GROUND-WATER RESOURCES

of

MORTON COUNTY, NORTH DAKOTA

by

D. J. Ackerman

U.S. Geological Survey

COUNTY GROUND-WATER STUDIES 27 — PART III
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

BULLETIN 72 — PART III
North Dakota Geological Survey
Lee Gerhard, *State Geologist*

Prepared by the U.S. Geological Survey
in cooperation with the North Dakota Geological Survey,
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Bismarck, North Dakota

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

Multiply inch-pound units	By	To obtain SI units
Acre	0.4047	hectare (ha)
Acre-foot (acre-ft)	.001233	cubic hectometer (hm^3)
Foot	.3048	meter (m)
Foot per day (ft/d)	.3048	meter per day (m/d)
Foot per mile (ft/mi)	.1894	meter per kilometer (m/km)
Foot squared per day (ft^2/d)	.09290	meter squared per day (m^2/d)
Gallon per day (gal/d)	3.785×10^{-3}	cubic meter per day (m^3/d)
Gallon per minute (gal/min)	.06309	liter per second (L/s)
Inch	25.40	millimeter (mm)
Mile	1.609	kilometer (km)
Square mile (mi^2)	2.590	square kilometer (km^2)

To convert degrees Fahrenheit (°F) to degrees Celsius (°C) use the following formula: °C=(°F-32)x5/9.

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ABSTRACT

The occurrence and characteristics of aquifers and the movement, quantity, and quality of water in aquifers in Morton County are described. The findings of this report are needed for the efficient development of the ground-water resources for irrigation, domestic, industrial, and municipal purposes.

Aquifers in the glacial drift and alluvium underlie only 10 percent of the county but have the greatest potential for large-scale development. These aquifers, composed of sand and gravel, occur in buried valleys and in major river valleys. In some localities yields may exceed 500 gallons per minute (30 liters per second) of water suitable for irrigation. Where a hydraulic connection exists between bedrock and glacial-drift aquifers, large withdrawals of water from the particular glacial-drift aquifer will result in an increase in dissolved-solids concentration and percent sodium.

Bedrock aquifers, consisting of very fine to fine-grained sandstones, yield less than 100 gallons per minute (6 liters per second). Water from the bedrock aquifers is generally soft, moderately saline, and useful for domestic, livestock, and some industrial uses.

The Fox Hills aquifer, which underlies all of the county, is the most extensive and continuous aquifer. The aquifer is exposed in the southeastern corner of the county, and lies at a depth of more than 1,500 feet (450 meters) in the northwestern corner of the county.

Bedrock aquifers above the Fox Hills aquifer are more discontinuous than the Fox Hills aquifer. Aquifers in the Hell Creek Formation, Ludlow and Connonball Formations undifferentiated, Tongue River Formation, and Sentinel Butte Formation underlie 90, 75, 45, and 20 percent of the county respectively.

The Pierre Formation, a thick shale that underlies the Fox Hills Formation, is the base of active flow systems. Aquifers below the Pierre Formation occur at depths greater than 3,000 feet (900 meters) and contain very saline water.

INTRODUCTION

The ground-water investigation of Morton County, North Dakota (fig. 1) was made cooperatively by the U.S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and the Morton County Water Management District. The results of the investigation are published in three separate parts. Part I is an interpretive report describing the geology of the

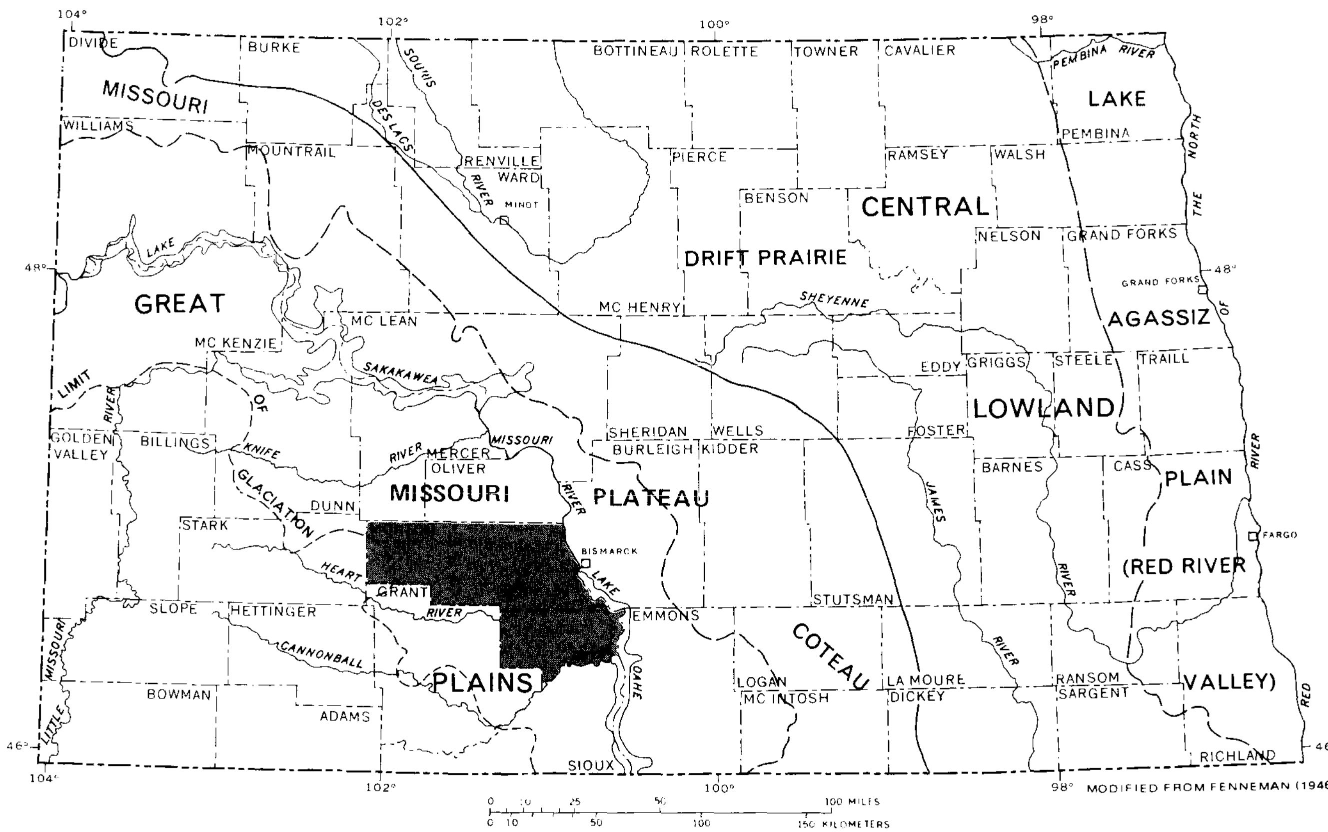


FIGURE 1.—Physiographic divisions in North Dakota and location of study area.

county (in preparation by the North Dakota Geological Survey); part II (Ackerman, 1977) is a compilation of the ground-water basic data; and part III (this report) is an interpretive report describing the ground-water resources. Part III is based primarily on data presented in part II.

Purpose

The purpose of the investigation in Morton County was to provide sufficient information about the ground-water resources of the county to plan its safe and intelligent development for irrigation, domestic, industrial, and municipal purposes. Specifically, the objectives were: (1) determine the location, extent, and nature of the aquifers; (2) evaluate the occurrence and movement of ground water, including the sources of recharge and discharge; (3) estimate the quantities of water stored in the aquifers; (4) estimate the potential yields to wells tapping the major aquifers; and (5) determine the chemical quality of ground water.

Previous Investigations

The first study of the geology and ground-water resources of Morton County was that of Simpson (1929). A bibliography of the geology of North Dakota spanning 1806-1959 by Scott (1972) lists a number of geologic investigations in Morton County. Coal investigation maps by Stephens (1970a, 1970b) and Barclay (1973, 1974) describing the surficial geology and lignite deposits of four quadrangles in western Morton County were used for stratigraphic control. Hydrogeologic investigations have been completed in the seven surrounding counties. These investigations by Randich and Hatchett (1966), Croft (1973), Trapp and Croft (1975), Armstrong (1978), and Randich (1979) provided additional control for all phases of this study. A soil survey of the county has been published (Edwards and Ableiter, 1951).

Acknowledgments

The collection of data for the report was made possible by the cooperation of the residents and officials of Morton County, and by the local well drillers. Several of the staff of the North Dakota State Water Commission contributed to the interpretation of the geohydrology of the area. Recognition is given to C. G. Carlson of the North Dakota Geological Survey for his contribution to the understanding of the geology and stratigraphy. Recognition is also given to the faculty and students of the University of North Dakota Geology Department for their help in understanding the depositional environments and stratigraphy of the bedrock formations.

Location-Numbering System

The data-collection sites in the tables are numbered according to a system of land survey in use by the U.S. Bureau of Land Management. The system is illustrated in figure 2. The first numeral denotes the township north of a base

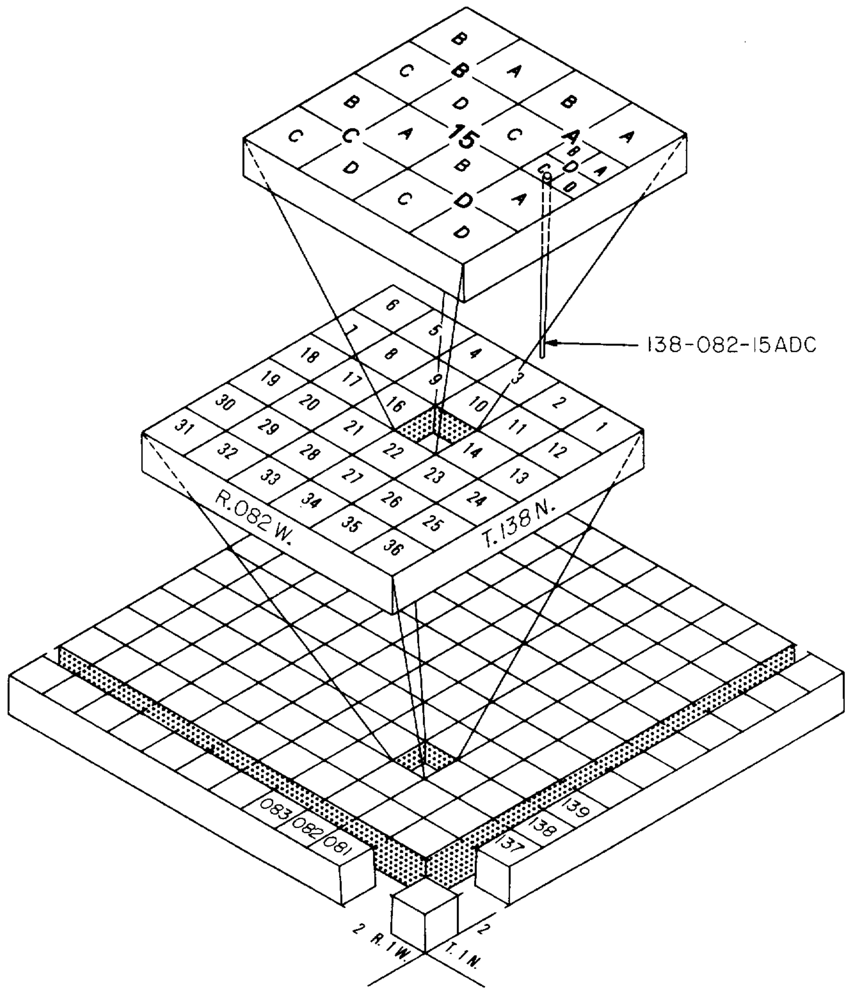


FIGURE 2.—System of numbering data-collection sites.

line, the second numeral denotes the range west of the fifth principal meridian, and the third numeral denotes the section in which the site 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 138-082-15ADC is in the SW¼SE¼NE¼ sec. 15, T. 138 N., R. 82 W. Consecutive final numerals are added if more than one site is recorded within a 10-acre (4-ha) tract.

Physical Setting

Geography

Morton County lies within the Missouri Plateau of the Great Plains physiographic province (Fenneman, 1946; fig. 1). Entrenched river valleys and isolated tablelands interrupt a landscape dominated by plains and lowlying hills. Surface altitudes generally increase in a westerly direction from about 1,620 feet (494 m) along the Missouri River to more than 2,500 feet (760 m) in the extreme western part of the county.

The county is drained by the Missouri River and three principal tributaries, the Heart, Cannonball, and Knife Rivers. The river valleys are entrenched 200 to 400 feet (60 to 120 m) below the surrounding plains.

The county has a land area of 1,920 mi^2 (4,970 km^2), and in 1970 had a population of 20,310 (U.S. Bureau of the Census, 1971). Of the population, 54.6 percent lives in Mandan and 18.2 percent lives in other incorporated cities.

The climate of Morton County is semiarid and is characteristic of the continental interior and this latitude. Winter temperatures may drop to −40°F (−40°C). Summer temperatures may exceed 100°F (38°C). The number of frost-free days averages about 125. The mean annual temperature is 41.1°F (5.1°C) at Mandan and 41.4°F (5.2°C) at New Salem for the period 1941-70 (U.S. Department of Commerce, 1973). For the same period mean annual precipitation is 16.77 inches (426.0 mm) at Mandan and 16.65 inches (422.9 mm) at New Salem. The annual mean of maximum daily air temperatures for the period 1963-74 is 51.9°F (11.1°C) at Mandan.

Geology

Morton County is on the southeast flank of the Williston basin, a broad structural and sedimentary basin underlying parts of Manitoba, Saskatchewan, Montana, South, and North Dakota. The basin contains shale, limestone, and sandstone of Cambrian to Tertiary age. The rocks are divided into numerous formations[1] (table 1) and have a combined thickness of more than 2 miles (3 km) in the northwestern corner of the county.

[1] The stratigraphic nomenclature used in this report is that in use by the North Dakota Geological Survey (Scott, 1972) at the time of this study and does not necessarily follow the usage of the U.S. Geological Survey.

TABLE 1. — Stratigraphic column, Morton County, North Dakota

Era	Period	Group	Formation	Lithology
Cenozoic	Quaternary		Unnamed units	Glacial drift and alluvium.
			Golden Valley	Sandstone, siltstone, and shale.
			Sentinel Butte	
		Fort	Tongue River	
	Tertiary	Union	Cannonball and Ludlow	Sandstone, siltstone, and shale.
Mesozoic			Hell Creek	Sandstone, siltstone, and shale.
			Fox Hills	Sandstone, siltstone, and shale.
		Montana	Pierre	Shale.
			Niobrara	Shale, calcareous.
			Carlile	Shale.
	Cretaceous	Colorado	Greenhorn	Shale, calcareous.
			Belle Fourche	Shale.
			Mowry	Shale.
			Newcastle	Sandstone.
		Dakota	Skull Creek	Shale.
			Fall River	
			Lakota	Sandstone and shale.
			Morrison	Shale.
	Jurassic		Sundance	Shale and sandstone.
			Piper	Limestone, anhydrite, salt, and shale.
	Triassic		Spearfish	
Paleozoic			Minnekahta	Limestone.
	Permian		Opeche	Shale, siltstone, and salt.
	Pennsylvanian		Minnelusa	Sandstone and dolomite.
			Amsden	Dolomite, limestone, shale, and sandstone.
			Heath	
		Big Snowy	Otter	Shale, sandstone, and limestone.
			Kibby	
	Mississippian		Charles	
		Madison	Mission Canyon	Limestone and evaporites.
			Lodgepole	Limestone.
			Bakken	Shale and siltstone.
			Three Forks	Shale, siltstone, and dolomite.
			Birdbear	Limestone.
			Duperow	
	Devonian		Souris River	Dolomite and limestone.
			Dawson Bay	
			Prairie	Halite.
			Winnipegosis	Limestone and dolomite.
			Interlake	Dolomite.
	Silurian		Stonewall	
			Stony Mountain	Limestone and dolomite.
			Red River	
	Ordovician		Roughlock	Shale, calcareous, and siltstone.
		Winnipeg	Ice Box	Shale.
			Black Island	Sandstone.
	Cambrian		Deadwood	Limestone, shale, and sandstone.

After the deposition of the sandstones, shales, and limestone (hereafter collectively called bedrock), glaciers advanced over most of the county. Upon retreat of these glaciers, melt water left thick deposits of glacial material (herein referred to as glacial drift) in some stream valleys. This glacial drift usually is thin and patchy in the surrounding plains.

Bedrock that crops out in the county ranges in age from Late Cretaceous to early Tertiary. A geologic map of Morton County (fig. 3) shows the area of outcrop of the formations. The structure-contour map of the top of the Pierre Formation (fig. 4) indicates that the Pierre and overlying formations dip to the northwest at a rate of about 8 to 17 ft/mi (1.5 to 3.2 m/km). A geologic section (pl. 1, in pocket) shows the vertical distribution of the formations. The bedrock above the Pierre Formation and the glacial drift and alluvium in buried stream valleys contain the principal aquifers; therefore, they are of primary concern in this report.

Aquifers in bedrock are related to the presence of sandstone. The sandstone occurrence within the individual formations is governed by environment of deposition. The two major types of depositional environments of the bedrock units were marine and terrestrial. The marine depositional environment of the Fox Hills and Cannonball Formations gave rise to a fairly continuous areal occurrence of sandstone whereas the terrestrial depositional environment of the other bedrock units gave a more discontinuous distribution of sandstone.

Aquifers in the glacial drift and alluvium are related to the presence of sand and gravel. The sand and gravel is a portion of the sediment deposited by melt water from glaciers and by runoff from local precipitation before and after glacial advances. The depositional environment of the drift and alluvium was variable and as a consequence sand and gravel occurrence is discontinuous.

AVAILABILITY AND QUALITY OF GROUND WATER

General Concepts of Ground-Water Occurrence

Nearly all the ground water is derived from precipitation. After precipitation falls to the Earth's surface, part is returned to the atmosphere by evaporation, part runs off into streams, and the remainder infiltrates into the soil. Some of the water that enters the soil is held by capillary action to make up for the water that has evaporated or has been used by plants during the preceding dry period. After the soil and plant requirements have been satisfied, the excess water, if any, will infiltrate downward until it reaches the zone of saturation. After the water enters the zone of saturation it becomes available to wells. Ground water moves under the influence of gravity from areas of recharge to areas of discharge. Ground-water movement generally is very slow; 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, well-sorted sand, and fractured rock generally are highly conductive, and commonly form aquifers. Fine-grained materials such as silt, clay, and shale usually have low hydraulic conductivity and restrict ground-water movement.

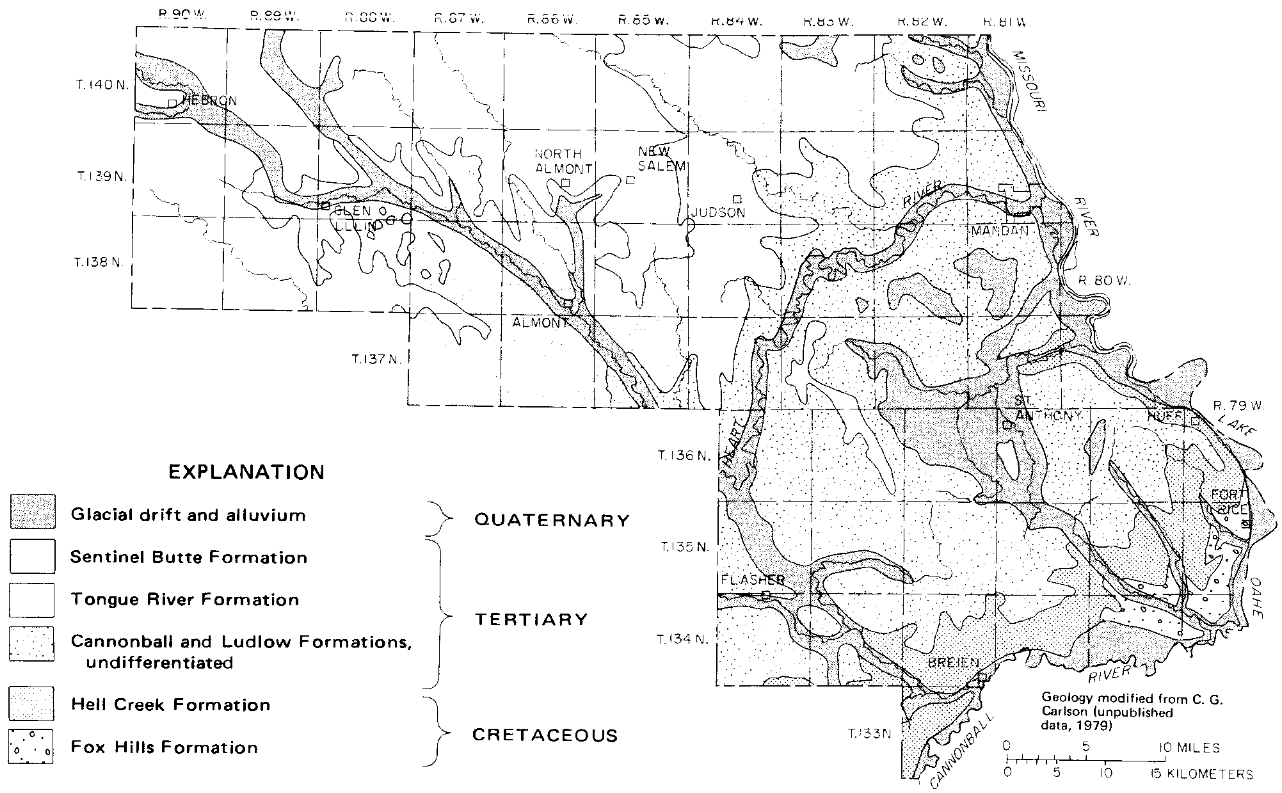


FIGURE 3.—Generalized surficial geology of Morton County.

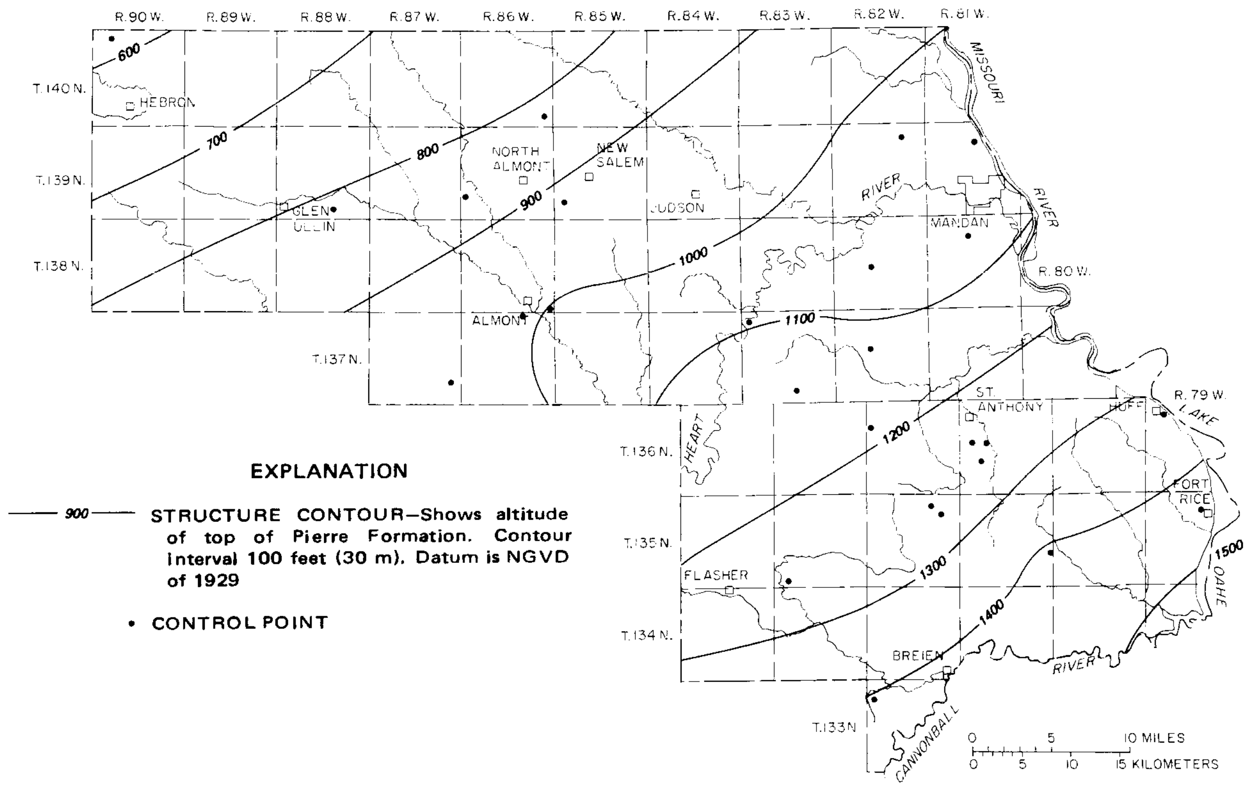


FIGURE 4.—Structure contours of the top of the Pierre Formation.

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. Recharge normally is sufficient to replace losses caused by natural processes and by pumping of wells. Long-term trends of several years may develop, however, during which there are net gains or losses in storage. Aquifers that are confined by deposits of fine-grained materials such as clay or silt are recharged very slowly. Replenishment of these aquifers is by seepage from fine-grained materials. The rate of recharge may increase as heads in the aquifers are reduced by pumping. However, declines in head may continue for several years before sufficient recharge is induced to balance the rate of withdrawal. In some situations this balance may never be achieved without curtailment of withdrawals. In parts of Morton County surface-water sources such as Lake Oahe, the Heart, Cannonball, and Missouri Rivers are in hydraulic connection with the aquifers. The aquifers may either receive recharge from losing streams or discharge into gaining streams depending on head relationships, which generally vary both in time and space.

Quality of Ground Water

All ground water contains dissolved minerals. The amount and kind of dissolved mineral matter in the water depends upon the solubility and types of rocks encountered, the length of time the water is in contact with the rocks, and the amount of carbon dioxide and soil acids in the water. Water that has been underground a long time, or has traveled a long distance from the recharge area, generally is more highly mineralized than water that has been in transit for only a short time or distance.

The dissolved mineral constituents in water are reported in milligrams per liter (mg/L) or micrograms per liter (ug/L). Micrograms per liter may be converted to milligrams per liter by dividing micrograms per liter by 1,000. Milliequivalents per liter (meq/L) is the unit chemical combining weight of a constituent in 1 liter of water. These units usually are not reported in tables of analyses but are used to calculate various ratios, such as the sodium-adsorption ratio (SAR), and to check the accuracy of a chemical analysis.

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

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, chloride, sulfate, nitrate, fluoride, dissolved solids, hardness, temperature, specific conductance, sodium-adsorption ratio, and percent sodium. The major chemical constituents, their significance to users, and the limits recommended by the U.S. Public Health Service are given in part II of this series (Ackerman, 1977).

The quality of water used for irrigation is an important factor in the yield and quality of irrigated crops. Irrigation classifications were determined for all water samples from aquifers in Morton County using a classification system developed by the U.S. Salinity Laboratory Staff (1954). Representative analyses are plotted in figure 5. Analyses of water from bedrock aquifers, other than the Sentinel Butte aquifers, generally show sodium-adsorption ratios of greater than 30. Therefore, analyses from these aquifers are not plotted in figure 5.

Ground Water in the Bedrock Aquifers

The Pierre Formation is assumed to be the base of active near-surface flow systems because it is thick and relatively impervious. Aquifers below the Pierre Formation occur at depths greater than 3,000 feet (900 m) below land surface. Chemical analyses of 12 water samples recovered during drill-stem tests of aquifers below the Pierre Formation showed a range of 20,000 to 400,000 mg/L dissolved solids. For practical purposes this study did not concern itself with the deep and saline waters.

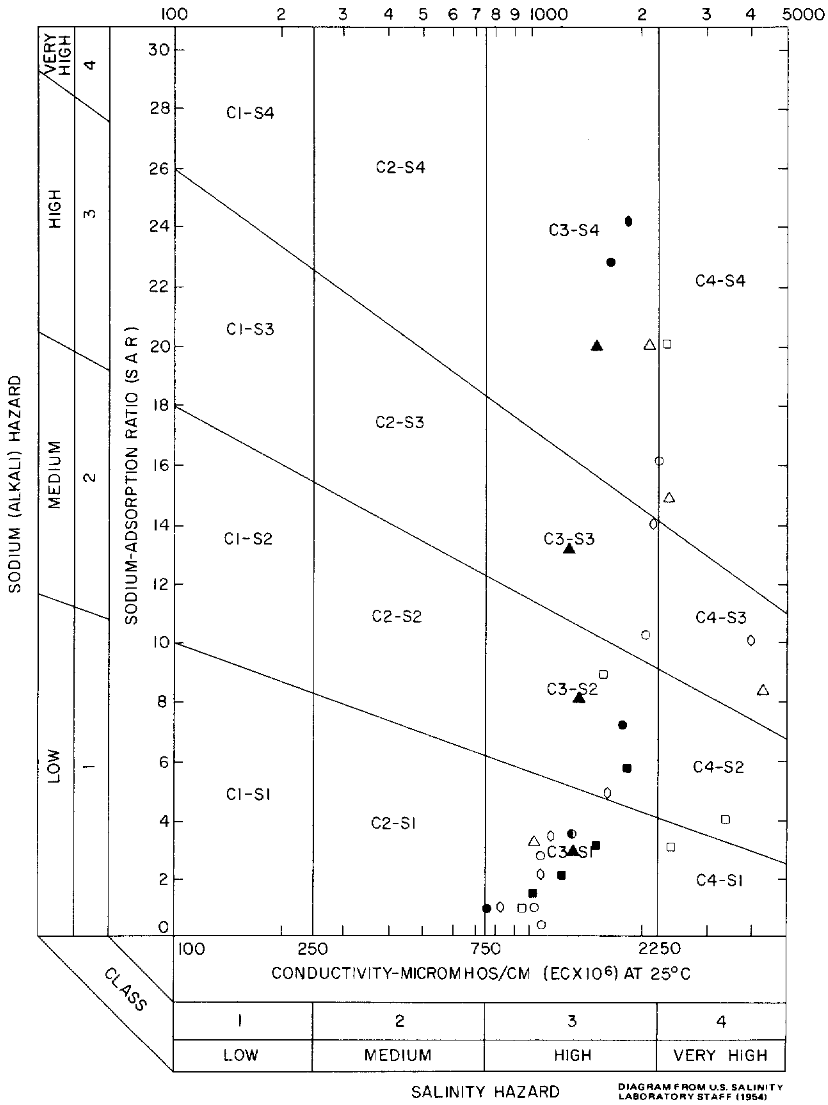
Fox Hills Aquifer

The Fox Hills Formation underlies all of Morton County (1,920 mi^2 or 4,970 km^2) and is exposed in the extreme southeastern corner of the county (fig. 3). The formation dips northwest (fig. 6) and lies at a depth of more than 1,500 feet (460 m) below the land surface in the extreme northwestern corner of the county. The formation is composed of a regressive association of marine and estuarine sandstones, siltstones, and shales. The lower contact with silty shale of the Pierre Formation is gradational. The upper contact with the mainly terrestrial sandstones, siltstones, and shales of the Hell Creek Formation also is gradational and in places exhibits an interfingering relationship.

The sandstones that form the Fox Hills aquifer generally occur at or near the top of the Fox Hills Formation. These sandstones are often called the Colgate Member in adjacent counties. Test drilling showed that the sandstones are laterally extensive and occur at approximately the same vertical positions within the formation. The Fox Hills aquifer is the largest and most continuous bedrock aquifer in Morton County.

The sandstone is predominately very fine grained, but locally is fine to medium grained. It is poorly sorted and contains 10 to 40 percent silt and clay. Porosity measurements on 10 core samples ranged from 35 to 40 percent.

Hydraulic conductivities of 10 sandstone core samples ranged from 0.29 to 2.0 ft/d (0.088 to 0.61 m/d) and had a geometric mean of 0.66 ft/d (0.20 m/d). However, hydraulic-conductivity estimates made from small-diameter core samples generally are low because the coring method disturbs the aquifer sample. Croft and Wesolowski (1970) found the hydraulic conductivity of the Fox Hills and lower Hell Creek Formations in Mercer and Oliver Counties to range from about 0.4 to 4 ft/d (0.1 to 1 m/d) with a geometric mean of 1 ft/d (0.3 m/d). The Mercer and Oliver County values are from flow tests and recovery



EXPLANATION

- □ SENTINEL BUTTE AQUIFERS
- ○ LITTLE HEART AQUIFER
- ■ HEART RIVER AQUIFER
- ◐ SQUARE BUTTE CREEK AQUIFER
- ▲ SIMS AQUIFER
- ◊ ELM CREEK AQUIFER
- △ KILLDEER AQUIFER
- ● SHIELDS AQUIFER
- ♦ ST. JAMES AQUIFER

FIGURE 5.—Diagram showing classifications of representative water samples for irrigation purposes.

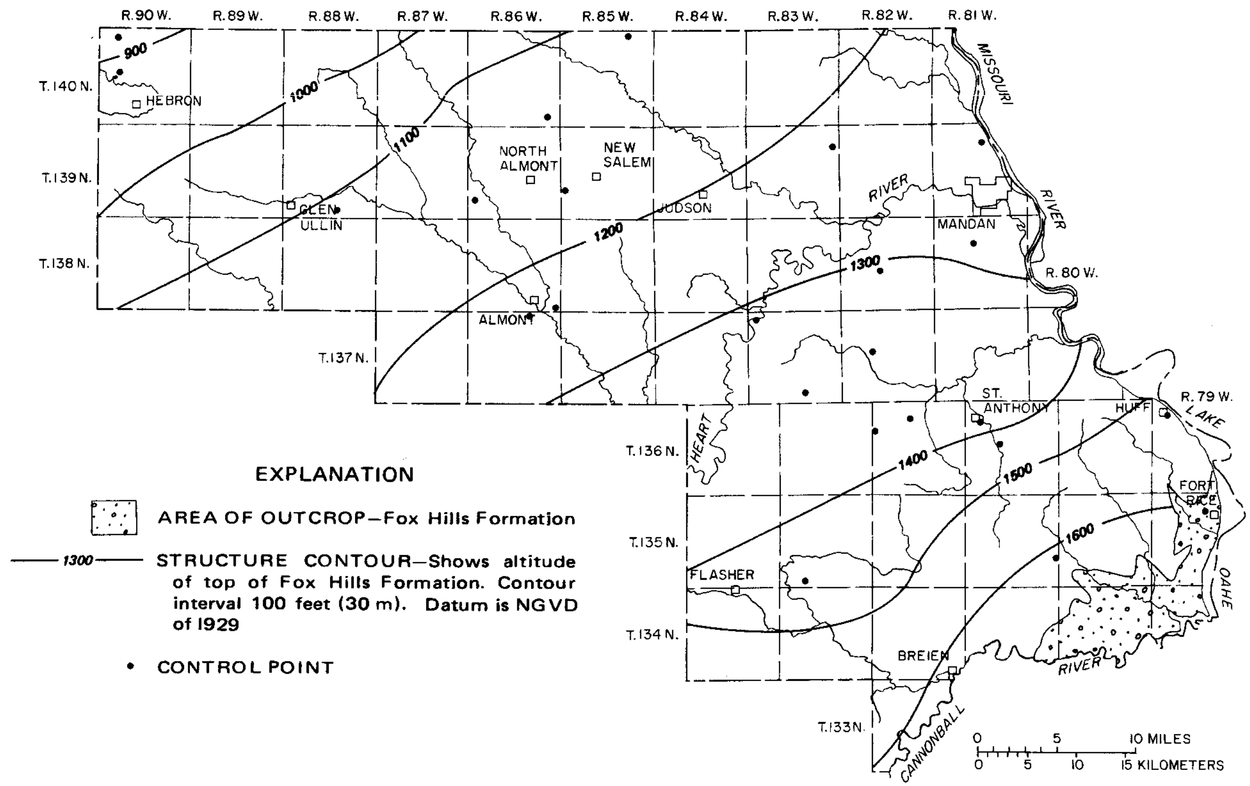


FIGURE 6.—Structure contours of the top of the Fox Hills Formation.

tests of wells and probably more accurately reflect the hydraulic conductivity of the formations.

The measured total thickness of sandstone in the Fox Hills Formation in Morton County ranged from 43 to 200 feet (13 to 61 m) and had an arithmetic mean of 100 feet (30 m).

The transmissivity of the Fox Hills aquifer should average about 100 ft^2/d (10 m^2/d) and range from 20 to 400 ft^2/d (2 to 40 m^2/d). These transmissivity values are in general agreement with those obtained in Mercer and Oliver Counties (Croft and Wesolowski, 1970) and in Grant and Sioux Counties (Randich, 1979). The storage coefficient of this artesian aquifer probably is similar (0.0001 to 0.00001) to that of the aquifer in Mercer and Oliver Counties (Croft, 1973).

According to the method of Meyer (1963), properly constructed wells in the Fox Hills aquifer should yield from 1 to 80 gal/min (0.06 to 5 L/s) with 50 feet (15 m) of drawdown after 1 day of pumping.

Flow through the aquifer is lateral throughout most of the county. Only small amounts of water are gained or lost due to leakage from or into overlying aquifers. Ground-water movement in the aquifer, as shown by the potentiometric map (fig. 7), generally is in an eastward direction. However, in the vicinity of the Cannonball River water movement is southward toward the river. The regional hydraulic gradient in the aquifer is 5 to 20 ft/mi (0.9 to 4 m/km). The valleys of the Cannonball and Missouri Rivers are the major areas of discharge for the aquifer.

The Fox Hills aquifer may be in hydraulic connection with the overlying lower Hell Creek aquifers as water levels of wells in the lower Hell Creek Formation are often less than 6 feet (2 m) above or below those of the Fox Hills at a given location. The nature of the relationship between the Fox Hills aquifer and the lower aquifers of the Hell Creek will be discussed further in the description of the Hell Creek aquifers.

In a few localities in the southeastern corner of the county the Fox Hills aquifer is in hydraulic connection with adjacent glacial-drift aquifers. At present, hydraulic gradients between the glacial-drift aquifers and the Fox Hills aquifer are gentle and usually favor movement of water into the glacial-drift aquifers.

Forty-four water samples were collected from 38 wells in the Fox Hills aquifer. The water-quality data for selected constituents or indices of general interest are summarized in the following table.

Water from the Fox Hills aquifer generally is a sodium bicarbonate type with moderate amounts of sulfate or chloride. In the southeastern one-third of the county concentrations of sulfate usually exceed 200 mg/L and chloride concentrations are less than 100 mg/L. In the remainder of the county, concentrations of sulfate usually are less than 10 mg/L and chloride concentrations usually are greater than 300 mg/L. Calcium and magnesium concentrations usually are less than 7 mg/L and hardness usually is less than 40 mg/L. The abundance of sodium relative to calcium and magnesium in the Fox Hills aquifer can be attributed to ion exchange of calcium and magnesium for the sodium on the clays in the aquifer.

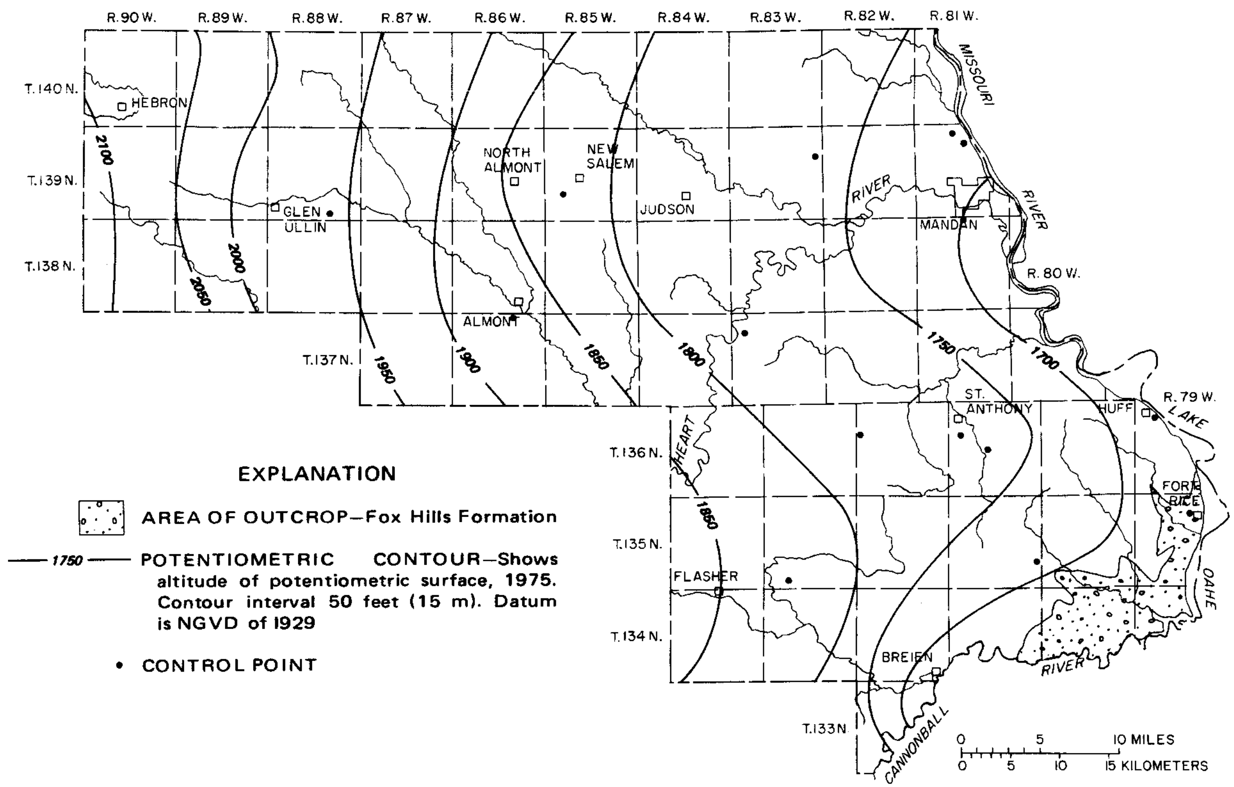


FIGURE 7.—Potentiometric surface of the Fox Hills aquifer, 1975.

Summary of selected water-quality constituents or indices for the Fox Hills aquifer
(Data are somewhat biased because of uneven areal sample density)

Constitutuents or indices	Class intervals / Number of values falling in each class interval						Range of values	Number of samples
Dissolved solids (mg/L)	<500	500-1,000	1,010-1,500	1,510-2,000	2,010-2,500	>2,500		
	0	2	9	22	5	0	812-2,270	38
Sulfate (mg/L)	<50	50-150	160-250	260-350	360-450	>450		
	18	2	6	5	1	6	.4-750	38
Chloride (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	13	6	1	1	0	17	.0-730	38
Fluoride (mg/L)	<0.50	0.50-0.90	0.91-1.2	1.3-1.7	1.8-3.0	>3.0		
	1	9	4	8	10	6	.4-4.5	38
Sodium (mg/L)	<20	20-100	110-250	260-500	510-750	>750		
	0	0	2	4	25	7	220-900	38
Percent sodium	<20	20-50	51-65	66-80	81-95	>95		
	0	0	1	1	1	35	64-99	38
Sodium-adsorption ratio	<1.0	1.0-5.0	5.1-10	11-15	16-20	>20		
	0	0	2	0	0	36	5.8-124	38
Hardness (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	34	1	1	1	0	1	8-270	38
Nitrate as Nitrogen (mg/L)	<0.25	0.25-1.0	1.1-5.0	5.1-10	11-15	>15		
	23	6	0	0	0	0	.07-.99	29

Water from the Fox Hills aquifer generally is unsuitable for irrigation. However, the sodium-hazard indices of a few of the samples indicate that locally the water may be of marginal quality for irrigation. All samples that were less than 97 percent sodium and had a sodium-adsorption ratio of less than 29 were in the immediate vicinity of a possible hydraulic connection with a glacial-drift aquifer.

Aquifers in the Hell Creek Formation

The Hell Creek Formation underlies 1,800 mi² (4,660 km²), or almost all of Morton County, and is exposed in the southeastern corner of the county (fig. 3). The formation dips to the northwest (fig. 8) and lies at a depth of nearly 1,200 feet (370 m) below land surface in the extreme northwestern corner of the county. The Hell Creek Formation is composed of estuarine, freshwater, and flood-plain sandstones, siltstones, and shales that generally are bentonitic and lignitic (Frye, 1969, p. 16). The contact with the underlying Fox Hills Formation is gradational and interfingering, whereas the contact with the overlying Cannonball and Ludlow Formations, undifferentiated, is conformable.

The sandstone beds of the Hell Creek Formation generally are not laterally extensive and often pinch out within a lateral distance of a few tens of feet (Frye, 1969, p. 18; and Laird and Mitchel, 1942, p. 10). Test drilling in Morton County indicated that the sandstones are inconsistent in vertical occurrence, but they are slightly more common near the base of the formation. The sandstones are very fine to fine grained, poorly sorted, and contain 22 to 49 percent silt and clay. Porosity measurements on 10 sandstone core samples ranged from 35 to 41 percent.

Hydraulic conductivities of 14 sandstone cores ranged from 0.000000095 to 2.18 ft/d (0.000000029 to 0.66 m/d). F. S. Riley of the U.S. Geological Survey Hydrologic Laboratory, who performed some of the analyses, attributed the extremely low hydraulic conductivities to the presence of substantial montmorillonite in the clay fraction of the sand (Riley, written commun., 1976). Lovas (1963) reported that the presence of 2 percent montmorillonite in an otherwise clean sand can lower the hydraulic conductivity by four orders of magnitude. Montmorillonite contents by weight of sandstone cores at 139-081-09AAA2 and 9AAA3 were 14 and 28 percent respectively. If the extremely low values of hydraulic conductivity that are due to montmorillonite in the clay fraction are ignored, the hydraulic conductivities of the cores would range from 0.32 to 2.18 ft/d (0.098 to 0.66 m/d) and have a geometric mean of 0.8 ft/d (0.2 m/d). Again the values are in general agreement with the data of Croft and Wesolowski (1970) for the Fox Hills and lower Hell Creek Formations of Mercer and Oliver Counties.

The total measured thickness of sandstone in the Hell Creek Formation ranged from 46 to 184 feet (14 to 56 m) and had an arithmetic mean of 100 feet (30 m). Using a hydraulic conductivity of 1 ft/d (0.3 m/d) and an aquifer thickness of 100 feet (30 m), the transmissivity would average 100 ft²/d (9 m²/d); the transmissivity probably ranges from about 10 to 350 ft²/d (0.9 to 33 m²/d).

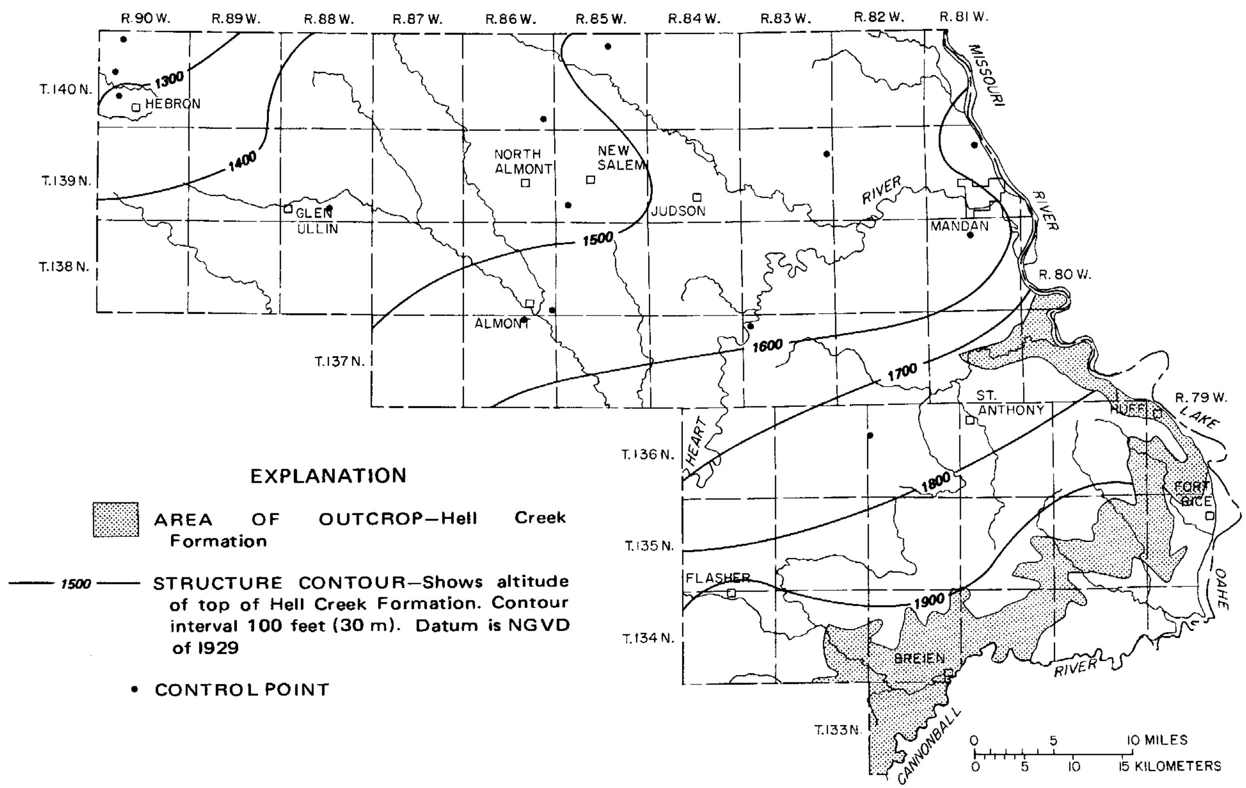


FIGURE 8.—Structure contours of the top of the Hell Creek Formation.

Properly constructed wells screened to all sandstones of the Hell Creek Formation at a specific site would yield 1 to 80 gal/min (0.06 to 5 L/s) with 50 feet (15 m) of drawdown after 1 day of pumping. Where it is not practical to screen all the sandstones or where the montmorillonite content of the sandstone is high, somewhat reduced yields would be expected.

Data were not sufficient to differentiate individual aquifers in the Hell Creek Formation. Consequently, no potentiometric maps could be drawn. Available data indicate that ground-water movement generally is lateral and in an eastward direction.

The valleys of the Heart, Cannonball, and Missouri Rivers are major areas of discharge for aquifers in the Hell Creek Formation. In the southeastern part of the county, aquifers in the Hell Creek Formation are in hydraulic connection with adjacent glacial-drift aquifers. At present, hydraulic gradients between the Hell Creek and glacial-drift aquifers are gentle and usually favor movement into the glacial-drift aquifers.

Water levels in wells completed in sandstones of the lower Hell Creek are often within 6 feet (2 m) of water levels of wells completed in the Fox Hills aquifer at the same location. The proximity of aquifers in adjacent formations and similarity of water levels have led some hydrologists to consider the Fox Hills and lower Hell Creek as one aquifer (Croft, 1973; Trapp and Croft, 1975). The concept of a Fox Hills-basal Hell Creek aquifer originated in eastern Montana (Taylor, 1965), where the sandstones of both formations often form a continuous sandstone sequence. In Morton County, however, from 25 to 90 feet (7.6 to 27 m) of siltstone and bentonitic shale divide the Fox Hills and Hell Creek sandstones, and the aquifers are considered to be separate. If future withdrawals from one aquifer or the other are sufficient to cause large differences in head across the siltstone and bentonitic shale layers separating the aquifers, the monitored response in the other would indicate whether a degree of hydraulic connection exists between the aquifers. This would then enable hydrologists to choose between or further modify their concepts of aquifers in the Fox Hills and Hell Creek Formations.

Forty-seven water samples were collected from 45 wells in aquifers in the Hell Creek Formation. The water-quality data for selected constituents and indices of general interest are summarized in the following table. The water generally is a sodium bicarbonate type. In the southeastern half of the county chloride concentrations usually are less than 150 mg/L and sulfate concentrations usually are greater than 200 mg/L. In the northwestern half of the county chloride concentrations are greater than 250 mg/L and sulfate concentrations are less than 20 mg/L.

Aquifers in the Cannonball and Ludlow Formations, Undifferentiated

The Cannonball and Ludlow Formations, which interfinger, were not differentiated in this report. The formations crop out over most of southeastern Morton County (fig. 3) and underlie the remainder of the county. The areal

Summary of selected water-quality constituents or indices for aquifers in the Hell Creek Formation
(Data are somewhat biased because of uneven areal sample density)

Constituents or indices	Class intervals / Number of values falling in each class interval						Range of values	Number of samples
Dissolved solids (mg/L)	<500	500-1,000	1,010-1,500	1,510-2,000	2,010-2,500	>2,500		
	0	4	15	23	2	1	818-2,990	45
Sulfate (mg/L)	<50	50-150	160-250	260-350	360-450	>450		
	24	6	4	3	2	6	0.8-1,150	45
Chloride (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	16	3	5	1	3	17	.0-500	45
Fluoride (mg/L)	<0.50	0.50-0.90	0.91-1.2	1.3-1.7	1.8-3.0	>3.0		
	3	2	9	3	15	13	.4-5.9	45
Sodium (mg/L)	<20	20-100	110-250	260-500	510-750	>750		
	0	0	1	9	31	4	140-980	45
Percent sodium	<20	20-50	51-65	66-80	81-95	>95		
	0	1	0	0	3	41	45-99	45
Sodium-adsorption ratio	<1.0	1.0-5.0	5.1-10	11-15	16-20	>20		
	0	0	1	1	1	42	3.2-9.4	45
Hardness (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	40	2	2	0	0	1	5-370	45
Nitrate as Nitrogen (mg/L)	<0.25	0.25-1.0	1.1-5.0	5.1-10	11-15	>15		
	27	10	0	0	0	0	.00-.77	37

extent of the formations is approximately 1,500 mi² (3,900 km²). The formations dip north-northwest (fig. 9) and lie at a depth of more than 800 feet (240 m) below land surface in the extreme northwestern corner of the county. The Ludlow Formation is composed of continental sandstones, siltstones, and shales and commonly contains thin beds of lignite. The Cannonball Formation is composed of marine and estuarine sandstones, siltstones, and shales.

The sandstones, which form aquifers, generally occur in three stratigraphic positions, but they are not laterally extensive. They are predominately very fine grained, poorly sorted, contain from 5 to 40 percent silt and clay, and have a porosity ranging from 38 to 46 percent. Hydraulic-conductivity measurements on nine sandstone core samples had a range of 0.043 to 8.2 ft/d (0.013 to 2.5 m/d) and a geometric mean of 1.2 ft/d (0.37 m/d).

The total measured thickness of sandstone in the Cannonball and Ludlow Formations ranged from 5 to 129 feet (2 to 39.3 m) and had a mean of about 40 feet (10 m). The transmissivity should average about 50 ft^2/d (5 m^2/d) and range from 1 to 200 ft^2/d (0.9 to 20 m^2/d).

Properly constructed wells screened to all sandstones in the Cannonball and Ludlow Formations should yield from 1 to 50 gal/min (0.06 to 3 L/s) with 50 feet (15 m) of drawdown after 1 day of pumping.

Data were not sufficient to differentiate individual aquifers in the Cannonball and Ludlow Formations; consequently, no potentiometric map was drawn. Available data indicate that ground-water movement generally is east or northeast in that part of Morton County north and west of the Heart River, and from local topographically high areas toward local stream valleys and the valley of the Missouri River in the area south and west of the Heart River. Major discharge areas occur in the valleys of the Missouri and Heart Rivers and Big Muddy Creek.

The aquifers in the Cannonball and Ludlow Formations may be in hydraulic connection with adjacent glacial-drift aquifers. At present the hydraulic gradients between the aquifers generally favor movement from the Cannonball and Ludlow aquifers into the glacial-drift aquifers, but gradients are gentle.

Forty-eight water samples were collected from 46 wells in the aquifers in the Cannonball and Ludlow Formations. Selected water-quality constituents or indices of general interest are summarized in the following table. The water generally is a sodium bicarbonate or sodium bicarbonate-sulfate type. In general, the water from the aquifers is undesirable for domestic use because of the high sulfate concentrations.

Although a few of the water samples from aquifers in the Cannonball and Ludlow Formations have a salinity or sodium hazard low enough to suggest that the water is acceptable for irrigation use, this rarely is true for most of the aquifers.

Aquifers in the Tongue River Formation

The Tongue River Formation crops out over one-fourth of the county (fig. 3) and underlies another one-fourth of the county. The total areal extent is about

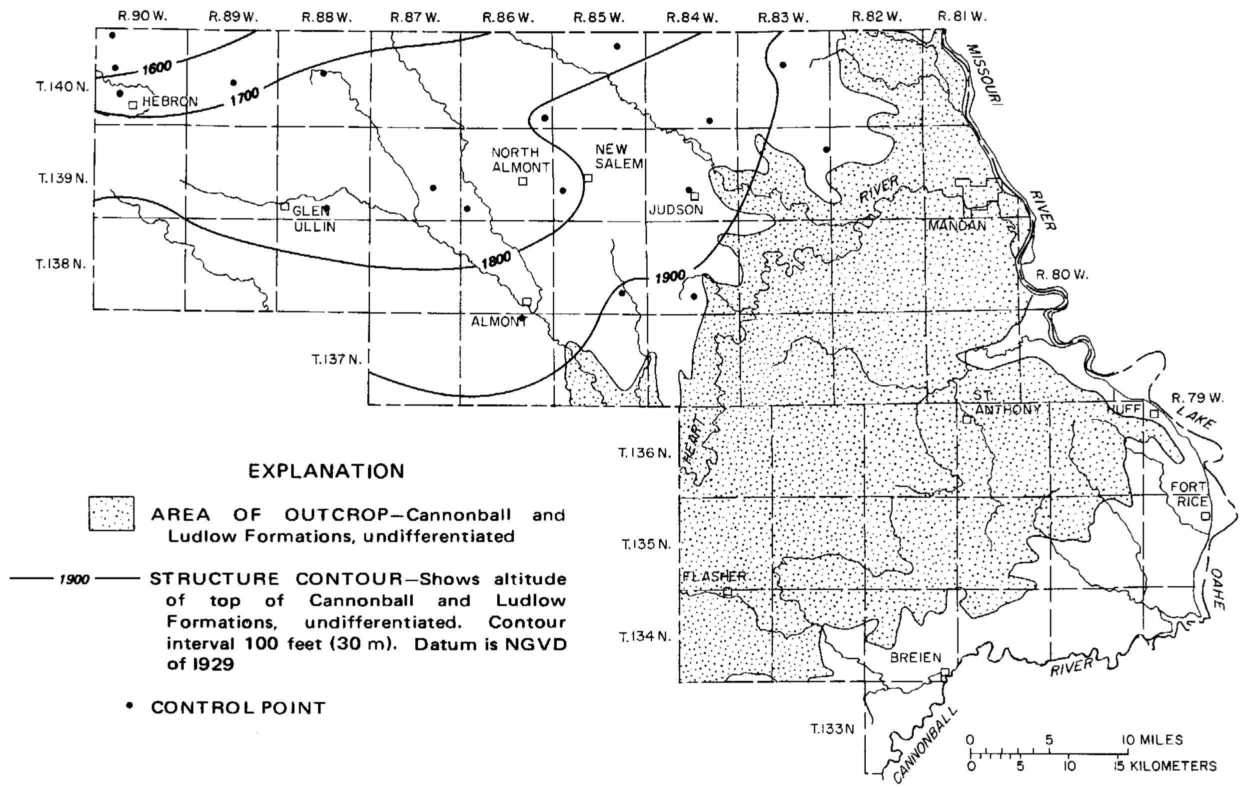


FIGURE 9.—Structure contours of the top of the Cannonball and Ludlow Formations, undifferentiated.

Summary of selected water-quality constituents or indices for aquifers in the Cannonball and Ludlow Formations
(Data are somewhat biased because of uneven areal sample density)

Constituents or indices	Class intervals / Number of values falling in each class interval						Range of values	Number of samples
Dissolved solids (mg/L)	<500	500-1,000	1,010-1,500	1,510-2,000	2,010-2,500	>2,500		
	1	1	17	17	4	6	214-10,200	46
Sulfate (mg/L)	<50	50-150	160-250	260-350	360-450	>450		
	7	8	4	8	3	16	4.9-6,400	46
Chloride (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	33	9	3	1	0	0	.0-160	46
Fluoride (mg/L)	<0.50	0.50-0.90	0.91-1.2	1.3-1.7	1.8-3.0	>3.0		
	9	8	9	6	8	6	.0-4.0	46
Sodium (mg/L)	<20	20-100	110-250	260-500	510-750	>750		
	0	1	1	6	30	8	29-2,000	46
Percent sodium	<20	20-50	51-65	66-80	81-95	>95		
	1	2	0	1	6	36	18-99	46
Sodium-adsorption ratio	<1.0	1.0-5.0	5.1-10	11-15	16-20	>20		
	0	2	2	1	0	41	10-79	46
Hardness (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	33	4	1	2	0	6	10-5,000	46
Nitrate as Nitrogen (mg/L)	<0.25	0.25-1.0	1.1-5.0	5.1-10	11-15	>15		
	23	16	4	0	0	1	.00-38	44

900 mi^2 (2,300 km^2). The formation generally dips to the northwest (fig. 10) and is more than 400 feet (120 m) below the land surface in the extreme northwestern corner of the county.

The formation is composed of terrestrial sandstones, siltstones, shales, and lignite. A detailed analysis of the depositional environments of the formation by Jacob (1973, 1974) lists three general forms of aquifers present in the Tongue River Formation. They are lignite beds and two types of sandstone bodies. No extensive or thick lignite beds were found during test drilling in Morton County, but a few private wells and springs are reported to be completed in lignites. The sandstones that form aquifers in the Tongue River Formation are discontinuous both laterally and vertically. Two forms of sandstone bodies can be distinguished: (1) linear bodies up to about 1,000 feet (300 m) wide, 60 feet (20 m) thick, and many miles long; (2) tabular bodies thousands of feet wide, 8-10 feet (2-3 m) thick, and decreasing in grain size from bottom to top. Most Tongue River sandstones in Morton County are probably of the linear type. Sandstone beds may occur or be absent at any given interval within the formation, but they are more common in the lower third of the formation.

The Tongue River sandstones are predominately very fine grained but in places are fine grained. The sandstone is poorly sorted and contains 10 to 40 percent silt and clay. The full thickness of the Tongue River Formation was penetrated in only two test holes drilled as part of this study, and partially penetrated in 12 other test holes and wells for which logs exist. The arithmetic mean of sandstone thickness was 100 feet (30 m) for these 14 test holes and wells. The range was from 5 to 180 feet (2 to 55 m). Hydraulic-conductivity and transmissivity data for aquifers in the Tongue River Formation are sparse. The similarity of aquifer materials to other bedrock aquifers; one hydraulic-conductivity value, 6 ft/d (2 m/d); and limited data from surrounding counties suggest that the aquifers have a hydraulic conductivity similar to the other bedrock aquifers. Transmissivity should average 100 ft^2/d (10 m^2/d) and range from 1 to 400 ft^2/d (0.9 to 40 m^2/d).

Properly constructed wells, screened to the full thickness of sandstone in the Tongue River Formation, should yield 1 to 100 gal/min (0.06 to 6 L/s) with 50 feet (15 m) of drawdown after 1 day of pumping.

Water levels of wells completed in sandstones in the lower third of the Tongue River Formation seem to fit one potentiometric surface. These sandstones in the lower third of the formation are called the lower Tongue River aquifer.

A potentiometric surface drawn for the lower Tongue River aquifer (fig. 11) indicates a general easterly direction of ground-water movement with local deviations.

Data were not sufficient to differentiate individual aquifers in the upper part of the Tongue River Formation, consequently ground-water movememt in the lignites and the sandstones of the upper part cannot be described adequately. At several locations wells in the upper part of the Tongue River Formation have water levels 20 to 50 feet (6 to 15 m) higher than wells in the lower part. Springs and perched water-table conditions are common in the outcrop area.

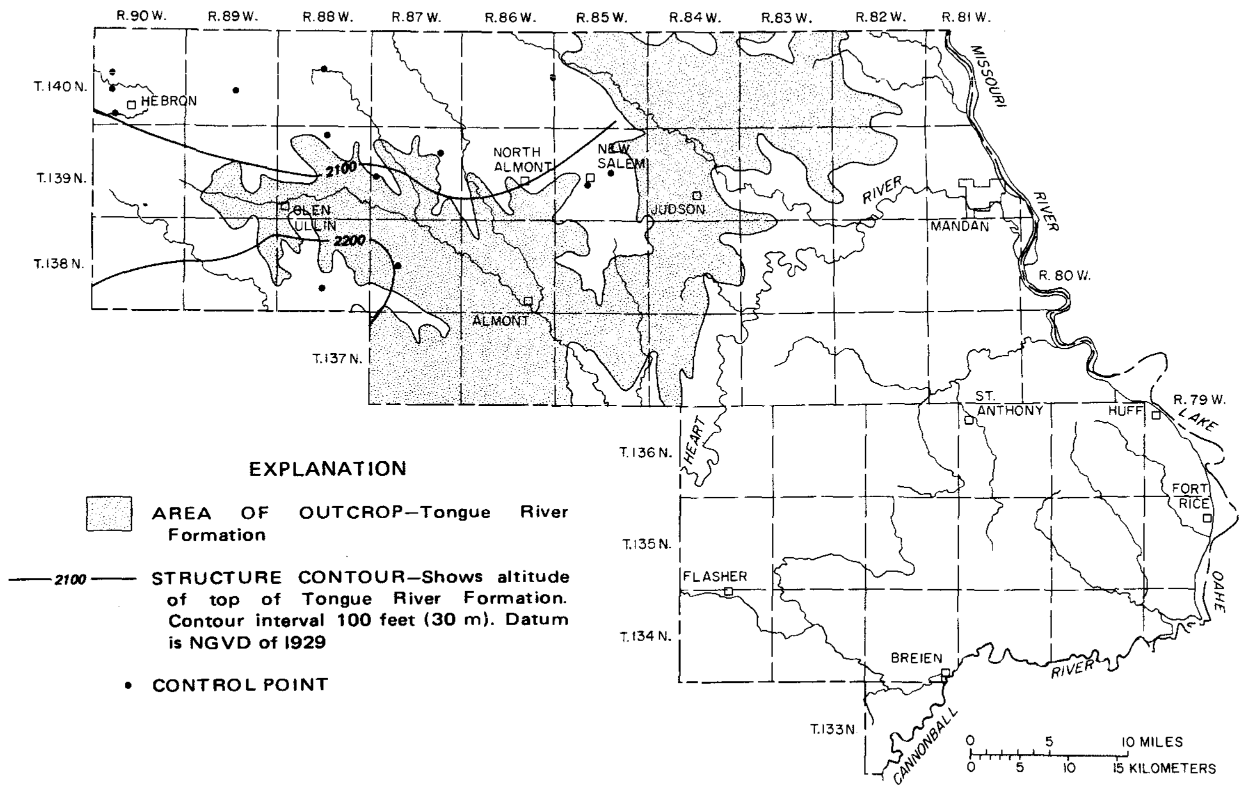


FIGURE 10.—Structure contours of the top of the Tongue River Formation.

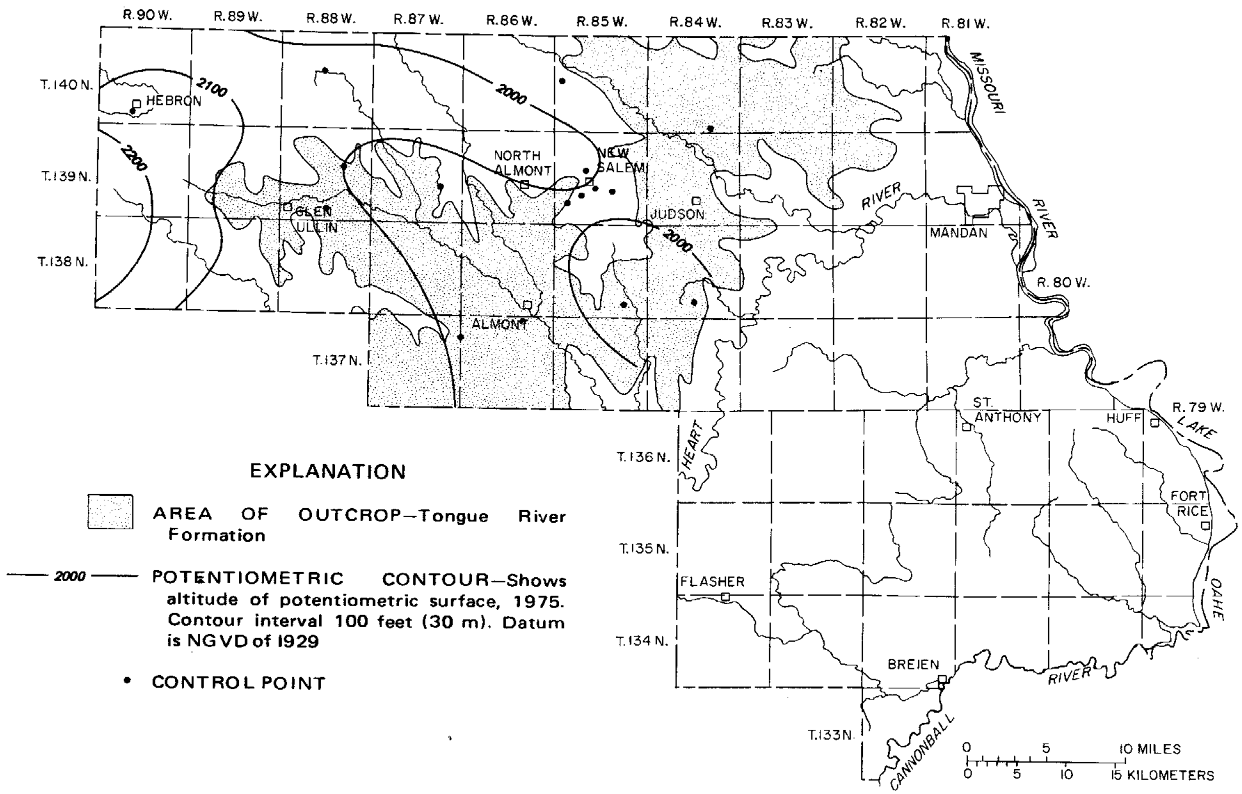


FIGURE 11.—Potentiometric surface of the lower Tongue River aquifer, 1975.

The valleys of the Heart River, Big Muddy Creek, and other small creeks are the major areas of discharge. Aquifers in the Tongue River Formation are in hydraulic connection with adjacent glacial-drift aquifers. Hydraulic gradients between aquifers favor movement from the Tongue River to glacial-drift aquifers, but gradients are gentle.

Water samples were collected from 64 wells and one spring. The water-quality data for selected constituents or indices of general interest are summarized in the following table. The water generally is a sodium bicarbonate type. Locally high sulfate concentrations make the water undesirable for domestic use. Colored water is common in the aquifers and occurs in both sandstones and lignites. The color is believed to be due to organic chemicals dissolved in the water. Any stratigraphic position in the aquifers may or may not produce colored water.

Although some water samples from aquifers in the Tongue River Formation have a salinity- or sodium-hazard classification low enough to suggest the water is acceptable for irrigation use, this is not true for the water from most of the aquifers in the Tongue River Formations.

Aquifers in the Sentinel Butte Formation

The Sentinel Butte Formation crops out in the northwestern one-fourth of Morton County (fig. 3) and has an areal extent of 400 mi^2 (1,000 km^2). The formation largely has been removed by erosion and reaches a full thickness at only one location in the extreme northwestern corner of the county. The formation generally is less than 100 feet (30 m) thick in Morton County.

The depositional environment of the Sentinel Butte Formation as reported by Chervin (1973) and Johnson (1973) is quite similar to that of the Tongue River Formation as described by Jacob (1973). Sandstones, which form the aquifers in the Sentinel Butte Formation, are discontinuous both laterally and vertically. No extensive or thick lignite beds were found during test drilling, but a few private wells and springs are reported to be completed in lignite.

The sandstones are predominately very fine grained, but are often fine grained. They are poorly sorted and often contain 10 to 40 percent silt and clay.

Because of their relatively high topographic position the sandstones of the Sentinel Butte Formation rarely have sufficient extent or saturated thickness to serve as aquifers. Usually only wells screened in the bottom of the formation have water levels that are high enough to make adequate wells. The potential yields of wells completed in the aquifers in the Sentinel Butte Formation probably are less than 50 gal/min (3 L/s).

Few observation wells were installed in the aquifers in the Sentinel Butte Formation; therefore, a precise statement cannot be made concerning ground-water movement within the aquifers. However, it is believed that most flow is on a local scale, from recharge at topographically high areas to discharge in nearby valleys and low areas. Springs and perched water-level conditions are common.

Summary of selected water-quality constituents or indices for aquifers in the Tongue River Formation
(Data are somewhat biased because of uneven areal sample density)

Constitutuents or indices	Class intervals / Number of values falling in each class interval						Range of values	Number of samples
Dissolved solids (mg/L)	<500	500-1,000	1,010-1,500	1,510-2,000	2,010-2,500	>2,500		
	0	7	33	22	2	1	441-3,290	65
Sulfate (mg/L)	<50	50-150	160-250	260-350	360-450	>450		
	10	12	15	17	7	4	.0-1,200	65
Chloride (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	64	1	0	0	0	0	.0-71	65
Fluoride (mg/L)	<0.50	0.50-0.90	0.91-1.2	1.3-1.7	1.8-3.0	>3.0		
	6	2	7	14	14	22	.1-6.3	65
Sodium (mg/L)	<20	20-100	110-250	260-500	510-750	>750		
	0	2	1	16	43	3	41-1,100	65
Percent sodium	<20	20-50	51-65	66-80	81-95	>95		
	0	2	1	2	7	53	22-99	65
Sodium-adsorption ratio	<1.0	1.0-5.0	5.1-10	11-15	16-20	>20		
	0	2	3	1	1	58	1.0-90	65
Hardness (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	50	7	2	1	0	5	8-370	65
Nitrate as Nitrogen (mg/L)	<0.25	0.25-1.0	1.1-5.0	5.1-10	11-15	>15		
	39	20	2	1	0	0	.05-10	62

Water samples from six springs and four wells were analyzed. Water-quality data for selected constituents or indices of general interest are given in the following table. The water cannot be typified except to say that it contains little chloride. In places water from the aquifers in the Sentinel Butte Formation is of marginal quality for irrigation (fig. 5).

Ground Water in the Glacial-Drift and Alluvial Aquifers

Aquifers in the undifferentiated glacial drift and alluvium have the greatest potential for the development of large yields in Morton County. The aquifers occur as sand and gravel deposits, both in buried ancestral valleys and in valleys of present-day rivers (pl. 2, in pocket), and underlie approximately 10 percent of the county. Where applicable, aquifer names are continued from adjacent counties (Elm Creek aquifer, Killdeer aquifer, Shields aquifer, Square Butte Creek aquifer, and St. James aquifer). Newly recognized aquifers are named after nearby prominent geographic features (Sims aquifer, Little Heart aquifer, and Heart River aquifer).

Where data permit, an estimate of the amount of water stored in an aquifer is given. The estimate, given in acre-feet, is a product of an average saturated thickness, estimated specific yield, and areal extent of the aquifer. The storage value represents static conditions and is for comparison purposes only. The quantitative evaluation of optimum yield of an aquifer from storage would require intensive study of that aquifer. Such and undertaking is beyond the scope of this report.

The potential yields of the glacial drift and alluvial aquifers are shown on plate 2. Yields were estimated from transmissivities determined from specific capacities of wells using methods given in Theis (1963) and Brown (1963). Transmissivities also were derived from saturated thicknesses and hydraulic conductivities, which were estimated from textural descriptions of test holes according to the method given by Keech (1964). The transmissivity estimates are comparable to the values obtained from aquifer tests in Morton County and other nearby counties. The criteria used for the yield estimates include the specific capacity at 24 hours of pumping, well diameter, and a close approximation of the storage coefficient. Corrections were made if the well only partially penetrated the aquifer.

The aquifers generally are lenticular and the largest yields usually are obtainable from the thickest parts. Wells penetrating aquifers in narrow valleys often have lower sustained yields than wells tapping aquifers of comparable thickness but having larger areal extent. The ground-water availability map should be used with the understanding that the estimated yields are for fully penetrating, properly screened and developed wells of adequate diameter. The map is intended as a general guide in the location of ground water and not as a map to locate specific wells. Few, if any, aquifers are so uniform in extent and physical properties that production wells may be drilled in them without preliminary test drilling.

Summary of selected water-quality constituents and indices for aquifers in the Sentinel Butte Formation
(Data are somewhat biased because of uneven areal sample density)

Constitutuents or indices	Class intervals / Number of values falling in each class interval						Range of values	Number of samples
Dissolved solids (mg/L)	<500	500-1,000	1,010-1,500	1,510-2,000	2,010-2,500	>2,500		
	0	2	3	3	1	1	568-3,200	10
Sulfate (mg/L)	<50	50-150	160-250	260-350	360-450	>450		
	0	0	2	0	3	5	160-1,900	10
Chloride (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	10	0	0	0	0	0	.0-28	10
Fluoride (mg/L)	<0.50	0.50-0.90	0.91-1.2	1.3-1.7	1.8-3.0	>3.0		
	2	6	0	1	1	0	.2-2.4	10
Sodium (mg/L)	<20	20-100	110-250	260-500	510-750	>750		
	0	2	1	4	3	0	48-750	10
Percent sodium	<20	20-50	51-65	66-80	81-95	>95		
	1	4	0	1	3	1	19-99	10
Sodium-adsorption ratio	<1.0	1.0-5.0	5.1-10	11-15	16-20	>20		
	0	5	1	1	2	1	1-70	10
Hardness (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	1	0	2	0	1	6	14-1,500	10
Nitrate as Nitrogen (mg/L)	<0.25	0.25-1.0	1.1-5.0	5.1-10	11-15	>15		
	3	2	2	1	0	1	.00-25	9

Elm Creek Aquifer

The Elm Creek aquifer occupies a buried valley that extends from south-central Mercer County to southern Morton County (pl. 2). The aquifer consists of the sand and gravel part of interbedded layers of clay, silt, sand, and gravel. The coarsest and most permeable material generally occurs along the axis and near the bottom of the valley. The aquifer ranges from ⅓ to 1½ miles (0.5 to 5 km) in width and averages ¾ of a mile (1.2 km) wide. Two geologic sections (B-B′ and C-C′; pl. 3, in pocket) drawn across the aquifer show that sand and gravel beds within the buried valley are not laterally continuous. However, three beds of sand and gravel usually are recognizable.

The grain size of the aquifer materials generally ranges from very fine sand to gravel. Hydraulic conductivities of the aquifer materials range from 10 to 400 ft/d (3 to 100 m/d). Logs of 50 test holes and wells indicate that the aquifer thickness ranges from 10 to 284 feet (3 to 86.6 m). Aquifer transmissivities should range from 100 to 20,000 ft^2/d (9 to 2,000 m^2/d). Storage coefficients probably range from 0.0001 where the aquifer is confined by extensive layers of silt and clay to 0.2 where the aquifer is near the surface. An aquifer test performed at 135-084-16 by the North Dakota State Water Commission indicated that the lower part of the aquifer had a transmissivity of 1,000 ft^2/d (100 m^2/d) and a storage coefficient of 0.0001 (R. W. Schmid, written commun., 1975).

Based on an areal extent of 60 mi^2 (160 km^2), an average saturated thickness of 80 feet (24 m), and an estimated specific yield of 0.2, about 610,000 acre-feet (760 hm^3) of water is in storage in the Elm Creek aquifer in Morton County. Potential yields to wells (pl. 2) range from 10 to 1,500 gal/min (0.6 to 95 L/s).

The general direction of ground-water movement and the locations of ground-water divides are shown on plate 2. Recharge to the aquifer is from precipitation over the aquifer, from lakes, from streams during periods of high flow, and from the Sims, Killdeer, and adjacent bedrock aquifers. The hydraulic gradient between the Elm Creek aquifer and adjacent bedrock aquifers favors movement of water into the Elm Creek aquifer, although the gradient is gentle. The aquifer discharges to the Cannonball and Heart Rivers, to small creeks, and to the Shields and Heart River aquifers.

Analyses of 51 water samples from 47 wells show the water in the Elm Creek aquifer is predominately sodium bicarbonate or calcium-magnesium bicarbonate types. A summary of the water-quality data for selected constituents or indices of general interest is given in the following table. The water generally increases in dissolved solids and in percent sodium with respect to depth in the aquifer and with increasing distance along the flow path. Water with the lowest dissolved solids and percent sodium occurs near Lake Patricia, a recharge area.

A general increase in sodium concentration has been observed in areas where bedrock aquifers contribute to the Elm Creek aquifer. Apparently the hydraulic connection between the aquifers is sufficient to add enough bedrock water to significantly alter the water quality of the Elm Creek aquifer. This alteration of water quality would become more pronounced if the hydraulic

Summary of selected water-quality constituents or indices for the Elm Creek aquifer
(Data are somewhat biased because of uneven areal sample density)

Constituents or indices	Class intervals / Number of values falling in each class interval						Range of values	Number of samples
Dissolved solids (mg/L)	<500	500-1,000	1,010-1,500	1,510-2,000	2,010-2,500	>2,500		
	0	16	15	5	9	2	512-3,070	47
Sulfate (mg/L)	<50	50-150	160-250	260-350	360-450	>450		
	1	11	6	9	4	16	2.5-1,500	47
Chloride (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	45	1	1	0	0	0	1.0-130	47
Fluoride (mg/L)	<0.50	0.50-0.90	0.91-1.2	1.3-1.7	1.8-3.0	>3.0		
	3	28	5	6	3	2	.1-7.6	47
Sodium (mg/L)	<20	20-100	110-250	260-500	510-750	>750		
	0	9	9	16	12	1	27-830	47
Percent sodium	<20	20-50	51-65	66-80	81-95	>95		
	7	5	11	11	11	2	11-98	47
Sodium-adsorption ratio	<1.0	1.0-5.0	5.1-10	11-15	16-20	>20		
	7	7	13	13	4	3	.5-58	47
Hardness (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	2	1	6	3	2	33	16-910	47
Nitrate as Nitrogen (mg/L)	<0.25	0.25-1.0	1.1-5.0	5.1-10	11-15	>15		
	43	2	2	0	0	0	.07-1.7	47

gradient between the Elm Creek aquifer and bedrock aquifers was increased by large withdrawals from the Elm Creek aquifer.

Water from the aquifer locally is suitable for irrigation (fig. 5).

Little Heart Aquifer

The Little Heart aquifer occupies a buried-valley system and a glacial lake basin in eastern Morton County under Little Heart Flats (pl. 2). Aquifer materials consist of the sand and gravel part of interbedded layers of clay, silt, sand, and gravel. The coarsest and most permeable material is found along the axes of the buried valleys and near bottoms of the buried valleys. Geologic section D-D′ (pl. 3) shows the relationship of the aquifer materials in one of the buried valleys. The part of the aquifer in the buried-valley system is generally ½ to 2 miles (0.8 to 3.2 km) wide and averages about ¾ of a mile (1.2 km) wide.

Aquifer materials generally range in size from very fine sand to a coarse gravel. Hydraulic conductivities of the aquifer materials range from 10 to 500 ft/d (3 to 150 m/d). Logs of 48 test holes and wells indicate that the aquifer thickness ranges from 0 to 260 feet (0 to 79 m). Transmissivities of the aquifer should range from 100 to 25,000 ft^2/d (9 to 2,300 m^2/d). The storage coefficient probably ranges from 0.2 where the aquifer is near the surface to 0.0001 where the aquifer is confined by extensive layers of silt and clay.

Based on an areal extent of 75 mi^2 (190 km^2), an average saturated thickness of 60 feet (20 m), and an estimated specific yield of 0.2, about 580,000 acre-feet (710 hm^3) of water is in storage in the Little Heart aquifer. Potential yields to wells (pl. 2) range from 10 to 1,700 gal/min (0.6 to 110 L/s).

The general direction of ground-water movement and the locations of ground-water divides are shown on plate 2. Recharge to the aquifer is from precipitation over the aquifer and from small streams such as Northwest Branch Cantepeta Creek and Little Heart River. The Little Heart aquifer is in hydraulic connection with the bedrock aquifers. At present the hydraulic gradients between these aquifers are gentle and usually favor movement of water into the Little Heart aquifer. The aquifer discharges to small streams, the Missouri River, and Lake Oahe. In the Little Heart Flats area evapotranspiration may be significant as the water table in that area is often within a few feet of land surface.

Analyses of water samples from 19 wells show the water generally is sodium bicarbonate or calcium-magnesium-sodium bicarbonate types. Water-quality data for selected constituents or indices of general interest are summarized in the following table.

The water generally increases in dissolved-solids and sodium concentrations with increasing distance along the flow path. The presence of a hydraulic connection with the bedrock aquifers suggests that large-scale development of the Little Heart aquifer should proceed with care to avoid inducing flow from the bedrock aquifers into the Little Heart aquifer. The high sodium water from the bedrock aquifer would degrade the water in the Little Heart aquifer for irrigation purposes.

Water from the aquifer locally is suitable for irrigation (fig. 5).

Summary of selected water-quality constituents or indices for the Little Heart aquifer
(Data are somewhat biased because of uneven areal sample density)

Constituents or indices	Class intervals / Number of values falling in each class interval						Range of values	Number of samples
Dissolved solids (mg/L)	<500	500-1,000	1,010-1,500	1,510-2,000	2,010-2,500	>2,500		
	0	12	4	3	0	0	535-1,740	19
Sulfate (mg/L)	<50	50-150	160-250	260-350	360-450	>450		
	0	3	6	6	0	4	93-520	19
Chloride (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	12	6	0	0	1	0	.0-210	19
Fluoride (mg/L)	<0.50	0.50-0.90	0.91-1.2	1.3-1.7	1.8-3.0	>3.0		
	7	9	2	1	0	0	.1-1.6	19
Sodium (mg/L)	<20	20-100	110-250	260-500	510-750	>750		
	0	6	5	5	3	0	21-610	19
Percent sodium	<20	20-50	51-65	66-80	81-95	>95		
	2	9	0	3	5	0	7-94	19
Sodium-adsorption ratio	<1.0	1.0-5.0	5.1-10	11-15	16-20	>20		
	2	8	1	3	2	3	.4-30	19
Hardness (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	0	2	2	0	2	13	81-580	19
Nitrate as Nitrogen (mg/L)	<0.25	0.25-1.0	1.1-5.0	5.1-10	11-15	>15		
	17	2	0	0	0	0	.05-.56	19

Killdeer Aquifer

The Killdeer aquifer occupies a buried valley that extends from northeastern Stark County to the buried valley of the Elm Creek aquifer east of Glen Ullin in Morton County (pl. 2). The aquifer consists of the sand and gravel part of interbedded layers of silt, clay, sand, and gravel. The coarsest and most permeable material generally occurs along the axis of the valley and near the bottom of the buried valley. The aquifer ranges in width from ½ to 1½ miles (0.8 to 2.4 km) and averages about ¾ of a mile (1.2 km) in width.

The grain size of aquifer materials generally ranges from very fine sand to gravel. Hydraulic conductivities of these materials range from 10 to 400 ft/d (3 to 100 m/d). Logs of 19 test holes and wells indicate that the aquifer thickness ranges from 3 to 388 feet (1 to 118 m). Aquifer transmissivities should range from 100 to 15,000 ft^2/d (9 to 1,400 m^2/d). The aquifer usually is confined by surficial silts and clays so the storage coefficient probably is in the range of 0.01 to 0.0001.

Based on an areal extent of 20 mi^2 (50 km^2), an average saturated thickness of 70 feet (20 m), and an estimated specific yield of 0.2, about 180,000 acre-feet (220 hm^3) of water is in storage in the Killdeer aquifer. Potential yields to wells (pl. 2) range from 10 to 1,300 gal/min (0.6 to 82 L/s).

The general direction of ground-water movement and the location of a ground-water divide are shown on plate 2. Recharge to the aquifer is from precipitation over the aquifer and from small creeks and rivers (such as Big Muddy Creek and Branch Knife River) during periods of high flow. Bedrock aquifers are in hydraulic connection with the Killdeer aquifer. The hydraulic gradient presently is gentle but favors water movement into the Killdeer aquifer. The aquifer discharges to the Elm Creek aquifer and to small streams.

Analyses of water samples from nine wells were not sufficient to permit a statement as to general water type. However, the water does appear to be similar to that from the Elm Creek aquifer in Morton County. A summary of the water-quality data for selected constituents or indices of general interest is given in the following table.

Water from the aquifer locally is suitable for irrigation (fig. 5).

Heart River Aquifer

The Heart River aquifer in Morton County occupies the valley underlying the Heart River from its intersection with the Elm Creek aquifer to the confluence of the Heart and Missouri Rivers (pl. 2). The aquifer consists of the sand and gravel part of the interbedded layers of clay, silt, sand, and gravel. The coarsest and most permeable material generally occurs near the bottom of the buried valley. Where the aquifer occupies the valley of the Heart River, it is ¼ to ¾ of a mile (0.4 to 1.2 km) wide. Where the aquifer occupies the valleys of the Heart and Missouri Rivers it is 1½ to 2 miles (2.4 to 3.2 km) wide.

The grain size of aquifer materials generally ranges from very fine sand to gravel. Hydraulic conductivities of these materials range from 10 to 400 ft/d

Summary of selected water-quality constituents or indices for the Killdeer aquifer
(Data are somewhat biased because of uneven areal sample density)

Constituents or indices	Class intervals / Number of values falling in each class interval						Range of values	Number of samples
Dissolved solids (mg/L)	<500	500-1,000	1,010-1,500	1,510-2,000	2,010-2,500	>2,500		
	0	2	2	1	0	4	635-9,700	9
Sulfate (mg/L)	<50	51-150	160-250	260-350	360-450	>450		
	0	1	1	1	1	5	78-6,500	9
Chloride (mg/L)	<50	51-100	110-150	160-200	210-250	>250		
	9	0	0	0	0	0	.4-8.2	9
Fluoride (mg/L)	<0.50	0.50-0.90	0.91-1.2	1.3-1.7	1.8-3.0	>3.0		
	1	4	1	2	0	1	.4-3.8	9
Sodium (mg/L)	<20	21-100	110-250	260-500	510-750	>750		
	0	0	2	2	2	3	130-1,500	9
Percent sodium	<20	21-50	51-65	66-80	81-95	>95		
	0	1	3	2	3	0	45-90	9
Sodium-adsorption ratio	<1.0	1.1-5.0	5.1-10	11-15	16-20	>20		
	0	1	4	1	2	1	3.5-24	9
Hardness (mg/L)	<50	51-100	110-150	160-200	210-250	>250		
	0	0	1	0	4	4	110-4,000	9
Nitrate as Nitrogen (mg/L)	<0.25	0.26-1.0	1.1-5.0	5.1-10	11-15	>15		
	6	3	0	0	0	0	.23-.68	9

(0.3 to 100 m/d). Logs of eight test holes and wells indicate that aquifer thickness ranges from 25 to 109 feet (7.6 to 33.2 m). Aquifer transmissivities range from 100 to 10,000 ft^2/d (9 to 900 m^2/d). The storage coefficient probably ranges from 0.0005 where the aquifer is confined by layers of silt and clay to 0.2 where the aquifer is near the surface.

Based on an areal extent of 25 mi^2 (65 km^2), an average saturated thickness of 50 feet (15 m), and an estimated specific yield of 0.2, about 160,000 acre-feet (200 hm^3) of water is in storage in the Heart River aquifer. Potential yields to wells (pl. 2) range from 10 to 600 gal/min (0.6 to 40 L/s).

The general direction of ground-water movement is shown on plate 2. The aquifer is recharged by precipitation over the aquifer, by the Heart and Missouri Rivers, and by the Elm Creek and bedrock aquifers. The aquifer discharges water to the Heart and Missouri Rivers. Water levels in well 138-080-06BCC and the stage of the Missouri River at Bismarck and below Mandan (U.S. Geological Survey, 1968-74) show a close correspondence; suggesting a hydraulic connection exists between the Missouri River and the aquifer in the area. A similar connection probably exists with the Heart River.

Analyses of 22 water samples from 19 wells show that water from the Heart River aquifer is predominately a calcium-magnesium-sodium bicarbonate type. A summary of the water-quality data for selected constituents or indices of general interest is given in the following table.

Water from the aquifer generally is suitable for irrigation (fig. 5).

Large-scale withdrawals of water from the Heart River aquifer may induce additional recharge from the bedrock aquifers and from the Heart and Missouri Rivers. The induced recharge from the bedrock aquifers would result in higher salinity and sodium concentrations. Induced recharge from the Heart and Missouri Rivers would deplete streamflow by decreasing the base flow or ground-water contribution to low flow. The depletion could be a significant portion of the streamflow of the Heart River at low flow.

Shields Aquifer

The Shields aquifer occupies the distributary channels of a buried valley and extends from the Elm Creek aquifer south to Grant County (pl. 2). The aquifer consists of the sand and gravel part of interbedded layers of clay, silt, sand, and gravel. The coarsest and most permeable material generally occurs along the axes and near the bottom of the channels. The aquifer ranges from ⅓ to 1½ miles (0.5 to 2.5 km) in width.

The grain size of the aquifer materials generally ranges from very fine sand to very coarse sand. Hydraulic conductivities of these materials range from 10 to 130 ft/d (3 to 40 m/d). Logs of 10 wells and test holes indicate that the aquifer thickness ranges from 16 to 226 feet (4.8 to 68.9 m). Aquifer transmissivities range from 100 to 13,000 ft^2/d (9 to 1,200 m^2/d). Storage coefficients probably range from 0.0001 where the aquifer is confined by layers of silt and clay to 0.2 where the aquifer is near the surface.

Summary of selected water-quality constituents or indices for the Heart River aquifer
(Data are somewhat biased because of uneven areal sample density)

Constituents or indices	Class intervals / Number of values falling in each class interval						Range of values	Number of samples
Dissolved solids (mg/L)	<500	500-1,000	1,010-1,500	1,510-2,000	2,010-2,500	>2,500		
	0	12	6	1	0	0	507-1,700	19
Sulfate (mg/L)	<50	50-150	160-250	260-350	360-450	>450		
	1	5	5	7	0	1	4.9-460	19
Chloride (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	15	3	1	0	0	0	5.4-120	19
Fluoride (mg/L)	<0.50	0.50-0.90	0.91-1.2	1.3-1.7	1.8-3.0	>3.0		
	10	6	1	1	1	0	.1-2.9	19
Sodium (mg/L)	<20	20-100	110-250	260-500	510-750	>750		
	0	6	9	3	1	0	62-570	19
Percent sodium	<20	20-50	51-65	66-80	81-95	>95		
	0	14	3	1	1	0	24-88	19
Sodium-adsorption ratio	<1.0	1.0-5.0	5.1-10	11-15	16-20	>20		
	0	15	3	0	1	0	1.4-19	19
Hardness (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	0	0	0	1	0	18	170-750	19
Nitrate as Nitrogen (mg/L)	<0.25	0.25-1.0	1.1-5.0	5.1-10	11-15	>15		
	14	3	2	0	0	0	.07-1.7	19

Based on an areal extent of 12 mi^2 (31 km^2), an average saturated thickness of 80 feet (24 m), and an estimated specific yield of 0.2, about 120,000 acre-feet (150 hm^3) of water is in storage in the Shields aquifer. Potential yields to wells (pl. 2) range from 10 to 1,000 gal/min (0.6 to 63 L/s).

The general direction of ground-water movement is shown on plate 2. Recharge to the aquifer is from precipitation over the aquifer, from small streams during high flow, from the Elm Creek aquifer, and from adjacent bedrock aquifers. The aquifer discharges to the Elm Creek aquifer and to small streams.

Analyses of water samples from nine wells show the water in the Shields aquifer is predominately sodium bicarbonate or sodium-calcium-magnesium bicarbonate types. A summary of the water-quality data for selected constituents or indices of general interest is given in the following table. The water generally increases in dissolved solids and in percent sodium with respect to depth in the aquifer and with increasing distance along the flow path.

Water from the aquifer locally is suitable for irrigation (fig. 5).

St. James Aquifer

The St. James aquifer occupies a buried valley in southern Morton County (pl. 2). The aquifer consists of the sand and gravel part of interbedded layers of clay, silt, sand, and gravel. The coarsest material generally occurs along the axis of the valley and near the valley bottom. The aquifer ranges from ¾ to 2 miles (1.2 to 3.2 km) in width.

The grain size of aquifer materials generally ranges from very fine sand to coarse gravel. Hydraulic conductivities of these materials range from 10 to 500 ft/d (3 to 150 m/d). Logs of nine test holes and wells indicate that the aquifer thickness ranges from 5 to 157 feet (2 to 48 m). Aquifer transmissivities should range from 100 to 18,000 ft^2/d (9 to 1,700 m^2/d). Storage coefficients probably range from 0.0005 where the aquifer is confined by lenses of silt and clay to 0.2 where the aquifer is near the surface.

Based on an areal extent of 8 mi^2 (20 km^2), an average saturated thickness of 40 feet (12 m), and an estimated specific yield of 0.2, about 41,000 acre-feet (50 hm^3) of water is in storage in the St. James aquifer. Potential yields to wells should range from 10 to 1,000 gal/min (0.6 to 63 L/s).

The general direction of ground-water movement is shown on plate 2. Recharge to the aquifer is from bedrock aquifers, precipitation over the aquifer, and from ephemeral streams. The aquifer discharges to the Cannonball River.

Analyses of water from three wells indicate that the water is a sodium bicarbonate type. The similarity of the water to that of the Hell Creek and Fox Hills aquifers indicates that most recharge to this aquifer probably comes from these aquifers.

Water from the aquifer generally is unsuitable for irrigation (fig. 5).

Summary of selected water-quality constituents or indices for the Shields aquifer
(Data are somewhat biased because of uneven areal sample density)

Constitutuents or indices	Class intervals / Number of values falling in each class interval						Range of values	Number of samples
Dissolved solids (mg/L)	<500	500-1,000	1,010-1,500	1,510-2,000	2,010-2,500	>2,500		
	2	2	5	0	0	0	465-1,400	9
Sulfate (mg/L)	<50	50-150	160-250	260-350	360-450	>450		
	0	2	2	3	0	2	120-470	9
Chloride (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	8	1	0	0	0	0	2.3-90	9
Fluoride (mg/L)	<0.50	0.50-0.90	0.91-1.2	1.3-1.7	1.8-3.0	>3.0		
	1	5	0	1	2	0	.2-2.9	9
Sodium (mg/L)	<20	20-100	110-250	260-500	510-750	>750		
	0	3	3	2	1	0	39-520	9
Percent sodium	<20	20-50	51-65	66-80	81-95	>95		
	1	3	2	0	3	0	17-94	9
Sodium-adsorption ratio	<1.0	1.0-5.0	5.1-10	11-15	16-20	>20		
	1	4	1	0	1	2	.8-25	9
Hardness (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	0	3	0	0	0	6	52-630	9
Nitrate as Nitrogen (mg/L)	<0.25	0.25-1.0	1.1-5.0	5.1-10	11-15	>15		
	9	0	0	0	0	0	.23-.23	9

Sims Aquifer

The Sims aquifer occupies a buried valley that is tributary to the buried valley of the Elm Creek aquifer in north-central Morton County (pl. 2). Aquifer materials consist of the sand and gravel part of interbedded layers of clay, silt, sand, and gravel. The coarsest and most permeable material occurs along the axis of the valley and near the valley bottom. The aquifer is 1/10 to ½ of a mile (0.16 to 0.8 km) wide and averages about ¼ of a mile (0.4 km) in width.

The grain size of aquifer materials generally ranges from very fine sand to gravel. The hydraulic conductivity of these materials ranges from 10 to 400 ft/d (3 to 100 m/d). Logs of 20 test holes indicate that the aquifer thickness ranges from 7 to 141 feet (3 to 43 m). Transmissivities of the aquifer range from 100 to 15,000 ft^2/d (9 to 1,400 m^2/d). The storage coefficient probably ranges from 0.2 where the aquifer is near the surface to 0.0005 where the aquifer is confined by intervals of silt and clay. An aquifer test at 139-086-34DAA by the North Dakota State Water Commission (R. B. Shaver, written commun., 1976) indicated that a middle level of the aquifer had a transmissivity of 1,400 ft^2/d (130 m^2/d).

Based on an areal extent of 5 mi^2 (13 km^2), an average saturated thickness of 45 feet (14 m), and an estimated specific yield of 0.2, about 29,000 acre-feet (36 hm^3) of water is in storage in the Sims aquifer. Potential yields to wells (pl. 2) range from 10 to 900 gal/min (0.6 to 60 L/s).

The general direction of ground-water movement in the Sims aquifer is shown on plate 2. Recharge to the aquifer is from precipitation over the aquifer and from Sims Creek and its tributaries. The hydraulic gradient between bedrock aquifers and the Sims aquifer favors movement of water into the Sims aquifer. The aquifer discharges to Sims Creek and its tributaries and to the Elm Creek aquifer.

Twelve water samples from eight wells were analyzed. The data were insufficient to typify the water. Water-quality data for selected constituents or indices of general interest are summarized in the following table. Colored water is present in the aquifer, but because of limited data no specific source for the color can be established. Water from sandstone and lignite aquifers may be contributing colored water and water high in sodium to the Sims aquifer. If this is the case, large withdrawals from the Sims aquifer could induce increased color and sodium concentrations in the water of the Sims aquifer.

Square Butte Creek Aquifer

The Square Butte Creek aquifer occupies the valley of Square Butte Creek and part of the valley of the Missouri River in Morton County (pl. 2). The aquifer consists of the sand and gravel part of interbedded layers of silt, clay, sand, and gravel. The coarsest and most permeable material occurs along the axis of the Square Butte Creek valley. The aquifer ranges from ¼ to 2 miles (0.4 to 3.2 km) in width and averages ¾ of a mile (1.2 km).

The grain size of aquifer materials ranges from very fine sand to gravel. The hydraulic conductivity of these materials ranges from 10 to 400 ft/d (3 to 100

Summary of selected water-quality constituents or indices for the Sims aquifer
(Data are somewhat biased because of uneven areal sample density)

Constitutuents or indices	Class intervals Number of values falling in each class interval						Range of values	Number of samples
Dissolved solids (mg/L)	<500	500-1,000	1,010-1,500	1,510-2,000	2,010-2,500	>2,500		
	0	6	2	0	0	0	675-1,050	8
Sulfate (mg/L)	<50	50-150	160-250	260-350	360-450	>450		
	0	2	4	2	0	0	140-370	8
Chloride (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	8	0	0	0	0	0	1.2-14	8
Fluoride (mg/L)	<0.50	0.50-0.90	0.91-1.2	1.3-1.7	1.8-3.0	>3.0		
	3	1	0	3	1	0	.2-2.3	8
Sodium (mg/L)	<20	20-100	110-250	260-500	510-750	>750		
	0	0	3	5	0	0	130-380	8
Percent sodium	<20	20-50	51-65	66-80	81-95	>95		
	0	2	1	1	4	0	43-92	8
Sodium-adsorption ratio	<1.0	1.0-5.0	5.1-10	11-15	16-20	>20		
	0	2	2	1	2	1	3.2-23	8
Hardness (mg/L)	<50	50-100	110-150	160-200	210-250	>250		
	1	2	1	1	0	3	43-480	8
Nitrate as Nitrogen (mg/L)	<0.25	0.25-1.0	1.1-5.0	5.1-10	11-15	>15		
	8	0	0	0	0	0	.23-.34	8

m/d). Test-hole and potentiometric data were not sufficient to give more information than an estimate of yield (pl. 2) and storage.

Based on an areal extent of 8 mi^2 (20 km^2), an average saturated thickness of 20 feet (6 m), and an estimated specific yield of 0.2, about 20,000 acre-feet (25 hm^3) of water is in storage in the Square Butte Creek aquifer. Potential yields (pl. 2) range from 10 to 200 gal/min (0.6 to 10 L/s).

Analyses of water from three wells were insufficient to draw general conclusions as to the water quality throughout the aquifer. The water from these three wells was similar to water from other glacial-drift aquifers. Dissolved solids ranged from 676 to 1,250 mg/L and all samples were a calcium-magnesium-sodium type.

Water from the aquifer locally may be suitable for irrigation (fig. 5).

GROUND-WATER UTILIZATION AND DEVELOPMENT

Domestic and Livestock

The major use of ground water in the county is for domestic and livestock purposes. Most wells are between 50 and 300 feet (15 and 90 m) deep, are developed in bedrock aquifers, and yield less than 10 gal/min (0.6 L/s). An estimate of the amount of water used daily is given in the following table. The domestic use represents the population of all of Morton County with the exception of Mandan, which uses the Missouri River as a water source.

Use	Individual requirements (gal/d)	Population	Estimated use (gal/d)
Domestic (rural)	a/63	b/ 9,217	580,000
Cattle	c/10	d/111,200	1,100,000
Milk cows	c/20	d/ 8,800	180,000
Hogs	c/ 3	d/ 15,100	45,000
Sheep	c/ 2	d/ 5,100	10,000
Chickens	c/ .04	d/ 29,000	1,200
Estimated total use (rounded)			2,000,000

a/ Murray and Reeves, 1972.
b/ U.S. Bureau of the Census, 1971.
c/ MacKichan and Kammerer, 1961.
d/ North Dakota State University, 1974.

Public Supplies

Five Morton County communities (Almont, Flasher, Glen Ullin, Hebron, and New Salem) and four housing developments near Mandan rely on ground-water sources for their public-use supplies. There is adequate ground water available in the vicinity of all communities to satisfy some future expansion by additional development of presently used aquifers or by developing adjacent or deeper aquifers.

Almont

The city of Almont, population 109 (1970 census), obtains its water supply from two wells in the Elm Creek aquifer. The wells, 34 and 60 feet (10 and 18 m) deep, are at 138-086-26CDD. Chemical analyses of the water from the wells are given in Ackerman (1977). Additional supplies of similar quality water could be developed in the Elm Creek or Sims aquifers. Water with less salinity and lower sulfate concentrations could also be obtained from deeper bedrock aquifers.

Flasher

The city of Flasher, population 467 (1970 census), obtains its water supply from a well in the Fox Hills aquifer. A standby well is completed in the Hell Creek aquifer. The wells are 426 feet (130 m) and 140 feet (43 m) deep respectively. Chemical analyses of water from the wells (134-084-03ADC and 134-084-03CBA) are given in Ackerman (1977). Additional supplies could be developed in these aquifers or in the Elm Creek aquifer.

Glen Ullin

The city of Glen Ullin, population 1,070 (1970 census), obtains its water supply from two wells in the Tongue River aquifer. The wells, 139-088-31DBB and 139-088-31DBC, are 335 and 345 feet (102 and 105 m) deep respectively. A chemical analysis of water from well 139-088-31DBB is given in Ackerman (1977). An additional well screened in the Fox Hills and the Hell Creek aquifers recently has been added to the water system. Additional supplies could be developed in the Fox Hills, Hell Creek, or Killdeer aquifers.

Hebron

The city of Hebron, population 1,103 (1970 census), obtains its water supply from three wells in the Tongue River aquifer. Data are available for two of these wells, 140-090-33AAC and 140-090-33ACD. They are 427 and 580 feet (130 and 177 m) deep respectively. Chemical analyses of water from these wells are given in Ackerman (1977). Additional supplies could be developed in the Fox Hills, Hell Creek, or Killdeer aquifers.

New Salem

The city of New Salem, population 943 (1970 census), obtains its water supply from the Tongue River aquifer. The wells are at 139-085-21AAD, 21ADC, and 21BDB and are 360, 347, and 350 feet (110, 106, and 107 m) deep respectively. Chemical analyses of water samples from these wells are given in Ackerman (1977). Additional supplies are being developed at or near 139-086-34 in the Sims aquifer. The Fox Hills aquifer is another additional source.

Housing Developments Near Mandan

Four housing developments north and west of Mandan obtain water supplies from the Fox Hills aquifer. Chemical analyses of water samples from these wells, 139-081-04BDA2, 16BCC, 16CCB, and 139-082-08BCC are given in Ackerman (1977). Some future expansion could be satisfied by wells developed in the Hell Creek aquifer or by additional development of the Fox Hills aquifer. At present treated water from the Missouri River is being considered as an alternative source.

Irrigation

Two irrigation wells have been completed in Morton County. One well at 134-082-25DD, completed in the undifferentiated glacial drift and alluvium in the Cannonball River valley, is not being used at present. The other well at 135-084-16AAA, completed in the Elm Creek aquifer, produces at 350 gal/min (22 L/s) against a head of 528 feet (161 m). A third permit has been issued for withdrawal from the Little Heart aquifer near 136-081-16 but no well has been drilled.

The potential for developing sufficient supplies for irrigation exists in a number of the glacial-drift aquifers (pl. 2). Should irrigation supplies be developed it is essential that water quality be acceptable to soil and crop types. Development should also proceed in such a manner as to avoid inducing large hydraulic gradients in the vicinity of hydraulic connections with bedrock aquifers so as to retain the water quality of the glacial-drift aquifer.

SUMMARY

Ground water in Morton County is available from aquifers in bedrock formations of Late Cretaceous and Tertiary age and from glacial drift and alluvium of Quaternary age.

Major bedrock aquifers occur in the Fox Hills, Hell Creek, Cannonball and Ludlow, and Tongue River Formations. The sandstones that form the aquifers are very fine to fine grained. The Fox Hills aquifer, which underlies the whole county, is the largest and most continuous bedrock aquifer in the county. Sandstone beds in the bedrock formations above the Fox Hills are more discontinuous than those of the Fox Hills Formation. Yields to individual wells in the bedrock aquifers usually are less than 100 gal/min (6 L/s). Water from the bedrock aquifers generally is of a sodium bicarbonate or sodium bicarbonate-sulfate type. The water is suitable for domestic, livestock, and some industrial uses, but probably not for irrigation. Ground-water movement in the bedrock aquifers usually is in a north or easterly direction.

Aquifers in the glacial drift and alluvium, undifferentiated, consist of the sand and gravel part of interbedded layers of clay, silt, sand, and gravel. The aquifers occur in buried valleys and in major river valleys. The largest yields, as much as 1,700 gal/min (107 L/s), are obtainable along the axes of the valleys.

Dissolved solids and percent sodium generally increase with respect to depth in the glacial-drift and alluvial aquifers and with increasing distance along the flow path. The water is suitable for domestic, livestock, and some industrial purposes. In some localities the aquifers yield water in sufficient quantity and of suitable quality for irrigation.

Where a hydraulic connection exists between bedrock and glacial-drift and alluvial aquifers, large withdrawals of water from the particular glacial-drift and alluvial aquifer will result in altered water quality in that aquifer — dissolved-solids concentration and percent sodium will increase.

Aquifer parameters for all aquifers in Morton County are summarized in the following table.

Summary of aquifer parameters for Morton County, North Dakota

Bedrock formation	Areal extent (mi^2)	Depth to top of formation (ft)	Sandstone thickness (ft)	Transmissivity (ft^2/d)	Potential yield (gal/min)
Fox Hills	1,920	0-1,500	43-200	20-400	1-80
Hell Creek	1,800	0-1,200	46-184	10-350	1-80
Cannonball-Ludlow	1,500	0-800	5-129	1-200	1-50
Tongue River	900	0-400	5-180	1-400	1-100
Sentinel Butte	400	—	—	—	50
Glacial-drift and alluvial aquifers	**Areal extent (mi^2)**	**Water in storage (acre-feet)**	**Aquifer thickness (ft)**	**Transmissivity (ft^2/d)**	**Potential yield (gal/min)**
Elm Creek	60	610,000	10-284	100-20,000	10-1,500
Little Heart	75	580,000	0-260	100-25,000	10-1,700
Killdeer	20	180,000	3-388	100-15,000	10-1,300
Heart River	25	160,000	25-109	100-10,000	10-600
Shields	12	120,000	16-226	100-13,000	10-1,000
St. James	8	41,000	5-157	100-18,000	10-1,000
Sims	5	29,000	7-141	100-15,000	10-900
Square Butte Creek	8	20,000	—	—	10-200
Total	213	1,740,000			

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DEFINITIONS 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.

Arithmetic mean – a computation of the center of a group found by dividing the sum of values in the group by the number of values.

Average – an estimate or approximate representation of an arithmetic mean or center of a group.

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

Gaining stream – a stream or reach of a stream whose flow is being increased by inflow of ground water.

Geometric mean – a computation of the center of a group found by dividing the sum of logarithms of values by the number of values.

Glacial drift – sediment deposited by glaciers or in the melt water from glaciers.

Ground water – water in the zone of saturation.

Ground-water divide – a line on a potentiometric surface on each side of which the potentiometric surface slopes downward from the line.

Head – the head is the height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point. See static head.

Hydraulic conductivity – if a porous medium is isotrophic and the fluid is homogeneous, the hydraulic conductivity of the medium is the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. Hydraulic conductivity is given in $(ft^3/d)/ft^2$, which for convenience is reduced to ft/d.

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

Infiltration – the movement of water from the land surface into the underlying soil or rock.

Losing stream – a stream or reach of a stream that is losing water to the ground. It replaces the term "influent stream."

National Geodetic Vertical Datum of 1929 (NGVD of 1929) – NGVD is a geodetic datum derived from a general adjustment of the first order level nets of both the United States and Canada. It was formerly called "Sea Level Datum of 1929" or "mean sea level" in this series of reports. Although the datum was derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts, it does not necessarily represent local mean sea level at any particular place.

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

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

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

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

Specific yield – the ratio of the volume of water which a material, after being saturated, will yield by gravity to the volume of the rock or soil.

Static head – the height above a standard datum of the surface of a column of water that can be supported by the static pressure at a given point. Head, when used alone, is understood to mean static head.

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. The storage coefficient is dimensionless.

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. Transmissivities are given in $(ft^3/d)/ft$, which for convenience is reduced to ft^2/d.

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.