GEOLOGY AND GROUND-WATER RESOURCES

of

HETTINGER and STARK COUNTIES,

NORTH DAKOTA

by

Henry Trapp, Jr. and M. G. Croft
U. S. Geological Survey

COUNTY GROUND-WATER STUDIES 16 — PART I
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

Prepared by the United States Geological Survey
in cooperation with the North Dakota State Water Commission
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SELECTED FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

A dual system of measurements — English units and the International System (SI) of units — is given in this report. SI is a consistent system of units adopted by the Eleventh General Conference of Weights and Measures in 1960. Selected factors for converting English units to SI units are given below.

Multiply English units	By	To obtain SI units
Inches	25.4	millimetres (mm)
Feet	.3048	metres (m)
Miles	1.609	kilometres (km)
Square miles (mi^2)	2.590	square kilometres (km^2)
Acres	.4047	hectares (ha)
Gallons	3.785	litres
Million gallons (Mgal)	3,785	cubic metres (m^3)
Acre-feet	1,233	cubic metres (m^3)
	1.233×10^{-3}	cubic hectometres (hm^3)
Gallons per minute (gal/min)	.06309	litres per second (l/s)
Million gallons per day (Mgal/d)	.04381	cubic metres per second (m^3/s)
Gallons per minute per foot [(gal/min)/ft]	.2070	litres per second per metre [(l/s)/m]
Feet per day (ft/d)	.3048	metres per day (m/d)
Square feet per day (ft^2/d)	.09290	square metres per day (m^2/d)
Feet per mile (ft/mi)	.18943	metres per kilometre (m/km)

GEOLOGY AND GROUND-WATER RESOURCES OF HETTINGER AND STARK COUNTIES, NORTH DAKOTA

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ABSTRACT

The sedimentary rocks of Paleozoic, Mesozoic, and Cenozoic age in Hettinger and Stark Counties, on the south-central flank of the Williston structural basin, are about 14,000 feet (4,270 metres) thick. They are gently folded into north-plunging anticlines and synclines. The major aquifer systems consist of interbedded fine- to medium-grained sandstone, siltstone, and claystone. As much as 100 gallons per minute (6.3 litres per second), per individual well, of usable ground water is available from the semiconsolidated rocks of Late Cretaceous and Tertiary age.

The Fox Hills and basal Hell Creek aquifer system underlies the entire area at depths greater than 1,100 feet (335 metres). The water in this system is a sodium bicarbonate type with a dissolved-solids concentration of 1,310 to 1,540 milligrams per litre. The transmissivity of the aquifer system ranges from 110 feet squared per day (10 metres squared per day) to 390 feet squared per day (36 metres squared per day). Wells should yield as much as 75 gallons per minute (5 litres per second).

The upper Hell Creek and lower Cannonball-Ludlow aquifer system underlies all of Hettinger and Stark Counties. The aquifer system contains a sodium bicarbonate type water with a dissolved-solids concentration ranging from 1,450 to 1,890 milligrams per litre.

The transmissivity of the basal sandstone member of the Tongue River Formation ranges from 70 feet squared per day (7 metres squared per day) to 530 feet squared per day (49 metres squared per day). Wells should yield as much as 100 gallons per minute (6.3 litres per second). Ground water in the basal sandstone member is generally a sodium bicarbonate type with a dissolved-solids concentration ranging from 704 to 1,470 milligrams per litre.

The Sentinel Butte aquifer system underlies most of Stark County. Analyses indicate the water is generally of a sodium sulfate type. Dissolved-solids concentration of the samples ranged from 378 to 11,700 milligrams per litre with a median value of 1,050 milligrams per litre.

Approximately 6,800 acre-feet (8.4 cubic hectometres) of water was obtained from ground-water and surface-water sources in 1969. Ground-water sources furnished about 40 percent of the total water supply.

INTRODUCTION

This geologic and hydrologic investigation was made cooperatively by the U.S. Geological Survey, the North Dakota State Water Commission, and the Hettinger and Stark Counties Water Management Districts.

Data referred to in this report are in Part II (Trapp, 1971) of this series unless otherwise referenced. The geologic names used in this report are those of the North Dakota Geological Survey and, in some instances, may differ from terms currently used by the U.S. Geological Survey. English units and abbreviations and the factors for conversion to the equivalent International System (SI) units and corresponding abbreviations are in front of the report.

Purpose and Objective of the Investigation

The purpose of the investigation in Hettinger and Stark Counties was to determine the quantity and quality of ground water available for municipal, domestic, livestock, industrial, and irrigation uses. The investigation began in July 1966. Specifically, the objectives were to: (1) determine the location, extent, and nature of the major aquifers and confining beds; (2) evaluate the occurrence and movement of ground water, including the sources of recharge and discharge; (3) estimate the potential yields of wells; and (4) determine the chemical quality of the ground water.

Previous Investigations

Geology

The earliest geologic investigations in Hettinger and Stark Counties were made to study the regional stratigraphy (Leonard, 1911) and the mineral resources such as clay (Clapp, Babcock, and Leonard, 1906) and lignite (Lloyd, 1914; Leonard, Babcock, and Dove, 1925). In the 1920's the Northern Pacific Railway Company mapped lignite deposits throughout much of the area. Although the information has not been published, the company made the information available.

Alden (1932) studied the regional land forms and glacial history of the Northern Great Plains. Hennen (1943) published a geologic cross section from Sentinel Butte in western North Dakota through Stark County to central Burleigh County. He attempted to show that certain Tertiary beds could be used for mapping over long distances. Brown (1948) disagreed with Hennen's conclusions.

Benson (1951) prepared a generalized geologic map of southwestern North Dakota that included Hettinger and Stark Counties. Benson (1952) also prepared a report on the Knife River area that included part of northeastern Stark County. Brant (1953) mapped lignite beds in Hettinger and Stark Counties. Hansen (1953) investigated limestone beds within the White River Formation in Stark and Hettinger Counties, and provided test-hole logs and detailed maps of the stratigraphy. Caldwell (1954) prepared geologic structure maps of western Stark County and adjoining areas.

Colton, Lemke, and Lindvall (1963) mapped the glacial features in northeastern and southeastern Stark County. Denson and Gill (1965) studied the Little Badlands area southwest of Dickinson for uranium. Anderson (1966) prepared subsurface geologic maps for southwestern North Dakota.

K. S. Soward and G. D. Mowat, of the U.S. Geological Survey (oral commun., 1970), have prepared geologic reports on the White Butte (Hettinger and Stark Counties) and Clark Butte (Hettinger, Stark, Morton, and Grant Counties) 15-minute quadrangles. The geologic studies were made to evaluate the lignite resources. Geologic contacts in these quadrangles were generalized from their preliminary maps. Some of the geologic interpretations in the vicinity of Dickinson and South Heart were based on unpublished work by C. E. Erdmann, U.S. Geological Survey.

The location, tonnage, and characteristics of lignite and overburden in western North Dakota are summarized by Pollard, Smith, and Knox (1972).

Ground Water

The earliest known investigation of the ground-water resources in Hettinger and Stark Counties was made by Simpson (1929). Between 1920 and 1930 declining water levels in the Dakota aquifer resulted in a statewide program of periodic inspection of flowing wells under the direction of the State Geologist. Several flowing wells in Hettinger and Stark Counties were inventoried and inspected periodically under this program.

Abbott and Voedisch (1938) published a summary of the municipal ground-water supplies in North Dakota. In 1938-39 the Works Projects Administration, in cooperation with the State, inventoried ground-water supplies in the two counties. As a result of the inventory, the U.S. Geological Survey began a program to monitor water-level changes in observation wells in Hettinger and Stark Counties. McLaughlin and Greenlee (1946) reported on the potential for increased withdrawals from the aquifers supplying municipal wells at Dickinson. The U.S. Bureau of Reclamation drilled test holes in 1946 at the Dickinson damsite in the Cannonball River valley near Mott. Tychsen (1950) provided additional information on the ground-water resources of the Dickinson area. In 1951-52, Powell and Paulson (1961) conducted a ground-water study and drilled several test holes in the Richardton area.

The U.S. Geological Survey made a reconnaissance study (unpublished) of the ground-water supplies for the city of New England in 1958, including an aquifer test using the municipal wells. Schmid (1963) investigated aquifers near Dickinson in an attempt to locate additional water supplies for the city. Lindvig (1964) reported the results of an aquifer test at Dickinson at a site recommended by Schmid (1963, p. 6).

Acknowledgments

The authors are grateful to the residents of Hettinger and Stark Counties and the operators of the municipal water systems who contributed valuable information. The following drilling contractors supplied logs of wells and test holes: Moe Drilling Co., Mann Drilling Co., Opp Well Drilling, Sander Drilling Co., Bandy Drilling Co., and Kruger Well Drilling Co. Richard D. Smith, of the University of North Dakota also furnished logs and other information. Burlington Northern, Inc. (formerly Northern Pacific Railway Co.) and the U.S. Bureau of Reclamation supplied maps and logs of wells and test holes. The North Dakota State Highway Department furnished logs and chemical analyses of water samples from wells at Interstate 94 rest stops, and the North Dakota State Department of Health and the State Laboratories Department furnished copies of other water analyses.

L. L. Froelich, geologist for the North Dakota State Water Commission, logged most of the test holes and wells drilled for the project. M. O. Lindvig, Director, Hydrology Division of the North Dakota State Water Commission, assisted in project planning, and G. O. Muri, North Dakota State Water Commission, provided chemical analysis of water samples.

Geographic Setting

Hettinger and Stark Counties are largely in the unglaciated Missouri Plateau section of the Great Plains physiographic province (fig. 1). Both counties are within the Missouri River drainage basin. Hettinger County is drained by the Cannonball River and several tributaries of Cedar Creek. Stark County is drained principally by the Heart River, tributaries of the Knife River, and by the Cannonball River.

The rolling plateau surface of the two counties is highly dissected by erosion. Scattered buttes, capped by resistant sandstone, limestone, or "scoria[1]" beds, are remnants of sedimentary strata that once covered the area more extensively. The highest point in Hettinger County is Black Butte (pl. 1, in pocket), north of Regent, with an altitude of 3,025 feet (922 m) above mean sea level. The highest point in Stark County is 3,061 feet (933 m) in the SW cor. sec. 17, T. 137 N., R. 97 W., at U.S. Coast and Geodetic Survey triangulation station Brown. The lowest point in the two-county area is in northeastern Stark County in the NE¼ sec. 27, T.

[1]Scoria is claystone baked by burning lignite beds.

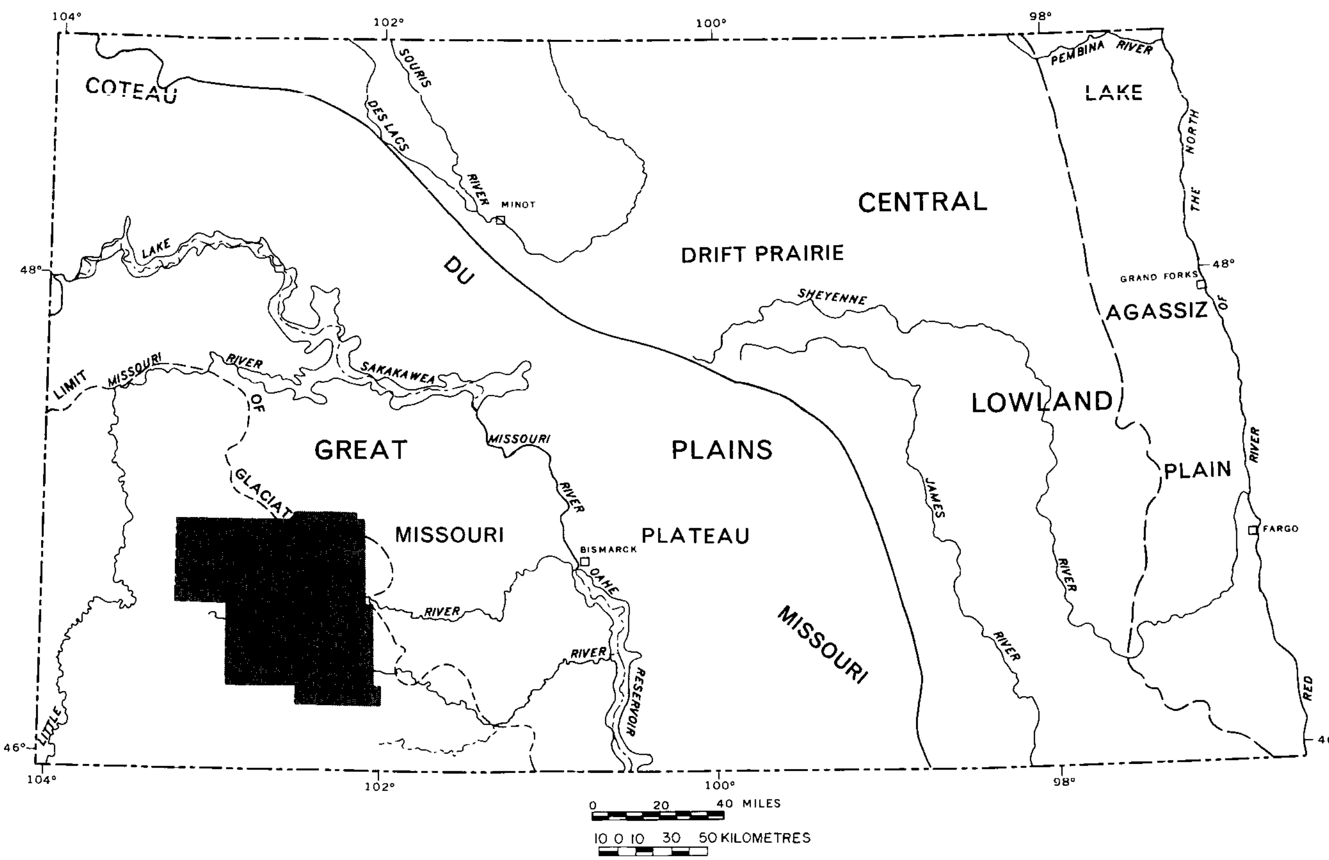


FIGURE 1.—Physiographic divisions in North Dakota and location of report area.

141 N., R. 91 W., where the Little Knife River leaves the county. Detailed measurements are lacking, but the altitude is about 2,050 feet (625 m). Total relief in the county is about 1,000 feet (305 m).

Hettinger County has an area of 1,135 mi² (2,940 km²) and a population of 5,075 (1970 census). The county seat and largest city is Mott (population 1,368). Other incorporated cities include New England (population 906), and Regent (population 344). The economy is based almost entirely on agriculture, principally dryland small-grain farming and feeding of beef cattle. Lignite mining was once a thriving industry and is expected to increase greatly in the near future. Gravel is intermittently quarried at Burt. There has been considerable seismic exploration for oil and some production has been reported.

Stark County has an area of 1,319 mi² (3,416 km²) and a population of 19,613 (1970 census). The largest city and county seat is Dickinson, population 12,405, which is the largest city and the main trading center in North Dakota southwest of the Missouri River. Other incorporated cities in Stark County are Belfield (population 1,130), Richardton (population 799), Gladstone (population 222), Taylor (population 162), and South Heart (population 132). The economy is based mainly on agriculture — principally dryland small-grain farming and feeding of beef cattle. There is also oil production and mining of lignite, gravel, and clay. Large strippable reserves of lignite are northwest of Dickinson (Pollard and others, 1972, fig. 1).

Climate

The climate in the two counties is characteristic of the interior of the continent and the latitude. Relatively large extremes in the weather occur rapidly. The mean annual precipitation at Dickinson is 15.50 inches (394 mm), and at Mott it is 15.80 inches (401 mm). The lowest annual precipitation on record in the area was 6.12 inches (155 mm) at Mott (1936) and the highest annual precipitation was 31.16 inches (791 mm) at Dickinson (1941). The mean annual snowfall is about 31 inches (787 mm), with a minimum of 9 inches (229 mm) at Mott during the winter of 1957-58 and a maximum of 74 inches (1,880 mm) at Dickinson during the winter of 1896-97. Most precipitation falls in summer thunderstorms, which can be intense and accompanied by hail. Precipitation in amounts of 1 inch (25 mm) or more occurs about twice a year.

The average annual temperature is 40.7°F (Fahrenheit; 4.8°C, Celsius) at Dickinson and 42°F (5.6°C) at Mott. The record high and low temperatures are 114°F (45.6°C) and −47°F (−43.9°C) at both cities.

Well-Numbering System

The wells, springs, and test holes in the tables are numbered according to a system based on the location in the public land classification of the U.S.

Bureau of Land Management. The system is illustrated in figure 2. 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 133-091-15DAA is in the NE¼-NE¼SE¼ sec. 15, T. 133 N., R. 91 W. Consecutive terminal numerals are added if more than one well is recorded within a 10-acre (4-ha) tract.

GEOLOGY OF THE GROUND-WATER RESERVOIR

Hettinger and Stark Counties are on the south-central flank of the Williston basin, a broad structural depression underlying parts of North and South Dakota, Montana, Manitoba, and Saskatchewan (Denson and Gill, 1965, pl. 5). The basin contains sedimentary rocks from the Cambrian through the Quaternary Period. These rocks are divided into numerous geologic formations (table 1) and have a combined thickness of at least 14,000 feet (4,270 m) in northwestern Stark County. During Late Cretaceous and Early Tertiary time, compression deformed and warped the rocks into gentle north-plunging anticlines and synclines (pl. 1). All rocks from the Deadwood Formation through the White River Formation are folded to some degree.

The rocks of Paleozoic and Mesozoic age have been penetrated by numerous oil and gas test holes in Hettinger and Stark Counties, and have been divided into numerous formations. Well logs and lithologic descriptions are available from the North Dakota Geological Survey, and only brief lithologic descriptions of the rocks older than the Fox Hills Formation of Cretaceous age are given here. The rocks older than the Fox Hills Formation are likely to yield saline water; they underlie the area at depths greater than is generally practical to drill water wells. They have an aggregate thickness ranging from about 9,000 feet (2,740 m) in southeastern Hettinger County to about 12,000 feet (3,660 m) in northwestern Stark County.

Most of the usable ground water in Hettinger and Stark Counties is in the semiconsolidated rocks of Late Cretaceous and Tertiary ages. These rocks, which include the Fox Hills and overlying formations (table 1), were studied in detail with special reference to their water-bearing properties and are shown in detail in cross sections (pls. 2 and 3, in pocket). Small quantities of water are available from the unconsolidated deposits of Quaternary age.

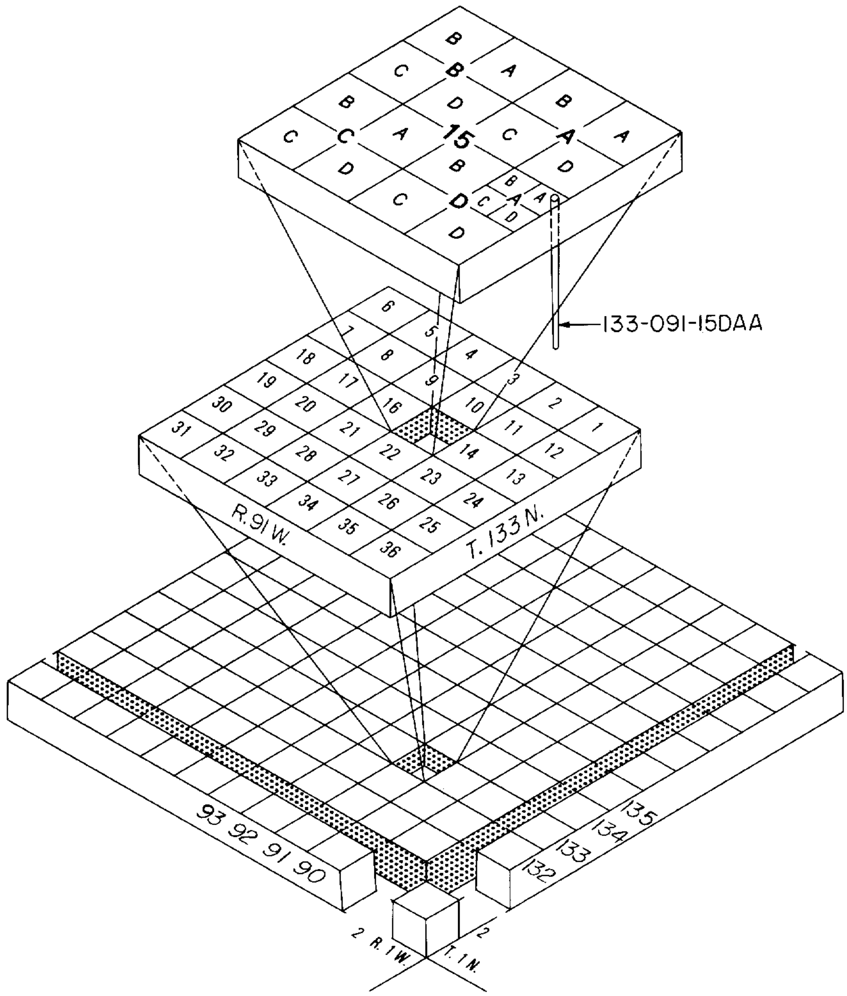


FIGURE 2.—System of numbering wells, springs, and test holes

TABLE 1. — Stratigraphic column, Williston basin North Dakota and adjacent areas (Modified from North Dakota Geol. Soc., 1954, p. 2)

Era	Period	Group	Formation
Cenozoic	Quaternary	Glacial drift	
	Tertiary		Arikaree White River Golden Valley
		Fort Union	Sentinel Butte Tongue River Cannonball and Ludlow
Mesozoic	Cretaceous		Hell Creek
		Montana	Fox Hills Pierre
		Colorado	Niobrara Carlile Greenhorn Belle Fourche
		Dakota	Mowry Newcastle Skull Creek Fall River Lakota
	Jurassic		Morrison Swift Rierdon Piper
	Triassic		Spearfish
Paleozoic	Permian		Minnekahta Opeche
	Pennsylvanian		Minnelusa
	Mississippian		Amsden
		Big Snowy	Heath Otter Kibbey
		Madison	Charles Mission Canyon Lodgepole Bakken
	Devonian		Three Forks
		Saskatchewan	Nisku Duperow
		Beaverhill Lake	Souris River Dawson Bay
			Prairie Winnipegosis
			Ashern
	Silurian	Interlake	Interlake
	Ordovician		Stony Mountain Red River Winnipeg
	Cambrian		Deadwood

Consolidated Rocks of Cambrian to Cretaceous Age

The Late Cambrian to Early Ordovician Periods are represented by the Deadwood Formation, a marine deposit of sandstone, shale, and limestone that gradually thins eastward across the Williston basin. The basin began to subside during Middle Ordovician time and was partially filled with a relatively thin deposit of clastic rocks of the Winnipeg Formation, followed by predominantly carbonate deposition of the Red River and Stony Mountain Formations, and the Silurian Interlake Formation. An unconformity occurs at the top of the Interlake Formation.

The rocks of Devonian age (Ashern, Winnipegosis, Prairie, Dawson Bay, Souris River, Duperow, Nisku, and Three Forks Formations) are predominantly carbonate deposits, with the exception of the Prairie Formation, which includes evaporite beds. The Bakken Formation consists mainly of shale and is overlain by alternating carbonate and evaporite deposits of the Lodgepole, Mission Canyon, and Charles Formations that form the Madison Group. The Big Snowy Group, which includes the Kibbey, Otter, and Heath Formations, consists predominantly of sandstone and shale. The Amsden, which rests unconformably on rocks of the Big Snowy Group, is shown as Mississippian, but is regarded by a few geologists as Pennsylvanian. The Pennsylvanian and Permian rocks, the Minnelusa, Opeche, and Minnekahta Formations, consist of marine sandstone and shale interbedded with evaporite and carbonate deposits.

The Spearfish Formation of Triassic age consists of nonmarine redbeds similar to the underlying Pennsylvanian and Permian Formations. The Piper Formation of Jurassic age consists of limestone, anhydrite, and shale and rests unconformably on the Spearfish. The Rierdon, Swift, and Morrison Formations consist mainly of sandstone and shale.

Semiconsolidated Rocks of Cretaceous Age

The Williston basin received thick deposits of sand, silt, and clay during the Cretaceous Period. These deposits, which were subsequently formed into sandstone and shale, are not exposed to land surface. The Lakota, Fall River, and Newcastle Formations are composed principally of sandstone; the Skull Creek, Mowry, Bell Fourche, Carlile, and Niobrara Formations consist mainly of dark-gray shale. The Pierre Formation is a thick gray marine shale overlain by alternating shale, siltstone, and sandstone of the Fox Hills and Hell Creek Formations. The top of the Pierre forms the base of the fresh-water-bearing units in the report area.

Fox Hills Formation

The Fox Hills Formation consists of interbedded very fine to medium-grained sandstone, siltstone, claystone, and rarely a few thin beds of carbonaceous and lignitic shale. The total thickness of the Fox Hills (pls. 2 and 3) ranges from 240 to 410 feet (73 to 125 m), and depth to the top of the formation ranges from 1,020 to 1,630 feet (311 to 497 m) below land surface. The formation is thickest in the northwestern part of the area.

The Fox Hills Formation is underlain by the Pierre Formation, a dark-colored marine shale. In most test holes and oil and gas logs the lower part of the Fox Hills contained less sand than the upper part. Drilling usually becomes more difficult upon entering the Pierre. Shale from the Pierre Formation generally is darker than shale from the Fox Hills. Croft (1970, p. 71 and 76, fig. 6, pl. 2) identified the top of the Pierre at a higher altitude in Mercer County than was mapped in this report.

In the Little Missouri valley of western North Dakota, the upper contact is locally unconformable within overlying strata (Frye, 1969, p. 20-23). The contact is easily identified where the uppermost member of the Fox Hills, the Colgate Member, which consists mainly of sandstone, is overlain by the Hell Creek Formation. In adjoining areas the Colgate Member weathers to a light-gray color, whereas the Hell Creek is brown. In many areas the lower part of the formation is mainly siltstone and claystone. Electric logs were used for correlation purposes in the geohydrologic sections (pls. 2 and 3).

Hell Creek Formation

The Hell Creek Formation does not crop out in the study area and is known only from well and test-hole data. The top of the Hell Creek is at depths of 800 to 1,140 feet (244 to 347 m) below land surface (pls. 2 and 3), and the formation is 220 to 510 feet (67 to 155 m) thick. Brown (1952, p. 92) recommended the Hell Creek-Ludlow contact be drawn at the base of the lowest coal bed. This was not practicable in all test holes or logs because of insufficient data; therefore, in some logs the contact is arbitrary. Lignite occurred near the contact in several test holes, but rarely at greater depths. In some cases, a thickening of the drilling fluid and a change to a dark-brown color were noted in test holes during penetration of the upper part of the Hell Creek. Frye (1969, pl. 2) divided the Hell Creek Formation from eastern Montana to central North Dakota into nine members. Beds of olive-gray siltstone and claystone, which are tentatively identified as the Bacon Creek Member of Frye (1969), divide the Hell Creek into two major aquifers (pls. 2 and 3). However, further detailed subdivision of the Hell Creek was not practicable for this study.

The Hell Creek consists of fine- to medium-grained sandstone, siltstone, bentonitic and carbonaceous claystone, and shale, with zones of sideritic nodules and concretions. Four samples were cored from the upper part of the Hell Creek in test hole 134-094-08DCC and particle-size distribution curves made. The samples (table 2) from a depth of 1,050 to 1,060 feet (320 to 323 m) consisted of very fine to fine-grained sandstone with clay and silt content ranging from 6.1 to 32.5 percent. Median particle diameter ranged from 0.09 to 0.2 mm. The effective particle diameter ranged from less than 0.002 to 0.09 mm. The coefficient of uniformity ranged from 1.7 to 70. The samples with high coefficient of uniformity values are poorly sorted.

In addition, particle-size distribution curves were made for two upper Hell Creek cores from test hole 141-090-19CCD in Mercer County. Both samples are clayey and silty fine-grained sandstone, much like the samples from test hole 134-094-08DCC. In the core from 892 feet (272 m), taken just below the top of the Hell Creek, clay and silt sizes constituted 49.4 percent of the sample. The core from a depth of about 1,028 feet (313 m) was 42.4 percent clay and silt. Median particle size was 0.065 and 0.096 mm, respectively, in the two samples, and effective diameter was less than 0.01 mm.

Semiconsolidated Rocks of Tertiary Age

Most of the rocks of Tertiary age are nonmarine claystone, siltstone, and sandstone derived from the west, and include the Ludlow, Tongue River, Sentinel Butte, Golden Valley, White River, and Arikaree Formations. An exception is the shallow marine rocks of the Cannonball Formation. Rocks of the Tongue River Formation are the oldest exposed in the study area (pl. 1).

Ludlow and Cannonball Formations

The Ludlow and Cannonball Formations of the Fort Union Group, which were deposited contemporaneously, are not exposed in the study area. Geologic cross sections (pls. 2 and 3) show an upper and a lower member of the Ludlow separated by the Cannonball Formation. The top of the Ludlow Formation occurs from 275 to 755 feet (84 to 230 m) below land surface. The two formations are 310 to 650 feet (94 to 198 m) thick (pls. 2 and 3). The Ludlow Formation was deposited in a continental environment, whereas the Cannonball was deposited in a marine environment and is the youngest marine strata known in the northern Great Plains.

The Ludlow Formation consists of fine-grained continental sandstone, green and brown carbonaceous claystone, siltstone, and lignite. The sandstone is generally coarser grained than the Cannonball and forms parts of

TABLE 2. — Analysis of particle-size distribution curves

Well	Geologic formation	Depth (feet)	Median particle diameter (D_{50}) (millimetre)	Effective particle diameter (D_{10}) (millimetre)	Coefficient of uniformity $\frac{D_{60}}{D_{10}}$	Hydraulic conductivity (From Johnson, 1963, fig. 21-22) ft/d
132-092-21DDD2	Tongue River	60-60.5	0.055	0.004	15	< 1
134-094-08DCC	Hell Creek	1050-1051	.09	—	—	—
134-094-08DCC	do.	1053-1054	.2	.09	2.4	19
134-094-08DCC	do.	1055-1056	.1	.002	70	< 1
134-094-08DCC	do.	1059-1060	.09	.06	1.7	8
134-096-25BBB2	Tongue River	310	.1	.04	2.7	4
134-096-25BBB2	do.	311	.09	.004	22.5	< 1
134-096-25BBB2	do.	311.5	.11	—	—	—
137-098-12BBB	Cannonball	741	.12	—	—	—
137-098-12BBB	do.	742-742.5	.09	—	—	—
137-098-12BBB	do.	743	.125	—	—	—
139-095-21DDD2	Sentinel Butte	180-180.5	.1	.0015	83	< 1
139-095-21DDD2	do.	182	.17	—	—	—
139-098-19CBB2	do.	60	.14	—	—	—
139-098-19CBB2	do.	61	.14	—	—	—
139-098-19CBB2	do.	62	.15	.075	2.1	12
140-094-03DDD2	do.	131.5-132	.15	—	—	—
140-094-03DDD2	do.	134-134.5	.16	—	—	—
140-094-03DDD2	do.	136-136.5	.13	.002	70	< 1

two major aquifers (pls. 2 and 3). The Cannonball Formation consists mainly of marine light-olive-gray to dark-greenish-gray nearly impermeable claystone and siltstone. The beds thin westward and interfinger with deposits of the Ludlow. Beds of fine-grained sandstone are present in some areas within the Cannonball and are locally an important aquifer. However, the major function of the formation in the ground-water system is that of a confining bed.

Samples from test hole 138-092-32DDD were examined by Robert H. Tschudy (written commun., 1971), U.S. Geological Survey, for plant spores and other microfossils. He stated:

> "Paleocene pollen and spores identified from these samples include the following: *Pistillipollenites, Ulmipollenites, Alnus, Abietineaepollenites, Maceopolipollenites, Osmundacidites, Erdtmanipollis, Azolla, Carya, Aquilapollenites, Inaperturopollenites, Stereisporites, Kurtzipites, Ghoshispora,* and *Wodenhouseia.*"

Two samples collected from 1,035 to 1,040 feet (315 to 317 m) and from 1,095 to 1,100 feet (334 to 335 m) contained abundant pollen and spores. There were no Cretaceous species in the assemblages. Therefore, the Hell Creek-Ludlow contact should probably be below 1,100 feet (335 m) rather than at 896 feet (273 m) as reported in part II (Trapp, 1971). The presence of *Azolla,* a fresh-water fern, and a few dinoflagellates suggest deltaic deposition.

Samples obtained from depths of 730 to 735 feet (222 to 224 m), considered to be from the Cannonball, did not contain hystrichospheres or dinoflagellates or any other evidence of marine deposition. Therefore, the interval from 730 to 735 feet (222 to 224 m) may be Ludlow rather than Cannonball as reported in part II. Samples collected from 750 to 810 feet (229 to 247 m) from the Cannonball, contained a few hystrichospheres and dinoflagellates, and samples collected from 830 to 835 feet (253 to 255 m) contained an abundant suite of marine fossils. However, the samples from 830 to 835 feet (253 to 255 m) also contained numerous pollen and spore specimens, suggesting that deposition was near shore rather than from mid-basin.

Particle-size distribution curves were made from cores of sandstone from the Cannonball from test hole 137-098-12BBB (table 2). In addition, curves were made for a Cannonball core sample from a depth of 647.5 feet (197.4 m) and for a Ludlow core sample from a depth of 770 feet (235 m) in test hole 141-090-19CCD in Mercer County. The samples ranged from clayey siltstone to fine-grained sandstone with from 17 to 88.2 percent clay and silt sizes. Median particle size for the samples from well 137-098-12BBB ranged from 0.09 to 0.125 mm.

Tongue River Formation

The Tongue River Formation of the Fort Union Group, the oldest rock strata exposed at the surface in the two-county area, crops out in the stream valleys of Hettinger County and eastern Stark County (pl. 1). The formation is predominantly sandstone interbedded with claystone, siltstone, lignite, carbonaceous shale, and bentonitic claystone. The HT Butte lignite bed, in the uppermost part of the Tongue River, is regionally extensive and a distinctive stratigraphic marker. The formation is typically lighter colored than the overlying Sentinel Butte.

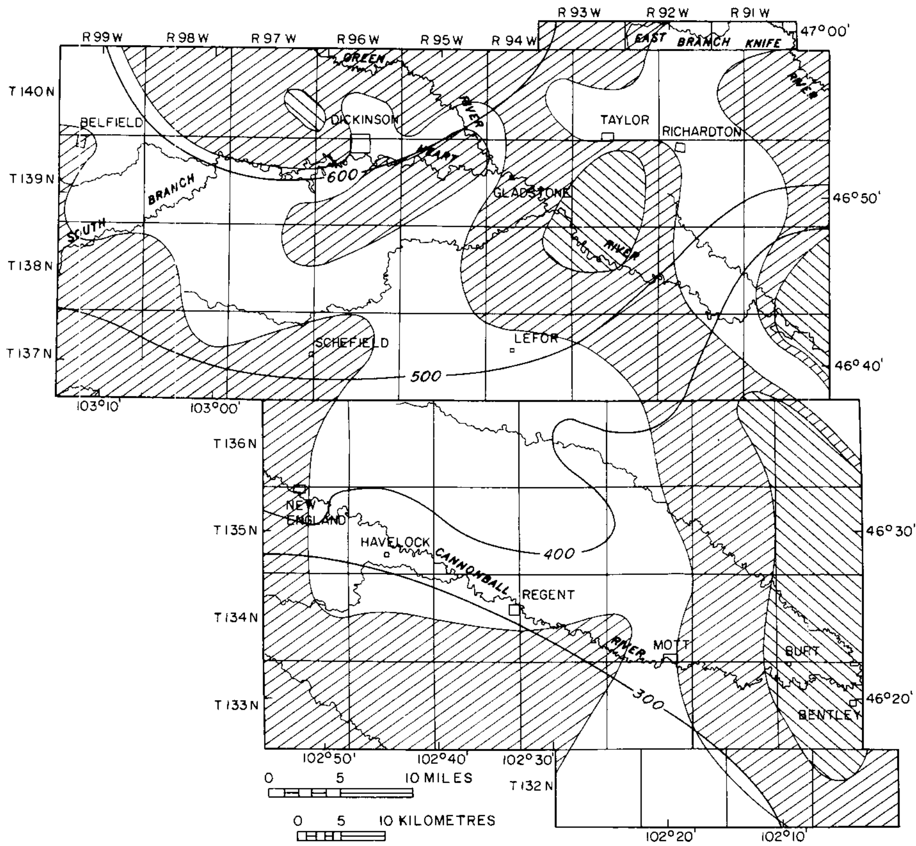
The Tongue River Formation varies from about 250 to at least 570 feet (76 to 174 m) in thickness. A basal sandstone member, which is an important source of ground water, is persistent, but quite variable in thickness, across the area (pls. 2 and 3). The maximum known thickness of the sandstone member is 199 feet (61 m) in well 137-091-13ACC2, but more commonly the thickness is about 50 feet (15 m). The aggregate sandstone thickness, excluding the interbedded siltstone and claystone, is shown in figure 3.

Particle-size distribution curves were made of cores from the Tongue River Formation from test holes 132-092-21DDD2 and 134-096-25BBB2. In addition, a particle-size distribution curve from a depth of 165 feet (50 m) in test hole 141-090-19CCD in Mercer County was reported. The samples ranged from sandy siltstone to very fine sandstone, with from 19.6 to 78.0 percent clay and silt sizes. Median particle size (table 2) of samples from Hettinger and Stark Counties ranged from 0.055 to 0.11 mm. The effective diameter ranged from less than 0.004 to 0.04 mm, and the coefficient of uniformity ranged from 2.7 to 22.5, indicating the sandstone was generally poorly sorted.

Geologic structure. – The geologic structure in Hettinger and Stark Counties (pl. 1) is shown by structure contours drawn on the top of the Tongue River Formation. This stratigraphic horizon was chosen: (1) because it underlies most of the study area, (2) because it is a fairly well defined contact, and (3) because the Tongue River and overlying Sentinel Butte Formations are important aquifers in the counties. The solid contours depict the configuration of this horizon where it occurs in the subsurface; the dashed contours represent the inferred position of the horizon before it was removed by erosion.

Structure contours (pl. 1) indicate that the rocks have been warped into synclines and anticlines. The synclinal folds plunge gently northward and are generally more distinct structures than the anticlines. The highest altitude of the top of the Tongue River Formation is near the southwestern corner of Hettinger County where it is more than 2,800 feet (853 m) above mean sea level. The lowest point is in northern Stark County where the top of

FIGURE 3.-- Aggregate sandstone thickness in and depth to the top of the basal sandstone member of the Tongue River Formation.



EXPLANATION

——— 300 ———

LINE OF EQUAL APPROXIMATE DEPTH TO TOP OF BASEL SANDSTONE MEMBER OF THE TONGUE RIVER FORMATION. INTERVAL 100 FEET (30 METRES). DATUM IS LAND SURFACE

AGGREGATE SANDSTONE THICKNESS, IN FEET METRES)

100-200
(30-61)

50-100
(15-30)

LESS THAN 50 (15)

the Tongue River is at an altitude of less than 1,900 feet (579 m). The regional gradient, therefore, is to the north at about 19 ft/mi (3.6 m/km).

Sentinel Butte Formation

The Sentinel Butte Formation, the uppermost formation of the Fort Union Group, forms the land surface in about 70 percent of Hettinger and Stark Counties (pl. 1). The formation consists of silty fine- to medium-grained sandstone, carbonaceous and bentonitic claystone, and lignite. Where the formation is overlain by younger rocks of Tertiary age and can be measured, the total thickness of the Sentinel Butte is about 450 feet (137 m). It is thickest a few miles south of Dickinson.

On weathered exposures, the Sentinel Butte Formation can usually be distinguished from the underlying Tongue River Formation by its overall darker color when viewed from a distance. The HT Butte lignite bed, in the uppermost part of the Tongue River, is generally overlain by the beds of sandstone at the base of the Sentinel Butte Formation. The color contrast between the Sentinel Butte and the Tongue River is rarely recognizable in the subsurface, and the formations were mapped using the sandstone beds at the base of the Sentinel Butte and the HT Butte lignite bed in the Tongue River.

Thick beds of sandstone in the lower part of the Sentinel Butte Formation are important sources of ground water in Hettinger and Stark Counties. The aggregate sandstone thickness, which excludes the interbedded siltstone and claystone, is shown in figure 4; the thickness is greatest northwest of Dickinson and east of Lefor. Commonly the sandstone is silty and cross-bedded and in some areas grades laterally into a montmorillonite sandy claystone.

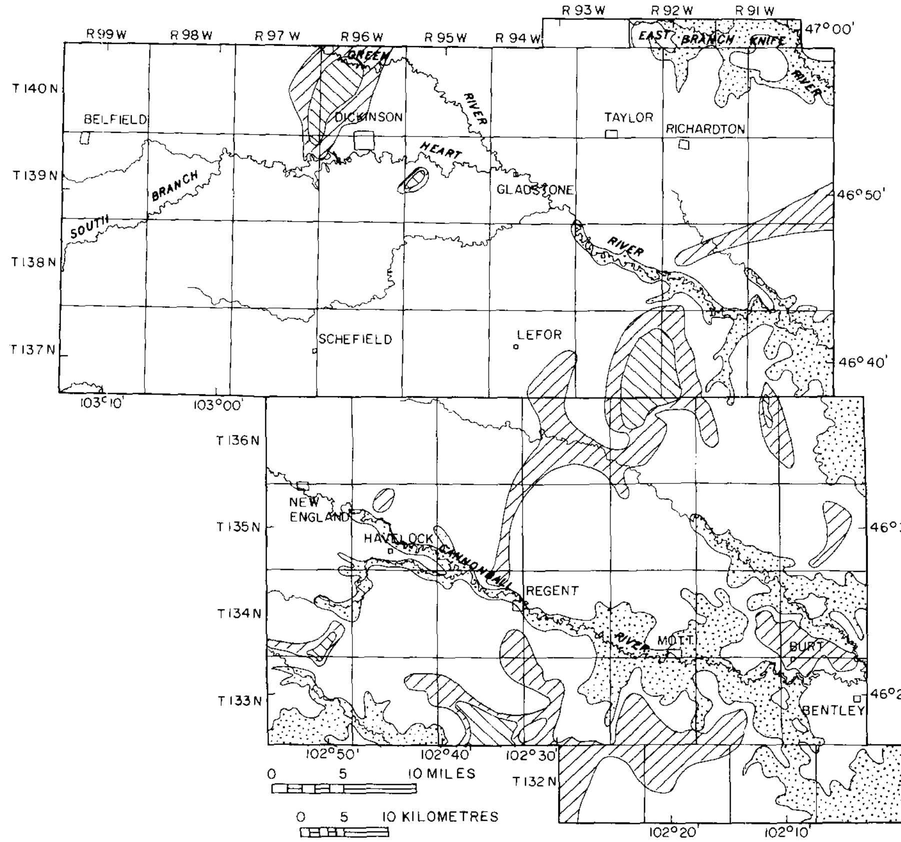
The upper part of the Sentinel Butte consists of interbedded sandstone, siltstone, and claystone interbedded with lignite. The sandstone and lignite are important sources of ground water. The aggregate sandstone thickness, exclusive of the basal sandstone member, is shown in figure 5. The greatest aggregate thickness, up to 220 feet (67 m), is in central Stark County.

Particle-size distribution curves were made from cores taken from the Sentinel Butte Formation in test holes 139-095-21DDD2, 139-098-19CBB2, and 140-094-03DDD. The curves indicate that the sandstone is very fine to fine-grained with 6 to 38 percent clay and silt. Median particle size (table 2) ranged from 0.1 to 0.17 mm; the effective diameter ranged from 0.0015 to 0.075 mm, and the coefficient of uniformity ranged from 2.1 to 83 (table 2), indicating the sandstone was generally poorly sorted.

Golden Valley Formation

The Golden Valley Formation crops out extensively in western Stark County and in northwestern Hettinger County, (pl. 1) and reaches a maximum

FIGURE 4.-- Aggregate sandstone thickness of the basal sandstone member of the Sentinel Butte Formation.



EXPLANATION

AGGREGATE SANDSTONE THICKNESS, IN FEET (METRES)

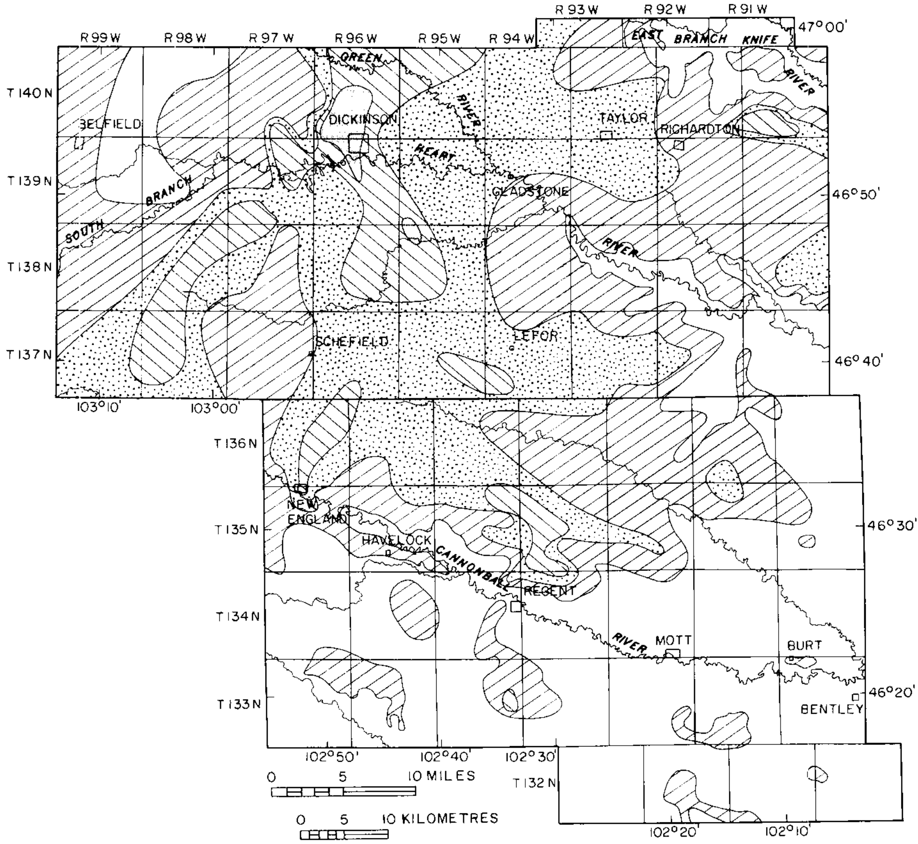
GREATER THAN 100 (30)

50-100 (15-30)

LESS THAN 50 (15)

OUTCROP OF UNDERLYING ROCKS AND QUATERNARY DEPOSITS

FIGURE 5.-- Aggregate sandstone thickness in the upper part of the Sentinel Butte Formation.



EXPLANATION

AGGREGATE SANDSTONE THICKNESS, IN FEET (METRES)

150-220 (46-67)

100-150 (30-46)

50-100 (15 30)

LESS THAN 50 (15)

OUTCROP OF UNDERLYING ROCKS

known thickness of 200 feet (61 m) on some buttes northeast of Dickinson. Benson (1952, p. 70-72) described two members of the Golden Valley Formation. The lower member typically has a basal bed of light-purplish-gray shale, a middle bed of tough white sandy claystone that in the upper part is stained yellow or orange, and an upper bed of light-gray to purplish shale. Where exposed, the lower member is very conspicuous, and Benson referred to it as a "marker bed." Benson's upper member of the Golden Valley Formation is predominantly a tan micaceous crossbedded sandstone with olive-drab claystone and siltstone and a few thin lignite beds.

The contact between the Golden Valley and underlying Sentinel Butte Formation in Hettinger and Stark Counties (pl. 1) was mapped by (1) tracing the marker bed described by Benson (1952), (2) using the base of the steeper slopes formed by the Golden Valley, (3) the presence of thicker and more numerous lignite beds in the Sentinel Butte, and (4) the altitude.

Clay from the lower member is used for brickmaking at Hebron in Morton County, N. Dak., and was once used for that purpose at Dickinson (Holland, 1957, p. 8). The Golden Valley supplies water to shallow wells in southwestern Stark and northwestern Hettinger Counties.

White River Formation

The White River Formation underlies about 38 mi^2 (98 km^2) of southwestern Stark County and about 3 mi^2 (8 km^2) of south-central Stark and north-central Hettinger Counties. A small outlier of White River also occurs in eastern Stark County (pl. 1). Its maximum thickness, in southwestern Stark County, is 200 to 250 feet (61 to 76 m).

The lower part of the White River Formation, which lies unconformably on the Golden Valley Formation, consists of conglomerate, arkose, tuffaceous sandstone, siltstone, and fresh-water limestone. The upper part of the White River in southwestern Stark County consists of pinkish-gray nodular claystone with thin interbeds of fluvial sandstone and conglomerate.

Except for small areas in southwestern Stark County, the White River Formation is not used as a source of ground water.

Arikaree Formation

The Arikaree Formation is the youngest Tertiary formation in Hettinger and Stark Counties. It caps several high buttes in southwestern Stark County and in north-central Hettinger County (pl. 1). In Hettinger County it consists of about 65 feet (20 m) of mostly medium- to coarse-grained crossbedded tuffaceous sandstone, which becomes conglomeratic toward the base (K. S. Soward, written commun., 1969). In southwestern Stark County, the Arikaree consists of about 8 feet (2 m) of tuffaceous sandstone (Denson and Gill, 1965, pl.3).

Because of its limited extent and topographic position, the rocks of the Arikaree Formation do not form a major aquifer.

Unconsolidated Deposits of Quaternary Age

Continental glaciers advanced into northeastern Stark County during the Quaternary Period (fig. 1), and deposited a thin mantle of till over the uplands. Clastic materials washed out of the glaciers as they melted and formed thick deposits of drift in the ice-marginal stream valleys in both Hettinger and Stark Counties.

The till in the uplands consists of weathered unsorted silt, sand, and gravel that rarely exceeds 10 feet (3 m) in thickness. For this reason it is not shown on plate 1. The till yields little or no water.

Undifferentiated drift and alluvium (pl. 1) underlie the valleys of the Heart, Green, and Knife Rivers. The glacial drift reaches a maximum thickness of 278 feet (85 m) in test hole 140-092-06DAA and is mapped as deposits that are dominantly sand and gravel and those that are mainly clay and silt. Some till also occurs below the stream valleys. Dissected sand and gravel deposits form discontinuous terraces above the present-day flood plains.

Quaternary deposits along the Cannonball River, Thirty-mile Creek, and Chanta Peta Creek are probably less than 50 feet (15 m) thick and consist of clay, silt, sand, and gravel deposited as alluvium. The maximum thickness penetrated in test holes was 24 feet (7.3 m) in 134-093-32CDD.

AVAILABILITY AND QUALITY OF GROUND WATER

Nearly all of the ground water from aquifers in Hettinger and Stark Counties 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 soil is held by capillarity and replaces water previously evaporated or transpired by plants. The excess water, if any, will infiltrate downward to the zone of saturation where it becomes available to wells.

Ground water moves under the influence of gravity from areas of recharge to areas of discharge. Ground-water movement is generally very slow; it may be only a few feet per year. The rate of movement is governed by the hydraulic conductivity of the material through which the water moves and by the hydraulic gradient. Gravel, fine to coarse sand, and fractured lignite generally are highly conductive. Deposits of these materials commonly form aquifers. Fine-grained materials such as siltstone, claystone, and shale usually have low conductivity. In many ground-water circulation systems, horizontal strata of high conductivity may be separated by clay layers of much lower conductivity. Clay layers can act in a manner similar to that of semipermeable membranes to cause the concentration of dissolved ions (McKelvey and Milne, 1962) in overlying strata as the water moves downward through the clay layers.

The water level in an aquifer fluctuates in response to recharge to and discharge from the aquifer. Aquifers exposed at land surface are recharged each spring and early summer by direct infiltration of precipitation. At the present time, recharge to these aquifers normally is sufficient to replace losses caused by natural processes and by pumping of wells, although long-term trends of several years may develop during which there are net gains or losses in storage. Aquifers that are confined by thick deposits of fine-grained materials, such as claystone or siltstone, are recharged very slowly. The rate of recharge may increase as heads in the aquifers are reduced by pumping. However, head declines may continue for several years before sufficient recharge is induced to balance the rate of withdrawal. In some cases this balance may never be achieved without a curtailment of withdrawals.

The ground water in Hettinger and Stark Counties contains dissolved mineral matter in varying degree. Rainfall begins to dissolve mineral matter as it falls, a process that continues as the water infiltrates through the soil. The amount and kind of dissolved mineral matter in water depends upon the solubility, the temperature, the types of rocks encountered, the amount of carbon dioxide and soil acids in the water, the length of time the water is in contact with the rocks, ion-exchange reactions, and bacterial processes.

In most natural fresh water, calcium and magnesium are the principal cations (Hem, 1970, p. 131-150) but they are commonly exchanged for sodium in the ground-water reservoir in many areas. Sulfate is generally derived from bacterial processes and weathering of shale and lignite, and is a common constituent in water from shallow wells. Chemical reduction of sulfate by bacteria (Hem, 1970, p. 158-159) removes sulfate from ground water and releases carbon dioxide, which increases the bicarbonate content.

Further in this report numerous references are made to ground-water types, such as sodium bicarbonate type, calcium bicarbonate type, etc. These classifications are based on the predominant cation (sodium, calcium, or magnesium) and anion (bicarbonate, sulfate, or chloride) dissolved in water, expressed in milliequivalents per litre.

The suitability of water for various uses is determined largely by the kind and amount of dissolved matter. The chemical constituents, physical properties, and indices most likely to be of concern are: iron, sulfate, nitrate, fluoride, dissolved solids, hardness, temperature, odor, taste, specific conductance, sodium-adsorption ratio, and percent sodium. The source of the major chemical constituents, their usability, and the limits recommended by the

U.S. Public Health Service (1962) are given in table 3. Additional information regarding drinking water standards may be found in "Drinking Water Standards" published by the U.S. Public Health Service (1962). Water-quality criteria for public supplies, farmsteads, industrial, and agricultural use were established by the Federal Water Pollution Control Administration (1972). Irrigation classifications in this report were derived by use of figure 6.

Aquifers in Deposits of Cretaceous and Tertiary Age

Fox Hills and Basal Hell Creek Aquifer System

Location, thickness, and lithology. – The Fox Hills Formation and the lower part of the Hell Creek Formation form a major aquifer system that underlies all of the study area and extends into the adjoining counties (pls. 2 and 3). The aquifer system includes all the Fox Hills Formation and beds that occur below the Bacon Creek(?) Member of the Hell Creek Formation (Frye, 1969). The aquifer system consists of fine- to medium-grained sandstone that is generally interbedded with siltstone and claystone. The top of the aquifer system is as much as 1,520 feet (463 m) deep in well 139-097-20BC (pl. 2) in the northern part of the area, but is 1,120 feet (341 m) deep in well 134-096-24CC (pl. 3) in the southern part of the area. The aquifer system is 410 to 530 feet (125 to 162 m) thick along the lines of section and is overlain and confined by nearly impermeable beds of siltstone and claystone that probably represent the Bacon Creek Member of Frye (1969).

Hydrologic characteristics. – A map of the potentiometric surface of the Fox Hills and basal Hell Creek aquifer system (fig. 7) indicates that ground water generally flows into the study area from counties to the southwest and moves eastward, except northwest of Dickinson where the gradient is to the north. They hydraulic gradient at Richardton is about 12 ft/mi (2 m/km). In addition, the aquifer system probably is recharged by percolation through confining beds from overlying aquifers in Hettinger and eastern Stark Counties. The aquifer discharges by underflow to the counties to the northeast, and upwards into overlying aquifers in western Stark County.

In September 1968, a specific capacity test was made of well 135-097-04DCA. The well was pumped with a small submergible pump for 223 minutes at a rate that initially was 7 gal/min (0.4 l/s), but gradually declined to 4.8 gal/min (0.3 l/s). Drawdown at the end of the test was 5.1 feet (1.6 m). Assuming an average discharge of about 5 gal/min (0.3 l/s), the specific capacity was 1 (gal/min)/ft [0.21 (l/s)/m] of drawdown. Water-level recovery was nearly complete 6 minutes after pumping ceased.

Figure 8 shows the transmissivity of the aquifer system in Hettinger and Stark Counties. The values range from 110 ft^2/d (10 m^2/d) near Belfield to 390 ft^2/d (36 m^2/d) at Gladstone and Schefield. The map was constructed

TABLE 3. — Major chemical constituents in water — their sources, effects upon usability, and recommended concentration limits
(Concentrations are in milligrams per litre)

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

Constituents	Major source	Effects upon usability	U.S. Public Health Service recommended limits for drinking water[1]
Silica (SiO_2)	Feldspar, ferromagnesian and clay minerals.	In presence of calcium and magnesium, silica forms a scale that retards heat transfer in boilers and on steam turbines.	
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 0.1 mg/l iron is present, it will precipitate when exposed to air; causing turbidity, staining plumbing fixtures, laundry and cooking utensils, and imparting tastes and colors to food and drinks. More than 0.2 mg/l is objectionable for most industrial uses.	0.3
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, 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.		
Bicarbonate (HCO_3) Carbonate (CO_3)	Limestone and dolomite.	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.	
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
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
Fluoride (F)	Amphiboles, apatite, fluorite, and mica.	Optimum concentration in drinking water has a beneficial effect on the structure and resistance to decay on children's teeth. Concentrations in excess of optimum may cause mottling of children's teeth.	Recommended limits depend on average of maximum daily temperatures. Limits range from 0.6 mg/l at 32°C to 1.7 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
Boron (B)	Tourmaline, biotite, and amphiboles.	Many plants are damaged by concentrations of 2.0 mg/l.	
Dissolved solids	Anything that is soluble.	More than 500 mg/l is not desirable if better water is available. Less than 300 mg/l is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	500

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

FIGURE 6.-- Classification of irrigation water.

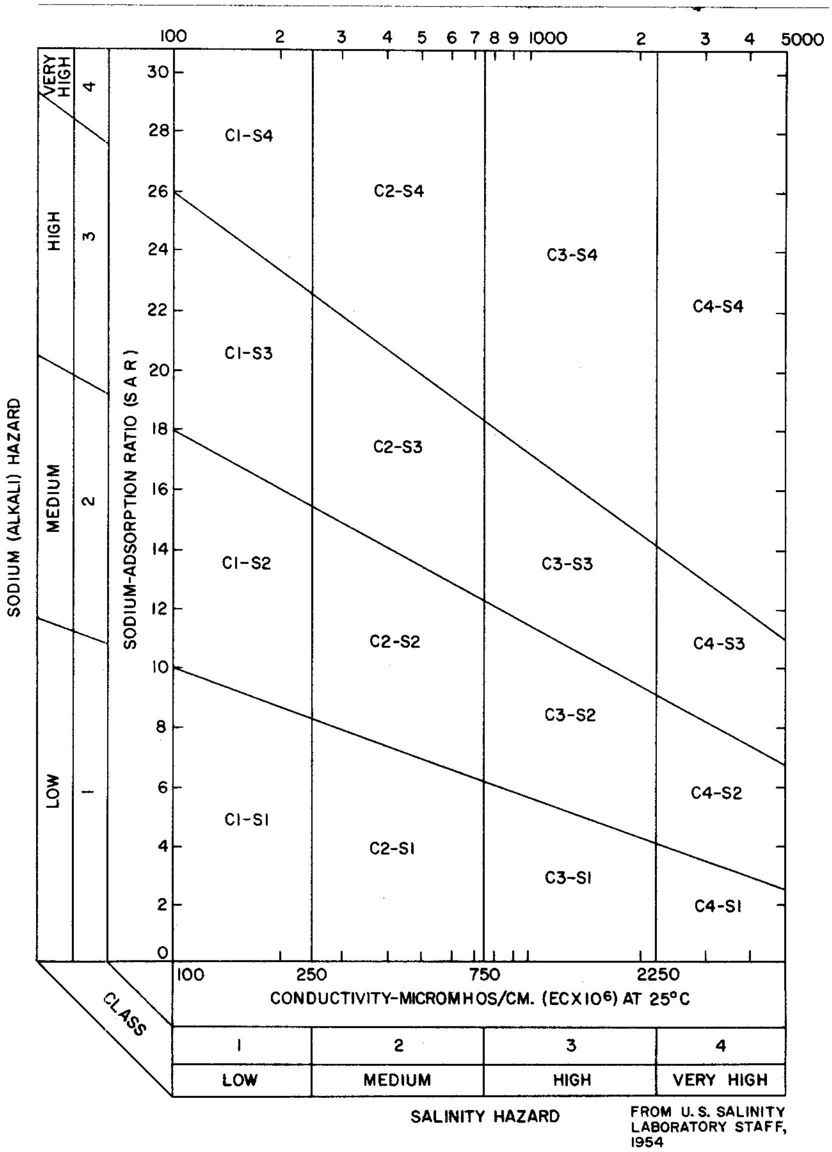
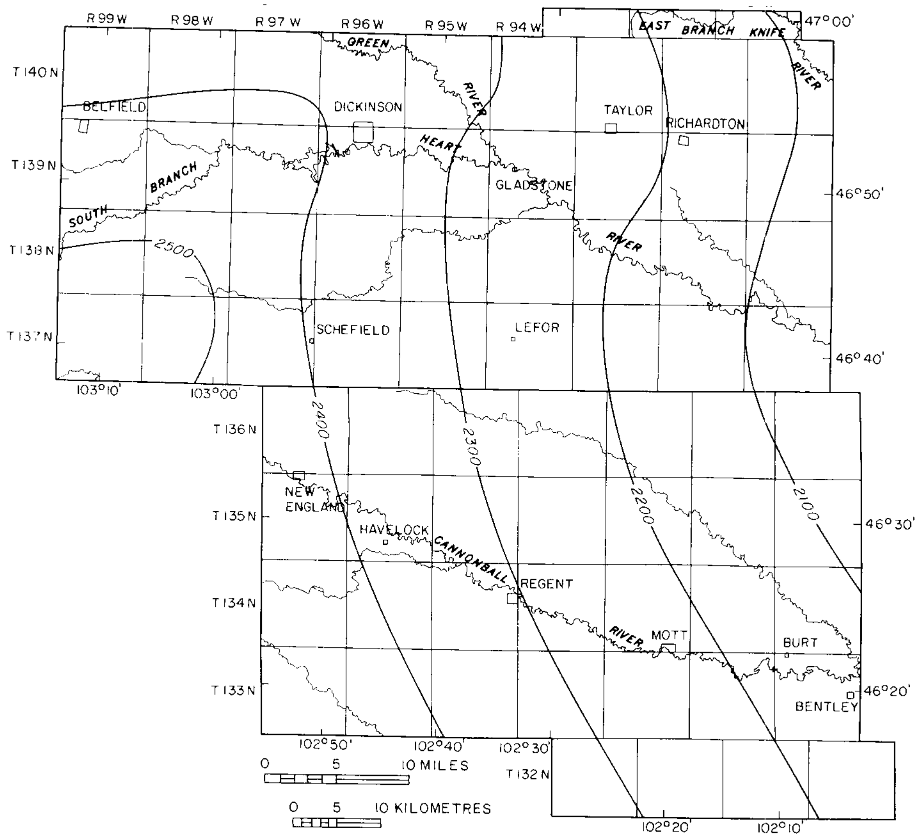


FIGURE 7.-- Potentiometric surface of the Fox Hills and basal Hell Creek aquifer system.



EXPLANATION

——— 2500 ———
POTENTIOMETRIC CONTOUR

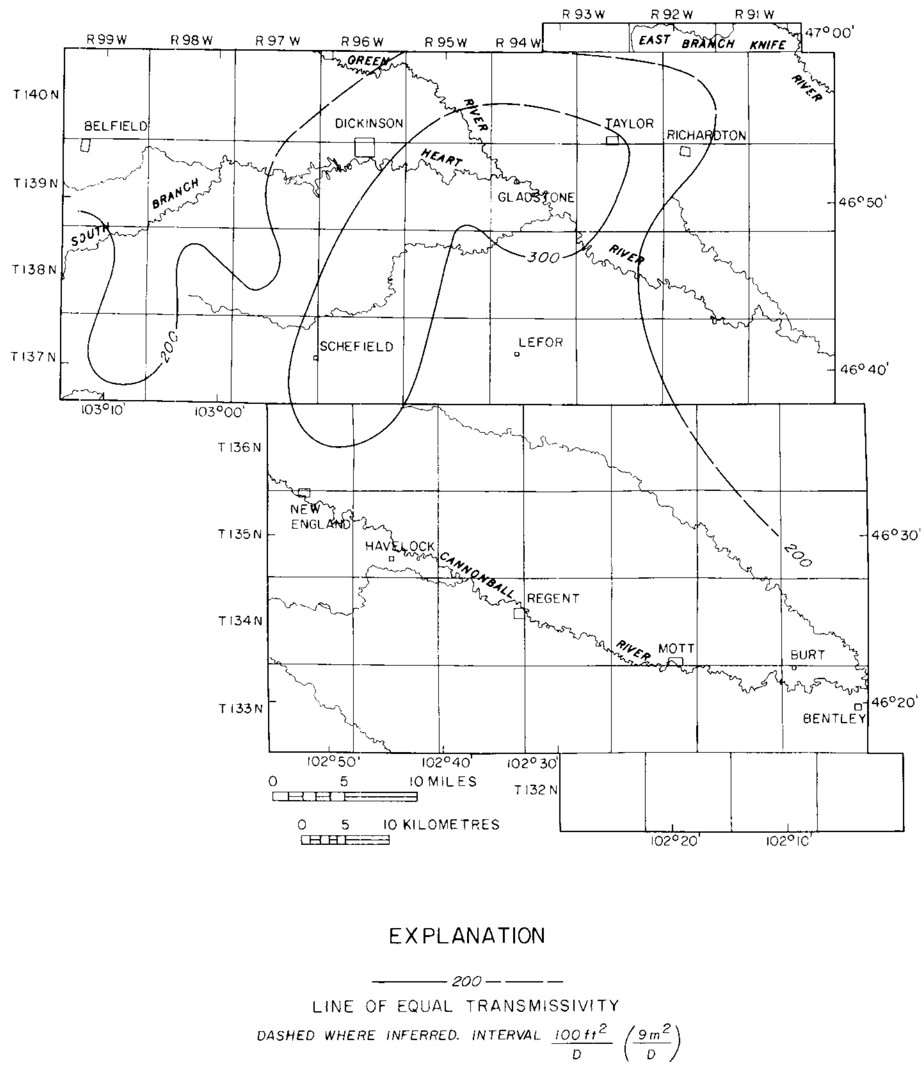
SHOWS ALTITUDE OF POTENTIOMETRIC SURFACE. CONTOUR INTERVAL 100 FEET (30 METRES) DATUM IS MEAN SEA LEVEL

from values calculated from resistivity curves of electric logs of oil, gas, and ground-water test holes (Alger, 1966; Croft, 1971).

Water quality. – Water samples from the Fox Hills and basal Hell Creek aquifer system had dissolved-solids concentrations ranging from 1,310 to 1,540 mg/l. The water was a sodium bicarbonate type (fig. 9), except for the sample from well 139-091-11DCD2 which was a sodium chloride type. All the water sampled was soft, with hardness ranging from 8 to 19 mg/l. Fluoride concentrations ranged from 3.7 to 4.5 mg/l. The water contained higher concentrations of fluoride, chloride and nitrate (fig. 9) than the samples from other aquifers in the area of study.

Water from the Fox Hills and basal Hell Creek aquifer system may not be suitable for prolonged irrigation because of high sodium-adsorption ratios

FIGURE 8.-- Transmissivity of the Fox Hills and basal Hell Creek aquifer system.

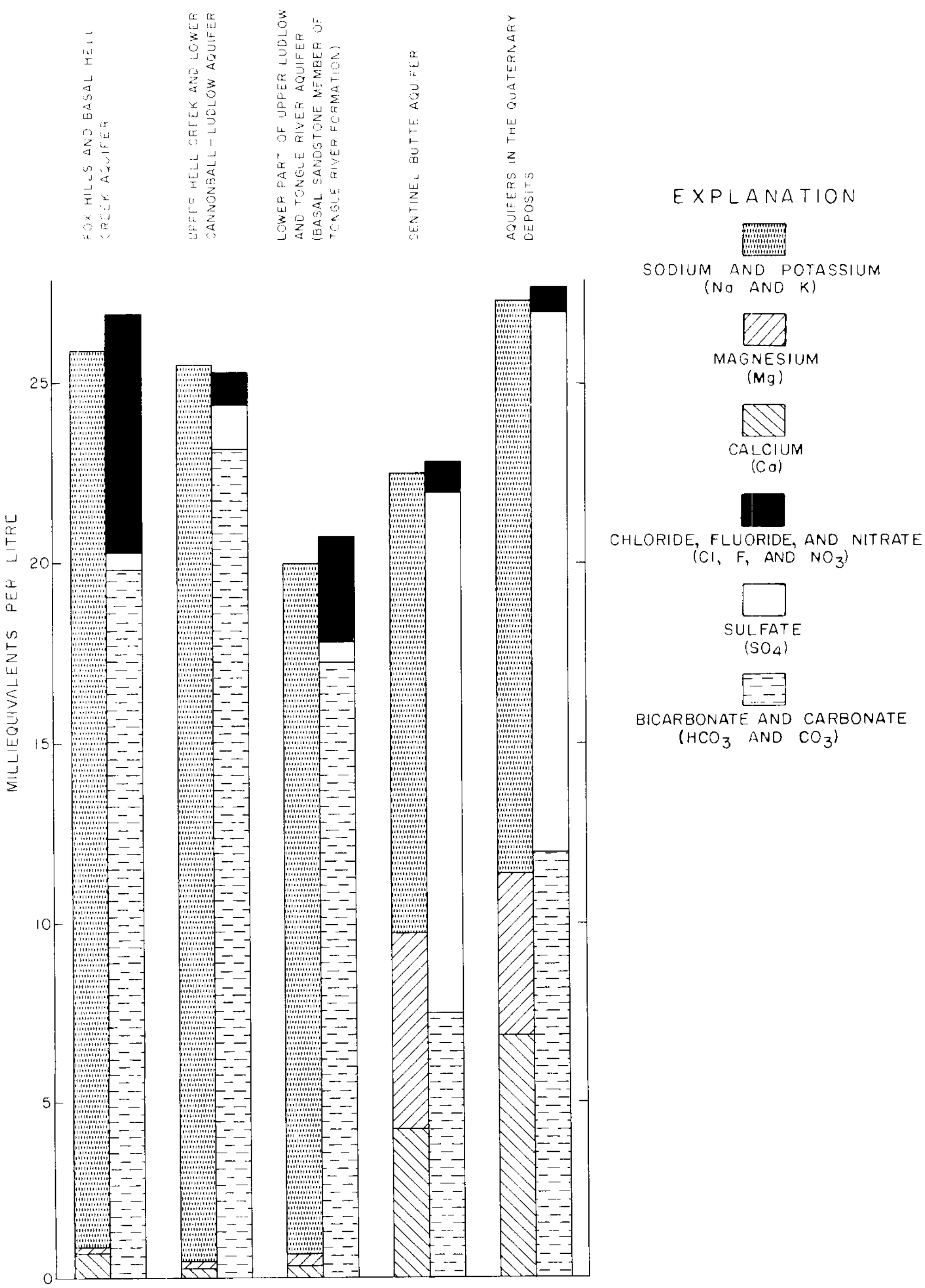


(fig. 6) and high residual sodium carbonate. Sodium-adsorption ratios ranged from 58 to 92, and therefore, the values were too large to plot in figure 6.

Utilization and potential for future development. – Only two wells are known to be withdrawing water from the Fox Hills and basal Hell Creek aquifer system in the two-county area — both supply water for rest-stop facilities along Interstate Highway I-94 in Stark County. The aquifer system has not been used more extensively in Hettinger and Stark Counties because of its depth and the general availability of satisfactory supplies from shallower aquifers. However, the aquifer system is more widely developed in some adjoining counties.

Small withdrawals from the aquifer system will cause large declines in head. The yield, in gallons per minute, of an efficient, fully penetrating

FIGURE 9.-- Average values of major constituents in water in the principal aquifer systems.



well with 50 feet (15 m) of drawdown after 24 hours of pumping may be approximated at any given location on the transmissivity map (fig. 8) by dividing the transmissivity by 5.3. Wells tapping the aquifer system should yield 25 to 75 gal/min (2 to 5 l/s).

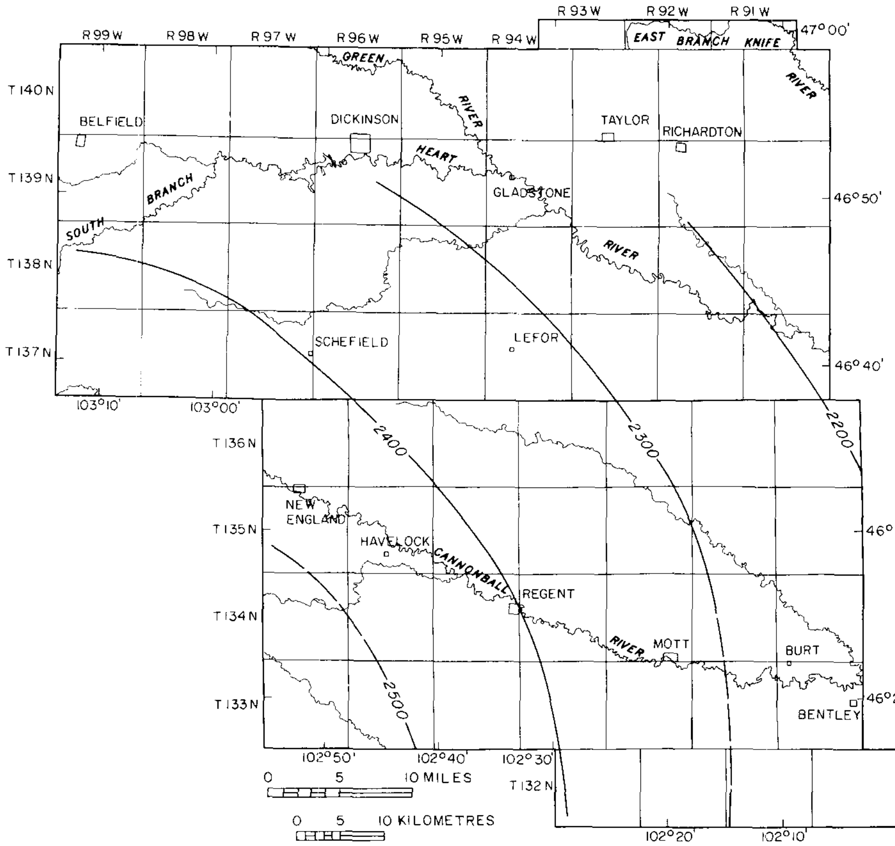
Upper Hell Creek and Lower Cannonball-Ludlow Aquifer System

Location, thickness, and lithology. – The upper Hell Creek and lower Cannonball-Ludlow aquifer system underlies all of Hettinger and Stark Counties. Nearly impermeable beds of siltstone and claystone, which probably represent the Bacon Creek Member of the Hell Creek Formation (Frye, 1969), separate the aquifer system from the underlying Fox Hills and basal Hell Creek aquifer system. At Regent (pl. 3) the top of the upper Hell Creek and lower Cannonball-Ludlow aquifer system is about 710 feet (216 m) below land surface. It is 280 to 530 feet (85 to 162 m) thick (pl. 2). The aquifer consists of beds of fine- to medium-grained sandstone in the upper part of the Hell Creek Formation and beds of fine-grained sandstone and lignite in the lower part of the Cannonball and Ludlow Formations. The sandstone throughout the aquifer system is interbedded with siltstone and claystone. Thick beds of nearly impermeable siltstone and claystone forming the middle and upper parts of the Cannonball Formation overlie and confine the aquifer system.

Hydrologic characteristics. – Most of the recharge to the aquifer system is underflow from counties to the southwest and from seepage through the Cannonball Formation from overlying aquifer systems. A map of the potentiometric surface of the aquifer system (fig. 10) was constructed for Hettinger and Stark Counties. The contours indicate that ground water is moving from the southwest to the northeast. The gradient is about 8 ft/mi (2 m/km). In Hettinger and eastern Stark Counties the head in the upper Hell Creek and lower Cannonball-Ludlow aquifer system is higher than the head in the Fox Hills and basal Hell Creek aquifer system (figs. 7 and 10). At Regent the head is about 100 feet (30 m) higher. There probably is percolation into the underlying Fox Hills and basal Hell Creek aquifer system in this area because of the higher head. However, in western Stark County the potentiometric maps indicate that the head is lower. The potentiometric map (fig. 10) indicates the aquifer discharges by underflow to the counties to the northeast.

The effective particle diameter of three cores from well 134-094-08DCC (table 2) ranged from 0.002 to 0.09 mm. Charts compiled by Johnson (1963, figs. 21 and 22) suggest that the three core samples have hydraulic conductivities of 1 to 19 ft/d (0.3 to 6 m/d) assuming a porosity of 35 percent. Drawdown data are available for two wells. Well 136-092-02CDA has a specific

FIGURE 10.-- Potentiometric surface of the upper Hell Creek and lower Cannonball-Ludlow aquifer system.



EXPLANATION

——— 2500 ——— —

POTENTIOMETRIC CONTOUR

SHOWS ALTITUDE OF POTENTIOMETRIC SURFACE. DASHED WHERE INFERRED. CONTOUR INTERVAL 100 FEET (30 METRES). DATUM IS MEAN SEA LEVEL

capacity of 0.2 (gal/min)/ft [0.04 (l/s)/m] of drawdown, and well 137-091-13ACC2 has a specific capacity of 0.33 (gal/min)/ft [0.07 (l/s)/m].

Water quality. – Analyses of water samples from seven wells tapping the aquifer system indicated (fig. 9) that the water was a sodium bicarbonate type. In these samples sodium and potassium constituted about 98 percent of the cations, and carbonate and bicarbonate constituted 92 percent of the anions. Sulfate constituted about 5 percent of the anions. Sulfate content was low, possibly due to sulfate reduction by bacteria. Chloride, fluoride, and nitrate constituted about 3 percent of the anions.

Dissolved solids ranged from 1,450 to 1,890 mg/l, and the median value was 1,500 mg/l. The samples contained 4.8 to 127 mg/l sulfate and 0.8 to 5.8 mg/l fluoride. The median value for fluoride was 2.4 mg/l. The water was soft; most samples had a calcium carbonate hardness of less than 20 mg/l. Boron ranged from 0.9 to 1.9 mg/l and iron ranged from 0 to 1.3 mg/l. Sodium-adsorption ratios ranged from 25 to 130, and the median was 76. Because most of the sodium-adsorption ratios were high, the samples were not classified for irrigation purposes in figure 6. Color values of four samples ranged from 20 to 270.

Utilization and potential for future development. – Several livestock and domestic wells and a public supply well at Regent tap the aquifer system for water supplies. In general the aquifer system is practically undeveloped. Wells tapping the aquifer system should yield as much as 100 gal/min (6 l/s). Flowing wells for livestock and domestic use have been drilled in the lowest part of the valley of the Green River southwest of Richardton. Well 137-091-13ACC2, which is 640 feet (195 m) deep, had a head of 46 feet (14 m) above land surface in 1968. Other flowing wells could be drilled in low areas along the river.

Upper Ludlow and Tongue River Aquifer System

Location, thickness, and lithology. – The aquifer system includes beds in the upper part of the Ludlow Formation and all of the Tongue River Formation. It underlies all of Hettinger and Stark Counties (pls. 2 and 3). In the southern part of the area the aquifer system is unconfined. It consists of fine- to medium-grained sandstone, siltstone, and fractured lignite interbedded with claystone. The sandstone has a low hydraulic conductivity. The aquifer system is as much as 430 feet (131 m) thick (pl. 2). Included is the basal sandstone member of the Tongue River Formation, which is 199 feet (61 m) thick in well 137-091-13ACC2.

Hydrologic characteristics. – The upper Ludlow and Tongue River aquifer system is recharged directly by precipitation and, where the aquifer system is exposed at the surface, by seepage from lakes, streams and reservoirs. A map of the potentiometric surface of the aquifer system (pl. 4A, in pocket) was constructed for Hettinger and Stark Counties using only wells tapping the lower part of the aquifer system. Many shallow wells tapping beds in the upper part of the Tongue River Formation and wells in the overlying Sentinel Butte aquifer system have higher heads than those shown on the potentiometric map, indicating that water is moving downward through the rocks and recharging the aquifer system. The contours on the map indicate that ground water generally is moving from the southwest to the northeast. The head in the aquifer system is as much as 100 feet (30 m) higher than the head in the underlying aquifer system in the southwestern part of the area (pl. 4A, and fig. 10); indicating that some water may be percolating downward to the upper Hell Creek and lower Cannonball-Ludlow aquifer system.

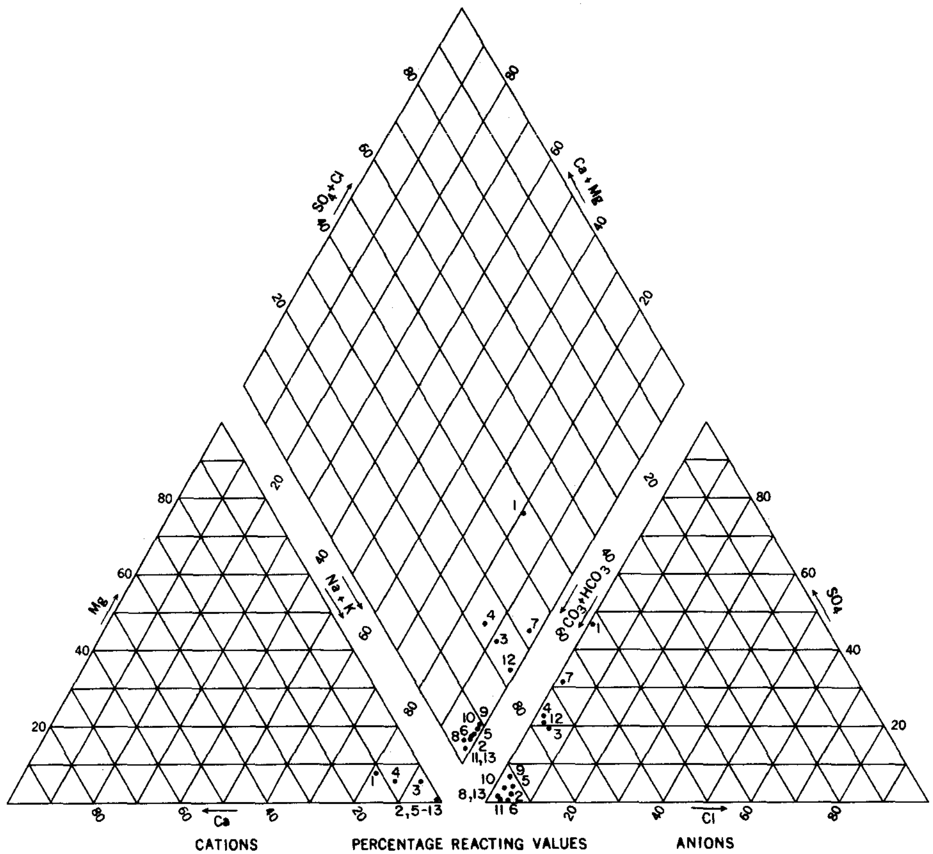
The contours show a depression caused by pumping at Belfield. In the northeastern part of the area the heads in the two aquifer systems are approximately equal.

The specific capacities, reported by drillers, of wells tapping the aquifer system in Hettinger and Stark Counties ranged from 0.01 to 7.2 (gal/min)/ft [0.002 to 1.5 (l/s)/m] of drawdown and averaged about 0.4 (gal/min)/ft [0.08 (l/s)/m] of drawdown. The highest specific capacity is for well 133-091-19BCD, which reportedly yielded 36 gal/min (2 l/s) with 5 feet (2 m) of drawdown from a 60-foot (18-m) sandstone bed in the upper part of the Tongue River Formation. Charts compiled by Johnson (1963, figs. 20 and 22) were used to estimate hydraulic conductivity of cores from wells 132-092-21DDD2 and 134-096-25BBB2. The median particle size of the cores suggests that the hydraulic conductivity should range from 0.1 to 27 ft/d (0.03 to 8 m/d), while charts based on effective diameter (Johnson, 1963, figs. 21 and 23) indicate a hydraulic conductivity range of about 1 to 4 ft/d (0.3 to 1 m/d).

The transmissivity values shown on plate 4B for the basal sandstone member of the Tongue River Formation were calculated from resistivity curves of electric logs of oil, gas, and ground-water test holes. Transmissivities (pl. 4B) range from 70 ft^2/d (7 m^2/d) southwest of Mott to 530 ft^2/d (49 m^2/d) at Belfield and south of Gladstone. The transmissivity lines of highest value, which are aligned in an east-west direction through central and eastern Stark County, show the location of thick beds of permeable sand that may have been deposited in an ancient stream channel. Well tapping the aquifer system should yield 1 to 100 gal/min (0.1 to 6.3 l/s).

Water quality. – Analyses of 13 water samples from wells tapping the basal sandstone member of the Tongue River Formation are plotted on a trilinear diagram (fig. 11). Sodium and potassium constituted more than 81 percent of the cations in all samples. In the wells greater than 300 feet (91 m) in depth, sodium and potassium constituted more than 98 percent of the cations. Although the analyses were not plotted on the trilinear diagram, water from shallow wells tapping the upper part of the aquifer system commonly contained several hundred milligrams per liter calcium and sulfate. In the water samples obtained from the basal sandstone, most of the calcium and magnesium probably was removed by cation exchange as the water passed through beds of siltstone and claystone at shallow depth. Figure 9 indicates that water in the basal sandstone member of the Tongue River Formation has fewer dissolved constituents than that in the overlying Sentinel Butte aquifer. This may be due to removal of ions as the water moves downward through clay layers.

Bicarbonate and carbonate (fig. 11) ranged from 52 to 97 percent of the anions, and sulfate ranged from less than 1 to 47 percent of the anions. Chloride constituted less than 5 percent of the anions in the samples. Water



No.	Well number	Depth (ft[1] below land surface)	Dissolved solids (mg/l)
1	132-092-09AAA	225	1010
2	133-092-05BAA2	310	1080
3	133-095-19DDD	214	1210
4	133-097-09AAA2	221	704
5	134-091-06DDC2	474	1470
6	134-093-35DCD	378	1230
7	135-091-20ACB	420	1310
8	137-094-04CBC	531	1380
9	138-092-32DDD	552	1360
10	138-093-24AAC	383	1150
11	139-094-08DBC2	650	1180
12	139-099-05ABC	680	1050
13	140-092-14ACC2	424	1200

[1]To convert feet to metres multiply the feet by 0.3048.

FIGURE 11.-- Major constituents in water from the basal sandstone member of the Tongue River Formation.

changes in anionic composition as it moves through the sandstone, as indicated by chemical diagrams on plate 4A. The pattern of each chemical diagram is determined by the percentage of individual anions or group of anions. As the water moves downgradient, the concentration of sulfate generally decreases. The percentage of bicarbonate and carbonate in the water increases. In well 133-097-09AAA2, in southwestern Hettinger County, sulfate constituted about 22 percent of the anions, bicarbonate and carbonate about 76 percent of the anions, and chloride constituted 2 percent of the anions. The concentration of sulfate was 134 mg/l. In Stark County most of the chemical diagrams have a different pattern. In well 137-094-04CBC, sulfate constituted about 1 per cent of the anions, bicarbonate and carbonate about 97 percent of the anions, and chloride about 2 percent of the anions. The concentration of sulfate was 9.9 mg/l. The decrease in sulfate and the increase in carbonate may be due to sulfate reduction by bacteria (Hem, 1970, p. 158-159; Kuznetsov and others, 1963).

Dissolved solids for the samples plotted on the trilinear diagram (fig. 11) ranged from 704 to 1,470 mg/l. The median value for dissolved solids was 1,080 mg/l. Water from well 132-092-09AAA contained 372 mg/l sulfate, and the water from well 139-094-08DBC2 contained 0.4 mg/l sulfate. Most of the water sampled was soft; calcium carbonate hardness ranged from 10 to 56 mg/l. However, water from well 132-092-09AAA, which is in the southeast corner of Hettinger County, had a calcium carbonate hardness of 158 mg/l. Fluoride ranged from 0.1 to 5.8 mg/l, boron from 0.48 to 1.5 mg/l, and iron from 0.07 to 2.3 mg/l. Sodium-adsorption ratios ranged from 10 to 69, had a median value of 55, and were generally too large to plot in figure 6. Many water samples were colored. Color values ranged from 5 to 7,000 units.

Utilization and potential for future development. – About 60 percent of the wells inventoried in Hettinger County and about 11 percent of those in Stark County obtain water from the aquifer for livestock and domestic use. Two municipal wells at Belfield tap the basal sandstone member of the Tongue River Formation. This member probably has the greatest potential for development of any aquifer above the Fox Hills and basal Hell Creek aquifer system. Wells tapping the sandstone should yield as much as 100 gal/min (6 l/s; pl. 4B).

Flowing wells constructed for livestock and domestic use tap the basal sandstone member in the valleys of the Heart, Cannonball, and Little Knife Rivers and several of their tributaries in Hettinger County and eastern Stark County (pl. 4A). Also outlined are other areas where flowing wells could probably be drilled. Allowing wells to flow indiscriminately wastes water and reduces the head.

Sentinel Butte Aquifer System

Location, thickness, and lithology. – The Sentinel Butte aquifer system underlies most of Stark County and the northern and central parts of Hettinger County (fig. 5). The aquifer system consists of fine to very fine grained sandstone and fractured lignite. Water-bearing sandstone beds can be found at various horizons in the Sentinel Butte Formation, but the most persistent sandstone occurs at the base of the formation (fig. 4). The aquifer system is as much as 245 feet (75 m) thick (pl. 2).

Hydrologic characteristics. – The Sentinel Butte aquifer system is recharged directly by precipitation and by seepage from lakes, streams, and reservoirs. A hydrograph of well 140-095-08AAA (fig. 12) shows that the water level rises in the spring during the thaw and following periods of precipitation. The water level is lowest during the fall and winter months when precipitation is light.

Lindvig (1964) described an aquifer test in the aquifer near Dickinson. The test well (140-096-31DBD) was drilled to a depth of 88 feet (27 m) and screened in the lower 30 feet (9 m). The producing zone consisted of 47 feet (14 m) of medium-grained sandstone interbedded with clay. The well

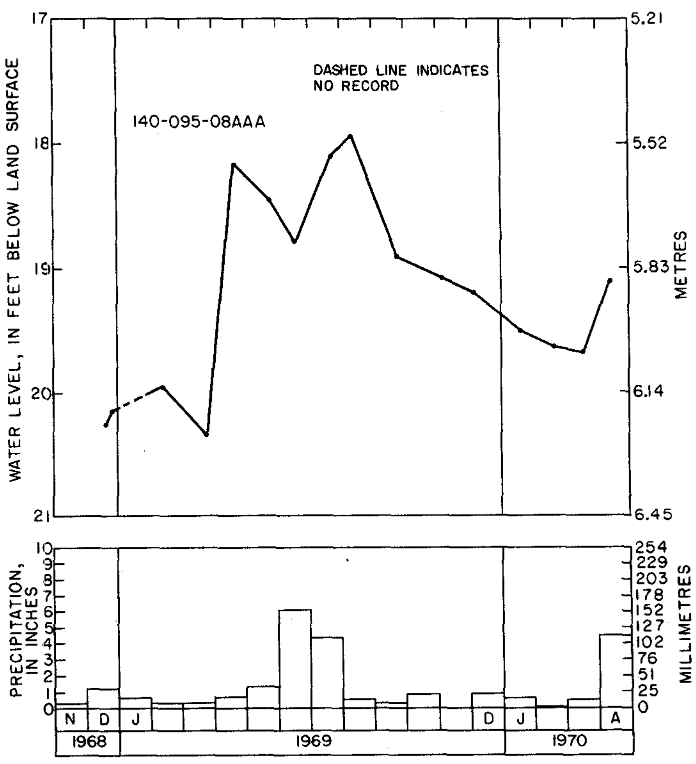


FIGURE 12.-- Water-level fluctuations in the Sentinel Butte aquifer system, and precipitation at the Dickinson Experiment Station, 1968-70.

was pumped for 1,100 minutes at a maximum rate of 80 gal/min (5 l/s). Drawdown was 40 feet (12 m). Values for transmissivity between 440 and 820 ft^2/d (41 and 76 m^2/d) and storage coefficient between 0.0007 and 0.008 were calculated from the observation-well data.

Dickinson municipal wells tap the same sandstone beds. McLaughlin and Greenlee (1946, p. 19-23) described aquifer tests made on two wells in the city field, Dickinson 3 (139-096-03BBC2) and Dickinson 7 (139-096-04ACA). Well 3 was pumped for 49 hours at an average rate of 105 gal/min (7 l/s) during the test. The transmissivity calculated from recovery data of three observation wells was 1,130 ft^2/d (105 m^2/d), and the storage coefficient was 0.001. Well 7 was pumped for 44.5 hours at 130 gal/min (8 l/s). The transmissivity calculated on the basis of this test was 600 ft^2/d (56 m^2/d) and the storage coefficient was 0.016.

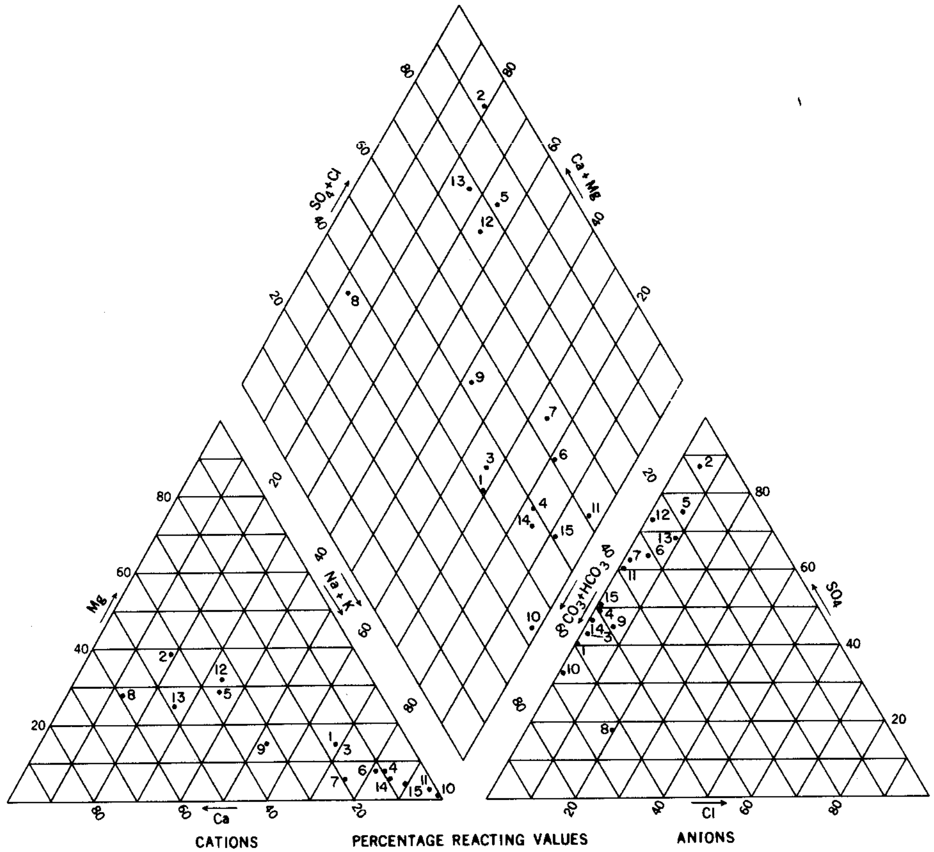
In November 1958, an unpublished aquifer test was made using a municipal well at New England. New England 1 (135-097-04DBA1) was pumped for about 37 hours. The pumping rate was about 50 gal/min (2 l/s). The static water level in the pumped well was 37.6 feet (11 m), and the drawdown at the end of the test was 10.24 feet (3.1 m).

The specific capacities of numerous wells tapping the Sentinel Butte aquifer system were determined from yield and drawdown data reported by drillers. The values ranged from 0.01 to 9.5 (gal/min)/ft [0.002 to 1.97 (l/s)/m] of drawdown. The average was 0.75 (gal/min)/ft [0.16 (l/s)/m]. The values were not adjusted for well diameter, and the length of pumping period varied considerably.

Wells in the Dickinson field have specific capacities as large as 9.5 (gal/min)/ft [1.97 (l/s)/m] of drawdown and wells in the New England municipal system have specific capacities as large a 8 (gal/min)/ft [1.66 (l/s)/m] of drawdown. Considerable effort was made to obtain highly efficient wells in these fields, and it is apparent that design and development was a major factor in obtaining the large specific capacities.

Water quality. – Forty-two water samples were collected from the Sentinel Butte aquifer system. Analyses of these samples indicated that the water generally was a sodium sulfate type (fig. 9). Sodium and potassium constituted about 57 percent of the cations in the average sample. The percentage of calcium and magnesium in the average sample was higher than in the samples from the underlying aquifers. Sulfate was the major anion.

Thirteen representative analyses from the aquifer system are plotted on a trilinear diagram (fig. 13) to show the variable character of the water and the change in cation concentration with depth. Sodium and potassium constituted more than 75 percent of the cations in wells greater than 150 feet (46 m) in depth due to exchange of calcium and magnesium for sodium. Sulfate constituted 17 to 87 percent of the anions in the samples and the concentration in many of the samples was higher in the shallower wells. Chloride constituted less than 10 percent of the anions in all but one sample.



No.	Well number	Depth (ft[1] below land surface)	Dissolved solids (mg/l)
Sentinel Butte aquifer			
1	135-092-08CCD	80	522
2	135-094-28CBB2	60	1530
3	135-097-04ADD1	105	975
4	136-093-02CBC	202	1670
5	136-093-22AAA2	122	3730
6	136-094-03DDD	224	1350
7	137-094-22DAC3	218	1400
8	137-094-32BBB1	112	390
9	137-098-04BAC	120	585
10	140-098-01DCC3	210	1570
11	140-098-19AAB3	150	1890
Glacial-drift and alluvial aquifers			
12	139-096-12ABD	25	1980
13	139-097-14DAB	30	1850
14	140-092-06DAA	278	2000
15	140-092-01BAA	101	2130

[1] To convert feet to metres multiply the feet by 0.3048.

FIGURE 13.-- Major constituents in water from the Sentinel Butte aquifer system and from aquifers in deposits of Quaternary age.

Dissolved solids for the samples ranged from 378 to 11,700 mg/l and had a median value of 1,050 mg/l. Sulfate ranged from 42 to 7,980 mg/l and had a median value of 417 mg/l. Calcium carbonate hardness ranged from 15 to 6,000 mg/l and had a median value of 225 mg/l. Although fluoride ranged from 0.0 to 6.7 mg/l, most of the water from the aquifer did not contain excessive fluoride. The samples contained 0.0 to 2.1 mg/l boron. Sodium-adsorption ratio ranged from 0.2 to 67. Much of the water was yellow to dark brown due to organic compounds. Color values ranged from 5 to 3,200.

Utilization and potential for future development. – About 38 percent of the wells inventoried in Hettinger County and about 79 percent of the wells inventoried in Stark County tap the Sentinel Butte aquifer system for livestock and domestic supplies. Most of these wells probably yield less than 50 gal/min (3 l/s) from beds of sandstone or fractured lignite. Municipal wells at New England and Dickinson developed in the aquifer system have yielded as much as 100 gal/min (6 l/s). Part of the water supply for the city of Richardton is obtained from lignite beds in the Sentinel Butte aquifer system.

Golden Valley Aquifer System

Shallow wells penetrate the Golden Valley Formation in southwestern Stark County, in the area west of Lefor in south-central Stark County, and in adjoining parts of northwestern Hettinger County. Logs of wells producing water from the aquifer system are not available, but sandstone and thin lignite beds in the lower part of the formation probably are the major sources of water. Well tapping the aquifer yield only small quantities of water.

Three partial analyses of water from the Golden Valley aquifer system are reported by Trapp (1971, table 5). The water from well 138-096-20AAD3 had a specific conductance of 1,220 micromhos/cm at 25°C and was probably a calcium sulfate type. The water from well 138-096-20AAD4 had a specific conductance of 2,000 micromhos/cm at 25°C and was probably a sodium sulfate type. The analysis of the water from well 139-097-34ACA2 showed that it was a bicarbonate type with a specific conductance of 824 micromhos/cm at 25°C. Sulfate constituted about 44 percent of the anions.

White River Aquifer System

The White River Formation forms the rimrock of scattered high buttes and underlies a relatively small area of southwestern Stark County. For this reason, it is not a major aquifer system in the area. Only a few shallow wells in southwestern Stark County obtain water from the aquifer system, which consists of a few thin beds of sandstone.

Denson and Gill (1965, table 9, p. 62) published a chemical analysis of water from a well, probably 137-097-18ABA2, which evidently taps the White River. The anion concentrations were not given, but various trace elements were determined. It was a sodium type water and contained 320 mg/l dissolved solids and 13 ug/l (micrograms per litre) dissolved uranium. The water also contained 7 ug/l of dissolved arsenic and dissolved selenium. The source of the high uranium and other trace elements probably is beds of volcanic ash.

Undifferentiated Lignite Aquifers in the Tongue River and Sentinel Butte Formations

Many livestock and domestic wells in the rural areas tap fractures and joins in undifferentiated beds of lignite for water supplies. The yield from most of these wells is probably less than 10 gal/min (0.6 l/s), but is sufficient for the intended use.

Water from lignite aquifers is highly variable in chemical quality; conductivity measurements of 71 samples ranged from 210 to 6,200 micromhos/cm at 25°C. The median was 1,700 micromhos/cm at 25°C. Dissolved solids ranged from 522 to 1,900 mg/l and had a median value of 1,190 mg/l. Much of the water was light to dark brown, due to organic compounds. Color values ranged from 1 to 7,000 and had a median value of 190.

Aquifers in Deposits of Quaternary Age

Deposits of Quaternary age underlie the major streams in Hettinger and Stark Counties (pl. 1). Test holes drilled into these deposits penetrated only thin beds of sand and gravel beneath the valleys of the Heart, Knife, and Green Rivers near Dickinson and the Cannonball River near Mott. These beds of sand and gravel are adequate for small water supplies, such as livestock and domestic needs.

Test holes drilled into deposits of Quaternary age in northeastern Stark County penetrated mainly till, clay, and silt, with the exception of three test holes. Test hole 140-092-06DAA penetrated 174 feet (53 m) of medium sand and gravel between depths of 104 and 278 feet (32 and 85 m). A nearby test hole at 06DAD penetrated 50 feet (15 m) of clayey sand. Test hole 140-092-01BAA penetrated a total of 64 feet (20 m) of water-saturated sand between 43 and 124 feet (13 and 38 m). These sand and gravel beds are confined to glacial melt-water channels and their areal extent is unknown.

Water-level fluctuations in well 140-092-06DAA are shown in figure 14. The water level rises in the spring during the thaw and during periods of precipitation and is lowest during the fall and winter months when precipitation is light.

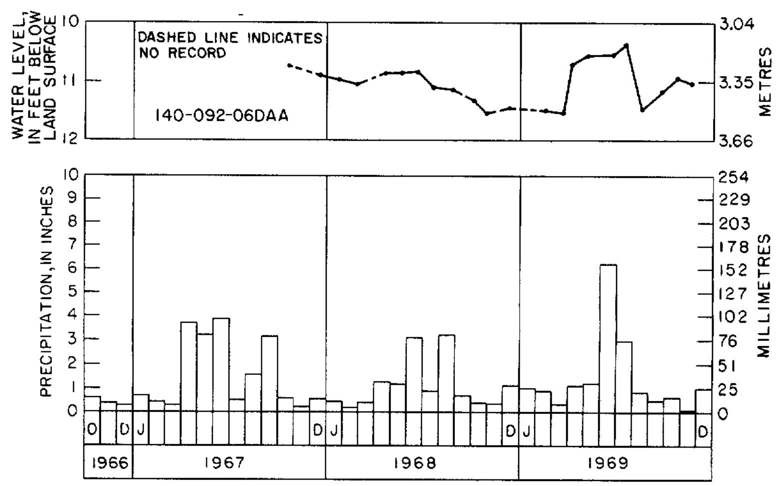


FIGURE 14.– Water-level fluctuations in aquifers in deposits of Quaternary age, and precipitation at Richardton, 1966-69.

Four chemical analyses of water were collected from deposits of Quaternary age and are plotted in figure 13. Sodium constituted 27 to 89 percent of the cations, and carbonate and bicarbonate constituted 26 to 53 percent of the anions. Sulfate constituted 46 to 73 percent of the anions and chloride less than 10 percent of the anions. The concentrations of sodium and bicarbonate were greatest in the water from the deepest wells. Dissolved solids for the samples ranged from 1,850 to 2,130 mg/l. Sulfate ranged from 697 to 1,100 mg/l, and fluoride ranged from 0.4 to 1.6 mg/l. Sodium-adsorption ratios ranged from 1.7 to 22.

USE OF GROUND WATER

Approximately 6,800 acre-feet (8.4 hm^3) of water was obtained from ground-water and surface-water sources in Hettinger and Stark Counties in 1969. Ground-water pumpage (table 4) was estimated to be at the rate of 2.50 Mgal/d (9,460 m^3/d) and furnished 41 percent of the total water supply. Ground-water withdrawal for livestock use was estimated from the livestock water-use rates estimated by Murray (1968) and the U.S. Department of Agriculture (1955). A briquetting plant east of Dickinson pumped about 15 Mgal (56,800 m^3) in 1969 for industrial use.

Five cities in Hettinger and Stark Counties pumped ground water from the major aquifers in 1969. The following section summarizes the source and water quality for the six principal cities in the study area.

TABLE 4. — Estimated use of ground water in million gallons per day in 1969

Livestock	1.25
Rural, self supplied	.40
Uncontrolled flowing wells	.35
Belfield, city of	.19
Mott, city of	.12
New England, city of	.10
Industrial and commercial, self supplied	.04
Richardton, city of	.03
Regent, city of	.02
Total	2.50

Belfield

The city of Belfield has two wells, 139-099-05ABC and 139-099-05ADC, that obtain water from sandstone at the base of the Tongue River Formation. The city reported a total withdrawal of about 70,700,000 gallons (268,000 m^3) in 1969, for an average of about 194,000 gal/d (734 m^3/d). Per capita use is about 170 gal/d (643 l/d). The city sells water for use in adjoining oil fields, which may account for the high per capita use rate.

An analysis of water from well 139-099-05ABC shows that the water is soft and a sodium bicarbonate type with 1,050 mg/l dissolved solids. The water contained 189 mg/l sulfate and 4.2 mg/l fluoride.

Dickinson

From 1906 to 1945 the city of Dickinson derived its water supply from wells tapping the Sentinel Butte aquifer system. The wells, located in secs. 3 and 4, T. 139 N., R. 96 W., ranged from 160 to 202 feet (49 to 62 m) in depth. The wells became uneconomical to pump in 1928, and the water contained fine sediment. Following an engineering firm's recommendations, new larger diameter wells were drilled, and new pumping and storage facilities were installed.

Water consumption had increased in 1937 to approximately 112 Mgal/yr (424,000 m^3/yr), and the water level in the aquifer system was 58 feet (18 m) below the 1919 level. Additional wells were drilled, extending the well field to the west, but by 1943 demand exceeded the capacity of the wells. About 125 Mgal/yr (473,000 m^3/yr) was withdrawn from the well field in 1943 and 1944. McLaughlin and Greenlee (1946, p. 25-27) concluded that it was not practicable to augment the supply by drilling additional wells in the existing well field. An engineering firm then recommended construction of a temporary plant to treat water from the Heart River. A small dam was already in existence. The city built the plant on an emergency basis, but the reservoir was too small for the needs of the city and the shallow water promoted algae growth. The plant's facilities were also inadequate to produce water of the desired quality. The plant was designed to operate only during the summer to augment the ground-water sources.

City officials then concluded that an improved surface-water supply was required to meet the needs of the city. The U.S. Bureau of Reclamation constructed Dickinson Dam in 1950. Edward Arthur Patterson Lake is capable of storing 6,900 acre-feet (8.5 hm^3) of water. Test holes drilled by the State Water Commission (Schmid, 1963, and Lindvig, 1964) did not locate an aquifer capable of supplying the city. Since 1967, the city has pumped essentially all its water from the lake and retains wells for emergency use only.

The city withdrew 1,429 acre-feet (1.8 hm^3) of water from Edward Arthur Patterson Lake in 1969 for an average daily consumption of 1.28 Mgal (4,830 m^3) or about 103 gallons (394 litres) per day per person. Peak daily summer demand exceeds 4.6 Mgal (17,400 m^3).

Mott

The city of Mott obtains water from three wells (133-093-02AAB, 134-093-35DBD, and 134-093-35DCD) that tap the basal sandstone member of the Tongue River Formation. The wells yield 70 to 100 gal/min (4 to 6 l/s). Average daily pumpage in 1969 ranged from 100,000 to 169,000 gallons (380 to 640 m^3). Per capita daily use is about 90 gallons (340 litres). Water from the Cannonball River is used for nondrinking purposes.

Water samples from the wells contained from 1,200 to 1,230 mg/l dissolved solids and fluoride concentrations of 4.9 to 5.9 mg/l. The water is soft.

New England

The city of New England has eight wells located in Tps. 135 and 136 N., R. 97 W., of which two wells are unused. The wells tap the Sentinel Butte aquifer system and range in depth from 84 to 105 feet (26 to 32 m). They yield 8 to 130 gal/min (0.5 to 31 l/s). In 1969 daily pumpage ranged from 61,200 to 180,000 gallons (231 to 681 m^3), and averaged about 100,000 gallons (380 m^3). Average daily per capita use was about 91 gallons (344 litres).

Water from wells 135-097-04ADD1 and 136-097-33DCC contained 975 to 1,290 mg/l dissolved solids, 125 to 268 mg/l hardness, and 0.6 to 1.1 mg/l fluoride. The water was light brown.

Regent

The city of Regent has two wells (134-095-13ACD and 134-095-13CDB) that are reported to be 546 to 900 feet (166 to 275 m) deep. The wells pump 35 and 22 gal/min (2 and 1 l/s), respectively, from the upper Hell Creek and lower Cannonball-Ludlow aquifer system. Average daily consumption in 1969 was estimated at 20,000 gallons (76 m^3), or about 60 gallons (200 litres) per person. Water is also obtained from the Cannonball River for nondrinking purposes.

The analysis of a water sample from well 134-095-13ACD showed that the water was a sodium bicarbonate type. The sample contained about 1,330 mg/l dissolved solids and 2.0 mg/l fluoride. The water was light brown.

Richardton

The city of Richardton obtains most of its water from a 40-foot (12-m) dug well (139-092-05AAB) with collecting galleries extending laterally into a lignite bed in the Sentinel Butte Formation, and from a spring (139-092-04BCB) with multiple openings. When the supply from these sources is not sufficient, water is obtained from a 640-foot (195-m) drilled well (139-092-05DBB). In 1969 the average daily pumpage was about 30,000 gallons (110 m^3).

The water from well 139-092-05AAB had a dissolved-solids concentration of 1,380 mg/l and a hardness of 628 mg/l. Water from the spring contained 1,590 mg/l dissolved solids. The sample from well 139-092-05DBB was soft and contained 1,170 mg/l dissolved solids and 5.8 mg/l fluoride. The city treats the water for iron.

SUMMARY

The stratigraphy, total thickness of the geologic formations, and water-yielding properties of the rocks in Hettinger and Stark Counties are summarized in the following table. Ground water is obtained from numerous undeveloped aquifer systems in the semiconsolidated rocks of Late Cretaceous and Tertiary age. Rocks beneath the Fox Hills Formation contain saline water that is unsuitable for most purposes.

The Fox Hills and basal Hell Creek aquifer systems and the lower part of the upper Ludlow and Tongue River aquifer system are important aquifers within the study area. They consist of fine- to medium-grained sandstone interbedded with siltstone and claystone and are relatively unused. Water in these aquifer systems contains moderate amounts of dissolved solids and is a sodium bicarbonate type.

The upper Hell Creek and lower Cannonball-Ludlow aquifer system is relatively unused. The water contains moderate amounts of dissolved solids and is of a sodium bicarbonate type.

Many livestock and domestic wells tap the Sentinel Butte aquifer system and derive water from beds of sandstone and fractured lignite. Municipal wells tapping the aquifer have yielded more than 100 gal/min (6 l/s). Most water samples contain moderate amounts of dissolved solids and are a sodium sulfate type.

The Golden Valley and White River aquifer systems and aquifers in deposits of Quaternary age are relatively minor sources of ground water. No water can be expected from wells tapping the Arikaree Formation.

Summary of geologic and hydrologic properties of major aquifers and chemical properties of ground water, Hettinger and Stark Counties

System	Formation	Thickness (feet)	Lithology	Aquifer system	Water-yielding properties	General water quality
Quaternary		0-278	Till, clay, silt, sand, and gravel.	Aquifers in deposits of Quaternary age.	Sand and gravel deposits generally too thin to be of importance, but locally may yield large quantities of water to wells.	Water type highly variable. Dissolved solids 1,850 to 2,130 mg/l from four samples.
Tertiary	Arikaree Formation	0-65	Crossbedded tuffaceous sandstone.		Does not yield water to wells.	
	White River Formation	0-250	Conglomerate, siltstone, arkose, tuffaceous sandstone, and fresh-water limestone.	White River	Yields several gallons per minute of water to shallow wells.	Sodium type water with low dissolved solids.
	Golden Valley Formation	0-200	Lower member consists of shale and sandy claystone; upper member of tan crossbedded sandstone, claystone, and thin lignite beds.	Golden Valley	Yields several gallons per minute of water to shallow wells.	Calcium or sodium sulfate type water with moderate dissolved solids.
	Sentinel Butte Formation	0-450	Silty fine- to medium-grained sandstone, carbonaceous and bentonitic claystone, and lignite. Thick sandstone beds at base.	Sentinel Butte	Yields as much as 100 gal/min to wells.	Most water is a sodium sulfate type. Dissolved solids 378 to 11,700 mg/l and have a median value of 1,050.
	Tongue River Formation	250-570	Sandstone interbedded with claystone, siltstone, carbonaceous shale, and lignite. Widespread sandstone bed at base.	Upper Ludlow and Tongue River	Basal sandstone should yield 1 to 100 gal/min to wells. Transmissivity of basal sandstone ranges from 70 ft²/d to 530 ft²/d.	Water from basal sandstone generally is a sodium bicarbonate type. Dissolved solids 704 to 1,470 mg/l.
	Ludlow and Cannonball Formations	310-650	Ludlow Formation; fine-grained sandstone, siltstone, carbonaceous claystone, and lignite of continental origin. Cannonball Formation: gray claystone, siltstone, and fine-grained sandstone of marine origin. These formations interfinger beneath the area.	Upper Hell Creek and lower Cannonball-Ludlow	Yields as much as 100 gal/min to wells.	Sodium bicarbonate type water. Dissolved solids 1,450 to 1,890 mg/l.
Cretaceous	Hell Creek Formation	220-510	Fine- to medium-grained sandstone, siltstone, carbonaceous and bentonitic claystone, and shale.			
	Fox Hills Formation	235-415	Fine- to medium-grained sandstone, siltstone, and claystone.	Fox Hills and basal Hell Creek	Yields 25 to 75 gal/min to wells. Transmissivity ranges from 110 ft²/d to 390 ft²/d.	Sodium bicarbonate type water. Dissolved solids 1,310 to 1,540 mg/l.
Cretaceous-Cambrian		9,000-12,000	Shale, sandstone, limestone, and evaporites.		Data not available	Saline.

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GLOSSARY OF SELECTED TERMS

Aquifer – 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.

Aquifer system – a series of interconnected permeable water-bearing rocks.

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

Artesian – artesian is synonymous with confined. Artesian water and artesian water body are equivalent, respectively, to confined ground water and confined water body. An artesian well obtains its water from an artesian or confined water body. The water level in an artesian well stands above the top of the artesian water body it taps. If pressure within the aquifer is sufficiently great, water may flow from the well at land surface.

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

Confined – as used in this report the term confined refers to an aquifer in which the water is under artesian pressure. See artesian.

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

Ground water – water in the zone of saturation.

Hydraulic conductivity – the capacity of a rock to transmit water — usually described as the rate of flow in cubic feet per day through 1 square foot 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 into soil or rock.

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

Percolation – movement of water through the interstices of a rock or soil.

Potentiometric surface – as related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells. The potentiometric surface is reported in feet above mean sea level.

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

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

$$\mathrm{SAR} = \frac{(\mathrm{Na}+)}{\sqrt{\dfrac{(\mathrm{Ca}+2) + (\mathrm{Mg}\ +2)}{2}}}$$

Ion concentrations are expressed in milliequivalents per liter. Experiments cited by the U.S. Department of Agriculture Salinity Laboratory (1954) show that SAR predicts reasonably well the degree to which irrigation water tends to enter into cation-exchange reactions in soil. Water having a high SAR can damage soil structure of some soils.

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 electric 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 centimetre, whereas sea water may have a conductance of about 50,000 micromhos per centimetre. Standard laboratory measurements report the conductivity of water in micromhos per centimetre 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.

Surface runoff – that part of the runoff which travels over the soil surface.

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.

Unconfined – as used in this report the term unconfined refers to an aquifer in which the water is under atmospheric pressure. See water table.

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

Water table – surface in an unconfined water body at which the pressure is atmospheric. Defined by the levels at which water stands in wells that penetrate the water body far enough to hold standing water.

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