrographs indicate an areal decline of water in storage — probably resulting from the decrease in precipitation during 1973-74.

The potentiometric surface of the Fox Hills aquifer in December 1973 is shown in figure 8. Ground water in the aquifer generally moves easterly to



EXPLANATION

GROUND WATER

- ○ TONGUE RIVER AQUIFER
- CANNONBALL-LUDLOW AQUIFER
- HELL CREEK AQUIFERS (>C4-S4)
- FOX HILLS AQUIFER (>C4-S4)
- SHIELDS AQUIFER
- ELM CREEK AQUIFER
- ST. JAMES AQUIFER
- BEAVER CREEK AQUIFER

SURFACE WATER

- △ CEDAR CREEK (NEAR PRETTY ROCK)
- ▲ CANNONBALL RIVER (AT BREIEN)
- HEART RIVER (NEAR LARK)

FIGURE 5.—Classifications of selected water samples for irrigation purposes.

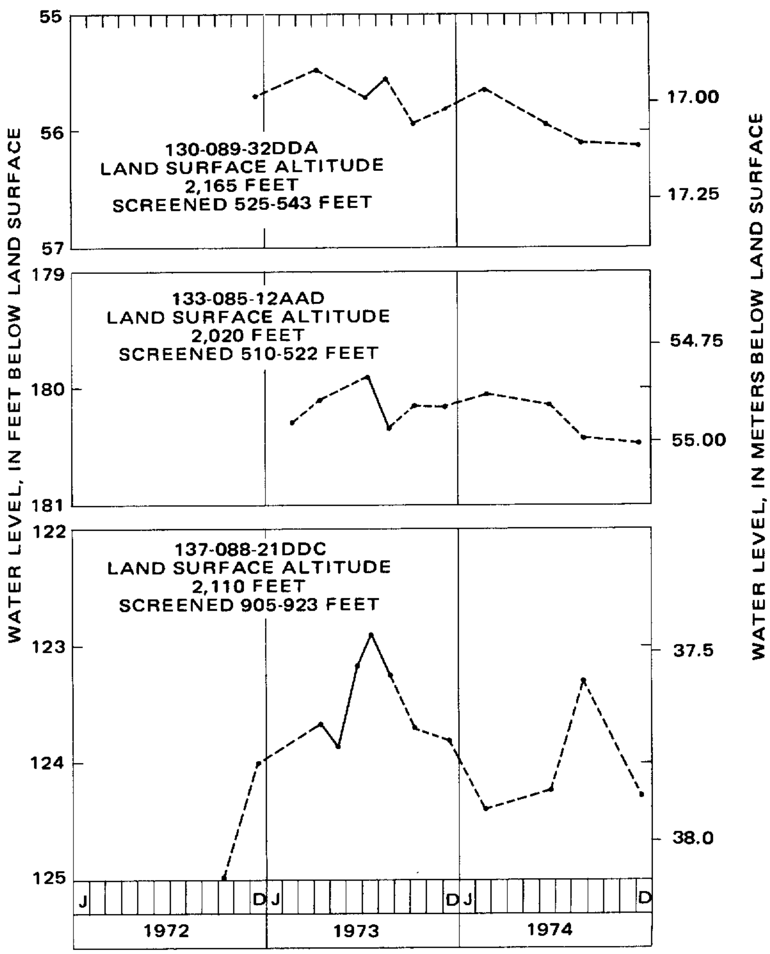


FIGURE 6.—Water-level fluctuations in the Fox Hills aquifer.

northeasterly under a hydraulic gradient ranging from 7 to 12 ft/mi (1.3 to 2.3 m/km). Local deviations to the general gradient due to a synclinal structure (pl. 4) occur in the central part of the area. Water is discharged where the aquifer crops out (fig. 3) along the Cannonball River and Lake Oahe in eastern Sioux County. In much of the study area the head in the Fox Hills aquifer is 50 to 100 feet (15 to 30 m) lower than the head in the overlying Hell Creek aquifers — indicating that the Hell Creek aquifers probably contribute some recharge to the Fox Hills aquifer.

Thirty-two water samples were collected for chemical analysis from 28 wells developed in the Fox Hills aquifer. Examination of the analyses indicates that the water generally is soft and is a sodium bicarbonate type. Dissolved-solids

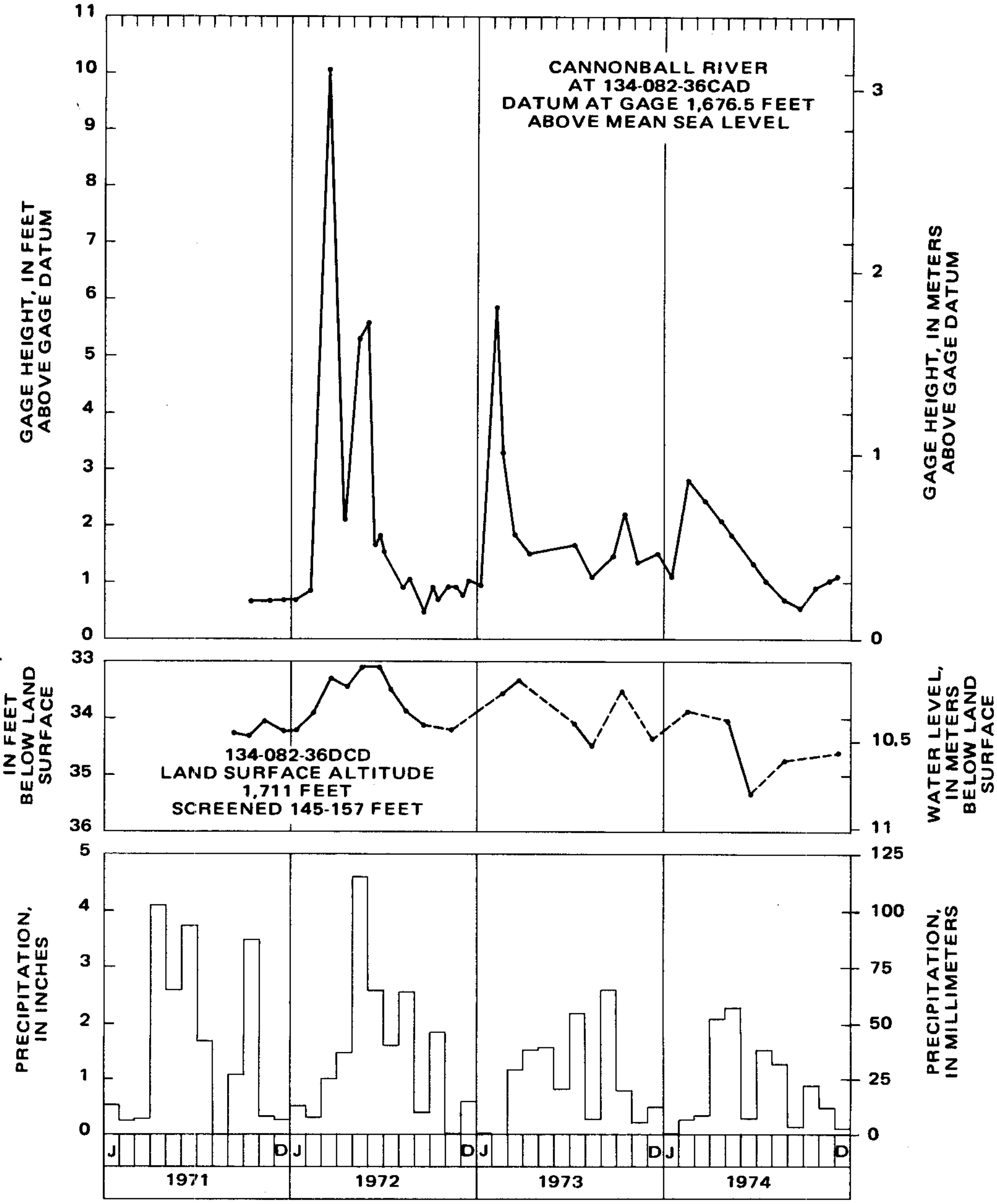


FIGURE 7.—Water-level fluctuations in the Fox Hills aquifer, stage changes in the Cannonball River, and precipitation at Breien, Sioux County.

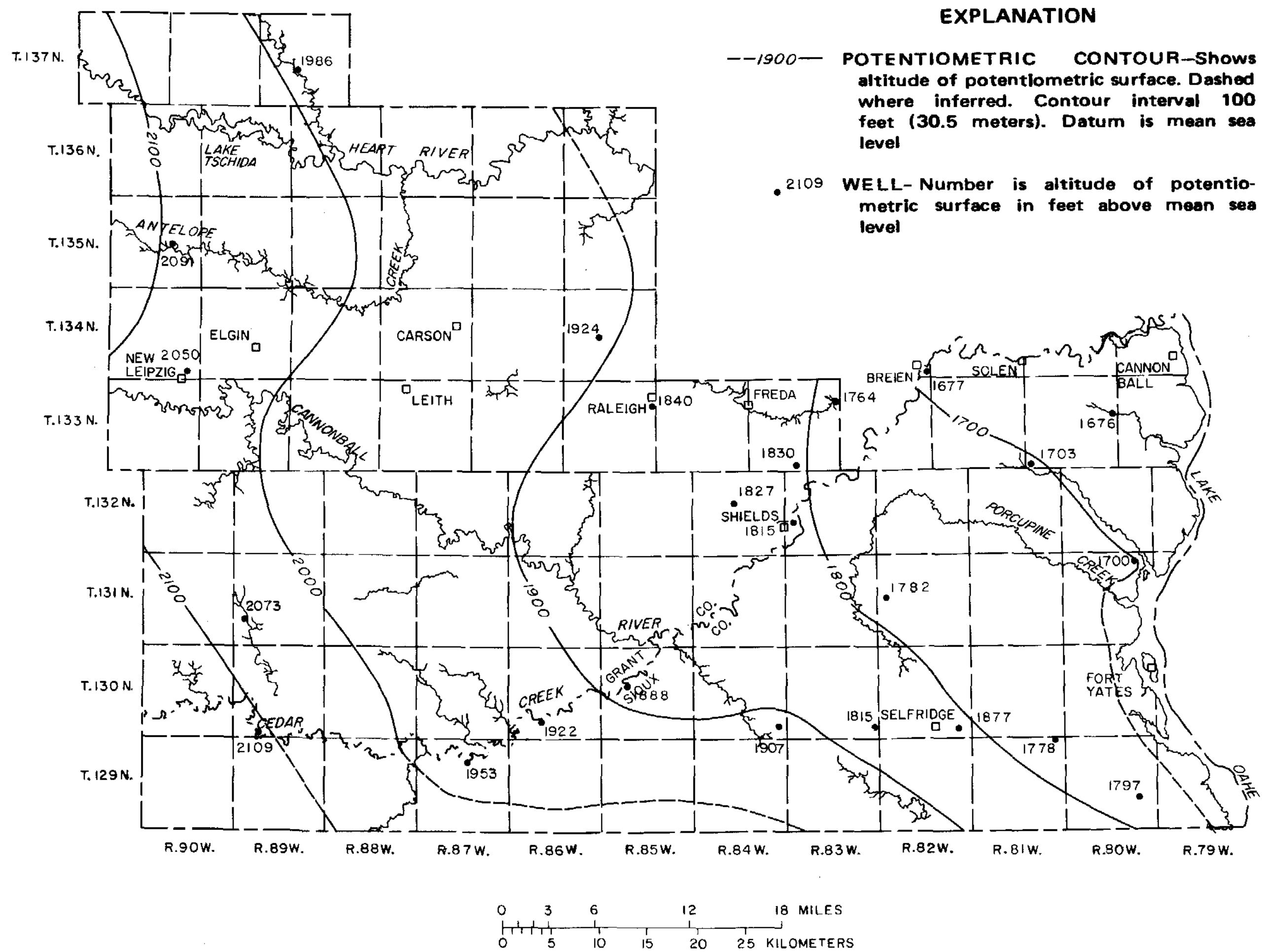


FIGURE 8.—Potentiometric surface of the Fox Hills aquifer, December 1973.

concentrations in the samples ranged from 296 to 2,020 mg/L and had a mean of 1,300 mg/L. Dissolved sodium ranged from 65 mg/L in the eastern outcrop area to 690 mg/L in northwestern Grant County where the aquifer is about 900 feet (270 m) below land surface. The sodium-adsorption ratio ranged from 1.7 to 87; the lower ratios were in the eastern part of the area and the higher ratios were in the northwestern part. Dissolved sulfate ranged from 1.6 in samples from the northwestern part of the area to 670 in samples from the eastern outcrop area. Sulfate concentrations exceeded the suggested limit (250 mg/L) in 11 of the 32 samples. Dissolved sodium and chloride concentrations increased and dissolved sulfate concentration decreased with increased depth below land surface — suggesting that sulfate sorption and chloride desorption are occurring, or that sulfate-reducing bacteria may be present in the aquifer or in the overlying sediments. There also is a possibility that some upward leakage is occurring along the flanks of the synclinal structure (pl. 4), as there are higher-than-average concentrations of chloride in ground water sampled along the sides of this structure.

Four water samples from the Fox Hills aquifer were analyzed for minor elements. The most abundant constituents found in all samples were strontium, which ranged from 0.09 to 0.17 mg/L; lithium; zinc; molybdenum; selenium; copper; and lead.

The water is suitable for livestock, most domestic, and some industrial uses. The salinity and sodium hazards for all the water except that near the outcrop are high to very high for irrigation.

Hell Creek aquifers

The Hell Creek Formation crops out in eastern Grant County and Central Sioux County (fig. 3). Beds of sandstone form aquifers in the upper, middle, and, in some places, the lower part of the formation. Only the upper sandstone beds appear to be continuous and areally extensive. The middle and lower sandstone beds vary considerably in stratigraphic position and thickness and are discontinuous in many places.

The Hell Creek aquifers (pls. 2-4) underlie all of Grant County and the western part of Sioux County. Measured thicknesses of the aquifers in 13 test holes are as follow: (1) the lower aquifer ranged from 10 to 55 feet (3 to 17 m) and had a mean of 23 feet (7 m); (2) the middle aquifer ranged from 6 to 60 feet (2 to 18 m) and had a mean of 34 feet (10 m); and (3) the upper aquifer ranged from 15 to 159 feet (4.6 to 48.5 m) and had a mean of 70 feet (21 m).

Sediment-size classifications of 12 core samples show that the aquifer materials consist of fine-grained sand, but include 9 to 43 percent silt and 5 to 23 percent clay. Size analyses of material from these samples show that the median particle diameter ranges from 0.03 to 0.20 mm, and the uniformity coefficient ranges from 14 to 380.

Laboratory tests on the core samples indicated that vertical hydraulic conductivities ranged from 28×10^{-6} ft/d (8.5×10^{-6} m/d) to 15×10^{-2} ft/d (4.6×10^{-2} m/d) and had a mean of 18×10^{-3} ft/d (5.5×10^{-3} m/d). Total porosity ranged from 28.1 to 47.0 percent and had a mean of 37.3 percent.

Slug tests were made on 11 observation wells developed in the Hell Creek aquifers. Transmissivities calculated from the slug tests ranged from 15 to 79 ft^2/d (1.4 to 7.3 m^2/d) and had a mean of 34 ft^2/d (3.2 m^2/d).

Potential yields to wells penetrating aquifers in the Hell Creek Formation range from 1 to 5 gal/min (0.06 to 0.3 L/s) for each 10 feet (3 m) of aquifer thickness.

The water levels plotted in figure 9 reflect seasonal variations in storage in the middle Hell Creek aquifer. They generally show seasonal fluctuations regardless of their depth below land surface. Where the lower Hell Creek aquifer is separated from the underlying Fox Hills aquifer by a confining bed of shale or siltstone generally less than 20 feet (6 m) thick, the water levels are only about 10 feet (3 m) higher than those in the Fox Hills aquifer.

The potentiometric surface of the upper Hell Creek aquifer in December 1973, is shown in figure 10. The regional direction of water movement is toward the northeast. However, in the outcrop area the potentiometric surface generally is a subdued reflection of the topographic surface. The hydraulic gradient in the discharge area is about 20 ft/mi (4 m/km); the regional gradient is much more gradual at about 5 to 10 ft/mi (0.9 to 2 m/km).

Thirty-six water samples were collected for chemical analysis from 29 wells developed in the Hell Creek aquifers. Examination of the analyses indicates that the water generally is soft and is a sodium bicarbonate type. Dissolved-solids concentrations in the samples ranged from 483 to 3,320 mg/L and had a mean of 1,280 mg/L. Dissolved sodium ranged from 170 to 900 mg/L. The sodium-adsorption ratio ranged from 6.5 in the outcrop area to 91 in northwestern Grant County. Dissolved sulfate ranged from 1.2 mg/L in north-central Grant County to 1,900 mg/L near the Cannonball River. Samples from the western and northwestern parts of the area contained less dissolved sulfate and more dissolved chloride than the samples from the outcrop area — suggesting that possibly sulfate sorption and chloride desorption are occurring, or that sulfate-reducing bacteria are present in the aquifer or in the overlying sediments.

Six water samples from the Hell Creek aquifers were analyzed for minor elements. The most abundant dissolved constituent found in all samples was strontium, which ranged from 0.10 to 0.12 mg/L. These samples contained larger concentrations of barium, copper, molybdenum, and zinc, and a lesser concentration of lithium than did samples from the underlying Fox Hills aquifer.

Water from the Hell Creek aquifers is suitable for livestock, most domestic, municipal, and some industrial uses. Although some water from the Hell Creek aquifers has salinity and sodium hazards low enough to permit its use for irrigation, the residual sodium carbonate is too high for most irrigation use.

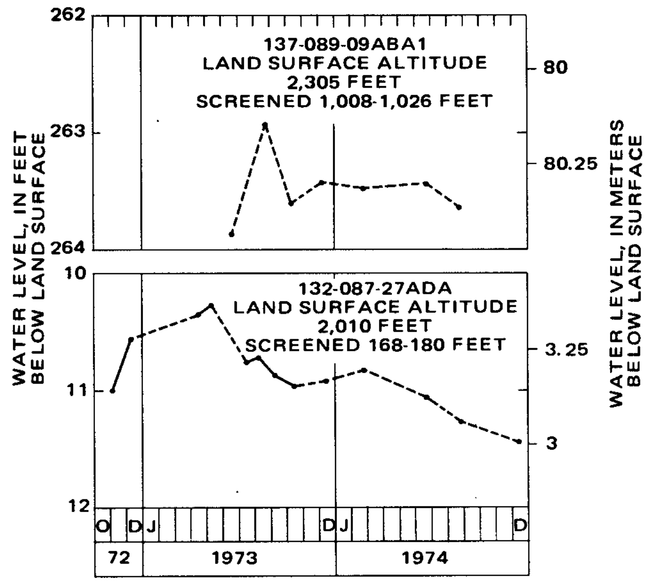


FIGURE 9.—Water-level fluctuations in the middle Hell Creek aquifer in Grant County.

Ground Water in Rocks of Tertiary Age

Cannonball and Ludlow aquifer, undifferentiated

The Cannonball and Ludlow Formations, undifferentiated, crop out in eastern and southern Grant County and in southwestern and central Sioux County (fig. 3), but in northwestern Grant County are as much as 445 feet (136 m) below land surface. Beds of sandstone occur in as many as three intervals within the Cannonball and Ludlow Formations. The sandstone beds are discontinuous and occur in both the Cannonball and Ludlow deposits. These sandstone beds often contain fossiliferous or limonitic concretion zones; the concretions are either round or lenticular, ranging from a few inches to several feet in the longest dimension. In the outcrop areas the sandstone beds form weathered, resistant benches topped with sandy soils. These benches have an undulating surface. Where buried, (in most of Grant County and in parts of Sioux County) the sandstone beds generally are saturated and form a major aquifer.

Measured thicknesses of the Cannonball and Ludlow aquifer in eight test holes ranged from 9 to 88 feet (3 to 27 m); mean thickness was 35 feet (11 m).

Sediment-size classifications of five core samples from the Cannonball and Ludlow aquifer show aquifer materials consist of fine-grained sand, but include 7 to 26 percent silt and 1 to 30 percent clay. Size analyses of material from these samples show that the median particle diameter ranges from 0.06 to 0.16 mm, and the uniformity coefficient ranges from 5.6 to 80.

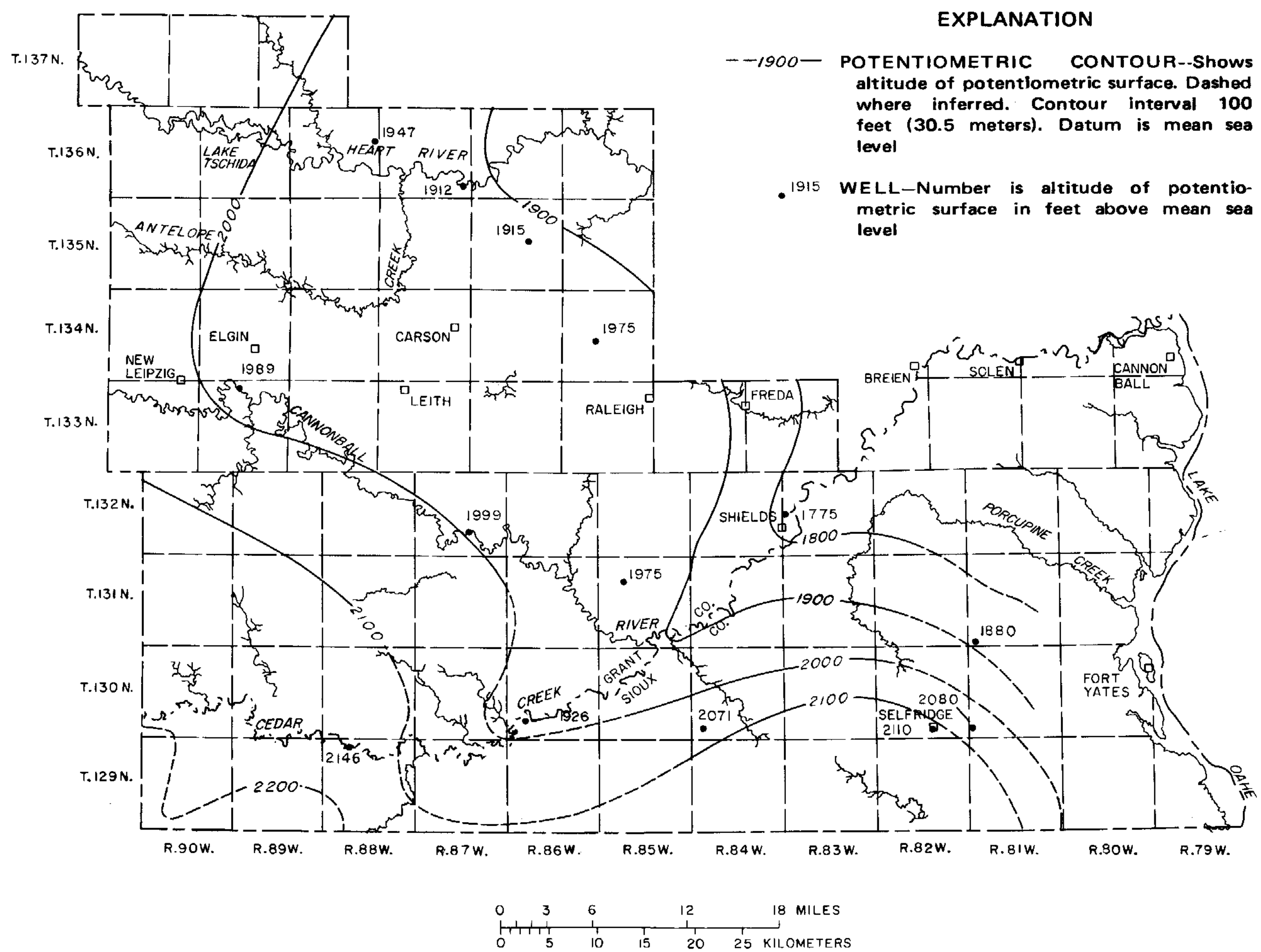


FIGURE 10.—Potentiometric surface of the upper Hell Creek aquifer, 1973.

Laboratory tests of four core samples from the Cannonball and Ludlow aquifer indicated that the vertical hydraulic conductivity ranged from 3.6×10^{-5} ft/d (1.1×10^{-5} m/d) to 25×10^{-2} ft/d (7.7×10^{-2} m/d) and had a mean of 15×10^{-2} ft/d (4.6×10^{-2} m/d). Total porosity ranged from 30.3 to 42.8 percent.

Flow or slug tests were made on three observation wells developed in this aquifer. The transmissivities calculated from these tests ranged from 16 to 290 ft^2/d (1.5 to 26.9 m^2/d) and had a mean of 111 ft^2/d (10.3 m^2/d).

Potential yields to wells penetrating the Cannonball and Ludlow aquifer are estimated to be from 5 to 150 gal/min (0.3 to 9.5 L/s).

Water levels plotted in figure 11 reflect seasonal variations and trends of water in storage in two intervals of the Cannonball and Ludlow aquifer. These and other measured water levels indicate that seasonal fluctuations in wells penetrating the Cannonball and Ludlow aquifer generally are less than 2 feet (0.6 m).

The potentiometric surface of the major parts of the Cannonball and Ludlow aquifer in December 1973 is shown in figure 12. Contours indicate that ground-water movement generally is toward the east from recharge areas in the west. Ground water is discharged in the Cedar Creek and Cannonball River valleys. The regional hydraulic gradient through Grant County generally is 5 to 10 ft/mi (0.9 to 2 m/km). In the ground-water discharge areas, however, the hydraulic gradient increases to about 15 to 20 ft/mi (2.8 to 4 m/km).

Wells developed in the Cannonball and Ludlow aquifer in the Cedar Creek and in the Heart River valleys flow. Observation well 137-090-30AAC, in the Heart River valley, had an initial flow of 100 gal/min (6.3 L/s) from the Cannonball and Ludlow aquifer. When the well was shut in, pressure readings showed the head to be 71 feet (22 m) above land surface.

Twenty-six water samples were collected for chemical analysis from 20 wells and one spring developed in the Cannonball and Ludlow aquifer. Analyses show that water in the recharge areas is very hard and is a calcium bicarbonate type, but in other areas the water ranges from soft to very hard and is either a

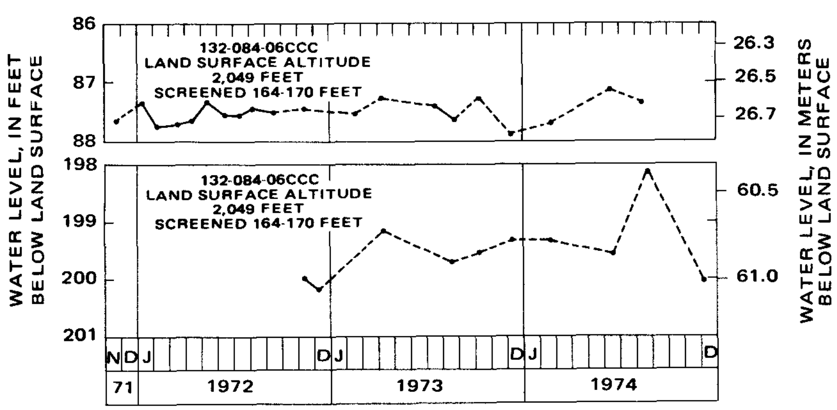


FIGURE 11.—Water-level fluctuations in the Cannonball and Ludlow aquifer, Grant County.

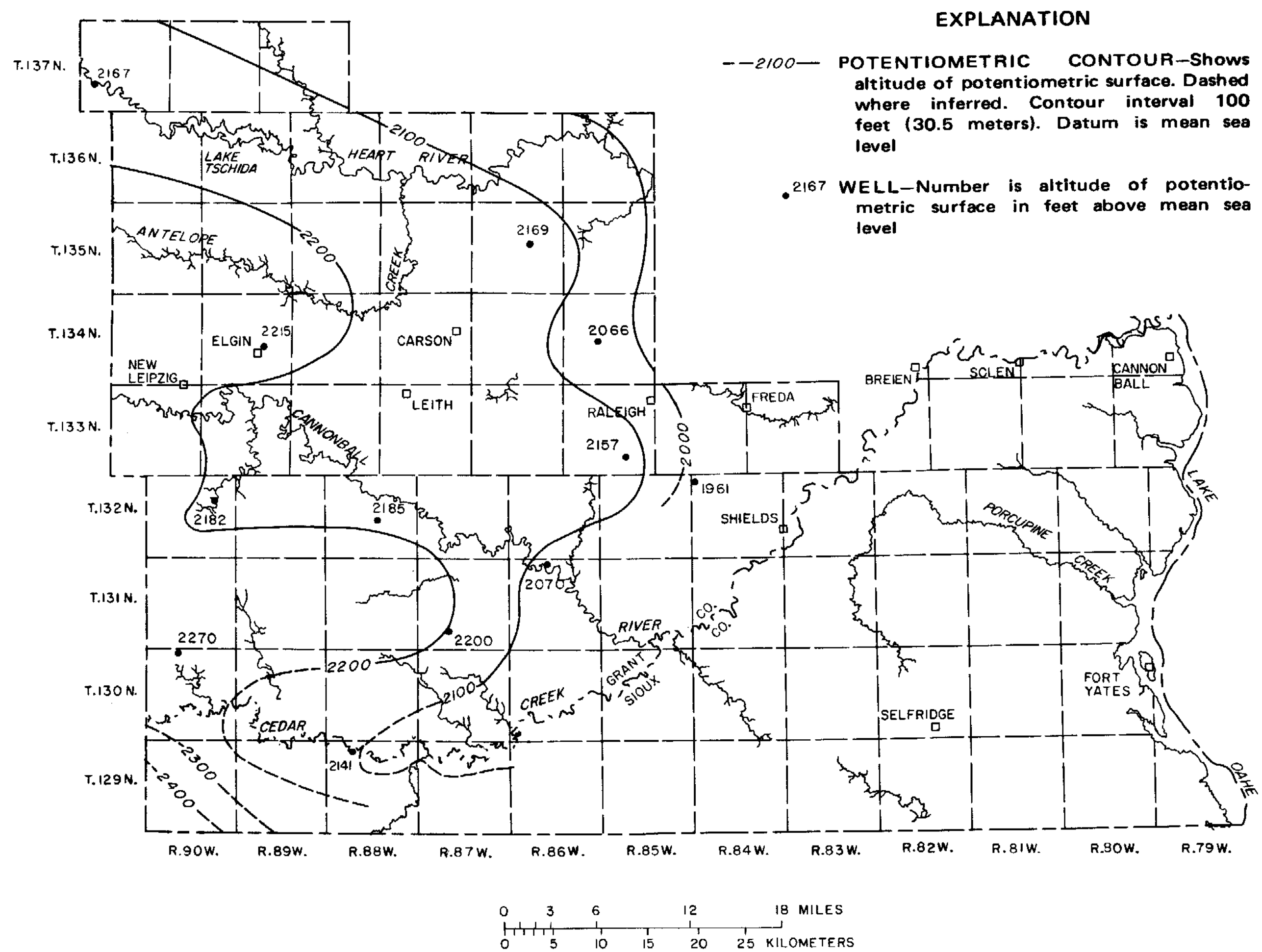


FIGURE 12.—Potentiometric surface of the Cannonball and Ludlow aquifer, 1973.

sodium bicarbonate or a sodium sulfate type. Sodium or calcium is the predominant cation, and bicarbonate or sulfate is the predominant anion. Dissolved-solids concentrations in the samples ranged from 412 to 2,840 mg/L and had a mean of 1,440 mg/L. Dissolved sodium ranged from 42 to 810 mg/L and had a mean of 481 mg/L. The sodium-adsorption ratio ranged from 0.8 in the outcrop area to 92 in the northwestern part of Grant County. Dissolved sulfate ranged from 0 to 1,300 mg/L and had a mean of 388 mg/L. Sulfate concentrations in 11 samples and iron concentrations in nine samples exceeded the limits recommended for drinking water (table 2).

Figure 13 shows a comparison between water quality in the Cannonball River at Breien and water quality in the aquifer that crops out in the stream valley upstream from the Breien station. Water in the Cannonball River during periods of low to moderate flows is chemically very similar to water in the Cannonball and Ludlow aquifer.

Three water samples from the Cannonball and Ludlow aquifer were analyzed for minor elements. The most abundant dissolved constituents found in all samples were zinc, which ranged from 0.01 to 2.00 mg/L, and strontium, which ranged from 0.13 to 1.10 mg/L. These samples contained larger concentrations of zinc, strontium, nickel, lead, and cyanide, and a lower concentration of vanadium than did samples from the underlying Hell Creek aquifers.

In the recharge areas, water from the Cannonball and Ludlow aquifer is suitable for most domestic, livestock, and municipal use. In discharge areas, and where the aquifers are buried, high sulfate and iron concentrations make the water undesirable for most domestic and municipal uses. Some water from the Cannonball and Ludlow aquifer has salinity and sodium hazards low enough to permit its use for irrigation, but most of the water contains too high a sodium concentration for irrigation use.

Tongue River aquifer

The Tongue River Formation underlies the northwestern one-third of Grant County and crops out in places along the Heart and Cannonball River valleys. Beds of sandstone occur in one or more intervals within the formation. The sandstone often contains ferruginous or fossiliferous oval nodules up to several feet in length. These nodules generally are cemented with calcium carbonate and are crossbedded. Some of the upper and middle sandstone beds form resistant cap rocks on buttes in the area. The lower, or basal, sandstone bed is the thickest and most extensive, forming the only major aquifer (pls. 2 and 4) in the Tongue River Formation.

Measured thickness of the Tongue River aquifer in 18 test holes ranged from 30 to 189 feet (9 to 57.6 m); mean thickness was 45 feet (14 m).

Sediment-size classifications of three core samples show that the aquifer materials consist predominantly of fine-grained sand but include 7 to 18 percent silt and 8 to 15 percent clay. Size analyses of materials from these samples show that the median particle diameter ranges from 0.08 to 0.16 mm, and the uniformity coefficient ranges from 11 to 63.

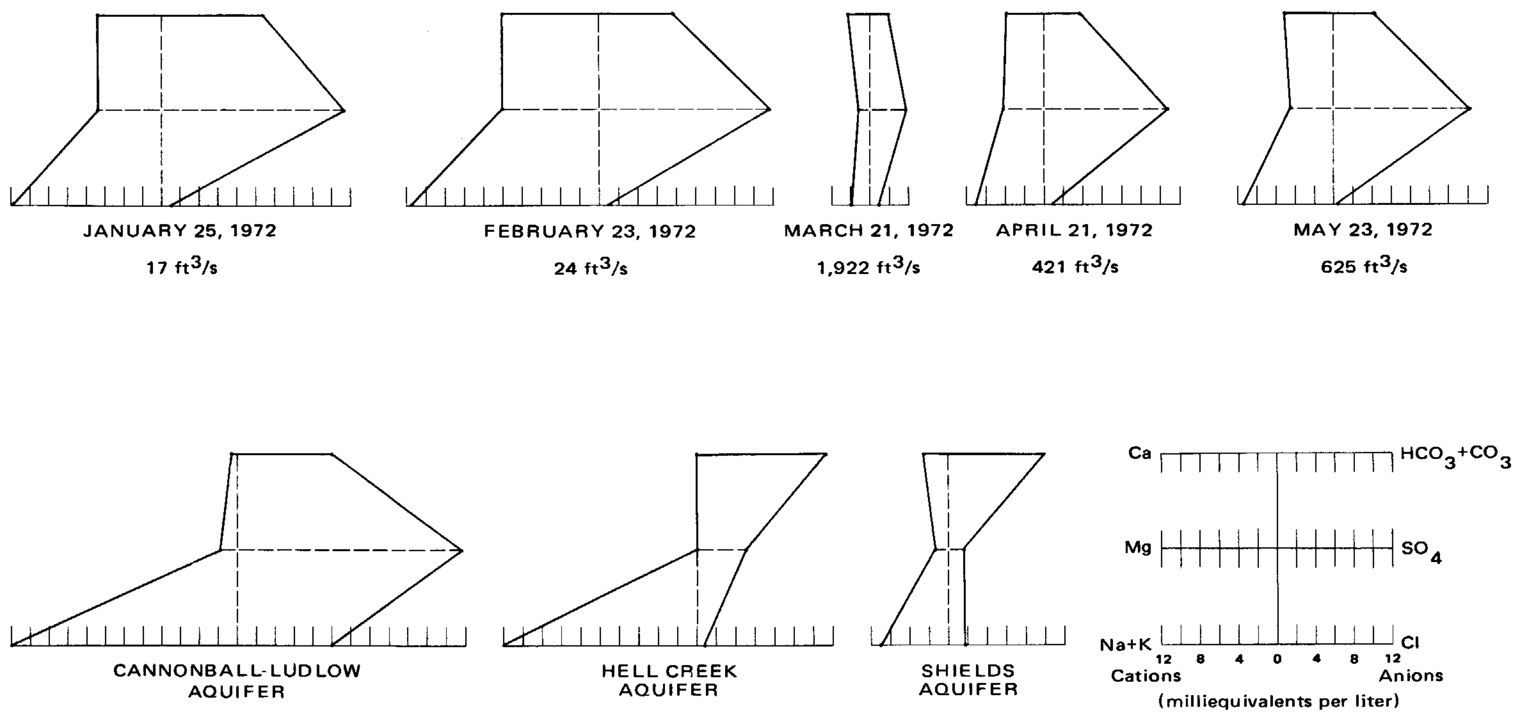


FIGURE 13.—Selected analyses of water from the Cannonball River at Breien and from major aquifers underlying the river upstream from the Breien station.

Laboratory tests of the core samples indicated that the vertical hydraulic conductivity ranged from 23x10^{-6} ft/d (7.1x10^{-6} m/d) to 19x10^{-2} ft/d (5.7x10^{-2} m/d). Total porosity for the samples ranged from 29.0 to 41.6 percent and averaged 35.8 percent.

Slug tests were made on two observation wells developed in the Tongue River aquifer. Transmissivities calculated from these tests were 21 and 24 ft^2/d (2.0 and 2.2 m^2/d).

Potential yields to wells penetrating the Tongue River aquifer are estimated to be from 5 to 100 gal/min (0.3 to 6.3 L/s).

Water levels plotted in figure 14 reflect seasonal variations of water in storage in the basal Tongue River aquifer. The fluctuations in well 132-090-14AAB2, which is in a ground-water discharge area, indicate a decrease in storage in the aquifer during the period of record. Fluctuations in wells 137-089-09ABA2 and 135-089-22CDD, which are in an area where the aquifer lies between 189 and 366 feet (58 and 112 m) below land surface, reflect regional water-level trends in the aquifer.

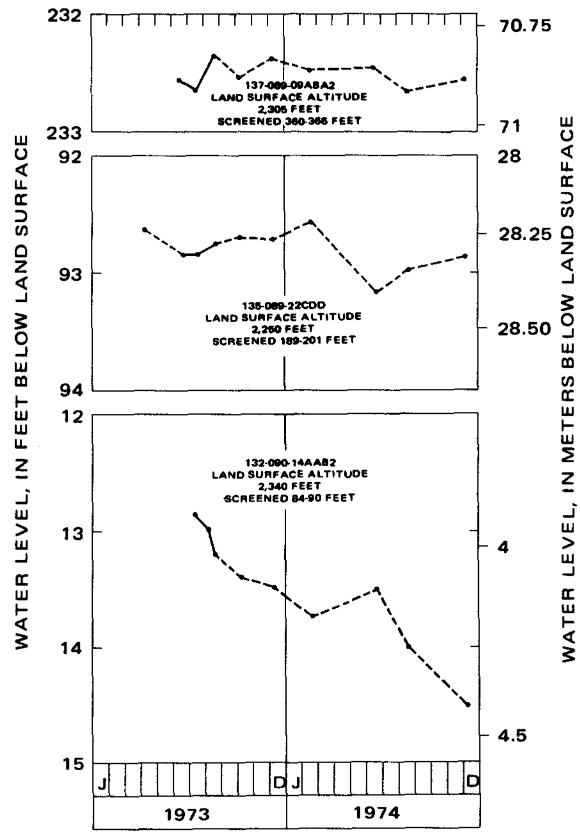


FIGURE 14.—Water-level fluctuations in the Tongue River aquifer, Grant County.

The potentiometric surface of the Tongue River aquifer during December 1973 is shown in figure 15. Contours indicate that ground-water movement is generally east to northeast, and that the hydraulic gradient is about 11 ft/mi (2.1 m/km). Local deviations indicate ground-water movement from topographic highs toward stream valleys.

Eleven water samples were collected for chemical analysis from 10 wells and one spring developed in the Tongue River aquifer. Water in seven of the samples was very hard and had the highest noncarbonate hardness in the area. Water in the other four samples was soft and had no noncarbonate hardness. The very hard water ranged from calcium bicarbonate or calcium sulfate type to sodium bicarbonate or sodium sulfate type. The soft water was all sodium bicarbonate or sodium sulfate type. Sodium and calcium were the predominant cations, and bicarbonate and sulfate were the predominant anions in water samples from the Tongue River aquifer in Grant County. Dissolved-solids concentrations in the 11 samples ranged from 368 to 1,720 mg/L and had a mean of 1,040 mg/L. The dissolved sodium ranged from 12 to 600 mg/L, and the sodium-adsorption ratio ranged from 0.3 to 52. Dissolved sulfate ranged from 61 to 880 mg/L and exceeded 250 mg/L in six of the 11 samples. Dissolved iron ranged from 0 to 3.1 mg/L and exceeded 0.3 mg/L in eight of the 11 samples.

Water from the Tongue River aquifer is suitable for most livestock use and for some industrial uses; however, the high sulfate and iron concentrations in many areas make it undesirable for domestic and municipal use. Although water from some parts of the Tongue River aquifer has salinity and sodium hazards low enough to permit its use for irrigation, water from other parts of the aquifer is classified hazardous for irrigation (Randich, 1975, table 4).

Sentinel Butte aquifers

The Sentinel Butte Formation occurs in a small part of northwestern Grant County (fig. 3). Resistant sandstone beds in the formation form a cap rock on buttes in this area. Logs of two test holes penetrating the formation show four to five sections of sandstone and lignite ranging from 2 to 10 feet (0.6 to 3.0 m) in thickness that may be potential aquifers. The basal section, which consists of poorly sorted very fine to fine-grained sandstone, appears to be the most extensive.

Potential yields to wells penetrating Sentinel Butte aquifers in Grant County probably would be less than 20 gal/min (1.3 L/s).

Ground Water in Glacial Deposits of Pleistocene Age

Aquifers with the greatest potential for ground-water development in the glacial deposits (Coleharbor Formation) are those associated with buried valleys in parts of northeastern and eastern Grant County and in central and eastern Sioux County. For convenience of discussion, identification, and future reference, aquifer names are continued from adjacent areas — Elm Creek aquifer

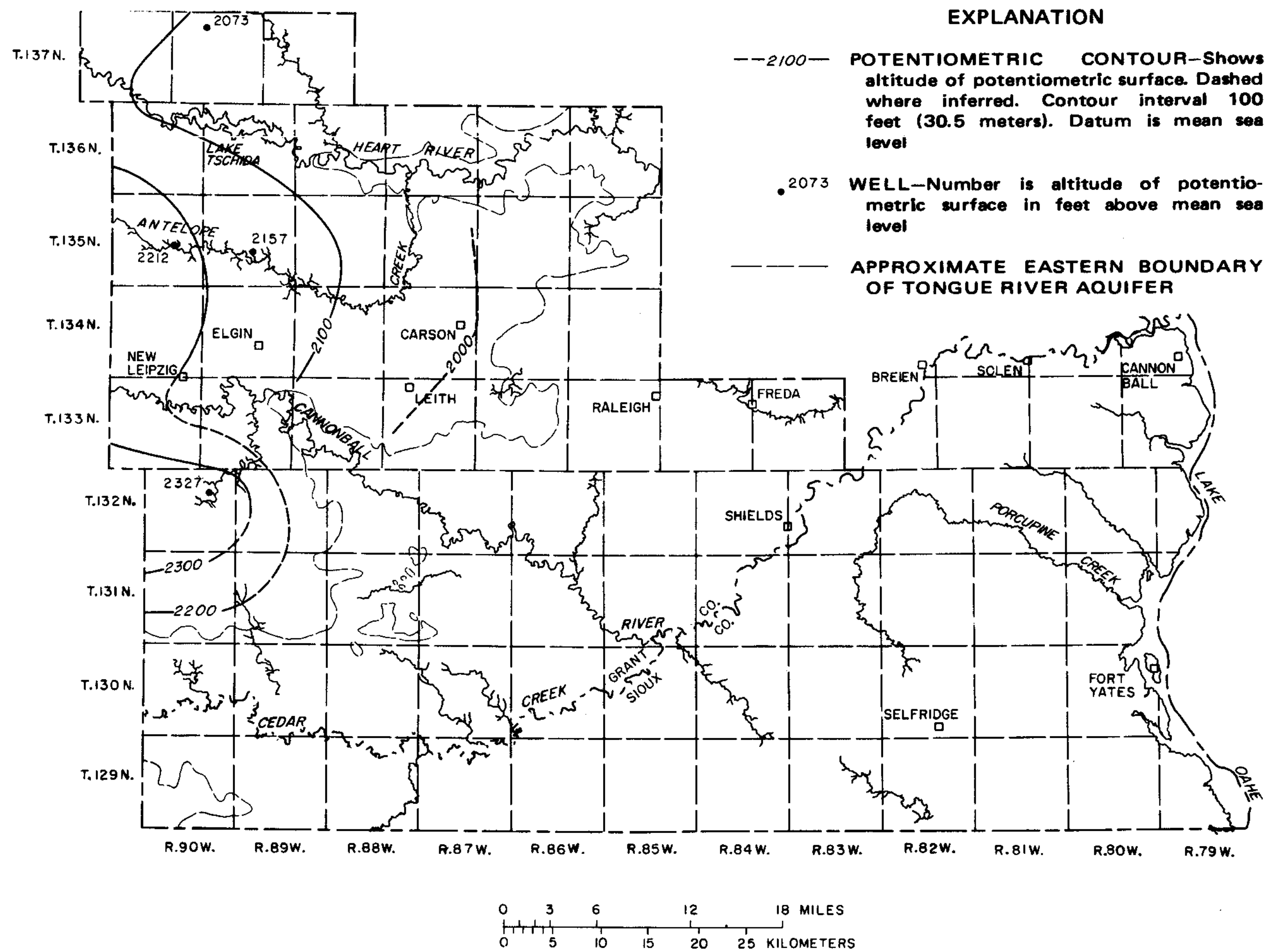


FIGURE 15.—Potentiometric surface of the Tongue River aquifer, December 1973.

(pl. 1). Newly recognized aquifers are named after local geographic features, such as streams or cities — Battle Creek, Beaver Creek, Shields, and St. James aquifers (pl. 1).

Where sufficient geohydrologic data are available, an estimate of ground water available from storage is given. Estimates are in acre-feet, and are products of areal extent, saturated thickness, and specific yield. These estimates are based on static conditions and do not take into account recharge, natural discharge, or ground-water movement. The quantitative evaluation of these factors is beyond the scope of this study.

The potential yields to properly constructed wells from these aquifers are shown on the ground-water availability map (pl. 1). The yield values are based on transmissivities calculated according to methods described by Keech (1964) and Meyer (1963, p. 339). The aquifers are lenticular in cross section, thus, the largest well yields are obtainable only by developing the thickest parts, and by screening the entire section.

The ground-water availability map should be used with the understanding that the estimated yields are for fully penetrating, properly screened and developed wells. The map is intended as a guide in the location of ground-water resources, and not as a map to locate specific production wells. Few if any aquifers are so uniform in areal extent and physical properties that production wells could be constructed in them without additional test drilling.

Although a large quantity of water is available for potential irrigation development in places, the quality of the water generally is undesirable. Should irrigation supplies be developed, it is essential that irrigation practices be acceptable to soil and crop types in the area.

Shields aquifer

The Shields aquifer occupies a buried bedrock valley in Grant and Sioux Counties. The aquifer extends from south-central Morton County southward toward Shields, then east beneath the present Cannonball River to Porcupine Creek. It underlies Porcupine Creek until the creek reaches Lake Oahe north of Fort Yates. The aquifer probably extends southward and underlies Lake Oahe to the South Dakota border (pl. 1). The Shields aquifer has an areal extent of about 30 mi^2 (80 km^2) in Grant and Sioux Counties.

Data from 48 test holes show that the aquifer generally consists of several sand and gravel beds (pl. 5, secs. D-D', E-E', and F-F', in pocket) that range in thickness from 5 to 139 feet (1.5 to 42.4 m). The mean aquifer thickness is about 90 feet (27 m). Test-hole data indicate that the coarsest, most permeable material generally is found along the central axis of the buried valley and at the valley bottom (pl. 5, secs. E-E' and F-F'). The most productive areas in the Shields aquifer are near Shields and near Fort Yates (pl. 1).

Water levels in the Shields aquifer range from about 5 to 95 feet (2 to 29 m) below land surface. The largest fluctuations occur near Fort Yates (fig. 16), where the aquifer is very responsive to stage changes in Lake Oahe. The fluctuations become very small beyond a 2-mile (3-km) distance from the lake.

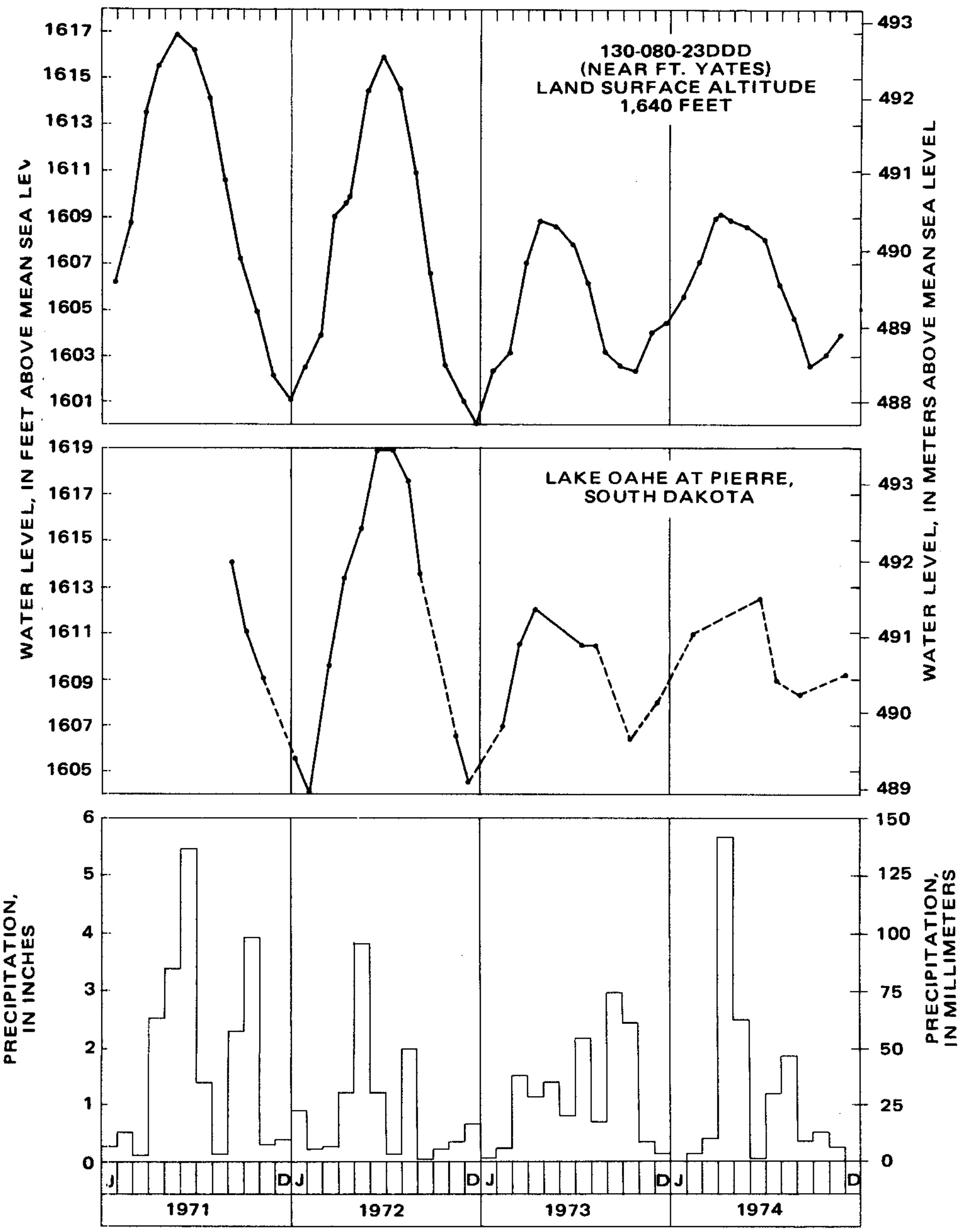


FIGURE 16.—Water-level fluctuations in the Shields aquifer, stage changes in Lake Oahe, and precipitation at Fort Yates, Sioux County.

Water levels generally fluctuate less than 1 foot (0.3 m) annually in other parts of the aquifer (fig. 17). The small fluctuations reflect gradual changes in storage — controlled largely by precipitation and by the hydraulically connected adjacent and underlying bedrock aquifers.

Recharge is derived from underlying bedrock aquifers and from infiltration of precipitation through sediments in the stream valleys overlying the aquifer.

The potentiometric surface in the Shields aquifer ranges from 1,860 feet (567 m) above mean sea level near Shields to about 1,604 feet (489 m) near Fort Yates. The average hydraulic gradient is about 50 ft/mi (9 m/km) southeast toward Lake Oahe, which is a ground-water discharge area. Low-flow measurements made on the Cannonball River upstream, on, and downstream from the aquifer show a relatively small gain in streamflow, and a small but progressive decrease in most dissolved minerals in the water at and downstream from the aquifer — indicating that some ground water from the Shields aquifer probably is contributing to flows in this reach of the Cannonball River. However, should water levels in the area be lowered by pumping, recharge would be induced from the Cannonball River.

Based on an areal extent of 30 mi^2 (80 km^2), a mean thickness of 90 feet (27 m), and an estimated specific yield of 15 percent, about 260,000 acre-feet (320 hm^3) of water is available to wells from ground-water storage in the Shields aquifer.

Analyses of 23 water samples from the Shields aquifer indicate that the water generally is very hard and is predominantly a sodium bicarbonate type. Dissolved-solids concentrations in the samples ranged from 413 to 1,600 mg/L and had a mean of 980 mg/L. Dissolved sulfate ranged from 15 to 680 mg/L, and iron from 0 to 15 mg/L. The sodium-adsorption ratio ranged from 0.8 to 34 and had a mean of 10. The irrigation classification of the water ranged from C2-S1 to C3-S4 (fig. 5) — indicating the water is suitable to marginal for irrigation.

At present (1974), several domestic and stock wells are developed in the aquifer. Pumpage from these wells has produced no noticeable fluctuation of water levels in the aquifer. Depending on the local aquifer thickness, hydraulic conductivity of the material penetrated, and proximity to other wells, properly constructed wells in the Shields aquifer should yield from 50 to 1,000 gal/min (3.2 to 63 L/s).

Elm Creek aquifer

The Elm Creek aquifer occupies a buried bedrock valley in northeastern Grant County, extending from and returning to Morton County. The aquifer underlies the Big Muddy Creek and Heart River valleys (pl. 1) and is hydraulically connected with the surface streams. The Elm Creek aquifer has an areal extent of about 7 mi^2 (20 km^2) in Grant County.

Data from three test holes show that the aquifer generally consists of several sand and gravel beds interbedded with clay (pl. 5, sec. H-H'). The aquifer ranges in thickness from 67 to 167 feet (20 to 50.9 m) and has a mean thickness of about 100 feet (30 m). Test-hole data indicate that the coarsest and most productive material is located along the central axis and at the bottom of the buried valley (pl. 5).

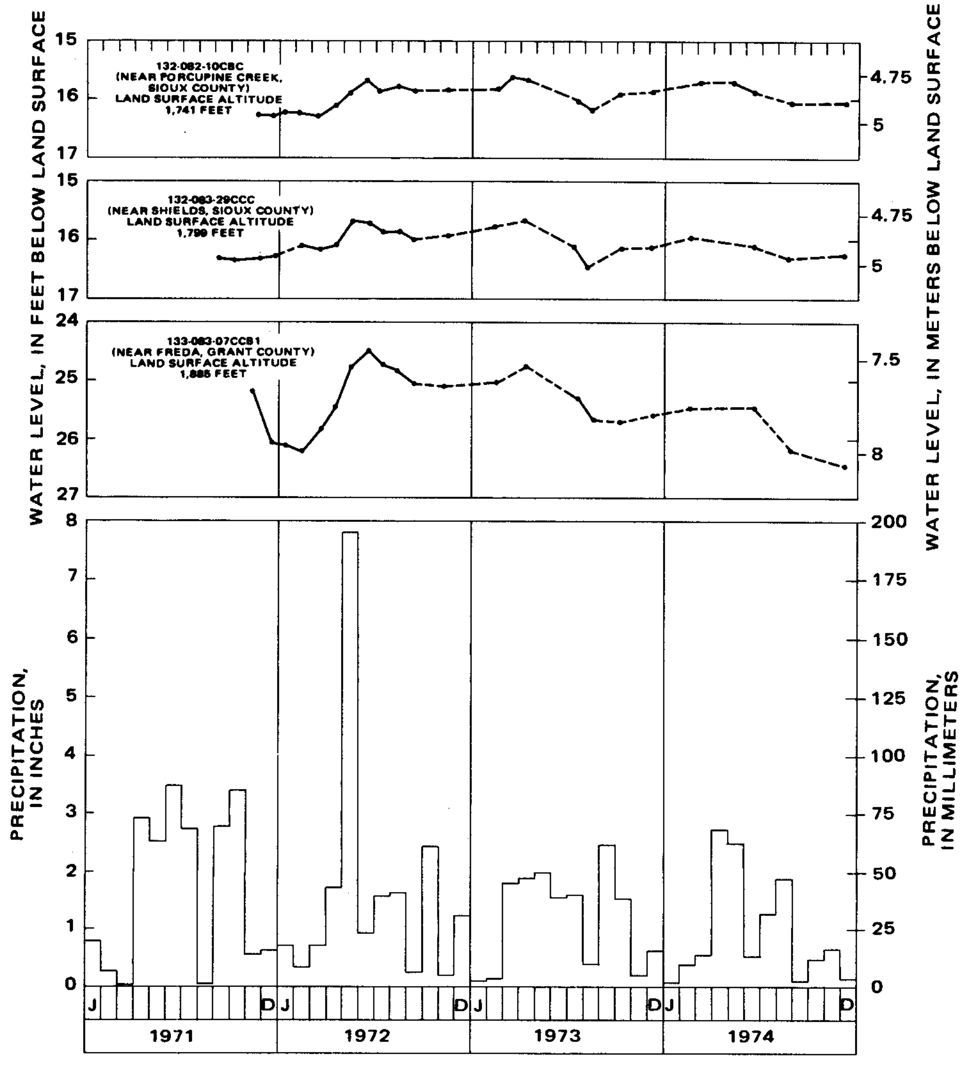


FIGURE 17.–Water-level fluctuations in the Shields aquifer and precipitation at Shields.

Water levels in the Elm Creek aquifer range from about 13 to 22 feet (4 to 6.7 m) below land surface. The hydraulic gradient is about 7 ft/mi (1 m/km) southeastward. Water levels in observation well 136-085-09BCD, gage height of the Heart River near Lark, and precipitation at Carson are shown in figure 18. These indicate that a hydraulic connection exists between the river and the underlying Elm Creek aquifer. The peak events in river stage and in ground-water level are the result of spring runoff. The other peaks, which represent a response to precipitation, generally are less pronounced. The base-flow recession in the Heart River and the decline in ground-water levels indicate a decrease of ground-water storage due to discharge to the river during a period of declining precipitation and streamflow.

Recharge is derived from precipitation by infiltration through sediments in the stream valley that overlie the aquifer. This recharge is favorable for sustaining large-yield development in the aquifer.

Low-flow measurements were made in October 1973, on the Heart River, at sites upstream from, on, and downstream (Morton County) from the Elm Creek aquifer. These measurements show an increase of 12 ft^3/s (0.34 m^3/s), more than 50 percent of the total flow, at the lower end of this reach of the Heart River, indicating major gains to the stream where it flows across the underlying Elm Creek aquifer. Water samples were collected from the Heart River for chemical analyses at the same time and place that low-flow measurements were made. These analyses indicate the concentrations of dissolved sodium and chloride increase, but concentrations of most other dissolved constituents decrease at successive downstream points. Dissolved solids in the surface-water samples increased from 941 mg/L upstream from the aquifer to 988 mg/L downstream from the aquifer. The changes in the chemical quality of water in the Heart River, even though small, when compared to the chemical quality of the water in the aquifer substantiate that a large part of the low-flow discharge in the downstream reach of the river is derived from ground-water discharge by the Elm Creek aquifer.

Based on an areal extent of 7 mi^2 (20 km^2), a mean thickness of 100 feet (30 m), and an estimated specific yield of 15 percent, about 67,000 acre-feet (83 hm^3) of water is available to wells from ground-water storage in the Grant County part of the Elm Creek aquifer.

Analyses of three water samples from wells developed in the Elm Creek aquifer indicate that the water is very hard and is a sodium bicarbonate-sulfate type. Dissolved-solids concentrations in the three samples were 819, 1,510, and 1,790 mg/L. The increase in dissolved solids is related directly to increasing depth below land surface in the aquifer. Dissolved sodium concentrations were 180, 500, and 580 mg/L; dissolved sulfate concentrations were 220, 510, and 630 mg/L; and iron concentrations were 2.2, 5.7, and 5.7 mg/L. Irrigation classifications of the water ranged from C3-S1 to C4-S4 (fig. 5), indicating the water is marginal to unsatisfactory for most irrigation use.

At present (1974), several domestic and stock wells are developed in the aquifer. Pumpage from these wells has produced no noticeable water-level fluctuations in the aquifer. Depending upon the local aquifer thickness and

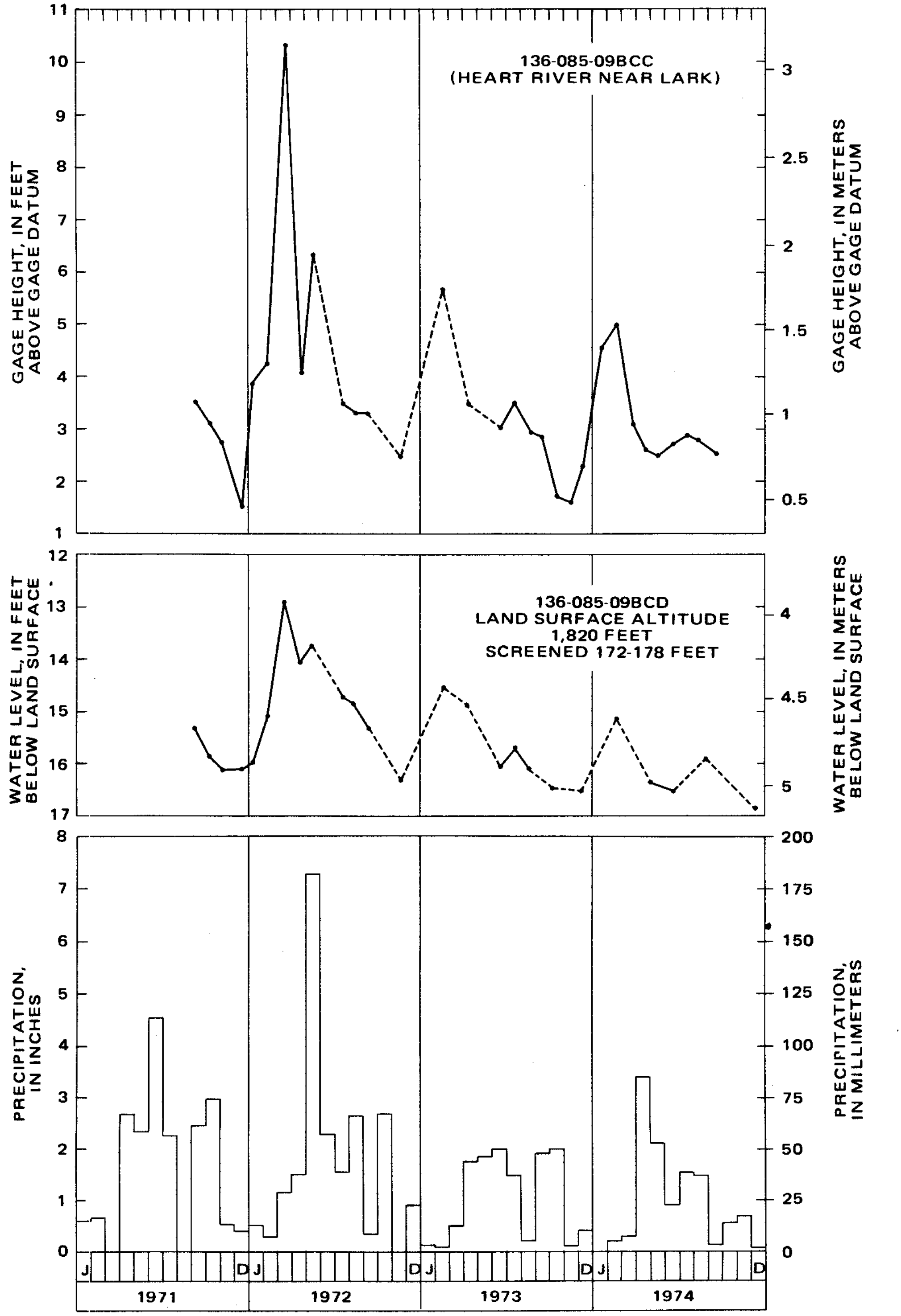


FIGURE 18.—Water-level fluctuations in the Elm Creek aquifer, stage changes in the Heart River, and precipitation at Carson, Grant County.

hydraulic conductivity of the material penetrated, properly constructed wells in the Elm Creek aquifer in Grant County could yield from 50 to 1,000 gal/min (3.2 to 63 L/s; pl. 1).

St. James aquifer

The St. James aquifer occupies a narrow buried bedrock valley — an extension of the Strasburg valley in Emmons County — in northeastern Sioux County. It extends from Emmons County northwest into Morton County. The aquifer is named after St. James Church and Cemetery, which are located near the aquifer in Sioux County. The aquifer is generally about 0.5-mile (0.8-km) wide and has an areal extent of about 3 mi^2 (8 km^2) in Sioux County.

Data from eight test holes show that the aquifer generally consists of several alternating sand and gravel beds (pl. 5, sec. G-G′) that range in thickness from 8 to 105 feet (2 to 32 m). The aquifer has a mean thickness of 28 feet (8.5 m). Test-hole data indicate that the coarsest and most productive aquifer material is located along the central axis and near the bottom of the buried valley (pl. 5).

Water levels in the St. James aquifer range from about 30 to 77 feet (9 to 23 m) below land surface. The shallowest water levels occur in localized shallow parts of the aquifer, whereas the deepest water levels occur in the major part of the aquifer near the bottom of the buried valley. Water movement in the aquifer is downward and southeast toward Lake Oahe. Recharge is derived from adjacent and underlying bedrock deposits and from infiltration of precipitation through surface sediments.

Based on an areal extent of 3 mi^2 (8 km^2), a mean thickness of 28 feet (8.5 m), and an estimated specific yield of 15 percent, about 8,000 acre-feet (10 hm^3) of water is available to wells from ground-water storage in the St. James aquifer in Sioux County.

Analysis of one water sample from the St. James aquifer indicates that the water is moderately hard and is a sodium bicarbonate type. The dissolved constituents in this sample are similar to those in samples from the Fox Hills aquifer, indicating that some ground water is moving from the adjacent Fox Hills aquifer into and through the St. James aquifer. The irrigation classification of the water sample was C3-S4 (fig. 5), indicating that the water generally is unsatisfactory for most irrigation use.

At present (1974), several domestic and stock wells are developed in both the shallow and deep parts of the aquifer. Pumpage by these wells has produced no noticeable water-level fluctuations in the area. Depending upon the local aquifer thickness, hydraulic conductivity, and proximity to recharge, properly constructed wells in the St. James aquifer in Sioux County could yield from 50 to 1,000 gal/min (3.2 to 63 L/s; pl. 1).

Beaver Creek aquifer

The Beaver Creek aquifer occupies a narrow glacial-diversion stream channel northwest of and underlying the main stem of Beaver Creek in northeastern Sioux County (pl. 1). The aquifer materials were deposited in a channel that was tributary to the Missouri River trench during Pleistocene time. The aquifer generally is less than 1 mile (1.6 km) wide, and has an areal extent of about 4 mi^2 (10 km^2).

Data from three test holes show that the aquifer consists of sand and gravel that ranges in thickness from 26 to 45 feet (7.9 to 14 m). The aquifer has a mean thickness of 36 feet (11 m). Test-hole and geologic data show the aquifer material is located at the bottom of the channel and usually is concentrated in curved sections.

Water levels in three observation wells developed in the Beaver Creek aquifer range from 27 to 72 feet (8.2 to 22 m) below land surface datum. A ground-water divide in the aquifer is at 133-080-01BA. From the divide ground water moves northwest toward the Cannonball River and southeast toward Lake Oahe. The hydraulic gradient toward Lake Oahe is about 3 ft/mi (0.6 m/km).

Recharge to the aquifer is derived from adjacent or underlying bedrock deposits and from infiltration of precipitation through surface sediments.

Based on an areal extent of 4 mi^2 (10 km^2), a mean thickness of 36 feet (11 m), and an estimated specific yield of 15 percent, about 14,000 acre-feet (17 hm^3) of water is available to wells from ground-water storage in the Beaver Creek aquifer in Sioux County.

Chemical analyses of two water samples from the Beaver Creek aquifer indicate that the water is moderately to very hard and is a sodium bicarbonate-sulfate type. Dissolved-solids concentrations in the two samples were 1,540 and 1,870 mg/l. Dissolved sulfate exceeded 250 mg/L in both samples and dissolved iron exceeded 0.3 mg/L in one sample. The dissolved constituents closely resemble those in samples from the Fox Hills aquifer, indicating that considerable ground water from the adjacent and underlying Fox Hills aquifer is moving into and probably through the Beaver Creek aquifer. The irrigation classifications of the water samples were C4-S3 and C3-S4 (fig. 5), indicating the water generally is unsatisfactory for irrigation.

At present (1974), several domestic and stock wells are withdrawing water from the aquifer. Pumpage from these wells has produced no noticeable water-level fluctuations in the area. Depending upon the local aquifer thickness, hydraulic conductivity, and proximity to recharge, properly constructed wells in the Beaver Creek aquifer could yield from 10 to 500 gal/min (0.6 to 31.5 L/s; pl. 1).

Battle Creek aquifer

The Battle Creek aquifer occupies a narrow glacial diversion channel in northeastern Sioux County that underlies the present Battle Creek valley. The aquifer generally is less than 0.5-mile (0.8-km) wide, and has an areal extent of about 4 mi^2 (10 km^2).

Data from three test holes indicate that the aquifer consists of discontinuous sand and gravel deposits that range in thickness from 6 to 41 feet (2 to 12 m). The aquifer has a mean thickness of 21 feet (6.4 m).

Domestic and stock wells located in that part of the aquifer east of State Highway 24 are reported to flow about 2 gal/min (0.1 L/s). Ground-water movement through the aquifer is southeastward toward Lake Oahe. Recharge to the aquifer is derived from adjacent and underlying bedrock deposits and from infiltration of precipitation through surface sediments.

Based on an areal extent of 4 mi^2 (10 km^2), a mean thickness of 21 feet (6.4 m), and an estimated specific yield of 12 percent, about 6,000 acre-feet (7 hm^3) of water is available to wells from ground-water storage in the Battle Creek aquifer.

Properly constructed wells in the Battle Creek aquifer generally would yield less than 50 gal/min (3.2 L/s).

Ground Water in Alluvial Deposits of Holocene Age

Alluvial deposits, mapped as the Walsh Formation (fig. 3), occur in most of the present stream and river valleys in Grant and Sioux Counties. They consist of clay, silt, sand, gravel, and often many combinations of these materials — clayey silt, silty sand, sandy gravel. The thicknesses of these deposits ranged from 4 to 81 feet (1 to 25 m) in 60 test holes. Alluvial deposits containing aquifers of potential importance occur in the Heart and Cannonball River valleys and in Cedar Creek valley (pl. 1). These aquifers obtain recharge water from infiltration of precipitation through surface soils and from high streamflow, which inundates the flood plains and saturates the underlying aquifers.

Heart River Valley aquifer

The Heart River Valley aquifer generally is less than 1 mile (1.6 km) wide and has an areal extent of about 12 mi^2 (31 km^2) in northern Grant County. Data from three test holes and data from private wells show that the aquifer consists predominantly of sand. The thickness generally ranges from 10 to 20 feet (3 to 6 m) with a mean of about 15 feet (4.6 m). The thickest and most productive areas lie within the flood plain near the present Heart River channel.

Based on an areal extent of 12 mi^2 (31 km^2), a mean thickness of 15 feet (4.6 m), and an estimated specific yield of 14 percent, about 16,000 acre-feet (20 hm^3) of water is available to wells from ground-water storage in the Heart River Valley aquifer. Potential yields to properly constructed wells generally would be less than 50 gal/min (3.2 L/s; pl. 1).

Cannonball River Valley aquifer

The Cannonball River Valley aquifer generally is less than 1 mile (1.6 km) wide and has an areal extent of about 25 mi^2 (65 km^2) in Grant and Sioux Counties (pl. 1). Data from eight test holes and private wells show the aquifer materials consist of mixed sand and gravel. The thickness generally ranges from 4 to 32 feet (1 to 9.8 m) with a mean of about 17 feet (5.2 m). The thickest and most productive areas are located beneath the present flood plain of the Cannonball River.

Based on an areal extent of 25 mi^2 (65 km^2), a mean thickness of 17 feet (5.2 m), and an estimated specific yield of 12 percent, about 33,000 acre-feet (41 hm^3) of water is available to wells from ground-water storage in the Cannonball River Valley aquifer. Because of the variable lithologies, saturated thickness, and extent of the aquifer deposits, potential yields to wells usually would be less than 50 gal/min (3.2 L/s; pl. 1).

Cedar Creek Valley aquifer

The Cedar Creek Valley aquifer generally is less than 1 mile (1.6 km) wide and has an areal extent of about 15 mi^2 (39 km^2) in Grant and Sioux Counties (pl. 1). Data from three test holes and data from private wells show the aquifer consists of sand and gravel beds. The thickness generally ranges from 6 to 25 feet (2 to 7.6 m) with a mean of about 15 feet (4.6 m). The thickest and most productive areas are located adjacent to the present stream channel and on the low-level terraces.

Based on an areal extent of 15 mi^2 (39 km^2), a mean thickness of 15 feet (4.6 m), and a specific yield of 15 percent, about 22,000 acre-feet (27 hm^3) of water is available to wells from ground-water storage in the Cedar Creek Valley aquifer. Potential yields to properly constructed wells generally would be less than 50 gal/min (3.2 L/s; pl. 1).

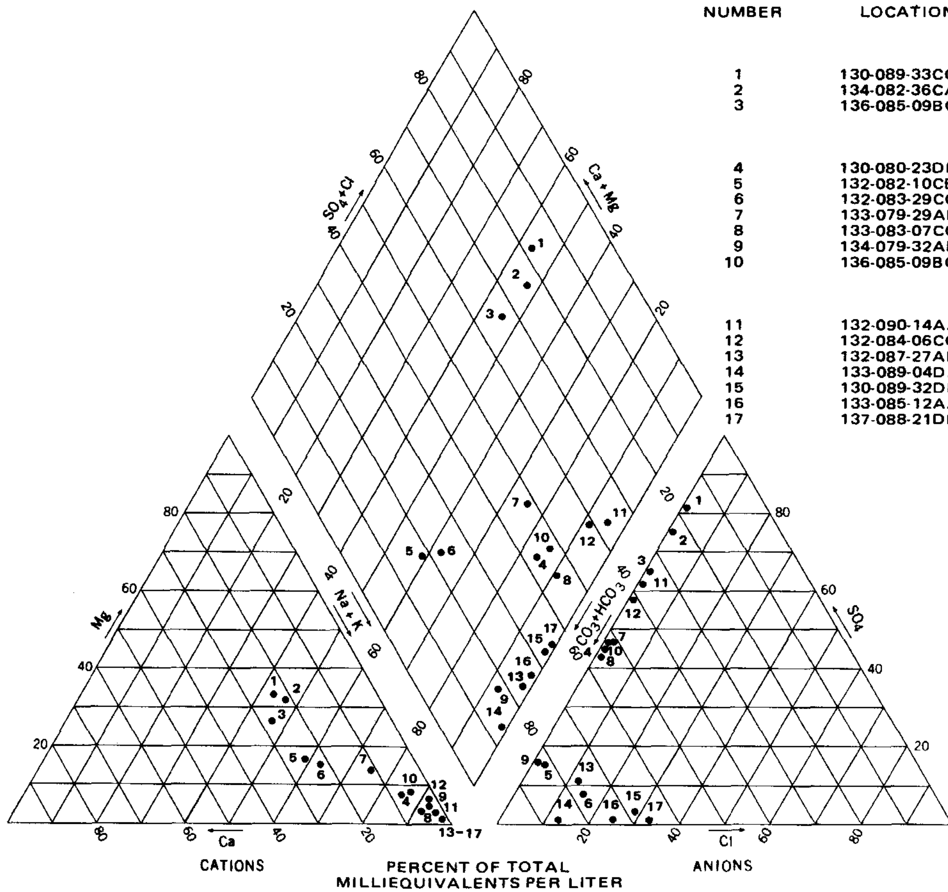
REGIONAL GROUND-WATER FLOW SYSTEM AND GEOCHEMICAL RELATIONSHIPS

Grant and Sioux Counties are located near the eastern edge of a large and complex regional ground-water flow system. This system includes aquifers in Cretaceous and Tertiary deposits as well as Pleistocene glacial-drift deposits and Holocene alluvial deposits. The scope of this investigation did not permit the collection and analysis of data to define all aspects of the ground-water flow system, but did indicate general areas of recharge, discharge, and direction of ground-water movement.

The ground-water flow system is recharged in the topographically high areas of Grant and Sioux Counties and in areas west of the counties. Ground water generally moves downward and northeastward toward the topographically lower areas in the eastern parts of the counties. Local deviations from the northeastward movement occur in the system where aquifers crop out in drainage valleys and where buried-valley aquifers are incised into the bedrock aquifers. Where these deviations occur, ground water from the bedrock aquifers is discharged into the streams and the buried-valley aquifers. The regional movement through the aquifers of Pleistocene and Holocene age generally is eastward toward Lake Oahe.

Figure 19 shows the major chemical constituents in water from major streams and aquifers in the Grant and Sioux Counties. Analyses of water from major streams, represented by plots 1-3, group closely together. The water is predominantly magnesium, calcium, or sodium sulfate types. The analyses of

WATER-ANALYSIS DIAGRAM



NUMBER	LOCATION	AQUIFER OR STREAM	DEPTH (FEET)	DISSOLVED SOLIDS (MG/L)
		STREAMS AND RIVERS		
1	130-089-33CCB	Cedar Creek	--	1,970
2	134-082-36CAD	Cannonball River	--	1,150
3	136-085-09BCC	Heart River	--	663
		GLACIAL-DRIFT AQUIFERS		
4	130-080-23DDD	Shields	190	1,430
5	132-082-10CBC	Shields	128	592
6	132-083-29CCC	Shields	243	684
7	133-079-29ABA	Beaver Creek	113	1,870
8	133-083-07CCB1	Shields	124	1,110
9	134-079-32ADD	Strasburg	288	1,040
10	136-085-09BCD	Elm Creek	178	1,790
		BEDROCK AQUIFERS		
11	132-090-14AAB2	Tongue River	90	1,720
12	132-084-06CCC	Cannonball-Ludlow	170	1,570
13	132-087-27ADA	Hell Creek	180	1,070
14	133-089-04DAD	Hell Creek	612	1,220
15	130-089-32DDA	Fox Hills	543	1,170
16	133-085-12AAD	Fox Hills	522	1,390
17	137-088-21DDC	Fox Hills	923	1,730

FIGURE 19.—Major constituents in water from major aquifers and from streams.

Tertiary Tongue River and Cannonball-Ludlow water show high concentrations of sodium sulfate (plots 11-12). In the Cretaceous Hell Creek and Fox Hills aquifers the sulfate concentration decreases somewhat and is replaced by an increased concentration of chloride, as shown by plots 13-17. The change from sulfate to chloride occurs where the Fox Hills aquifer lies several hundred feet beneath other Cretaceous and Tertiary aquifers. Brackish water from deeper aquifers may be moving upward in the vicinity of a synclinal structure in Grant County (pl. 4). The Fox Hills aquifer contains sodium bicarbonate-sulfate type water where it crops out in eastern Sioux County. The glacial-drift aquifers are represented by plots 4-10. Analyses from the glacial-drift aquifers plot between the surface-water analyses and the deeper bedrock analyses, indicating that the drift aquifers generally contain a mixture of recharge from bedrock water and precipitation.

The geologic framework controlling the regional hydrology in Grant and Sioux Counties indicates that hydraulic connections exist between the glacial-drift and bedrock aquifers. Therefore, large-scale development of any one aquifer probably would affect the entire system to some degree in the area of development. The magnitude of the effect would be dependent upon the size and the location of the development.

GROUND-WATER UTILIZATION

During this study, information was collected on 1,610 wells and test holes in Grant and Sioux Counties. The principal uses of ground water in the counties are for domestic, livestock, and municipal supplies. The use of ground water for irrigation and by industry probably will increase in the future. Water-level measurements in selected observation wells will be continued as part of a statewide program to monitor ground-water resources. The purpose of the statewide program is to provide data to governmental agencies responsible for managing the water resources of the State.

Rural Domestic and Livestock Use

Rural domestic and stock wells were from 8 to 394 feet (2.4 to 129.1 m) deep, were cased with 2- to 4-inch (5.1- to 10.1-cm) pipe, and commonly produced less than 10 gal/min (0.6 L/s). Estimated consumption of ground water from these wells is summarized in the following table.

Use	Individual requirements[1] (gal per day)	Population Grant County	Population Sioux County	Estimated total consumption (gal per day)
Domestic	100	[2] 3,263	[2] 1,953	520,000
Cattle	20	[3] 72,000	[3] 38,000	2,200,000
Hogs	3	[3] 14,600	[3] 3,000	53,000
Sheep	2	[3] 6,500	[3] 4,400	22,000
Chickens	.04	[3] 8,000	[3] 25,000	1,300
Estimated total consumption (rounded)				2,800,000

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

Public Supplies

Four incorporated communities — Carson, Elgin, Leith and New Leipzig — in Grant County and three — Fort Yates, Selfridge, and Solen — in Sioux County rely on ground-water sources for their municipal supplies. Adequate quantities of ground water are available in the vicinity of each community to accommodate some future expansion by additional development of present well fields, or, in some cases, by development of deeper aquifers.

Carson

The city of Carson obtains its municipal supply from four wells developed in the Tongue River aquifer. The wells range in depth from 70 to 90 feet (21 to 27 m) and yield from 20 to 50 gal/min (1.2 to 3.2 L/s). Total yearly pumpage from the well field was 7 Mgal (26,000 m^3) in 1972 and 8 Mgal (30,000 m^3) in 1973. The water is very hard and a calcium bicarbonate type. Dissolved solids in the water ranged from 392 to 617 mg/L.

Elgin

The city of Elgin obtains its municipal supply from six wells. Five of the wells, all about 68 feet (21 m) deep, are developed in the Tongue River aquifer, and the sixth well, 867 feet (264 m) deep, is developed in a Hell Creek aquifer. The five wells developed in the Tongue River aquifer yield from 15 to 35 gal/min (0.9 to 2.2 L/s), and are used as the primary municipal supply. The well developed in the Hell Creek aquifer yields 45 gal/min (2.8 L/s) and is used only as a standby supply. Total yearly pumpage from the wells in the Tongue River aquifer is about 17 Mgal (64,000 m^3).

The water from wells in the Tongue River aquifer is very hard and of a calcium bicarbonate-sulfate type. Dissolved-solids concentrations in water from these wells ranged from 926 to 1,400 mg/l. Water from the well in the Hell Creek aquifer is soft and is a sodium bicarbonate-chloride type.

Leith

Although Leith is an incorporated community, there is no public supply system; residents obtain their water from private wells developed in the Tongue River aquifer.

New Leipzig

The city of New Leipzig obtains its municipal supply from four wells. Two of the wells, 431 and 560 feet (131 and 171 m) deep respectively, are developed in the Cannonball and Ludlow aquifer, and produce about 3.1 Mgal/yr (12,000 m^3/yr); a third well, 285 feet (86.9 m) deep, is developed in the Tongue River aquifer, and produces about 1.4 Mgal/yr (5,300 m^3/yr); the fourth well, 880 feet (268 m) deep, is developed in the Fox Hills aquifer and produces about 2.3 Mgal/yr (8,700 m^3/yr). In 1973 total water use by the city of New Leipzig was 6.8 Mgal/yr (26,000 m^3/yr).

Water from the wells developed in the Cannonball and Ludlow aquifer is soft and of a sodium bicarbonate type. Dissolved-solids concentrations in water from these wells ranged from 1,210 to 2,080 mg/L. Water from the well developed in the Fox Hills aquifer is soft and of a sodium bicarbonate-chloride type. The dissolved-solids concentration in water from this well was 1,250 mg/L.

Fort Yates

The city of Fort Yates formerly obtained its municipal supply from two wells about 133 feet (41 m) deep developed in the Fox Hills aquifer. Annual pumpage from these wells was about 3 Mgal/yr (11,000 m^3/yr). Water from these wells is very hard and of a sodium bicarbonate-sulfate type. Fort Yates now obtains its water supply from Lake Oahe. The water treatment plant at Fort Yates processed about 79 Mgal (300,000 m^3) in 1974.

Selfridge

The city of Selfridge obtains its municipal supply from wells about 140 feet (43 m) deep developed in Hell Creek aquifers. These wells yield about 6.3 Mgal (24,000 m^3) of water annually. The water is soft and of a sodium bicarbonate-sulfate type.

Solen

The city of Solen obtains its municipal supply from one well 210 feet (64 m) deep developed in the Fox Hills aquifer. This well yields about 2.5 Mgal (9,500 m^3) of water annually. The water is soft and of a sodium bicarbonate type. Dissolved-solids concentration in water from this well is about 1,500 mg/L.

SUMMARY AND CONCLUSIONS

Ground water in Grant and Sioux Counties is available from aquifers in bedrock formations of Late Cretaceous and Tertiary age, in glacial drift of Pleistocene age, and in alluvial deposits of Holocene age. Rocks older than Late Cretaceous age generally occur at depths greater than 2,500 feet (760 m) and contain brackish or saline water. The major bedrock aquifers occur in the Fox Hills and Hell Creek Formations of Late Cretaceous age and the Cannonball, Ludlow, and Tongue River Formations of Tertiary age. Aquifers in glacial buried-valley deposits of Pleistocene age are located in the northeastern and eastern parts of Grant County and in central and eastern Sioux County. Shallow aquifers in alluvial deposits of Holocene age lie beneath the flood plains in major river valleys. The Fox Hills aquifer is the largest and most extensive aquifer studied in the two-county area.

The aquifers occurring in the bedrock consist predominantly of very fine to medium sand, and potential well yields generally do not exceed 150 gal/min (9.5 L/s). Most domestic, livestock, and municipal supplies in Grant and Sioux Counties are obtained from the bedrock aquifers. Wells developed for domestic and stock use usually yield less than 10 gal/min (0.6 L/s), while the municipal wells generally yield from 20 to 50 gal/min (1.3 to 3.2 L/s). The total combined withdrawal from these aquifers in Grant and Sioux Counties is approximately 2.8 Mgal/d (11,000 m^3/d). The water generally is soft, varies from a sodium bicarbonate-sulfate type to a sodium bicarbonate-chloride type, and is high in dissolved constituents.

Ground-water movement in the bedrock aquifers generally is northeast and downward through the regional aquifer system. The aquifers are recharged in the topographically high areas of Grant and Sioux Counties and in regions farther west. The water becomes increasingly saline as it moves from recharge areas toward the discharge areas in the drainage valleys. As the water percolates downward, the chemical quality changes. from sodium and calcium bicarbonate-sulfate types to a sodium bicarbonate-chloride type.

Aquifers in glacial deposits of Pleistocene age that have the greatest potential for development are those in buried valleys. They are composed of sand and gravel and include the Shields, Elm Creek, St. James, Beaver Creek, and Battle Creek aquifers. Approximately 355,000 acre-feet (438 hm^3) of available ground water is in storage in these glacial-drift aquifers underlying about 48 mi^2 (124 km^2) in Grant and Sioux Counties (table 3). Test drilling and other data indicate that the largest yields would be obtainable along the central axes of the valleys. Ground-water movement through these aquifers generally is east to southeast toward Lake Oahe. Recharge is derived from adjacent or underlying bedrock aquifers and from infiltration of precipitation through surface materials. Discharge occurs where major streams intercept the aquifers.

The predominant dissolved constituents found in grosnd water from glacial-drift aquifers are calcium, magnesium, sodium, bicarbonate, and sulfate. Iron is present in amounts that may be objectionable if the water is to be used for domestic or industrial purposes.

TABLE 3. — Summary of data for glacial-drift and alluvial aquifers

	Aquifer	Approximate areal extent (square miles)	Estimated amount of water available from storage (acre-feet)	General water type	Potential yield to wells (gal/min)
Glacial drift	Shields	30	260,000	Sodium bicarbonate	50-1,000
	Elm Creek	7	67,000	Sodium bicarbonate-sulfate	50-1,000
	St. James	3	8,000	Sodium bicarbonate	50-1,000
	Beaver Creek	4	14,000	Sodium bicarbonate-sulfate	10-500
	Battle Creek	4	6,000		Less than 50
Alluvium	Heart River Valley	12	16,000		Less than 50
	Cannonball River Valley	25	33,000		Less than 50
	Cedar Creek Valley	15	22,000		Less than 50
	TOTALS	100	426,000		

Alluvial deposits of Holocene age consist of clay, silt, sand, and gravel. The coarser deposits form aquifers in the Heart and Cannonball River valleys and in Cedar Creek valley. About 70,000 acre-feet (86 hm^3) of available ground water is in storage in the aquifers (table 3) underlying about 52 mi^2 (135 km^2) in Grant and Sioux Counties. Recharge is obtained from precipitation and from high streamflow. The thickest, most productive areas occur beneath the flood plains and terraces in the stream valleys.

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DEFINITIONS OF SELECTED TERMS

Aquifer – an aquifer is a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Confining bed – a body of "impermeable" material stratigraphically adjacent to one or more aquifers.

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

Hydraulic conductivity – if a porous medium is isotropic and the fluid is homogeneous, the hydraulic conductivity of the medium is the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. It replaces the term "field coefficient of permeability," which embodies the inconsistent units gallon, foot, and mile.

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

Hydrograph – a graph showing stage, flow, water level, precipitation, or other hydrologic properties with respect to time.

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

Porosity – the porosity of a rock or soil is its property of containing interstices or voids and may be expressed quantitatively as the ratio of the volume of its interstices to its total volume. It may be expressed as a decimal fraction or as a percentage.

Potentiometric surface – a surface that represents the static head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells. It replaces the term "piezometric surface."

Slug test – injecting a given quantity or "slug" of water into a well and measuring responses to determine the transmissivity at the site under certain conditions.

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 replaces the term "coefficient of transmissibility."

Uniformity coefficient – a numerical expression of the variety in particle sizes in mixed natural soils, defined as the ratio of the sieve size through which 60 percent (by weight) of the material passes to the sieve size that allows 10 percent of the material to pass. It is unity for a material whose particles are all of the same size, and it increases with variety in size (as high as 30 for heterogeneous sand).

Water table – that surface in an unconfined water body (aquifer) at which the pressure is atmospheric.