GROUND-WATER RESOURCES

of

DICKEY AND LA MOURE COUNTIES, NORTH DAKOTA

by

C. A. Armstrong
U.S. Geological Survey

COUNTY GROUND-WATER STUDIES 28 — PART III
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

BULLETIN 70 — 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,
North Dakota State Water Commission,
U.S. Bureau of Reclamation,
Dickey County Water Management District, and LaMoure County
Water Management District

1980

GROUND-WATER RESOURCES

of

DICKEY AND LA MOURE COUNTIES, NORTH DAKOTA

by

C. A. Armstrong
U.S. Geological Survey

COUNTY GROUND-WATER STUDIES 28 — PART III
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

BULLETIN 70 — 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,
North Dakota State Water Commission,
U.S. Bureau of Reclamation,
Dickey County Water Management District, and LaMoure County
Water Management District

1980

Bismarck, North Dakota

CONTENTS

ILLUSTRATIONS

Page

TABLES

Table

SELECTED FACTORS FOR CONVERTING INCH-POUND UNITS TO THE INTERNATIONAL SYSTEM (SI) OF METRIC UNITS

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 unit	By	To obtain SI unit
Acre	0.4047	hectare (ha)
	.004047	square kilometer (km^2)
Acre-foot	1,233	cubic meter (m^3)
	.001233	cubic hectometer (hm^3)
Cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
Foot	.3048	meter (m)
Foot per day (ft/d)	.3048	meter per day (m/d)
Foot squared per day (ft^2/d)	.0929	meter squared per day (m^2/d)
Foot per mile (ft/mi)	.1894	meter per kilometer (m/km)
Gallon	3.785	liter (L)
	.003785	cubic meter (m^3)
Gallon per day (gal/d)	.003785	cubic meter per day (m^3/d)
Gallon per minute (gal/min)	.06309	liter per second (L/s)
Gallon per minute per foot [(gal/min)/ft]	.207	liter per second per meter [(L/s)/m]
Inch	25.40	millimeter (mm)
Mile	1.609	kilometer (km)
Million gallons (Mgal)	3,785	cubic meter (m^3)
	.003785	cubic hectometer (hm^3)
Million gallons per day (Mgal/d)	3,785	cubic meter per day (m^3/d)
Pound-force per square inch (lbf/in^2)	6.895	kilopascal (kPa)
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.

GROUND-WATER RESOURCES OF DICKEY AND LA MOURE COUNTIES, NORTH DAKOTA

By

C. A. Armstrong

ABSTRACT

This investigation was made to determine the quantity and quality of ground water available in Dickey and LaMoure Counties, N. Dak. It was determined that ground water is available from glacial-drift and bedrock aquifers.

The major aquifers in the glacial drift are the Spiritwood aquifer system and the Nortonville, Ellendale, Guelph, Oakes, LaMoure, and Edgeley aquifers. These aquifers range in depth from 0 to 304 feet (0 to 85 meters) below land surface. Maximum yields from individual wells in these aquifers range from 500 to as much as 1,500 gallons per minute (32 to 95 liters per second). Water samples from the aquifers contained the following minimum, maximum, and mean concentrations of dissolved solids: Spiritwood system — 345, 1,430, and 859 milligrams per liter; Nortonville — 944, 1,890, and 1,470; Ellendale — 541, 2,280, and 1,090; Guelph — 710, 1,440, and 1,160; Oakes — 293, 798, and 470; LaMoure — 248, 1,120, and 571; and Edgeley — 308, 945, and 466.

The bedrock aquifers are the Black Island aquifer of Ordovician age, the Lakota-Fall River aquifer and the Newcastle aquifer system of Early Cretaceous age, and the Pierre aquifer of Late Cretaceous age.

The Black Island aquifer is at depths ranging from 1,421 to 3,000 feet (433 to 914 meters) and should yield as much as 700 gallons per minute (44 liters per second). Two water samples from the aquifer contained 2,520 and 3,800 milligrams per liter dissolved solids.

The Lakota-Fall River aquifer is at depths ranging from 1,100 to 2,200 feet (335 to 670 meters). Well yields generally are small, but as much as 1,000 gallons per minute (63 liters per second) should be obtainable locally. Dissolved-solids concentrations in samples from the aquifer ranged from 2,030 to 4,850 milligrams per liter and had a mean of 2,400.

The Newcastle aquifer system underlies the area at depths ranging from 790 to somewhat more than 2,000 feet (240 to 610 meters), and is separated into two aquifers. Well yields generally are less than 80 gallons per minute (5 liters per second). Dissolved-solids concentrations in samples ranged from 2,060 to 4,590 milligrams per liter and had a mean of 2,700.

The Pierre aquifer generally yields less than 5 gallons per minute (0.3 liters per second). Water samples from the aquifer contained dissolved-solids concentrations of 1,400 to 8,630 milligrams per liter and had a mean of 3,500.

INTRODUCTION

Dickey and LaMoure Counties are located in southeastern North Dakota (fig. 1) and have a combined area of about 2,282 mi^2 (5,910 km^2) — 1,144 mi^2 (2,963 m^2) in Dickey County and 1,138 mi^2 (2,947 km^2) in LaMoure County. The study of the geology and ground-water resources of the counties began in July 1973 as a cooperative investigation by the U.S. Geological Survey, the North Dakota State Water Commission, the North Dakota Geological Survey, the U.S. Bureau of Reclamation, the Dickey County Water Management District, and the LaMoure County Water Management District. The field investigation was completed in December 1976. The results of the study are published in three parts. The North Dakota Geological Survey mapped the geology of the counties and will publish the results as part I, geology. The ground-water data collected during the investigation were published as part II, basic data (Armstrong, 1978). All the data used in this report (part III, ground-water resources), unless otherwise referenced, are from part II. A detailed hydrologic description of the Oakes aquifer, determined with the aid of a digital ground-water-flow model, will be published as an open-file report at a later date.

Purpose and Scope

The primary purpose of the investigation was to determine the quantity and quality of ground water available for municipal, domestic, livestock, irrigation, and industrial uses in Dickey and LaMoure Counties, North Dakota. A secondary purpose was to develop a simulation model of the aquifer near Oakes. The specific objectives were to: (1) determine the location, extent, and nature of the major aquifers; (2) evaluate the occurrence and movement of ground water, including the sources of recharge and discharge; (3) estimate the quantities of water stored in the aquifers; (4) estimate the potential yields to wells tapping the major aquifers; (5) determine the chemical quality of the ground water; and (6) estimate the water use.

Geologic and hydrologic records were collected from 1,473 wells and test holes to help determine the location and extent of the aquifers. Water levels were measured periodically in 174 observation wells to evaluate patterns of recharge to and discharge from the aquifers. Data from four aquifer tests made during this investigation and from four previous tests were used to determine the transmissivities and storage coefficients of glacial-drift aquifers at specific sites, and to establish a basis for estimating transmissivities of glacial-drift aquifers elsewhere in the area. Physical and chemical properties of ground water were determined from 442 water samples obtained from selected wells in the counties.

Location-Numbering System

The location-numbering system used in this report (fig. 2) is based on the federal system of rectangular surveys of the public lands. The first numeral denotes the township, the second denotes the range, and the third denotes the

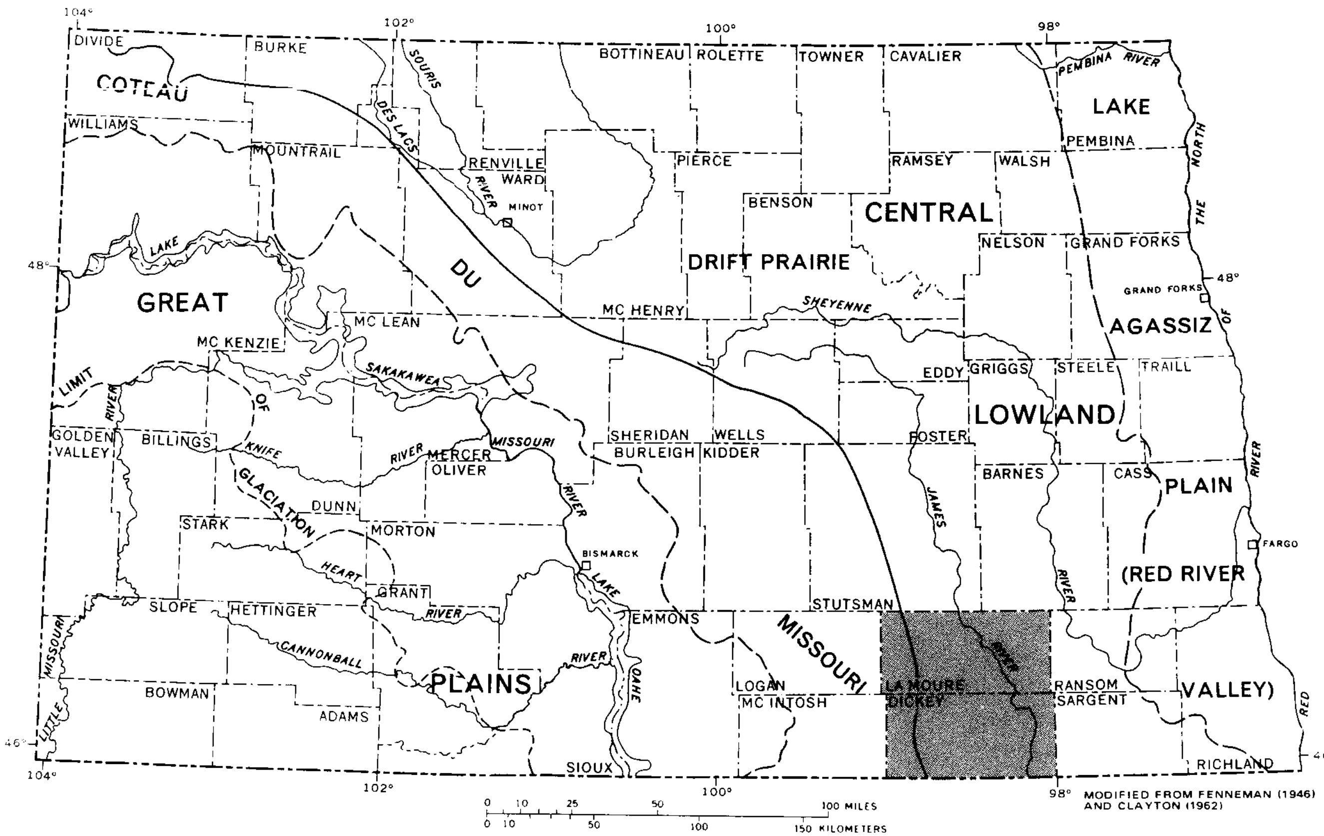


FIGURE 1.—Physiographic divisions in North Dakota and location of study area.

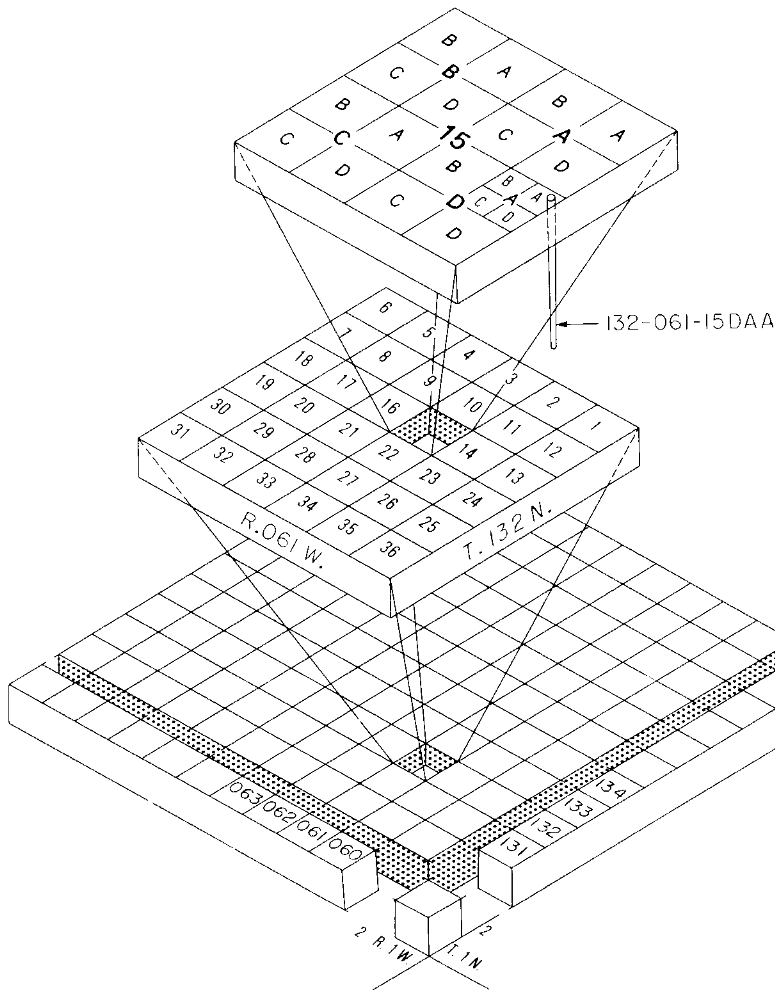


FIGURE 2.—Location-numbering system.

section in which the well, spring, or test hole is located. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre or 4-ha tract); thus well 132-061-15DAA would be located in the NE¼NE¼SE¼ sec. 15, T. 132 N., R. 61 W. Consecutive terminal numbers are added if more than one well or test hole is recorded within a 10-acre (4-ha) tract. This numbering system is also used in this report for the location of small areas.

Previous Investigations

Nettleton (1892) and Meinzer and Hard (1925) described the artesian conditions in the Dakota aquifer in Dickey and LaMoure Counties. Hard (1929) described ground-water conditions in most of the two-county area with emphasis on the Dakota aquifer. Ground-water data for Dickey and LaMoure Counties were included by Simpson (1929) in a report on the geology and ground-water resources of North Dakota. Abbott and Voedisch (1938) discussed the municipal ground-water supplies of North Dakota, including those in Dickey and LaMoure Counties, and tabulated chemical analyses of ground water used by the cities and villages. Rasmussen (1947) studied ground-water occurrence in the deposits of ancient Lake Dakota in southeast Dickey County. Colton, Lemke, and Lindvall (1963) mapped the glacial geology of North Dakota, including Dickey and LaMoure Counties. The ground-water resources of a 20-mi^2 (52-km^2) area around Ellendale, Dickey County, were studied by Lindvig (1965). Naplin (1973) reported on the ground-water resources of a 198-mi^2 (513-km^2) area near Ellendale in the south-central part of Dickey County. Naplin (1976) also studied the ground-water resources of a 195-mi^2 (505-km^2) area near Edgeley, LaMoure County.

Acknowledgements

Appreciation is expressed to the Dickey and LaMoure County Commissioners, Water Management Board members, county and city officials, and water-plant operators for assistance and cooperation in collection of field data.

Appreciation also is expressed to the many well drillers who furnished well logs, and to the farmers and ranchers of the counties for allowing access to their lands and for providing information on wells. Particular recognition is due the following North Dakota State Water Commission employees: M. O. Lindvig and R. B. Shaver for their aid during aquifer tests, and C. E. Naplin, G. L. Sunderland, L. D. Smith, Jr., and R. L. Cline for their aid in the logging of test holes.

Population and Economy

The populations of Dickey and LaMoure Counties were 6,976 and 7,117, respectively, in 1970 (U.S. Bureau of the Census, 1971). The cities with the largest populations in Dickey County were Oakes, 1,742; Ellendale (county seat), 1,517; Monango, 112; Fullerton, 110; and Forbes, 88. The cities with the largest populations in LaMoure County were LaMoure (county seat), 951; Edgeley, 888; Kulm, 625; Marion, 215; Verona, 140; Dickey, 118; Jud, 110; and Berlin, 76.

The economy of the counties is based largely on agriculture. Small grains, corn, sunflowers, flax, and hay are the principal crops. Cattle and dairy products are other important sources of farm income.

Climate

The climate of Dickey and LaMoure Counties is semiarid to subhumid. According to the U.S. Environmental Data Service (1973) the mean annual precipitation at Ellendale, Dickey County, is 21.13 inches (537 mm) and at Edgeley, LaMoure County, is 18.74 inches (476 mm). About 70 percent of the precipitation generally falls from April through August when it is most needed for the germination and growth of crops. Most of the summer precipitation is from thunderstorms and is extremely variable.

The mean annual temperature at Ellendale is 42.5°F (5.8°C) and at Edgeley is 40.7°F (4.8°C). Summer daytime temperatures usually are warm, ranging from 75°F to 85°F (24°C to 29°C). However, temperatures exceeding 90°F (32°C) commonly occur each summer. The maximum recorded temperature since 1962 was 108°F (42°C) on July 11, 1973 at Ellendale and 107°F (42°C) on July 11, 1973 at Edgeley. The minimum temperature recorded since 1962 was −37°F (−38°C) on January 1, 1968 at Ellendale and was −37°F (−38°C) January 15, 1972 at Edgeley. The average number of days between the last freeze (32°F or 0°C) in the spring and the first freeze in the fall ranges from about 120 to 130 (North Dakota State University, 1977, p. 3).

Physiography and Drainage

Dickey and LaMoure Counties are, for the most part, in the Drift Prairie district of the Central Lowland province (fig. 1). The Drift Prairie is characterized by low topographic relief except where streams have been incised. The western part of the two counties is in the Coteau du Missouri district of the Great Plains province and is characterized by small hills and isolated depressions. Local relief in the Coteau commonly is greater than 50 feet (15 m).

Maximum topographic relief in the two counties is 954 feet (291 m). The highest altitude is 2,240 feet (683 m) above NGVD (National Geodetic Vertical Datum, 1929) on a hill in sec. 29, T. 129 N., R. 66 W. (U.S. Army Map Service, 1964). The lowest altitude is about 1,286 feet (392 m) above NGVD in sec. 34, T. 129 N., R. 60 W. where the James River flows into South Dakota.

Drainage on the Drift Prairie is in a late youthful stage and moderately well developed. Flow is either to the James or Maple Rivers. The principal tributaries of the James River are Bear Creek on the east and Bone Hill and Cottonwood Creeks on the west. Maple Creek and the South Fork Maple River are the principal tributaries of the Maple River.

Drainage on the Coteau du Missouri is in an early youthful stage and is poorly developed. Surface runoff is toward undrained or poorly drained depressions. Some of the depressions fill up and overflow into lower ones or drain into tributaries, which eventually lead to the James or Maple Rivers.

OCCURRENCE AND QUALITY OF GROUND WATER

General Concepts

Nearly all of the ground water of economic importance in Dickey and LaMoure Counties is derived from precipitation. Part of the precipitation that falls on the Earth's surface is returned directly 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 capillarity and is evaporated from the soil or transpired by plants. The remainder percolates downward until it reaches the zone of saturation. When the water enters the zone of saturation, it becomes ground water and is available to wells.

Ground water moves by gravity from areas of recharge to areas of discharge. Ground-water movement generally is very slow; it may be only a few feet per year. The rate of movement is governed by the hydraulic conductivity of the material through which the water moves and by the hydraulic gradient. Well-sorted coarse materials such as gravel or coarse sand generally have a high hydraulic conductivity and form good aquifers. Fine-grained materials such as silt, clay, and shale usually have a low hydraulic conductivity and are poor aquifers. Fractures also contribute to the hydraulic conductivity of a material. Large interconnected fractures have a high hydraulic conductivity; whereas, small poorly connected fractures have a low hydraulic conductivity.

The water level in an aquifer fluctuates in response to changes in the rate of recharge to and discharge from the aquifer. Aquifers generally are recharged each spring and early summer by infiltration of precipitation either directly into the aquifers or through the overlying materials. At the present rate of use, recharge generally is sufficient to replace discharge by natural processes and by pumping of wells, although periods of several years may occur during which there are net gains or losses in ground-water storage. Aquifers that are confined by thick deposits of fine-grained materials are recharged very slowly. The rate of recharge may increase as heads in the aquifers are lowered by pumping. Head declines may continue for several years before a sufficient rate of recharge is induced to balance the rate of withdrawal. In some cases this balance may never be achieved without a curtailment of withdrawals.

Ground water in Dickey and LaMoure Counties contains dissolved mineral matter in varying amounts. Rain, as it falls, begins to dissolve mineral matter suspended in the air and continues to dissolve mineral matter as the water infiltrates through the soil. The amount and kind of dissolved minerals in water depend upon the solubility and types of rocks encountered, and other physical, chemical, and bacterial conditions that the water encounters.

The suitability of water for various uses is determined largely by the kind and amount of dissolved minerals and by the water's physical properties. The sources of the major chemical constituents, their effects on usability, and the limits recommended by the National Academy of Sciences-National Academy of Engineering (1972) are given in table 1. The chemical constituents, physical properties, and characteristics most likely to be of concern in Dickey and LaMoure Counties are iron, sulfate, nitrate, fluoride, dissolved solids, hardness, temperature, color, odor, taste, specific conductance, SAR (sodium-adsorption ratio), and percent sodium.

Numerous references are made in this report to ground-water types, such as sodium bicarbonate type or calcium bicarbonate type. These types are identified from inspection of the analyses, and represent the predominant cation(s) (sodium, calcium, or magnesium) and anion(s) (bicarbonate, sulfate, or chloride), calculated in milliequivalents per liter (Hem, 1970).

As a general reference, this report uses the following classification of water hardness (Durfor and Becker, 1964, p. 27). Hardness as used in this report refers to calcium-magnesium hardness and does not include noncarbonate hardness.

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

Two indices used to show the suitability of water for irrigation are SAR and specific conductance. The SAR is related to the sodium hazard; the specific conductance is related to the salinity hazard. These two indices are combined to make 16 classifications as shown in several illustrations further in the report. For additional information on water quality as related to irrigation, the reader is referred to "Diagnosis and Improvement of Saline and Alkali Soils" (U.S. Salinity Laboratory Staff, 1954).

Aquifer Properties

Aquifer properties — especially hydraulic conductivity, transmissivity, saturated thickness, and storage coefficient or specific yield — are used in evaluating the water-yielding properties of aquifers. These properties are used to estimate the quantity of water available from the aquifer and the yields to wells penetrating the aquifer. Aquifer properties were determined from pumping tests using methods developed by Theis (1935), Jacob (1940), and Stallman (1963).

Hydraulic conductivities of materials in the glacial-drift aquifers were estimated from lithologic logs using the following empirical values:

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

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

Constituents	Major source	Effects upon usability	National Academy of Sciences — National Academy of Engineering (1972) recommended limits for drinking water
Silica (SiO_2)	Feldspars, ferromagnesian, and clay minerals.	In presence of calcium and magnesium, silica forms a scale that retards heat transfer in boilers and on steam turbines.	
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, calcite, aragonite, dolomite, and clay minerals.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate, and silica to form scale in heating equipment. Calcium and magnesium retard the suds-forming action of soap. High concentrations of magnesium have a laxative effect.	
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, dolomite, magnesite, and clay minerals.		
Sodium (Na)	Feldspars, clay minerals, evaporites, and cation exchange with calcium and magnesium on clay minerals.	More than 50 mg/L (milligrams per liter) sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers.	
Potassium (K)	Feldspars, feldspathoids, some micas, and minerals.		
Bicarbonate (HCO_3)	Limestone, dolomite, and anaerobic processes.	Upon heating of water to the boiling point, bicarbonate is changed to steam, carbonate, and carbon dioxide. Carbonate combines with alkaline earths (principally calcium and magnesium) to form scale.	
Carbonate (CO_3)			
Sulfate (SO_4)	Gypsum, anhydrite, and oxidation or weathering of sulfide minerals in lignite.	Combines with calcium to form scale. More than 500 mg/L tastes bitter and may be a laxative.	250 mg/L
Chloride (Cl)	Halite and sylvite.	In excess of 250 mg/L may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 mg/L.	250 mg/L
Fluoride (F)	Amphiboles, apatite, fluorite, and mica.	Optimum concentration in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. Concentrations in excess of optimum may cause mottling of children's teeth.	Recommended maximum limits depend on annual average of maximum daily temperatures. Maximum limits range from 1.4 mg/L at 32°C to 2.4 mg/L at 10°C.
Nitrate (NO_3) as Nitrogen (N)	Nitrogeneous fertilizers, animal excrement, legumes, and plant debris.	More than 20 mg/L may cause a bitter taste and may cause physiological distress. Concentrations greatly in excess of 10 mg/L have been reported to cause methemoglobinemia in infants.	10 mg/L
Iron (Fe)	Natural sources: Amphiboles, ferromagnesian minerals, ferrous and ferric sulfides, oxides, carbonates, and clay minerals. Man-made sources: well casings, pump parts, and storage tanks.	If more than 100 ug/L (micrograms per liter) iron is present, it will precipitate when exposed to air causing turbidity, staining plumbing fixtures, laundry, and cooking utensils, and imparting tastes and colors to food and drinks. More than 200 ug/L iron is objectionable for most industrial uses. High concentrations of manganese cause difficulty in water-quality control.	300 ug/L
Manganese (Mn)			50 ug/L
Boron (B)	Tourmaline, biotite, and amphiboles.	Many plants are damaged by concentrations of 2,000 ug/L.	
Dissolved solids	Anything that is soluble.	Less than 300 mg/L is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	Because of the wide range of mineralization, it is not possible to establish a limiting value.

Material	Hydraulic conductivity (ft/d)	(m/d)
Gravel	330-530	100-160
Sand and gravel	260-330	80-100
Coarse sand	200	60
Medium sand	100	30
Fine sand	50	15
Very fine sand	10	3
Silt	.6-6	.2-2

Where a range is given in the above values, the lower value was used unless a high degree of sorting was indicated on the log.

The transmissivity of an aquifer at a particular site was estimated by multiplying the hydraulic conductivity by the saturated thickness of each lithologic unit and adding these products for all units in the section. If more than one aquifer is present at a site the total transmissivity is the sum of the transmissivities of the separate aquifers. Generally very fine sand and silt beds were omitted from estimates if they did not contribute more than 5 percent of the total transmissivity.

Meyer (1963, p. 338-340, fig. 100) published a chart relating well diameter, specific capacity, coefficient of storage, and transmissivity. The relation shows that for coefficients of storage less than 0.0005 and for transmissivities within the range 270 ft^2/d to 13,000 ft^2/d (25 to 1,200 m^2/d) the ratio of transmissivity to specific capacity is about 270:1. The ratio is larger for transmissivities greater than 13,000 ft^2/d (1,200 m^2/d). In most artesian aquifers the storage coefficient falls within the range of 0.00005 to 0.0005, and the graph shows that within this range large changes in the storage coefficient correspond to relatively small changes in specific capacity. Therefore, in artesian aquifers having transmissivities of as much as 13,000 ft^2/d (1,200 m^2/d) the specific capacity of an efficient, fully penetrating well of adequate diameter may be approximated by dividing the transmissivity by 270. The same chart shows that for aquifers having a greater coefficient of storage, the specific capacity will be greater with the ratio of transmissivity to specific capacity approaching 130:1 when storage coefficient values, such as are found in water-table aquifers, are greater than 0.1. The yield of a potential well at a specific site is obtained by multiplying the specific capacity by a drawdown value of 30 feet (9 m). Where 30 feet (9 m) of drawdown was not available, one-half the saturated thickness was used to obtain yield.

All of the described criteria were used to determine yields shown on plate 1 (in pocket).

GEOLOGIC UNITS AND THEIR WATER-BEARING PROPERTIES

Dickey and LaMoure Counties are underlain by rocks that range from Precambrian through Holocene (table 2) in age. The sedimentary rocks of Cretaceous and older age are about 1,000 to 1,200 feet (300 to 370 m) thick in

TABLE 2. — Generalized stratigraphy and water-yielding characteristics of geologic units in Dickey and LaMoure Counties

Age	Group	Unit name	Description	Thickness (feet)	Water-yielding characteristics
Quaternary		Alluvium and glacial drift, undifferentiated	Till, sand, gravel, silt, clay.	0-600	Yields of as much as 1,500 gal/min (95 L/s) to major aquifers.
Tertiary				Absent	
Cretaceous	Montana Group	Pierre Formation	Shale, claystone, and bentonite.	800	Yields as much as 50 gal/min (3.2 L/s) from fractures.
	Colorado Group	Niobrara Formation	Calcareous shale and siltstone.	to	Locally may yield small quantities of water.
		Carlile Formation	Shale.		Does not yield water to wells.
		Greenhorn Formation	Calcareous shale.		Does not yield water to wells.
		Belle Fourche Formation	Shale.	1,800	Does not yield water to wells.
	Dakota Group	Mowry Formation	Shale.	80	Does not yield water to wells.
		Newcastle Formation	Sandstone, shale, and siltstone.	to	Could yield as much at 600 gal/min (38 L/s), but generally yields less than 80 lal/min (5 L/s).
		Skull Creek Formation	Shale.	420	Does not yield water to wells.
		Fall River Formation and Lakota Formation, undifferentiated	Sandstone and shale.	35 to 276	Could yield as much as 1,000 gal/min (63 L/s), but generally yields less than 100 gal/min (6 L/s).
Jurassic		Morrison Formation	Siltstone and claystone.	0-150	Not known to yield water.
Triassic					
Permian				Absent	
Pennsylvanian					
Mississippian		Madison Formation	Limestone.	0-350	May contain some available water in joints and caverns.
Devonian		Duperow Formation	Dolomite and shale.	0-75	Does not yield water.
Silurian				Absent	
Ordovician		Red River Formation	Limestone and dolomite.	0-550	May contain some water in joints and small caverns.
	Winnipeg Group	Roughlock Formation	Shale, siltstone, and sandstone.	0	Locally may yield small quantities of water.
		Icebox Formation	Shale.	to	Not known to yield water.
		Black Island Formation	Sandstone, siltstone, and shale.	220	May yield as much as 700 gal/min (44 L/s).
Cambrian		Deadwood Formation	Sandstone and limestone.	0-90	Will yield water from sandstone.
Precambrian basement rocks.			Schist and granite.	—	

the southeastern part of the area and are as much as 3,950 feet (1,200 m) in the western part of the area. These rocks dip west-northwest into the Williston basin. Unconformably overlying the Cretaceous rocks is a muntle of glacial drift that is as much as 600 feet (180 m) thick.

Geologic units that contain aquifers of economic importance in Dickey and LaMoure Counties are: (1) Black Island Formation[1] of Ordovician age; (2) Lakota, Fall River, and Newcastle Formations of Early Cretaceous age; (3) Pierre Formation of Late Cretaceous age; and (4) glacial drift of Quaternary age.

Ground Water in Rocks of Pre-Cretaceous Age

The uppermost sedimentary rocks of pre-Cretaceous age generally are more than 1,200 feet (370 m) below lsd (land surface datum) in the east-central part of the area and are as much as 2,500 feet (760 m) below lsd in the western part. Pre-Cretaceous sedimentary rocks are missing in the southeastern part of Dickey County where the Cretaceous sedimentary rocks directly overlie the Precambrian granite or schist (fig. 3).

Geophysical and sample logs from five oil-test holes located at 129-063-11BD (Strasburg, 1954), 129-066-22BB, 130-063-34DD, 133-064-18BB, and 133-066-09CC (Anderson, 1953), indicate that the pre-Cretaceous sedimentary rocks are composed principally of limestone, shale, sandstone, siltstone, and some dolomite (table 2). Some of the limestone is reported to be porous and may contain joints and caverns. Locally the limestone units may yield small to large quantitites of water. Three Cambrian or Ordovician sandstone units that are sufficiently permeable to yield water occur in the western part of Dickey and LaMoure Counties. These units are in the Deadwood, Black Island, and Roughlock Formations.

The sandstones in the Deadwood and Roughlock Formations probably would yield some water, but data are insufficient to determine hydrologic properties or the quality of water. The Deadwood and Roughlock Formations probably are present in the central and northeastern parts of the counties also, but data are insufficient for identification.

Black Island Aquifer

The Black Island Formation of the Winnipeg Group of Ordovician age ranges in depth from 1,421 feet (433 m) in eastern LaMoure County to 3,000 feet (910 m) in southwestern Dickey County. It is as much as 140 feet (43 m) thick and is composed of interbedded sandstone, siltstone, and shale (Steven Harris, oral commun., 1976). Anderson (1953) described 110 feet (34 m) of fine to medium sandstone and shale in the Winnipeg sand in an oil test drilled at

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

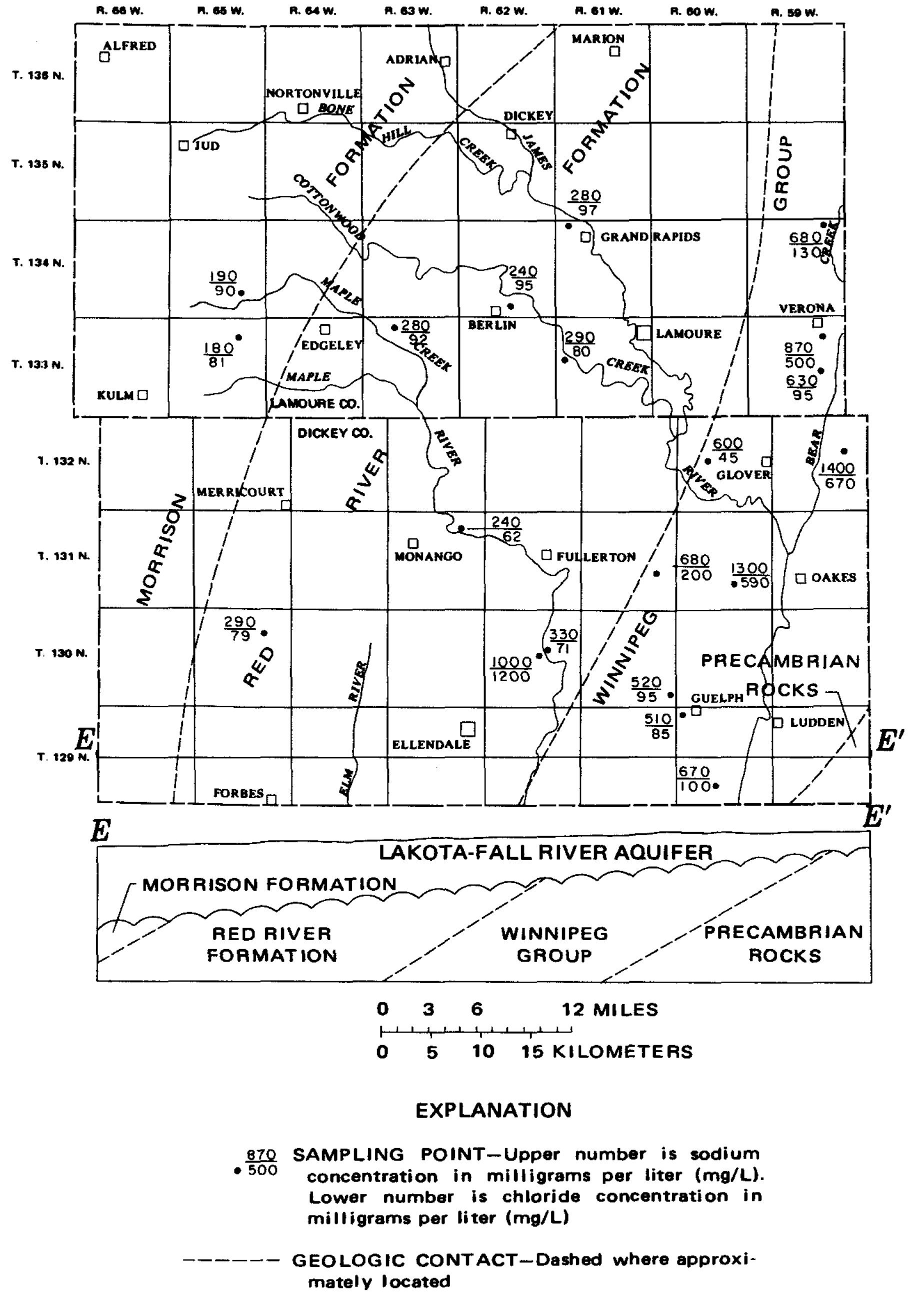


FIGURE 3.—Subcrop map of pre-Cretaceous rocks and concentrations of sodium and chloride ions in the overlying Lakota-Fall River aquifer.

133-065-12BAA. The lower 80 feet (24 m), however, is glauconitic and probably is part of the Deadwood Formation. Electrical logs of two oil tests, one at 130-063-34DD and one at 129-066-22BB, indicate that individual sandstone beds in the Black Island Formation are as much as 18 feet (5.5 m) thick and aggregate sandstone thicknesses are as much as 57 feet (17 m).

The mean hydraulic conductivity of the Black Island aquifer, based on the grain size, is about 80 ft/d (24 m/d); however, using a method described by Croft (1971, p. B265-B269), the mean hydraulic conductivity calculated from the two electrical logs is about 100 ft/d (30 m/d). Because of uncertainties of temperature corrections using Croft's method, the mean hydraulic conductivity of 80 ft/d (24 m/d) is assumed to be more nearly correct. The transmissivity of the aquifer is estimated to be about 2,000 ft^2/d (190 m^2/d) and the specific capacity of a properly constructed well at least 8 inches (203 mm) in diameter should be about 7 (gal/min)/ft [1.5 (L/s)/m] of drawdown. Thus, yields should be about 700 gal/min (44 L/s) with 100 feet (30 m) of drawdown.

Well 129-063-14BAD is the only well known to be finished in the Black Island aquifer in Dickey and LaMoure Counties. The well provides water for about 10 homes in the southwestern part of Ellendale. Various reports indicate that in 1954 the well flowed at a rate between 700 and 1,000 gal/min (44 and 63 L/s) through a 5-inch (127-mm) pipe with a pressure of about 450 lbf/in^2 (3,100 kPa). M. O. Lindvig (1965, p. 11) reported that by 1965, the pressure had declined to about 40 to 60 lbf/in^2 (276 to 414 kPa). However, Lindvig's estimate was made at one outlet when any one of several outlets may have been open, so his estimate probably is low. The well still is capable of flowing at a rate of more than 100 gal/min (6 L/s) but, because of valves and restricting pipe diameters, the flow generally is small.

Well 134-059-01CCB, reportedly completed in the Dakota Group, probably is finished in a Winnipeg sandstone — possibly the Black Island aquifer. The pressure at the well was about 100 lbf/in^2 (690 kPa) when it was drilled in 1968.

The source of recharge for the Black Island aquifer is not known, but it probably occurs, at least in part, in the outcrop areas in the Black Hills. If wells 129-063-14BAD and 134-059-01CCB are finished in the same or in a connected horizon, the apparent movement of water across the two-county area is in a northeasterly direction. Discharge is by movement into the adjacent counties to the east and northeast and by leakage into the overlying beds.

Water from the Black Island aquifer in the study area is very hard and is a sodium sulfate type. In 1974 and 1976 the dissolved-solids concentrations in the water from well 134-059-01CCB were 2,590 and 2,520 mg/L; sodium, sulfate, and chloride concentrations were 830 and 820, 980 and 1,000, and 480 and 490 mg/L, respectively. The iron concentrations were 0 and 200 ug/L. In 1977 a sample from well 129-063-14BAD contained 3,800 mg/L dissolved solids; sodium, sulfate, and chloride concentrations were 1,200, 1,700, and 680 mg/L, respectively. The iron concentration was 3,500 ug/L. In 1964 a sample from the same well contained only 900 ug/L iron. The difference probably is due to greater solution of iron from the well casing. The water samples taken during this investigation contained 91 and 90 percent sodium and had SAR values of 33 and 32.

Ground Water in Rocks of Cretaceous Age

Aquifers in the Dakota Group

The Dakota Group of Early Cretaceous age underlies all of Dickey and LaMoure Counties. Aquifers in the Dakota Group occur in the Lakota and Fall River Formations, undifferentiated, locally known as the third flow, and in the Newcastle Formation, locally known as the first and second flows. However, if any of the aquifers is thin or missing, there is uncertainty as to which aquifer a well might be completed in.

Lakota-Fall River aquifer

The Lakota Formation was deposited on an erosional surface of Precambrian granite in the extreme southeastern corner of Dickey County, on the formations in the Winnipeg Group and Red River Formation in the eastern and central parts of Dickey and LaMoure Counties, and on the Morrison Formation in the western part of the two counties (fig. 3). The Fall River Formation was in turn deposited on the Lakota Formation. The two formations are similar and have not been differentiated in this report. The irregular erosional surface causes considerable differences in the thickness of the Lakota-Fall River interval and locally there may have been areas of nondeposition.

The Lakota-Fall River aquifer in Dickey and LaMoure Counties ranges in depth from about 1,100 feet (335 m) in the southeast part of Dickey County to 2,200 feet (670 m) in the western part of LaMoure County. The aquifer, although locally missing, generally ranges in thickness from about 35 feet (11 m) in the eastern part of the area to 276 feet (84 m) in the western part and has a mean thickness of about 106 feet (32 m).

Using a method described by Croft (1971, p. B265-B269), the hydraulic conductivities calculated from electrical logs of five oil-test sites in the western half of the area ranged from 80 to 180 ft/d (24 to 55 m/d). Because of the uncertainty of aquifer temperatures, which are critical in Croft's method, these conductivities may be in error by as much as 20 percent. Transmissivities estimated for the five sites ranged from about 12,000 to 22,000 ft^2/d (1,100 to 2,000 m^2/d). Assuming that similar hydraulic conductivities exist in the eastern part of the study area where the aquifer is thinner, transmissivities may be as low as 2,800 ft^2/d (260 m^2/d). Therefore, the 24-hour specific capacities of properly constructed wells should range from about 1.5 to 82 (gal/min)/ft [0.3 to 17 (L/s)/m] of drawdown. The larger specific capacities would be in the western part of the area where the aquifer thicknesses are greater.

The first well drilled into the Lakota-Fall River aquifer in the two-county area was completed at a depth of 1,363 feet (415 m) at Ellendale in 1908 (Simpson, 1929). The well flowed at a rate of 800 gal/min (50 L/s) through a 3-inch (76-mm) casing at a pressure of 196 lbf/in^2 (1,350 kPa). Simpson (1929) reported that by 1923 the pressure had declined to not more than 60 lbf/in^2 (414 kPa). Officials of the city of Ellendale reported that the well eventually ceased to flow and was destroyed before 1974.

Measurements made during this study indicate water levels in the Lakota-Fall River aquifer will rise to an altitude of about 1,650 feet (503 m) above NGVD 4 miles (6 km) west of Fullerton and 1,560 feet (475 m) about 8 miles (13 km) north-northeast of Oakes. These measurements indicate an apparent gradient of about 4 ft/mi (0.8 m/km) in an easterly direction.

Yields from wells completed in the Lakota-Fall River aquifer generally are less than 10 gal/min (0.6 L/s) because the wells are constructed with small-diameter pipe. Locally in the western part of the two-county area potential yields of as much as 1,000 gal/min (63 L/s) should be obtainable; however, in order to obtain this yield, large-diameter wells would have to be constructed and screened in the entire aquifer to reduce head and friction losses. In the eastern part of the area potential yields were not estimated because of lack of dependable data.

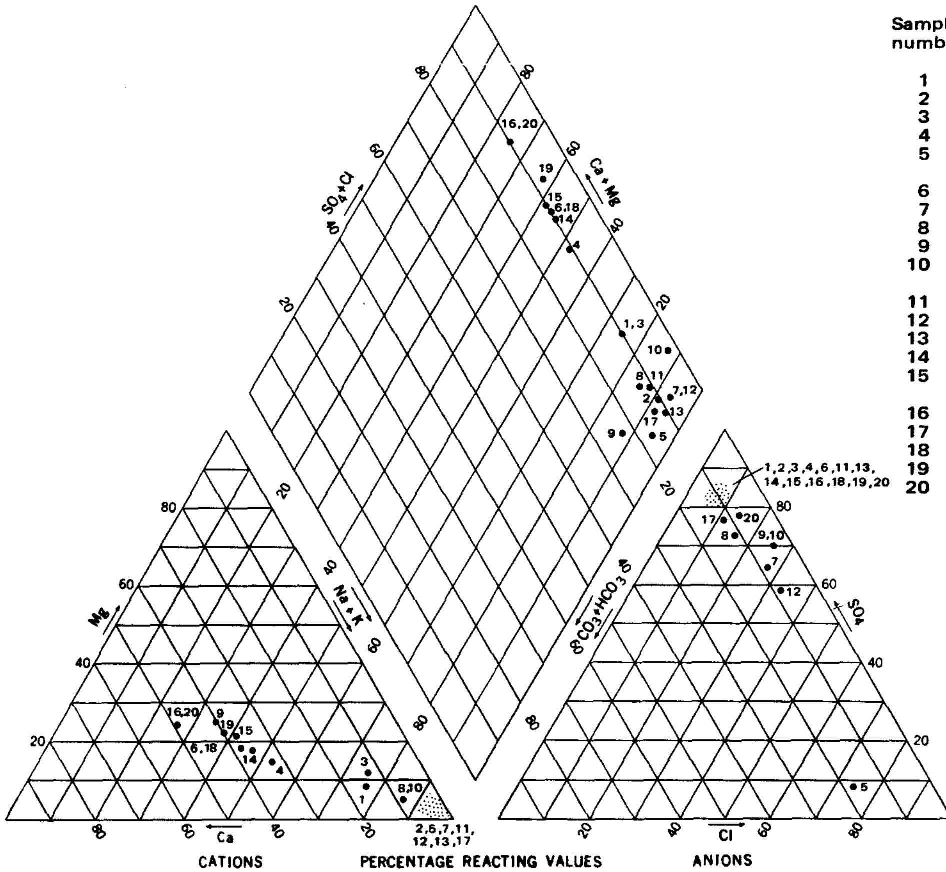
Recharge to the aquifer apparently occurs in the Black Hills area of South Dakota (Darton, 1909) and by upward migration of water from underlying aquifers (Swenson, 1968). The great variations in water quality in the Lakota-Fall River aquifer also indicate that there is considerable upward leakage from the underlying Ordovician and possibly from Jurassic beds in the northwest. The only known discharge from the aquifer is by wells. However, there probably is considerable lateral discharge of water from Dickey and LaMoure Counties eastward into Ransom and Sargent Counties and probably northeastward into Barnes and Stutsman Counties. Also some upward migration of water into the lower Newcastle aquifer may occur.

Water from the Lakota-Fall River aquifer in Dickey and LaMoure Counties is either a sodium sulfate, a calcium sulfate, or a sodium chloride type (fig. 4). Generally, the proportion of sodium to calcium and chloride to sulfate increases from west to east (fig. 3) and with depth. Much of the increase in the proportion of sodium to calcium from west to east probably is due to ion exchange on clay particles; however, the increase with depth probably is due to upward movement of water from the underlying Red River Formation and Winnipeg Group.

Dissolved-solids concentrations in water samples from 20 wells ranged from 2,030 to 4,850 mg/L. The mean concentration was 2,410 mg/L. All samples containing more than the mean concentration were from the lower part of the aquifer. Sodium concentrations ranged from 180 to 1,400 mg/L and had a mean of 560. Sodium ranged from 24 to 94 percent of the cations present. Sulfate concentrations ranged from 200 to 2,400 mg/L and had a mean concentration of 1,260 mg/L. Hardness ranged from 68 to 1,200 mg/L and had a mean of 540 mg/L. Iron concentrations ranged from 290 to 10,000 ug/L. Most of the large variation in the quantity of iron in the samples probably is due to variations in dissolved iron in the aquifer, but some may be due to electrolytic and chemical reactions of the water with the steel pipe in the wells. Sampling techniques may also have caused some of the variation.

The samples had SAR values that ranged from 2.3 to 43 and irrigation classifications that generally ranged from C4-S1 to C4-S4; one sample was classified C3-S2 (fig. 5), and four samples were too high to be classified.

The water is used locally for domestic and stock purposes. Some residents use the water for their drinking water supply and report no ill effects; however,



Sample number	Well location	Dissolved solids (mg/L)
1	129-060-06CCA	2050
2	129-060-28CCB	2190
3	130-061-25ACA	2040
4	130-062-15ADB	2050
5	130-062-15CBB	2740
6	130-065-11CAB	2040
7	131-060-27ABA	3990
8	131-061-23DDC	2310
9	131-063-11CCB	2070
10	132-059-14ACA	4850
11	132-060-17DAA	2080
12	133-059-11AAB2	2810
13	133-059-23BCC	2100
14	133-061-18ACB	2030
15	133-063-05ADD	2170
16	133-065-11DAC	2210
17	134-059-02AAA	2060
18	134-061-06DCA	2140
19	134-062-34CAA	2070
20	134-065-26CDC	2290

FIGURE 4.—Distribution of common cations and anions in the Lakota-Fall River aquifer.

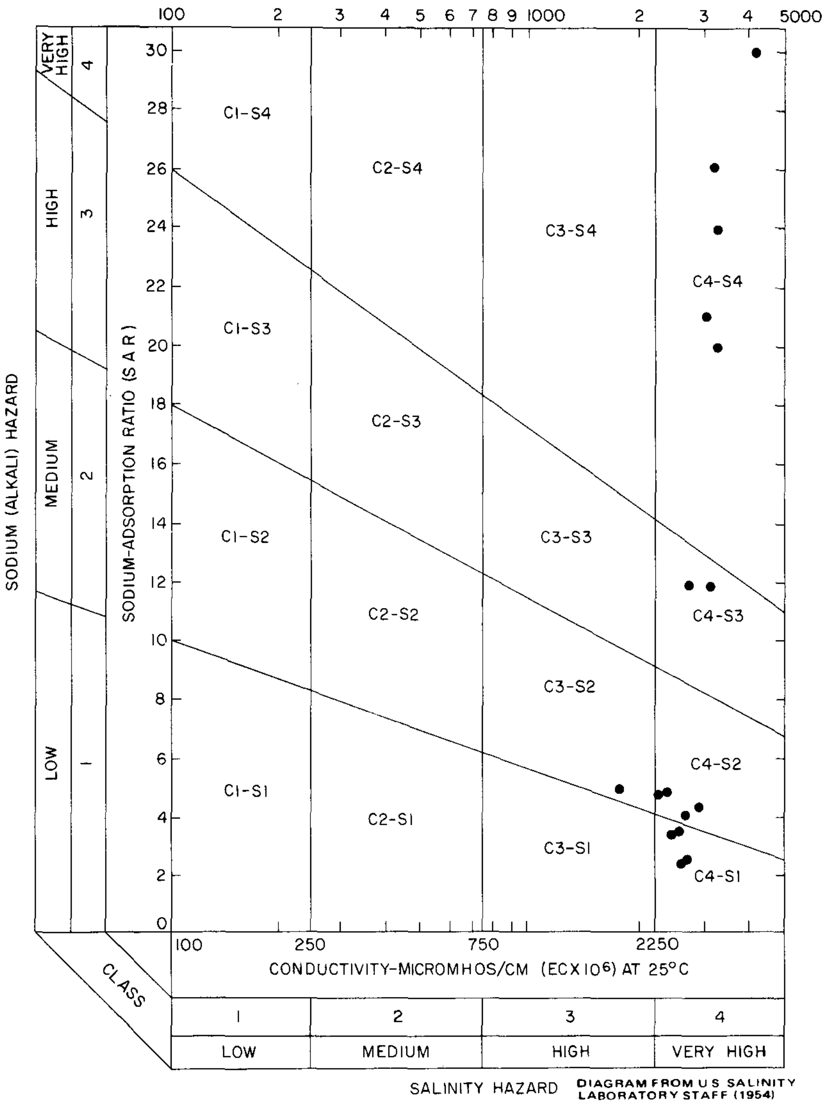


FIGURE 5.—Irrigation classifications of water from the Lakota-Fall River aquifer.

persons not used to drinking the water generally report having some intestinal discomfort.

Newcastle aquifer system

The Newcastle Formation underlies all of Dickey and LaMoure Counties. According to Hard (1929, p. 14) depths to the top of the formation range from 790 feet (240 m) near Oakes to more than 2,000 feet (610 m) in the western part of the area. However, an electrical log of an oil test at 133-066-09CCC in southwestern LaMoure County shows the top of the Newcastle to be at a depth of only 1,788 feet (545 m). Comparison of the top of the Newcastle on this log with the corresponding top on the log of an oil test at 133-064-18BB (about 10 miles east) indicates an apparent dip of about 8 ft/mi (1.5 m/km) to the west. The actual dip probably is about 9 to 12 feet/mi (1.7 to 2.3 m/km) northwestward toward the center of the Williston basin in McKenzie County, N. Dak.

The Newcastle Formation consists of complex deposits made up of deltaic, beach, and other marine sediments as well as brackish and fresh-water fluvial and deltaic deposits. The result is a series of interbedded sand, silt, and clay lenses, most of which have been indurated or partially indurated into sandstone, siltstone, and shale beds. Hard (1929, p. 15) states that "the Dakota consists of a great number of layers that range from a few inches to 100 feet or more in thickness and differ widely in shape and permeability. Some are uniform in thickness; others thin out and disappear altogether; some are lens-shaped. They range from coarse-grained porous sand to fine compact sand; some beds are so thoroughly consolidated and hard***; others are so loose as to cave in or rise as slush from the drill." For the most part Hard's discussion of the "Dakota" refers to what is now considered the Newcastle Formation.

The thickness of the Newcastle Formation determined from five electrical logs ranged from 135 to 300 feet (41 to 91 m). The thickness indicated on 25 partial drillers' logs (Armstrong, 1978, table 4) ranged from 10 to 168 feet (3 to 51 m) and had a mean of 93 feet (28 m). The partial logs were determined primarily from drilling time and the feel of the drilling rig. They probably represent only the aquifer parts of the Newcastle Formation and do not include any thick indurated, clayey or silty sandstones or shale that may exist in the upper or lower parts of the formation because the drillers generally pick the top and bottom of the sandstone as the top and bottom of the formation.

Although the Newcastle Formation is composed of many lenticular beds of sandstone, some of which may or may not be connected hydraulically, the formation generally is considered to be a system divided into two recognizable aquifers separated by relatively thick confining beds composed of siltstone or shale. Siltstone and shale beds only a few feet thick generally are included as part of the aquifers. Most of the "Lakota Formations" shown on the partial drillers' logs are in the lower aquifer of the Newcastle system.

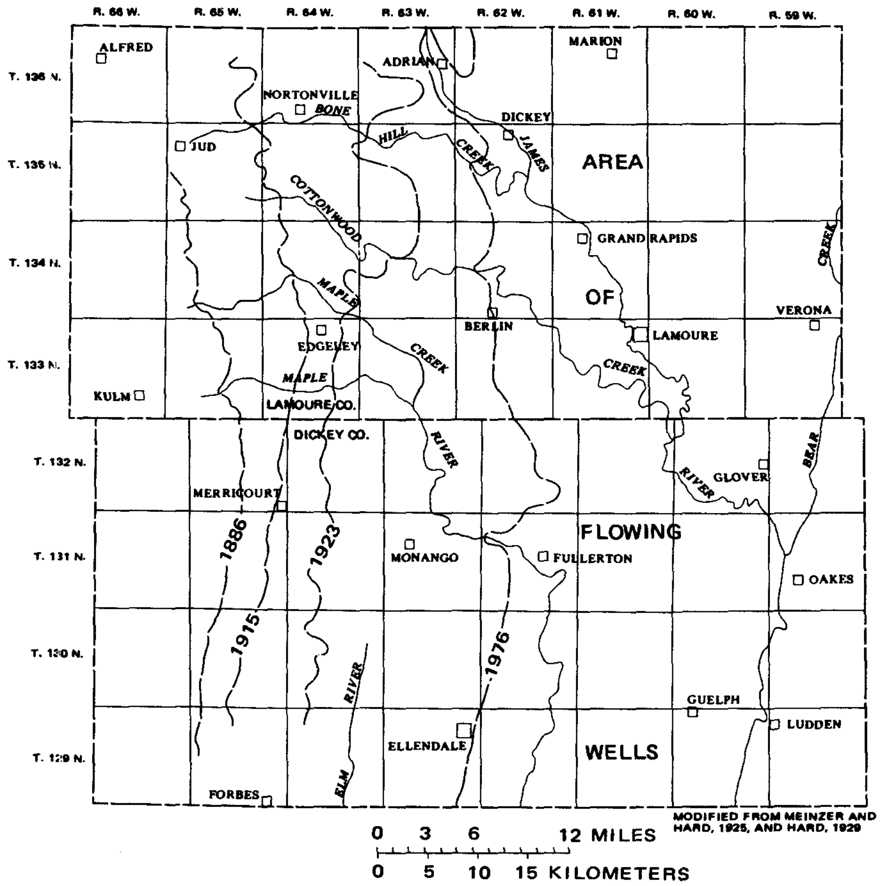
The transmissivity of the aquifers in the Newcastle system varies from place to place because of variations in thickness and hydraulic conductivity. Hydraulic conductivities determined from electrical logs generally are in the 10 to 50 ft/d (3 to 15 m/d) range, but a few beds 1 to 5 feet (0.3 to 1.5 m) thick have hydraulic conductivities of about 100 ft/d (30 m/d). The hydraulic conductivities determined from the electrical log of oil test 133-066-09CC are lower than those for oil test 133-064-18BB to the east and south. The oil test at 133-066-09CC apparently is in a transition area between most of Dickey and LaMoure Counties where parts of the Newcastle Formation are considered to be a good aquifer and Logan and McIntosh Counties where the formation is not considered a usable aquifer. Hard (1929, p. 64) determined that the specific capacity of 23 wells ranged from 0.9 to 3.6 (gal/min)/ft [0.2 to 7.5 (L/s)/m] of drawdown. Using the determined specific capacities as a basis, the transmissivities should range from 25 to 1,000 ft^2/d (2.3 to 93 m^2/d). Wenzel and Sand (1942, p. 44) calculated a coefficient of storage of 0.0011, which indicates some leakage into the aquifer.

Most wells that flow from the upper aquifer generally have only a few feet of head and flow at less than 10 gal/min (0.6 L/s). If the wells were pumped, larger yields could be obtained. Some wells in the eastern part of LaMoure County reportedly finished in the lower aquifer have as much as 50 feet (15 m) of head and are reported to have flowed at rates as high as 80 gal/min (5 L/s), but now are controlled to flow less than 10 gal/min (0.6 L/s). Depths of some of these wells, however, indicate they may be finished in the Lakota-Fall River aquifer. Wells that do not flow are pumped; generally they are in use intermittently and yield from 5 to 20 gal/min (0.3 to 1.3 L/s).

The major source of recharge to the Newcastle aquifer system probably is west of the study area because the head in the aquifer system decreases in an easterly direction. Higher heads in the underlying Lakota-Fall River aquifer suggest that leakage also contributes some recharge. The rate of recharge from all sources cannot be ascertained, but Hard (1929, p. 66) stated "***the rate of recharge or eastward percolation is about equal to the 417 gallons a minute estimated by Simpson as the quantity needed for present beneficial use***." This quantity amounts to about 3,300 gal/min (208 L/s) across the two-county area. Whatever the actual quantity of recharge is, the present discharge is greater than recharge.

In 1886 wells tapping the aquifer system would flow as far west as the lower slopes of the Coteau du Missouri. Since then the cones of depression caused by the flows have spread and coalesced causing the potentiometric surface to continually decline. Hence, the area in which wells flow has continually decreased in size (fig. 6). Wells finished in the lower aquifer have a higher head and will flow a few miles west of the 1976 line shown in figure 6.

The decreases in heads are apparent throughout the Newcastle aquifer system. Hard (1929) reported that the original head in a well in the aquifer at Ellendale in 1886 was either 402 or 333 feet (123 or 101 m) above lsd; 1,854 or 1,785 feet (565 or 544 m) above NGVD. He apparently believed the lower figure most likely to be correct. Nettleton (1892, table opposite p. 74) reported that the head had declined to 264 feet (80 m) by 1890. By 1964, the water level in a nearby well, 129-063-12DBA, believed to tap the same horizon, had decreased to land surface (M. O. Lindvig, oral commun., 1978). In August 1977,



EXPLANATION

—1886— WESTERN LIMIT OF FLOWING WELLS AND YEAR OF LIMIT

FIGURE 6.—Area in which wells tapping the Newcastle aquifer system flowed at land surface, 1886, 1915, 1923, and 1976.

the water level was 5 feet (1.5 m) below lsd at an altitude of about 1,452 feet (443 m) above NGVD. Thus, there has been a total decrease in head of at least 333 feet (101 m) since 1886. The head in a well in Edgeley was about 138 feet (42 m) above lsd at an altitude of about 1,690 feet (515 m) in 1892. By 1919 the head had dropped to about 15 feet (4.6 m) below lsd at an altitude of about 1,537 feet (468 m; Simpson, 1929, p. 152). The large head declines during the early years of development were caused primarily by the large withdrawals of water from storage, but some of the decline probably was caused by the loss of gas pressure. Water-level measurements in well 134-064-24DC between 1964 and 1976 indicate that the head decline had ceased or become unnoticeable near the well. The rate of head decline has slowed or stopped in areas where wells no longer flow and only small quantities of water are discharged by pumping.

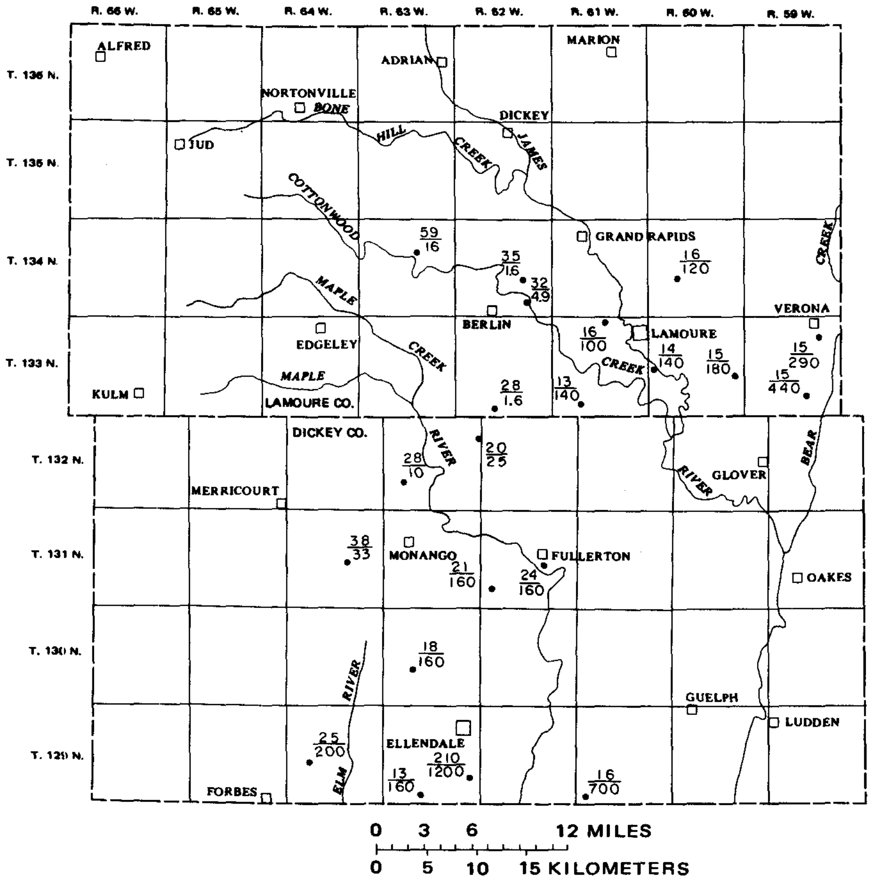
Water-level data collected during this investigation were compared to data from Hard (1929, p. 58). The comparison indicates a change has occurred in the direction and slope of the potentiometric surface. In 1976 the head in well 134-064-24DC, about 3 miles (4.8 km) northeast of Edgeley, was at an altitude of about 1,550 feet (472 m) above NGVD; the water level in well 134-062-33BCD at Berlin was at land surface, approximately 1,465 feet (447 m); and the water level in well 131-062-15ACB at Fullerton was reported to be near land surface, which is at an altitude of 1,440 feet (439 m). These heads indicate that the slope of the potentiometric surface has changed from about 4 ft/mi (0.76 m/km) to the east as reported by Hard (1929, p. 58) to about 10 ft/mi (1.9 m/km) to the southeast. The change in direction of slope probably is caused by the combined flow from wells that are more concentrated in the area east of Ellendale and south of LaMoure.

Water from the upper aquifer generally is a sodium chloride type. Even though sodium and chloride are predominant, there appears to be a pattern of distribution of the calcium and sulfate concentrations. In LaMoure County the concentration of calcium generally decreases from west to east (fig. 7), possibly because of ion exchange on clay particles, and the sulfate concentrations increase. In Dickey County the decrease of calcium from west to east is not as apparent, but the concentration of sulfate generally does increase. The probable source of the calcium and sulfate is upward leakage from the lower aquifer. The water from the lower aquifer is a sodium sulfate type.

Dissolved-solids concentrations in 27 water samples obtained from the aquifer system ranged from 2,060 to 4,590 mg/L and had a mean of 2,700 mg/L; however, only three of the samples contained more than 3,000 mg/L. The greater concentrations of dissolved solids occurred in the upper aquifer. Sodium concentrations ranged from 330 to 1,900 mg/L and had a mean of 960 mg/L. Only one sample contained more than 1,200 mg/L sodium. Sodium ranged from 47 to 96 percent of the cations, and had a mean of 92 percent. Sulfate concentrations ranged from 1.6 to 1,200 mg/L and had a mean of 415 mg/L. Concentrations of sulfate exceeded the mean in nine samples. Chloride concentrations generally ranged from 67 to 130 mg/L in the lower aquifer and 380 to 2,700 mg/L in the upper aquifer. However, 17 of 21 samples from the upper aquifer contained chloride concentrations in the 990 to 1,400 mg/L range. Hardness ranged from 59 to 770 mg/L and had a mean of 132 mg/L. Only one sample had a hardness greater than 240 mg/L. Iron concentrations in the samples ranged from 0 to 6,400 ug/L and had a mean of 1,124 ug/L. The large variations in iron concentrations in the samples probably are due to both variations in the aquifer system and pipe corrosion.

The samples had SAR values that ranged from 5.2 to 62. One sample had an irrigation classification of C4-S2 and three others had a C4-S4 classification; the other 23 were too high to be classified.

The water is used locally for domestic and stock use and as public supplies in Fullerton, Ludden, and Verona.



EXPLANATION

16/120 SAMPLING POINT—Upper number is calcium concentration in milligrams per liter (mg/L). Lower number is sulfate concentration in milligrams per liter (mg/L)

FIGURE 7.—Concentrations of calcium and sulfate ions in the upper Newcastle aquifer.

Pierre Aquifer

The Pierre Formation directly underlies the glacial drift in the western two-thirds of Dickey County, and all of LaMoure County except the southeastern corner where the Niobrara Formation underlies the drift (fig. 8). The relationship between the Niobrara or Pierre Formations and the glacial drift is shown on plate 2 (in pocket). The Pierre consists of as much as 600 feet (180 m)

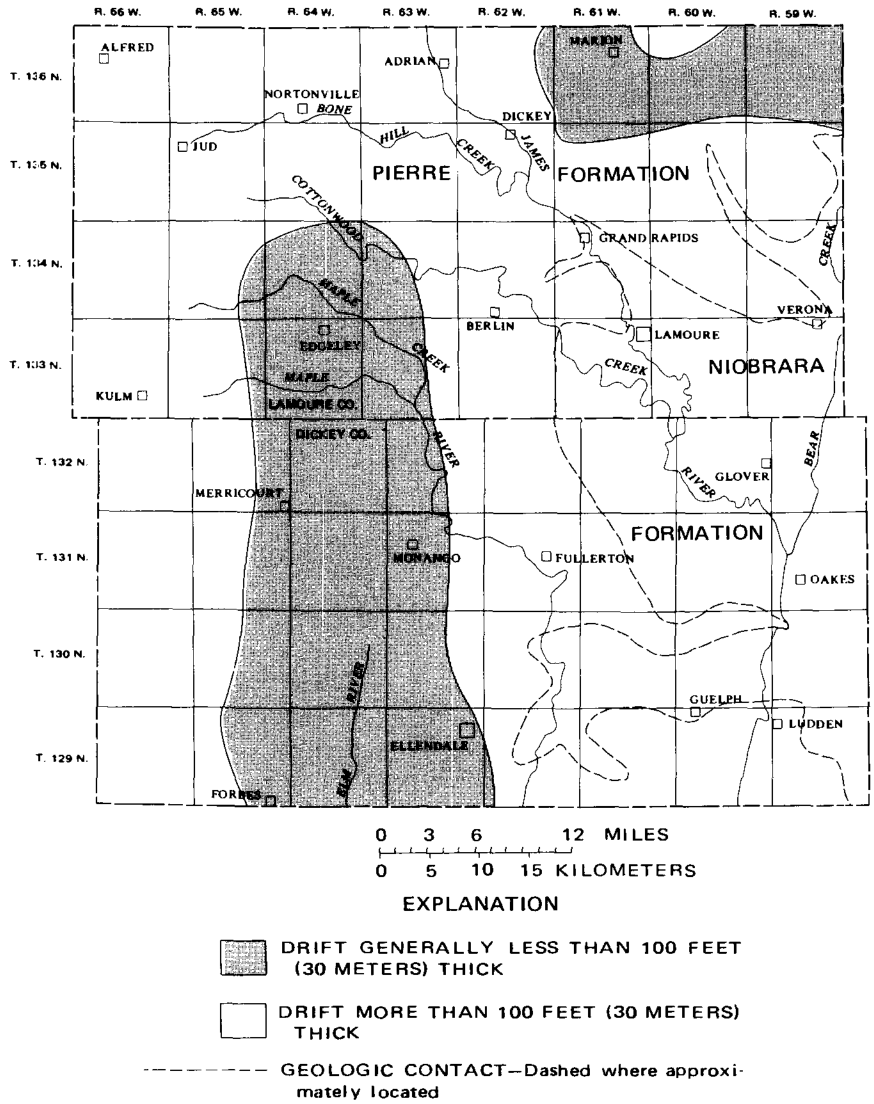


FIGURE 8.—Bedrock geology map showing areas of thin glacial drift.

of black shale and claystone with some yellowish to white bentonite layers, which are most common in the lower part of the formation.

The Pierre Formation crops out locally or is overlain by thin deposits of glacial drift that are less than 100 feet (30 m) thick in the northeastern and southwestern parts of LaMoure County and in west-central Dickey County. The upper part of the Pierre Formation consists of a black fissile fractured shale, which forms an aquifer. The fractures generally are larger and more common in the upper 10 to 50 feet (3 to 15 m) of the shale and become smaller with depth. However, they may extend more than 100 feet (30 m) into the formation. In areas where the glacial drift is thin or missing, the Pierre aquifer is a major source of water for many of the farms. Elsewhere in the two-county area the Pierre aquifer supplies water to a few scattered wells.

Generally yields greater than 5 gal/min (0.3 L/s) should not be expected from wells tapping the Pierre aquifer, and continuous pumping at higher rates will cause excessive declines in water levels. Locally, however, in the area of thin drift the fracture system appears to be somewhat better developed and yields as high as 50 gal/min (3 L/s) can be obtained.

Recharge to the Pierre aquifer is derived mainly from vertical leakage through the overlying glacial drift. In areas where the fracture system is within a few feet of the land surface or has a close hydraulic connection to the glacial drift, water is able to move rather quickly into the shale and along the fractures towards areas of discharge, which generally are the nearest well or stream valley. In such areas, water-level fluctuations in the shale are closely related to periods of precipitation. Where the fracture system is poorly developed, water will move very slowly through the shale from areas of recharge to areas of discharge. Water-level fluctuations generally are small in areas where the fracture system is poorly developed. However, pumping only small quantities of water in these areas may create large cones of depression, and water-level declines would be greater than in a sand aquifer of comparable size.

Six water samples were obtained from Pierre wells during this investigation; two were sodium-magnesium sulfate type, one was sodium sulfate type, one was sodium chloride type, one was sodium bicarbonate-chloride type, and one was sodium chloride-bicarbonate type. Dissolved-solids concentrations ranged from 1,400 to 8,630 mg/L and had a mean of 3,500 mg/L. Sodium concentrations ranged from 300 to 1,200 mg/L and had a mean of 790 mg/L. The sodium concentrations ranged from 40 to 90 percent of the cations present. Sulfate concentrations ranged from 48 to 4,200 mg/L and had a mean of 1,300 mg/L. Chloride concentrations ranged from 67 to 1,600 mg/L and had a mean of 710 mg/L. Hardness ranged from 200 to 3,900 mg/L. Iron concentrations ranged from 40 to 480 ug/L.

The samples had SAR values that ranged from 5.5 to 33 and irrigation classifications of C4-S2, C4-S3, and C4-S4. Two samples had values that were too high to be classified.

The better quality water generally is used for all stock and domestic purposes, while the poorer quality water generally is used for stock and sanitation purposes.

Ground Water in Rocks of Quaternary Age

Dickey and LaMoure Counties are mantled by rocks of Quaternary age (glacial drift and alluvium), except locally where the Pierre Formation crops out. Glacial drift ranges from less than 100 feet (30 m) thick in the thin drift area shown in figure 8 to as much as 594 feet (181 m) in the Coteau du Missouri area in the northwestern part of LaMoure County.

The glacial drift in Dickey and LaMoure Counties may be divided into two main types based on lithology and inferred origin. The types are till and glacioaqueous deposits. Till is deposited from glacial ice by dumping, pushing, lodgment, and ablation. The composition of the till depends largely upon the type of rock over which the glacial ice had moved. It is a nonsorted, nonstratified sediment that consists of a mixture of clay, silt, sand, gravel, and boulders. Over a large area the percentages of each type of material in the till may vary considerably.

The glacioaqueous deposits are composed largely of sand and gravel that has been sorted and stratified by glacial melt water. Locally, the deposits may consist of stratified silt and clay. The glacioaqueous deposits occur as (1) sediments in preglacial and interglacial valleys buried by till, (2) surficial outwash sediments, (3) deltaic and lake sediments, and (4) isolated pockets of sand and gravel surrounded by clay or till.

Alluvial deposits generally are composed of sand, gravel, and silt that have been sorted and deposited by streams. They are similar in composition to outwash deposits, which were sorted and deposited by glacial melt water. In this report the glacial drift and alluvium are not differentiated.

The glacial-drift aquifers with the greatest potential for development of large supplies of water in Dickey and LaMoure Counties are those associated with buried valleys, surficial outwash deposits, and deltaic and lake sediments.

For convenience of discussion, identification, and future reference, aquifer names are continued from adjacent areas where the aquifers had been previously identified. Newly recognized aquifers are named after local geographic features.

Where sufficient geohydrologic data are available, an estimate of ground water available from storage is given. The estimates are based on static conditions and do not take into account recharge, natural discharge, or ground-water movement. The aquifers are lenticular in cross section, thus, the largest well yields are obtainable only by developing the thickest parts, and by screening the entire section.

Spiritwood Aquifer System

The Spiritwood aquifer system, originally named by Huxel (1961), is the largest glacial-drift aquifer in the two-county area. The system is comprised of glaciofluvial materials that were deposited in a drainage system that once extended across much of the northern and east-central part of North Dakota. The aquifer materials, consisting of sand, gravel, and silt, were deposited in a valley by water flowing in channels. The less permeable materials were deposited on the flood plains. After a channel was filled, water was diverted to a new channel, which in turn was filled. This process of deposition continued until the lower parts of the valley were filled. Locally, low divides between the channels also were buried. One of these divides forms a persistent barrier about 14 miles

(23 km) long separating two channels in the Spiritwood aquifer system. Other shorter barriers also exist. These barriers are shown as 0 to 50 gal/min (0 to 3 L/s) yield areas within the Spiritwood aquifer system (pl. 1). The mode of deposition together with known anomalous areas indicate that the Spiritwood aquifer system is much more complex than can be shown with available data.

Most tributary valleys appear to be only a few miles in length. One, however, extends from the vicinity of sec. 21, T. 131 N., R. 59 W. southward to near Ludden, thence to South Dakota (pl. 1), where it is considered part of the Deep James aquifer (Koch and others, 1973).

The glaciofluvial phase of deposition was followed by the deposition of glacial till. Isolated deposits of sand and gravel are interspersed in the overlying till but apparently are not hydraulically connected to the underlying aquifer.

In the study area the aquifer system extends from T. 136 N., Rs. 62 and 63 W. in the north-central part of LaMoure County to T. 131 N., R. 59 W. in east-central Dickey County (pl. 1). The aquifer system ranges from about 3 to 9 miles (4.8 to 14 km) in width, is as much as 304 feet (93 m) deep, and underlies about 195 mi^2 (505 km^2) in Dickey and LaMoure Counties.

The Spiritwood aquifer system consists of lenticular deposits of sand and gravel interbedded with clay and silt. It ranges in thickness from less than 1 foot (0.3 m) at the edges to 137 feet (93 m), and has a mean aggregate thickness of about 50 feet (15 m).

A 100-hour aquifer test was made on the Spiritwood aquifer system northeast of Oakes using a 199-foot (60.7-m) irrigation well at 131-059-22ABC and four observation wells spaced at 100 and 500 feet (30 and 150 m) south and 250 and 1,000 feet (76 and 305 m) north of the pumped well. The pumping rate was maintained at 870 gal/min (55 L/s). Analyses of the test (R. B. Shaver, written commun., 1977), using methods developed by Theis (1935) and Jacob (1940), obtained transmissivity values ranging from 18,500 to 31,700 ft^2/d (1,720 to 2,900 m^2/d) and storage coefficients ranging from 0.0003 to 0.0005. The variations in transmissivity and storage are due to variations of aquifer thickness and grain size at the observation wells. The specific capacity of the pumped well at the end of 24 hours was 70 (gal/min)/ft [14.5 (L/s)/m] of drawdown, and at the end of the test was 67 (gal/min)/ft [13.9 (L/s)/m] of drawdown. The decrease in specific capacity is attributed largely to boundaries of low permeability that occur both to the east and west of the pumped well. Private drilling in the area indicates that both of these boundaries are at a distance of about one-half mile (0.8 km). The data collected during the latter part of the test indicate leakage, apparently through the overlying silty beds.

A 76-hour aquifer test was made on the Spiritwood aquifer system northeast of LaMoure, N. Dak., using a 225-foot (68.6-m) deep, potential irrigation well, 134-060-36CCB, as the pumping well and three observation wells spaced 200, 500, and 1,000 feet (60, 150, and 305 m) to the north. The pumping rate for the test was 1,260 gal/min (79.5 L/s). Analysis of the data (R. B. Shaver, written commun., 1977) using methods developed by Theis (1935) indicated transmissivities of 15,500 to 24,100 ft^2/d (1,440 to 2,240 m^2/d) and a storage coefficient of about 0.0004. The transmissivity variations are due primarily to differences in aquifer thicknesses, which ranged from 35 to 53 feet (11 to 16 m) at the observation wells. The specific capacity at the end of 27 hours was 19.8 (gal/min)/ft [4.09 (L/s)/m] of drawdown. This test indicates the presence of two boundaries, one about 2,000 to 3,000 feet (610 to 910 m) northeast of the pumped wells, the other about 4,000 feet (1,200 m) to the south. Later water-level measurements made in observation wells during pumping of the installed irrigation well showed the latter boundary extends at least 2 miles (3.2 km) to the northwest of the irrigation well and more than 9 miles (14.5 km) to the southeast.

Because of the facies changes within the Spiritwood aquifer system, extension of yield data from one area to another within the aquifer is tenuous, but correlations made where conditions are similar usually are valid. The yields from individual wells in the Spiritwood aquifer system depend mainly upon the thickness and the hydraulic conductivity of the sand and gravel at the well location and the distance of the well from impermeable boundaries. Wells located in the thicker and coarser sand and gravel lenses generally will yield from 500 to 1,000 gal/min (32 to 63 L/s), and locally individual well yields of as much as 1,500 gal/min (95 L/s) may be obtained. Yields generally decrease toward the aquifer boundaries because of the thinning of the sand and gravel and the low permeability of the materials in the boundaries. Test holes drilled in the vicinity of Twin Lakes indicate thinner sand lenses and lower yields — less than 500 gal/min (32 L/s; pl. 1).

Recharge to the Spiritwood aquifer system is from precipitation and snowmelt that infiltrates through the overlying glacial drift. Water-level fluctuations in the aquifer generally are small. Yearly fluctuations generally are less than 3 feet (0.9 m), except in areas where heavy pumping occurs. The large drawdown in 1977 shown in figure 9 is the result of pumping an irrigation well located about a mile (1.6 km) west of the observation well. The highest water levels occur following spring snowmelt.

The potentiometric surface (fig. 10, sec. A-A′) in northern LaMoure County generally slopes towards the James River, and indicates leakage into the river. However, the configuration of the potentiometric surface indicates the geologic setting in the aquifer system is more complex than is shown on section A-A′ (fig. 10). The nearly flat potentiometric surfaces indicate areas of high permeability; whereas, the steep surfaces indicate areas of low permeability. These surface variations indicate that there are at least three channels of high permeability separated by boundaries of low permeability. The low permeability areas apparently occur between test holes 136-062-06DDD and 136-063-01CCC, and between test holes 136-063-10BBB and 136-063-08AAB.

Southeast of the Twin Lakes area (pl. 1) the potentiometric surface generally slopes to the southeast. However, a depression in the potentiometric surface where Bear Creek crosses the aquifer system indicates there also is some leakage into the creek.

Discharge from the aquifer system is through wells, seepage into the James River and Bear Creek, and by movement downgradient into Sargent County.

Water from the Spiritwood aquifer system generally is a sodium bicarbonate type. However, locally, calcium, sulfate, or chloride are the predominant

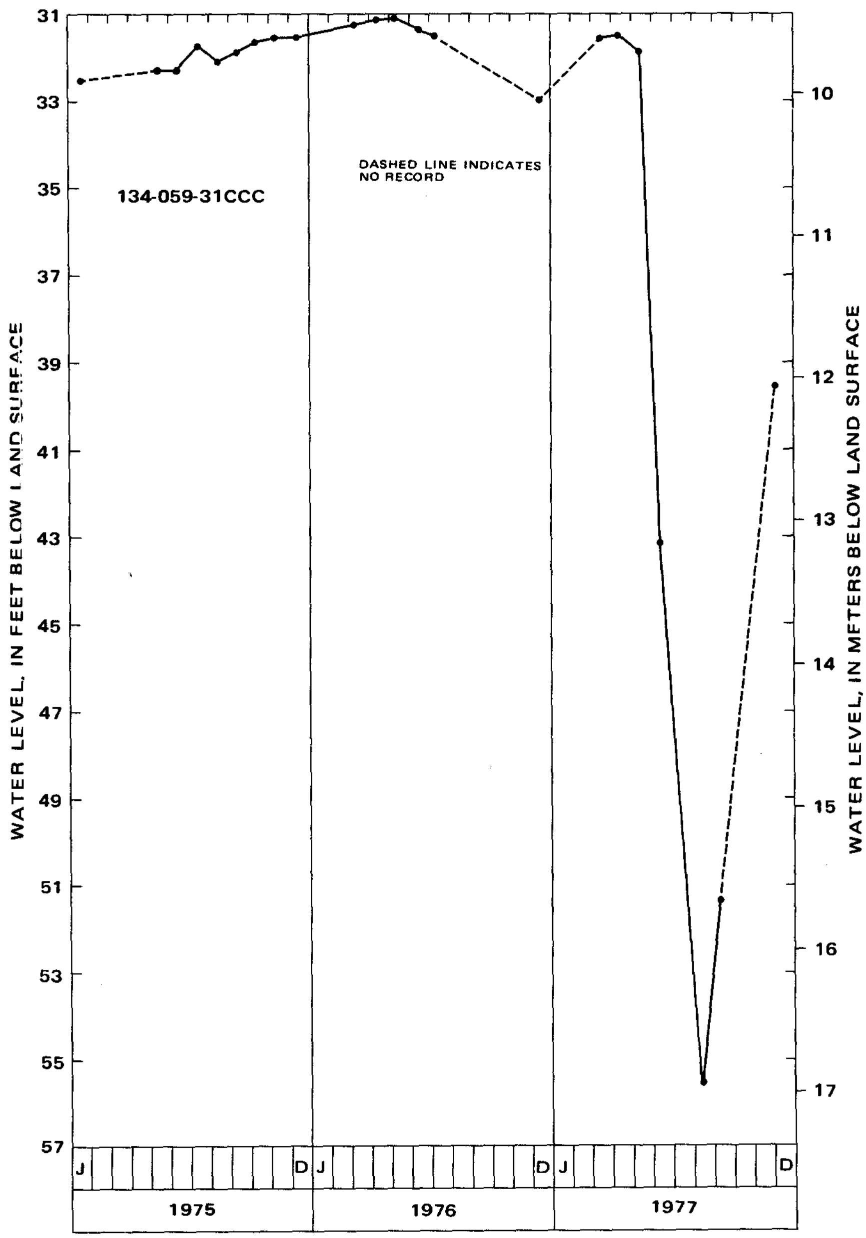


FIGURE 9.—Water levels in the Spiritwood aquifer system.

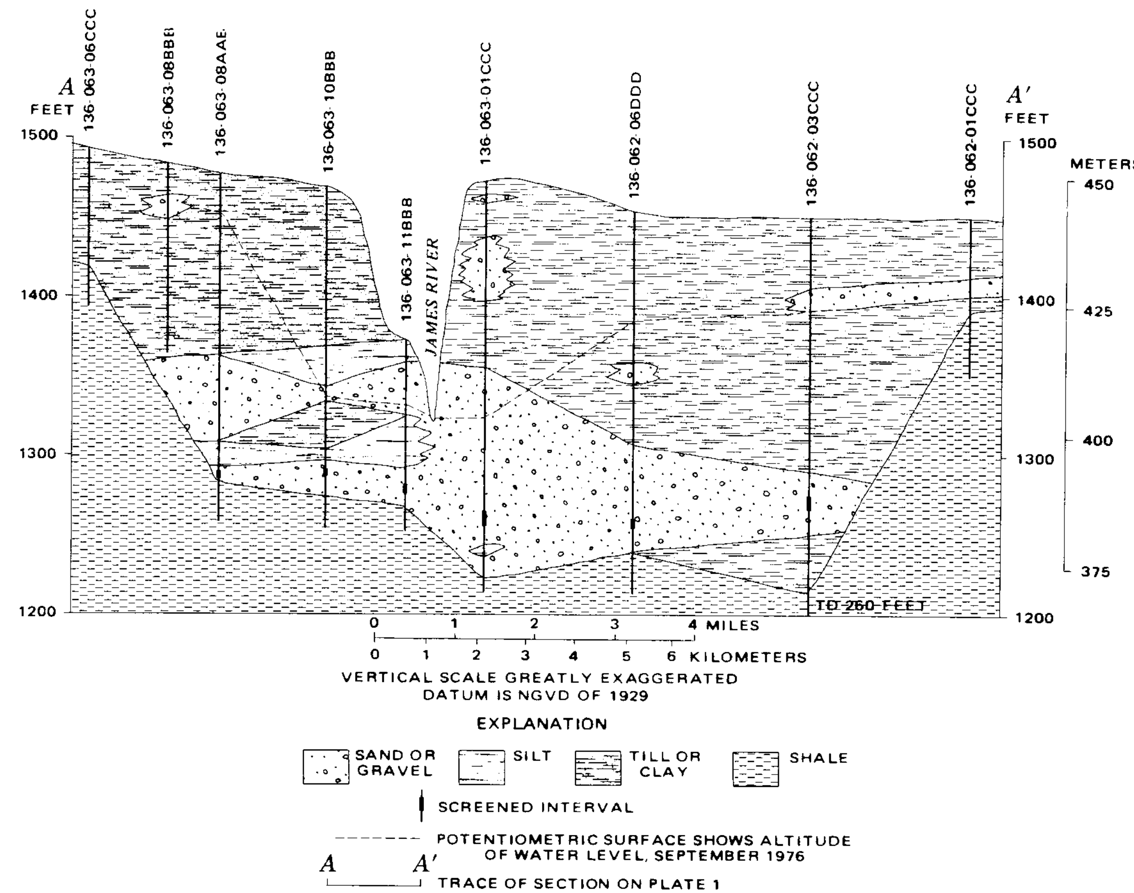


FIGURE 10.—Geohydrologic section through the Spiritwood aquifer system.

ions. Dissolved-solids concentrations in samples from 40 wells in the aquifer ranged from 345 to 1,430 mg/L and had a mean of 859. Sodium concentrations ranged from 9.6 to 380 mg/L and had a mean of 203 mg/L. The sodium ranged from 6 to 84 percent of the total cations and had a mean of about 57 percent. Sulfate ranged from 33 to 430 mg/L and had a mean of 215 mg/L. Sulfate concentrations exceeded 250 mg/L in 14 samples. Chloride concentrations ranged from 2.5 to 280 mg/L and had a mean of 72 mg/L. Hardness ranged from 150 to 530 mg/L, but only five samples contained less than 180 mg/L. Iron concentrations ranged from 40 to 2,900 ug/L.

The samples had SAR values that ranged from 0.2 to 13 and specific conductances that ranged from 520 to 2,190 umho/cm. The irrigation classifications of the 40 samples are shown in figure 11.

Based on a mean thickness of 50 feet (15 m), an areal extent of 195 mi^2 (505 km^2), and an estimated specific yield of 0.15, about 936,000 acre-feet (1,150 hm^3) of water is available from storage in the aquifer. Silts and clays, that overlie or are interbedded in the aquifer also contain considerable water in storage, but the rate of drainage is too slow to add significantly to the water available within a period of a few years.

Nortonville Aquifer

The Nortonville aquifer is confined to a narrow buried valley that extends southward from the north border of LaMoure County in secs. 4 and 5, T. 136 N., R. 64 W. to the South Dakota border at the south edge of sec. 33, T. 129 N., R. 61 W. in Dickey County. It probably is equivalent to part of the Deep James aquifer of South Dakota (Koch and others, 1973).

The Nortonville aquifer ranges from about 0.5 to 2.2 miles (0.8 to 3.5 km) in width and has a mean width of about 0.75 mile (1.2 km). It underlies an area of about 42 mi^2 (109 km^2). The aquifer consists of lenticular deposits of sand and gravel interbedded with silt and silty clay. The depth to the top of the aquifer in 22 test holes ranged from 91 to 230 feet below lsd. Northwest of North Dakota Highway 13 scattered deposits of sand and gravel interbedded with silt and till overlie the major aquifer. Some of these deposits may be hydraulically connected to the major part of the aquifer, but they are not considered as part of the aquifer because of the lack of data. South of State Highway 13 the Nortonville aquifer underlies the Ellendale aquifer. The two aquifers are separated by either till or silty clay. There is no known hydraulic connection between the aquifers, although there probably is some leakage. Test drilling indicates the aquifer generally ranges from 7 to 102 feet (2 to 31 m) in thickness and has a mean thickness of about 40 feet (12 m).

Two aquifer tests were conducted using the 155-foot (47-m) irrigation well 136-064-29AAD1 and four observation wells. The first test was conducted in the fall of 1976 when the well was pumping at a rate of 960 gal/min (60.6 L/s). This test was terminated during the 26th hour when the drawdown became so great that air began entering the pump. The second test was conducted in the spring of 1977. The well was pumped at a rate of 528 gal/min (33 L/s) for 100 hours, then a similar period of recovery was observed. Both tests indicate that

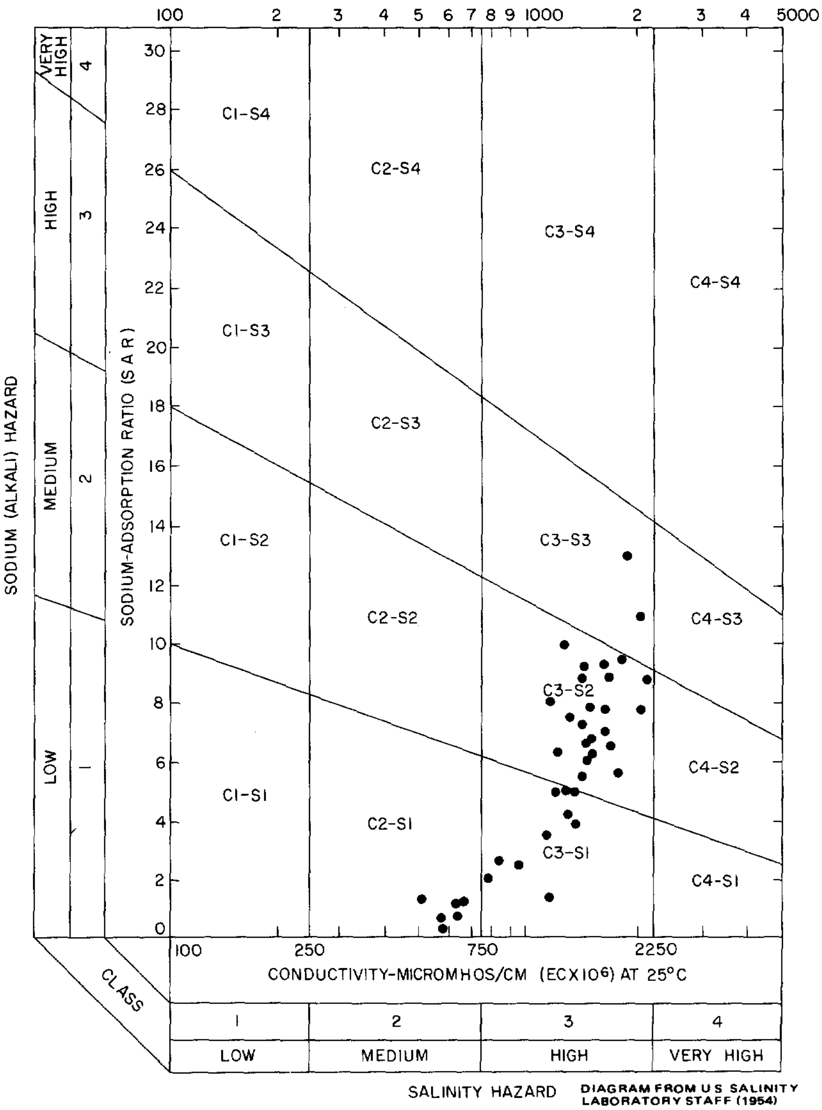


FIGURE 11.—Irrigation classifications of water from the Spiritwood aquifer system.

the transmissivity is about 5,000 ft^2/d (465 m^2/d), and the storage coefficient is 0.0001. The specific capacity at 24 hours was 16 (gal/min)/ft [3.3 (L/s)/m] of drawdown, and at 100 hours was 13.4 (gal/min)/ft [2.8 (L/s)/m] of drawdown. The reduction of specific capacity with time is due to the presence of nearly impermeable boundaries (valley walls) at the edges of the aquifer.

The yield from individual wells in the Nortonville aquifer should range from about 50 to 600 gal/min (3 to 38 L/s), assuming 30 feet (9 m) of drawdown. In 1977 only one large-capacity irrigation well, which was drilled in 1971, pumped from the aquifer. The well was reportedly pumped at rates in excess of 800 gal/min (50 L/s), but before the pumping season was over the water level had declined to a level where the well was pumping air and water. The yield was not measured at the end of the pumping season, but was much less than the 800 gal/min (50 L/s) reported earlier in the year. The total pumpage from the well in 1976 was estimated to be about 270 acre-feet (0.33 hm^3).

The principal source of recharge to the aquifer is from precipitation and snowmelt that infiltrates through the overlying glacial drift; however, some recharge is derived from the adjacent sediments, and there also may be some leakage from the Ellendale aquifer.

Water-level fluctuations in the undeveloped part of the aquifer south of Nortonville generally were less than 3 feet (0.9 m) during the period of record. However, water levels in observation well 136-064-09CCC1, 2.25 miles (3.6 km) north of the irrigation well, fluctuated more than 9 feet (2.7 m; fig. 12). The rate of recovery of the water levels from September to December 1976 indicates slow recharge. The precipitation record shows that most recharge is derived from snowmelt and spring rains.

The gradient of the potentiometric surface, as determined from widely scattered water-level measurements, averages about 2 ft/mi (0.4 m/km) in a southerly direction, and indicates that the aquifer discharges some water into South Dakota. The only other known discharge is by pumpage of wells. The potentiometric surface of the aquifer generally is a few feet higher than the lowest part of most of the intermittent streams that cross the aquifer so there also may be some discharge into the stream valleys. However, the stream beds generally are dry during much of the summer so that the evapotranspiration probably exceeds any ground-water discharge that may occur during the dry periods.

Water in the Nortonville aquifer generally is a sodium type, but either bicarbonate, sulfate, or chloride may be the dominant anion. Water samples were taken from 12 wells, most of them in the northern part of the aquifer. Dissolved-solids concentrations ranged from 944 to 1,890 mg/L and had a mean of 1,470 mg/L. Sodium concentrations ranged from 200 to 630 mg/L and had a mean of 400 mg/L. Sodium constituted 53 to 91 percent of the cations. Sulfate concentrations ranged from 30 to 670 mg/L and had a mean of 370 mg/L. Chloride concentrations ranged from 100 to 840 mg/L and had a mean of 290 mg/L. The higher chloride concentrations occurred in samples taken from wells finished in the deeper parts of the aquifer, and may be due to percolation of water containing high chlorides from the upper part of the underlying or adjacent Pierre Formation. Hardness ranged from 100 to 550 mg/L and had a mean

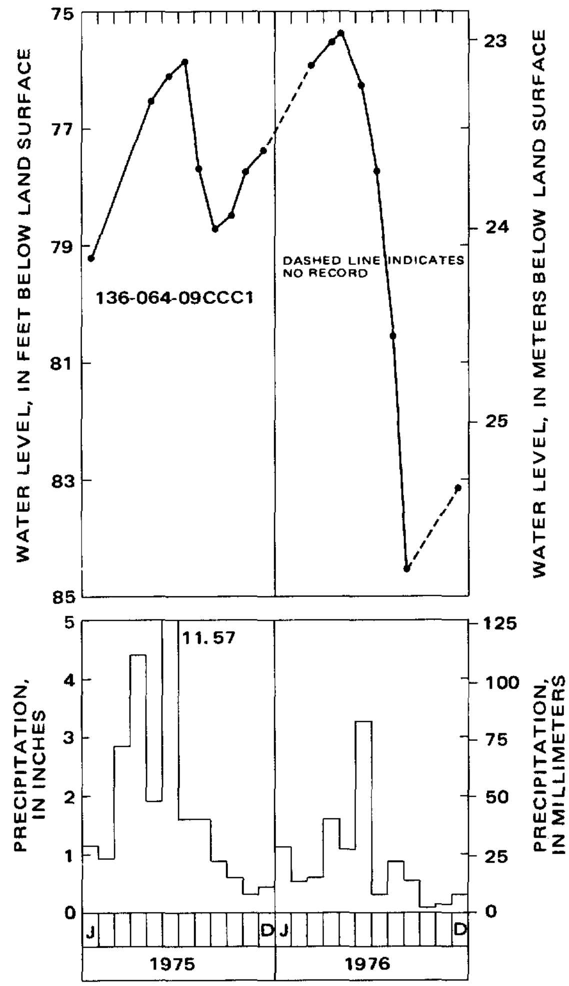


FIGURE 12.—Water levels in the Nortonville aquifer and precipitation at LaMoure.

of 330 mg/L. Iron concentrations ranged from 40 to 1,300 ug/L but exceeded the recommended limit of 300 ug/L in only three samples. Manganese concentrations ranged from 20 to 1,800 ug/L and exceeded the recommended limit of 50 ug/L in 11 samples.

The samples had SAR values that ranged from 4.7 to 22 and specific conductances that ranged from 1,610 to 3,440 umho/cm. The irrigation classifications were C3-S2, C3-S3, C4-S2, C4-S3, and C4-S4.

Based on an area of 42 mi^2 (109 km^2), a mean thickness of 40 feet (12 m), and a specific yield of 0.15, about 161,000 acre-feet (197 hm^3) of water is available from storage in the aquifer.

Ellendale Aquifer

The Ellendale aquifer, named by Naplin (1973), was deposited in a valley that apparently was an ancestral course of the James River. The valley extends from the vicinity of Grand Rapids, LaMoure County, to beyond T. 129 N., R. 61 W. In South Dakota the equivalent aquifer is either the Middle James aquifer or the Elm aquifer (Koch and others, 1973). The northernmost part of the Ellendale aquifer coalesces with the LaMoure aquifer and the two have not been differentiated. The coalesced aquifers are separated from the underlying Spiritwood aquifer system by till. The Ellendale aquifer overlies the Nortonville aquifer from about 3 miles (5 km) south of Berlin, LaMoure County, to the South Dakota border, but the aquifers are separated by more than 40 feet (12 m) of till or silty clay (fig. 13).

The Ellendale aquifer ranges from about 1.25 to 6 miles (2 to 9.7 km) in width and underlies about 125 mi^2 (324 km^2). It consists of lenticular deposits of sand and gravel interbedded with silt and silty clay. The top of the aquifer generally lies from about 50 to 95 feet (15 to 29 m) below land surface, but it may be as much as 165 feet (50 m) or as little as 24 feet (7 m). It may be that most, if not all, of the deposits within 50 feet (15 m) of land surface are isolated sand and gravel lenses that contribute only small quantities of leakage to the major part of the aquifer. The aggregate thickness of sand and gravel deposits ranges from 5 to 81 feet (1.5 to 25 m) and has a mean of 33 feet (10 m).

A 5-day (120-hour) aquifer test at 130-062-36CCB was made in July 1970 by C. E. Naplin (1973, p. 20). The test indicated a transmissivity of 3,300 ft^2/d (307 m^2/d) and a storage coefficient of 0.0004. The specific capacity of the well was 7 (gal/min)/ft [1.4 (L/s)/m] of drawdown. Pumping the well at 310 gal/min (20 L/s) caused the water level in an observation well at 2 miles (3.2 km) distance to drop 0.66 foot (0.2 m).

Yields from individual wells in the Ellendale aquifer, assuming 30 feet (9 m) of drawdown, should range from about 15 gal/min (0.9 L/s) near the edges to about 500 gal/min (32 L/s) in the thicker sections of the aquifer. Locally, where unusual thicknesses of gravel occur, yields somewhat greater than 500 gal/min (32 L/s) may be obtainable.

Recharge to the aquifer is from precipitation and snowmelt that infiltrates through the overlying glacial drift. Some recharge is derived from the percolation of water from the adjacent till or Pierre Formation. Small quantities of poor quality recharge also may be derived from leaky wells finished in the Dakota aquifers or from infiltration from small ponds formed by overflow from the Dakota wells.

Water-level fluctuations in the undeveloped part of the aquifer generally were less than 2 feet (0.6 m) during the period of record. Figure 14 shows water-level fluctuations in observation well 130-061-29BBB, which is approximately 1.1 miles (1.8 km) from the city of Ellendale's two supply wells. The general decline of the water level is due primarily to the pumpage of water from the city wells. The small rises in the water levels reflect recharge from precipitation and the smaller quantity of water pumped by the city during the periods of precipitation.

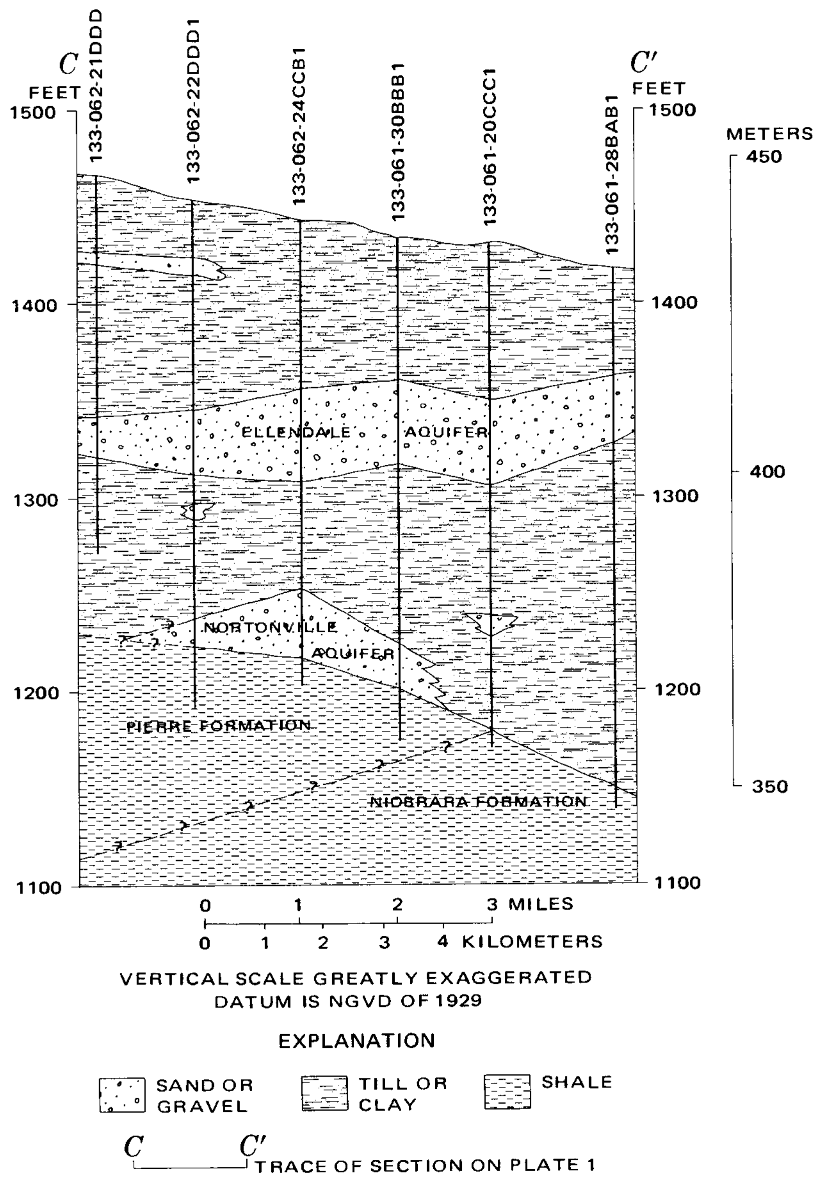


FIGURE 13.—Geohydrologic section showing the Ellendale and Nortonville aquifers.

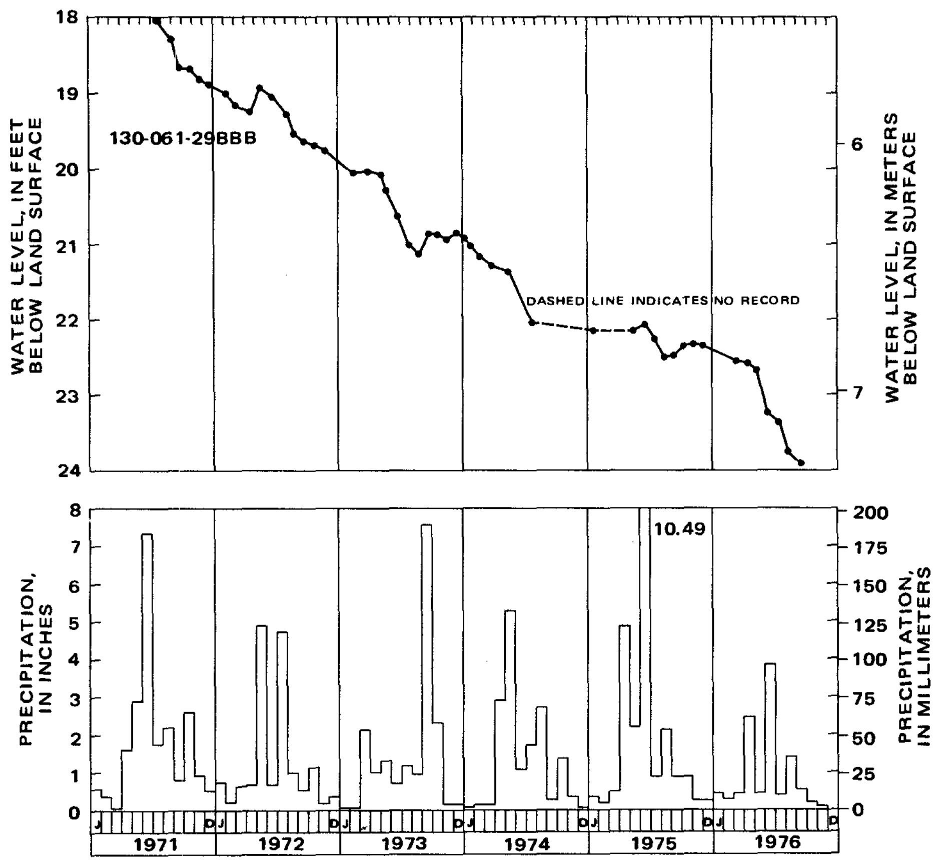


FIGURE 14.—Water levels in the Ellendale aquifer and precipitation at Ellendale.

Discharge is through pumpage, through upward leakage into the Maple River and Cottonwood Creek in the southern and central parts of the aquifer, and by leakage into the James River in the northern part of the aquifer. Some water also percolates into South Dakota.

Water from the Ellendale aquifer, for the most part, is a sodium-calcium sulfate type. However, locally the water may be either a calcium sulfate or a calcium bicarbonate type. Dissolved-solids concentrations in samples from 35 wells in the aquifer ranged from 541 to 2,280 mg/L and had a mean of 1,090 mg/L. Sodium concentrations ranged from 23 to 260 mg/L and had a mean of 170 mg/L. The sodium ranged from 6 to 54 percent of the total cations. Sulfate ranged from 110 to 700 mg/L and had a mean of 445 mg/L. Chloride concentrations ranged from 1.9 to 140 mg/L, but only two samples from near the western edge of the aquifer contained more than 80 mg/L. Hardness ranged from 270 to 780 mg/L and had a mean of 479 mg/L. Iron concentrations ranged from 0 to 2,000 ug/L. The analysis of the water sample from well 130-062-35DAD was not included in the statistics because the well probably was contaminated.

The samples had SAR values that ranged from 0.4 to 5.2 and specific conductances that ranged from 816 to 2,400 umho/cm. The irrigation classification of 31 of the 35 samples was C3-S1; three of the samples were classed as C3-S2, and one was C4-S2.

Based on an area of 125 mi^2 (324 km^2), an average thickness of 33 feet (10 m), and a specific yield of 0.15, about 396,000 acre-feet (488 hm^3) of water is available from storage.

Guelph Aquifer

The Guelph aquifer, like the Ellendale aquifer, apparently was deposited in an ancestral course of the James River. The north end of the aquifer abuts against the present river valley and is marked by several small springs. About 2 miles (3.2 km) north of highway 11, the south end appears to terminate in lake clays and silt deposits. However, test holes are few and scattered and the aquifer may continue to the south or southwest and coalesce with the Ellendale aquifer.

The Guelph aquifer generally is from 1.5 to 2 miles (2.4 to 3.2 km) wide, and underlies an area of about 20 mi^2 (52 km^2). The aquifer consists of lenticular deposits of sand and gravel interbedded with till, silt, and silty clay. The top of the saturated part of the aquifer ranges in depth from about 19 feet (6 m) in the north where it is unconfined to as much as 73 feet (22 m) in the south. The aggregate thickness of saturated sand and gravel deposits ranges from 24 to 53 feet (7.3 to 16 m) and has a mean of about 35 feet (11 m).

Yields from individual wells in the central parts of the aquifer should be between 500 and 1,000 gal/min (32 and 63 L/s), assuming 30 feet (9 m) of drawdown. Yields of 250 to 500 gal/min (16 to 32 L/s) should be obtainable from most other parts of the aquifer (pl. 1).

Recharge is principally from precipitation and snowmelt that infiltrates to the aquifer or percolates into the aquifer from the adjacent sediments. Minor quantities of recharge also may be derived by leakage from wells tapping the Dakota aquifers.

Discharge from the aquifer is by pumpage, by springs, and by underflow northward to the James River. Some discharge also occurs by transpiration in topographically low areas where the water table is near the land surface.

The water in the Guelph aquifer generally is a calcium and(or) sodium sulfate type. However, magnesium may be a major cation and locally bicarbonate is the dominant anion. Seven water samples were obtained from the aquifer. Dissolved-solids concentrations ranged from 710 to 1,440 mg/L and had a mean of 1,160. Sodium was the predominant cation in three of the seven samples. Sulfate ranged from 270 to 620 mg/L and had a mean of 477 mg/L. Hardness ranged from 540 to 920 mg/L and had a mean of 644 mg/L. Iron ranged from 150 to 2,800 ug/L and exceeded the recommended limit in three samples. Manganese ranged from 480 to 1,200 ug/L and exceeded the recommended limit in all seven samples.

The samples from the aquifer had SAR values that ranged from 0.5 to 4.9 and specific conductances of 1,020 to 2,120 umho/cm. Four of the seven samples had an irrigation classification of C3-S1, the other three had a classification of C3-S2.

Based on an area of 20 mi² (52 km²), an average thickness of 35 feet (11 m), and an estimated specific yield of 0.15, about 67,000 acre-feet (83 hm³) of water is available from storage.

Oakes Aquifer

The Oakes aquifer is located in southeastern Dickey and southwestern Sargent Counties in North Dakota and northeastern Brown and northwestern Marshall Counties in South Dakota, where it is considered to be part of the Middle James aquifer (Koch and others, 1973). In Dickey County the aquifer is bounded on the west by the James River and extends northward to sec. 1, T. 131 N., R. 59 W.

The aquifer was deposited in two stages on an undulating surface. During the early stage the aquifer materials were deposited as valley fill. Later, the valley became blocked in South Dakota and a glacial lake, Lake Dakota, was formed. The lake extended from the block to about 3 miles (5 km) north of Oakes. The aquifer materials deposited during this stage consist of deltaic and lake deposits that now form most of the present land surface in the area except in the northeastern part where a younger till covers the aquifer. The valley-fill deposits consist of fine to coarse sand and gravel interbedded with silt and clay, the deltaic materials generally consist of fine to medium sand and silt, and the lake deposits generally are composed of silt and silty clay. The northern part of the aquifer overlies the Spiritwood aquifer system (fig. 15). Generally there is more than 40 feet (12 m) of silt, clay, or till between the two aquifers, but locally good quality of water in the Spiritwood aquifer system indicates that in places, at least, there is leakage from the Oakes aquifer to the Spiritwood aquifer system.

The Oakes aquifer is as much as 8 miles (13 km) wide, 16 miles (26 km) long, and underlies an area of about 93 mi² (240 km²). Aquifer thicknesses vary considerably within short distances; as much as 55 feet (17 m) in a distance of half a mile (0.8 km). Selected drillers' logs and test-hole data, which include electrical logs, indicate that the aggregate saturated thickness of sand and gravel in the aquifer ranges from about 2 to 99 feet (0.6 to 30 m) and has a mean of about 30 feet (9 m).

Two aquifer tests were conducted in the Oakes aquifer prior to this project. The first was made at well 131-059-21DA. The well was pumped for 24 hours at a rate that varied from 525 to 500 gal/min (33.1 to 31.5 L/s) and averaged about 508 gal/min (32 L/s). The data, although questionable because of the varied pumping rate and the method of disposal of the pumped water, indicate a transmissivity of about 13,800 ft²/d (1,280 m²/d).

The Science and Education Administration, Federal Research, Mandan, N. Dak. (oral commun., 1978), conducted an aquifer test at 130-059-13C in 1970.

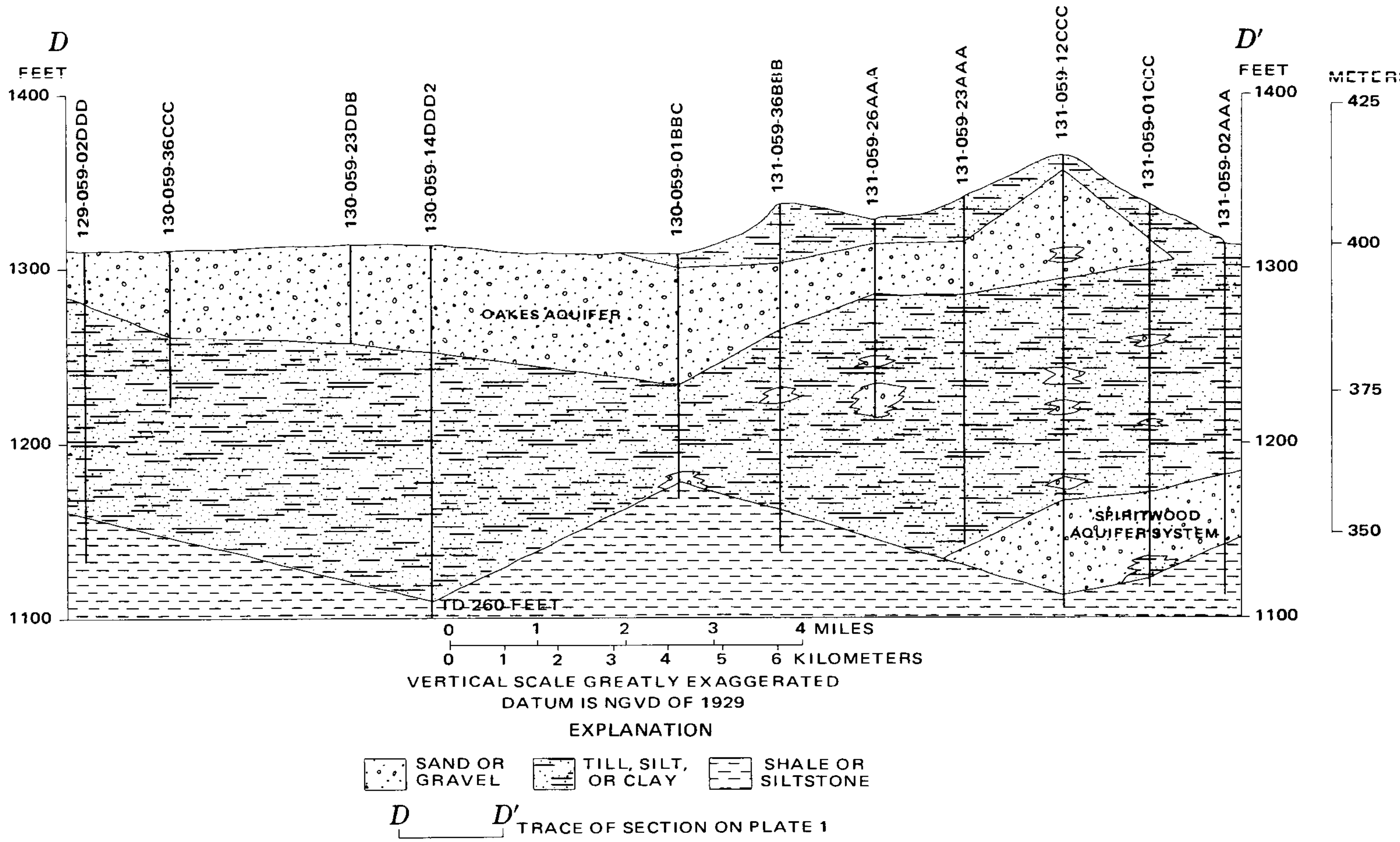


FIGURE 15.—Geohydrologic section showing the Oakes aquifer and the Spiritwood aquifer system.

Calculations using distance-drawdown data from three different observation wells at 49 days, 84 days, and 184 days indicate that the respective transmissivities are 11,300, 8,400, and 8,800 ft^2/d (1,050, 780, and 818 m^2/d). The calculated storage coefficients are 0.085, 0.004, and 0.03, respectively. The variations in transmissivity calculations at the three observation-well sites probably are due to variations both in grain size of the aquifer materials and in the thickness of the aquifer.

Yields from wells in the Oakes aquifer range from a few gallons per minute from some domestic and stock wells to as much as 1,350 gal/min (85 L/s) from an irrigation well. Yields in the valley part of the aquifer generally range between 500 and 1,350 gal/min (32 and 85 L/s; pl. 1), but yields of as much as 1,500 gal/min (95 L/s) could be obtained. Elsewhere yields may vary from a few gallons per minute to as much as 900 gal/min (57 L/s). Differences of as much as 500 gal/min (32 L/s) can occur within the same quarter section (65 ha).

The primary source of recharge to the Oakes aquifer is direct infiltration of precipitation and snowmelt. Some lateral movement of water from the adjacent parts of the aquifer in Sargent County and from the till confining the north edge of the aquifer occurs. In addition, about 1,100 acre-feet (1.4 hm^3) of water is pumped from the James River for irrigation south of Oakes and part of this infiltrates into the aquifer. The aquifer also may be recharged from the Spiritwood aquifer where the Spiritwood and Oakes aquifers may be locally connected. The poor quality of water reported in a few wells, such as 130-059-01BBC, indicates that there probably is or has been some leakage from old Dakota wells.

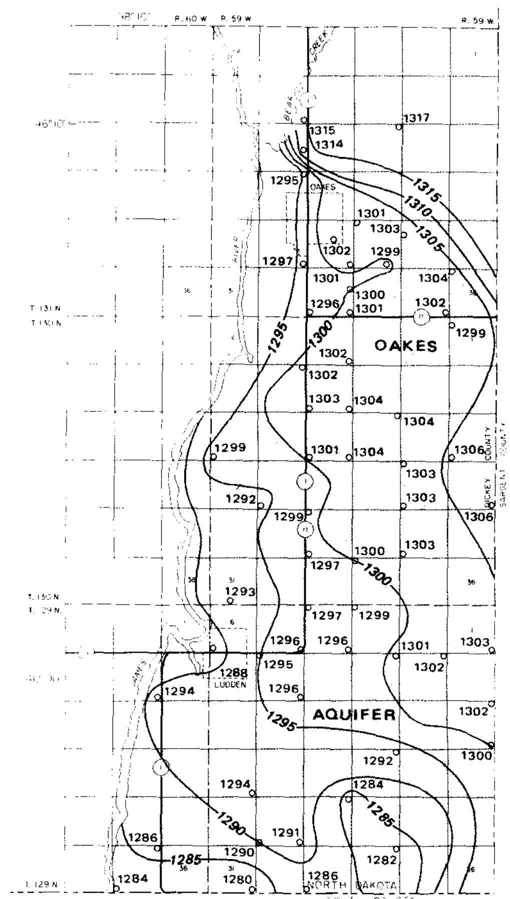
A digital model of the Oakes aquifer was made as part of this study. The model indicates that about 15 percent of the mean annual precipitation, or about 22,300 acre-feet (27.5 hm^3) of water, becomes recharge. Water-level fluctuations indicate that most of the recharge is derived from snowmelt and occasional large rainstorms. Water in the aquifer generally moves in a southwesterly direction toward the James River and South Dakota (fig. 16).

Discharge from the Oakes aquifer occurs by evapotranspiration, pumpage, leakage into the Spiritwood aquifer system and the James River, and movement into South Dakota. Approximately 3,300 acre-feet (3.3 hm^3) of water was pumped from the Oakes aquifer in 1976.

Water samples were collected from 49 wells in the Oakes aquifer; of these, 16 wells were sampled periodically. The analyses of the periodic samples show small changes in the concentrations of most ions. The cause of these changes is not known, but they may be related to soil conditions during recharge events.

Water from the Oakes aquifer generally is a calcium bicarbonate type. The only known exceptions are samples from wells 130-059-01BBC, 130-059-25CBC, 130-059-25CBD, and 131-059-20AAA2. Water from 130-059-01BBC is a sodium chloride-bicarbonate type and probably indicates leakage from an old Dakota well. The water samples from wells 130-059-25CBC and 130-059-25CBD have a high nitrate concentration, apparently showing contamination from fertilizer. These samples are not included in the following discussion.

Dissolved-solids concentrations in water from the Oakes aquifer ranged from 293 to 798 mg/L and had a mean of 470 mg/L. Sodium concentrations



0 1 2 3 KILOMETERS

0 1 2 3 4 MILES

EXPLANATION

1302 OBSERVATION WELL—Number is water level in feet above National Geodetic Vertical Datum of 1929

—1300— WATER-TABLE CONTOUR—Shows altitude of water table, August 1976. Contour interval 5 feet (1.5 meters)

FIGURE 16.—Water-table map of the Oakes aquifer, Dickey County.

ranged from 0.6 to 110 mg/L and had a mean of about 25 mg/L. Sodium also ranged from 1 to 48 percent of the total cations. Sulfate concentrations ranged from 4.7 to 260 mg/L. However, sulfate concentrations in most wells were less than 100 mg/L. Chloride concentrations ranged from 1.1 to 91 mg/L and had a mean of 14 mg/L. Hardness ranged from 83 to 730 mg/L, but water from only two wells contained less than 180 mg/L. Iron concentrations ranged from 0 to 8,300 ug/L, and manganese ranged from 0 to 4,200 ug/L. The samples had SAR values that ranged from 0.0 to 3.0, and specific conductances ranged from 194 to 1,300 umho/cm. Irrigation classifications of water from the aquifer were C1-S1, C2-S1, and C3-S1.

Based on an areal extent of 93 mi^2 (240 km^2), an average saturated thickness of 30 feet (9 m), and an estimated specific yield of 0.15, about 268,000 acre-feet (330 hm^3) of water is available from storage.

LaMoure Aquifer

The LaMoure aquifer was deposited as surficial outwash, terrace deposits, abandoned channel deposits, and James River alluvium. It is similar to and may be a continuation of the Jamestown aquifer in Stutsman County (Huxel and Petri, 1965). However, for the purpose of this report, the aquifer is defined as hydraulically connected segments that are located adjacent to the James River from the confluence of Bone Hill Creek and the James River in LaMoure County to the edge of the Oakes aquifer about a mile (1.6 km) northwest of Oakes, Dickey County. The northern part of the aquifer overlies the Spiritwood aquifer system and generally is separated from the underlying aquifer by many feet of clay or till, except where the James River has eroded through the intervening materials. The northward trend of the Ellendale and LaMoure aquifers suggests that the two aquifers may merge in the vicinity of Grand Rapids, LaMoure County.

The LaMoure aquifer ranges from about 0.50 to 2 miles (0.8 to 3.2 km) in width and is about 37 miles long. It underlies an area of about 23 mi^2 (60 km^2). The aquifer consists of lenticular deposits of sand and gravel interbedded with clay and silt. Locally, boulders are common near the base of the aquifer. Silt and clay lenses are most common near the edges, and may be thin or missing in the central part of the aquifer. The thickest and coarsest sections of the aquifer generally are in abandoned channels of the James River, but the high terraces north of Grand Rapids also contain considerable coarse gravel and small boulders. The saturated thickness ranges from less than a foot at the edges to as much as 98 feet (30 m) in the central part. Selected test-hole data indicate that the mean saturated thickness of the aquifer is about 46 feet (14 m).

There are five segments in the LaMoure aquifer that generally will yield more than 500 gal/min (32 L/s) to wells (pl. 1). The first and northernmost segment is a high terrace on the northeast side of the James River about 1.5 miles (2.4 km) north of Grand Rapids. The second segment is generally on the west side of the river and extends from about 1.5 miles (2.4 km) south of Grand Rapids to west of LaMoure. The third segment is located on the east side of the

James River in an abandoned oxbow about 2.5 miles (4 km) southeast of LaMoure. The fourth segment is located on the west side of the James River adjacent to the Dickey-LaMoure county line. The fifth segment is located on the west side of the James River about 2 miles (3 km) south of the Dickey-LaMoure county line. Generally these segments are less than 0.5 mile (0.8 km) wide.

An aquifer test was made in segment three of the aquifer by R. B. Shaver in 1975 (written commun., 1976). The test used irrigation well 133-060-15CAC1 and six observation wells. The irrigation well is 109 feet (33 m) deep and screened through about one-third of the aquifer. The well was pumped at a rate of 924 gal/min (58.3 L/s) for about 65 hours (3,890 minutes). The data were analyzed using time-drawdown and distance-drawdown methods developed by Theis (1963) and Jacob (1940). The transmissivity of the aquifer was calculated to be about 101,000 ft^2/d (9,380 m^2/d). The mean hydraulic conductivity was about 1,100 ft/d (335 m/d). Using a method described by Lohman (1972, p. 34-40) it was determined that the vertical hydraulic conductivity is about 20 percent of the horizontal hydraulic conductivity. A storage coefficient of 0.1 was calculated. However, this coefficient probably is low because the test was terminated by a power failure and the effects of slow drainage within the aquifer could not be determined. The specific capacity of the pumped well at the end of 24 hours was 252 (gal/min)/ft [52 (L/s)/m] of drawdown and at the end of the test it was 239 (gal/min)/ft [49 (L/s)/m].

The specific capacity of the pumped well, the available drawdown, and the coarse material in the aquifer indicate that a properly constructed well theoretically could be pumped at a rate of more than 7,000 gal/min (440 L/s). Currently there are seven wells, including the test well, in this segment of the aquifer that could be pumped at comparable rates. If all seven wells were pumped simultaneously at the theoretical high rate, the aquifer soon would be nearly dewatered. Therefore, pumping rates in segment three should be restricted to no more than 1,500 gal/min (95 L/s). The aquifer is thinner in the other four segments and maximum yields as large as 1,000 gal/min (63 L/s) could not be maintained. Elsewhere in the aquifer yields from 50 to 250 gal/min (3.2 to 16 L/s) should be obtainable.

Recharge to the aquifer is primarily from precipitation and snowmelt. Other sources of recharge to the aquifer are: (1) return of irrigation water pumped from the James River and from the irrigation wells, (2) flooding by the James River, and (3) leakage from the adjacent till. The quantity of recharge to the aquifer is not known. The period of water-level record, 1975-76, is too short to determine quantitatively the long-term effects of precipitation, pumpage, and drought on the recharge and discharge in the aquifer. Figure 17 shows the effects of recharge and discharge on the water levels in observation wells 133-060-08DDD and 133-060-15CCC. The large rise of the water levels in June and July 1975 was due primarily to the effects of the 11.57 inches (294 mm) of rain that fell in June.

Water levels in wells finished in the LaMoure aquifer are higher than the level of water in the adjacent James River, this indicates that the hydraulic

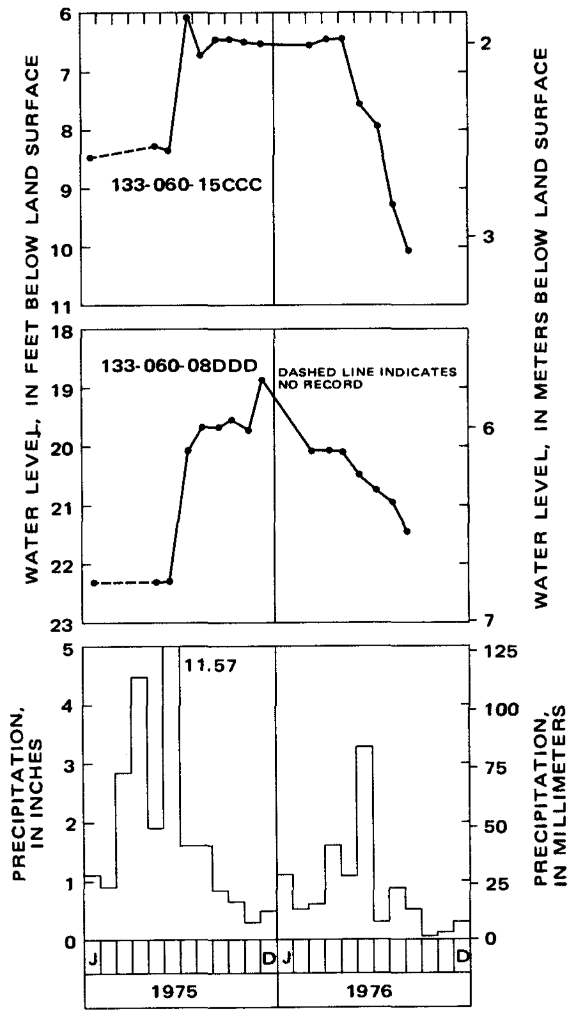


FIGURE 17.—Water levels in the LaMoure aquifer and precipitation at LaMoure.

gradient generally slopes toward the James River. Water levels in four observation wells in segment three indicate a ground-water divide occurs near observation well 133-060-15CCC. Gradients from the divide are about 1.8 ft/mi (0.34 m/km) to the west and about 7 ft/mi (1.3 m/km) to the south.

Discharge from the aquifer is by pumpage, leakage into the James River, and evapotranspiration.

Water from the LaMoure aquifer generally is a calcium bicarbonate type, but locally sodium may be the major cation and sulfate may be the major anion.

Water from wells 134-061-21DAA and 134-061-21DBD2 in the LaMoure aquifer is similar to water in well 131-061-20ADD in the Ellendale aquifer and probably indicates a hydraulic connection between the two. Dissolved-solids concentrations in 21 samples from the LaMoure aquifer ranged from 248 to 1,120 mg/L and had a mean of 571 mg/L. Sodium concentrations ranged from 6.9 to 130 mg/L and had a mean of 47 mg/L. The sodium ranged from 5 to 37 percent of the cations. Sulfate concentrations ranged from 30 to 400 mg/L and had a mean of 130 mg/L. However, samples from only four of 21 wells exceeded 250 mg/L sulfate. Chloride concentrations ranged from 1.4 to 130 mg/L and had a mean of 39 mg/L. Hardness ranged from 220 to 610 mg/L. Iron concentrations ranged from 0 to 3,100 ug/L, and manganese ranged from 120 to 860 ug/L. The samples had SAR values that ranged from 0.2 to 2.4. Specific conductances ranged from 400 to 1,590 umho/cm. The irrigation classifications of water from the 21 wells in the aquifer were either C2-S1 or C3-S1.

Based on an areal extent of 23 mi^2 (60 km^2), a mean saturated thickness of 46 feet (14 m), and an estimated specific yield of 0.15, about 102,000 acre-feet (126 hm^3) of water is available from storage.

Edgeley Aquifer

The Edgeley aquifer, named by Naplin (1976), consists of outwash that, for the most part, was deposited on the Pierre Formation. Locally the aquifer rests on till. The aquifer is located about 3 miles (4.8 km) north of Edgeley and occupies an area of about 6 mi^2 (16 km^2). However, the extent of area that will yield more than 250 gal/min (16 L/s) is only about 2 mi^2 (3.2 km^2). The aquifer consists of fine sand to coarse gravel that generally is clean and well sorted; however, clay and silt lenses are scattered throughout. The aquifer ranges in thickness from 2 to 39 feet (0.6 to 12 m) and has a mean saturated thickness of 10 feet (3 m; Naplin, 1976).

A 120-hour aquifer test was made on the Edgeley aquifer in October 1973 under the direction of R. W. Schmid (Naplin, 1976). The specific capacity of the pumped well after 24 hours was 15.3 (gal/min)/ft [3.17 (L/s)/m] of drawdown. Schmid's interpretation of the test data indicated a transmissivity of 5,000 ft^2/d (460 m^2/d) and a storage coefficient of 0.075. A reinterpretation of Schmid's data by the author indicates transmissivities range from 3,500 to 5,000 ft^2/d (325 to 460 m^2/d) and storage coefficients range from 0.075 to 0.14.

Yields from individual wells in the aquifer depend upon the pump capacity, screened interval, saturated thickness, and hydraulic conductivity at the particular well site. In 1976 three irrigation wells located in the more productive part of the aquifer were pumped at rates of 500 to 800 gal/min (32 to 50 L/s). Yields from domestic and stock wells are limited by the pump size and generally are less than 30 gal/min (1.9 L/s).

Recharge to the aquifer is from infiltration of rainfall and snowmelt. It is not known how much recharge there is, but a digital model (M. R. Burkart, written commun., 1977) indicates about 25 percent of the precipitation, or about 4.6

inches (117 mm) in normal years, reaches the water table. In dry years the percentage of precipitation that reaches the water table probably is less because soil moisture requirements have to be met before recharge can occur.

Figure 18 shows water-level fluctuations in observation well 134-064-22BBB2. The high in July 1975 was caused by recharge derived from more than 5 inches (127 mm) of rain that fell near the end of June. Precipitation in 1976 was less than in 1975; consequently, the water level declined in 1976.

Discharge from the aquifer is by seepage into the Maple River on the southwest and sloughs on the south and east, by evapotranspiration, and by pumpage.

Water from the Edgeley aquifer generally is a calcium-magnesium bicarbonate type; however, sodium and sulfate ions may be present in significant proportions. Dissolved-solids concentrations in samples from nine wells tapping the aquifer ranged from 308 to 945 mg/L and had a mean of 466 mg/L. Sodium concentrations ranged from 17 to 220 mg/L and had a mean of 57. The sodium ranged from 12 to 74 percent of the total cations; however, only one sample contained more than 33 percent. Sulfate concentrations ranged from 32 to 310 and had a mean of 108 mg/L. Only three samples had sulfate concentrations exceeding the mean. Chloride concentrations generally were low with only one sample containing as much as 100 mg/L. Hardness ranged from 160 to 530 mg/L. Iron concentrations ranged from 860 to 6,900 ug/L, and manganese ranged from 160 to 740 ug/L. The samples had SAR values that ranged from 0.5 to 7.6; only one sample had a value greater than 2.1. Specific conductances ranged from 508 to 1,400 umho/cm. The irrigation classification of water from seven of the nine wells was C2-S1, the others were C3-S1 and C3-S2.

Based on an areal extent of 6 mi^2 (16 km^2), a mean saturated thickness of 10 feet (3 m), and an estimated specific yield of 0.15, about 5,800 acre-feet (7.2 hm^3) of water is available from storage.

Undifferentiated Glacial-Drift Aquifers

Undifferentiated glacial-drift aquifers are interspersed within the till in most of Dickey and LaMoure Counties. The aquifer materials consist of sand and gravel that was deposited in long, narrow channels wherever there was sufficient glacial melt water to cause sorting. Thus, the areas most likely to contain these aquifers are where elongate surface depressions occur, or where several sloughs are in a chain. Some of these areas also may be mantled with thin surficial-outwash deposits that may be saturated. The undifferentiated glacial-drift aquifers generally have not been traced beyond the individual well or test hole where they were encountered.

The small size of most of the undifferentiated glacial-drift aquifers severely restricts their capacity to yield water. However, they generally yield enough for domestic and stock supplies. Many of the aquifers probably could not sustain yields of as much as 10 gal/min (0.6 L/s); a few, however, will yield more. The aquifers most likely to have the greater yields are those associated with the elongate surface depressions or chains of sloughs.

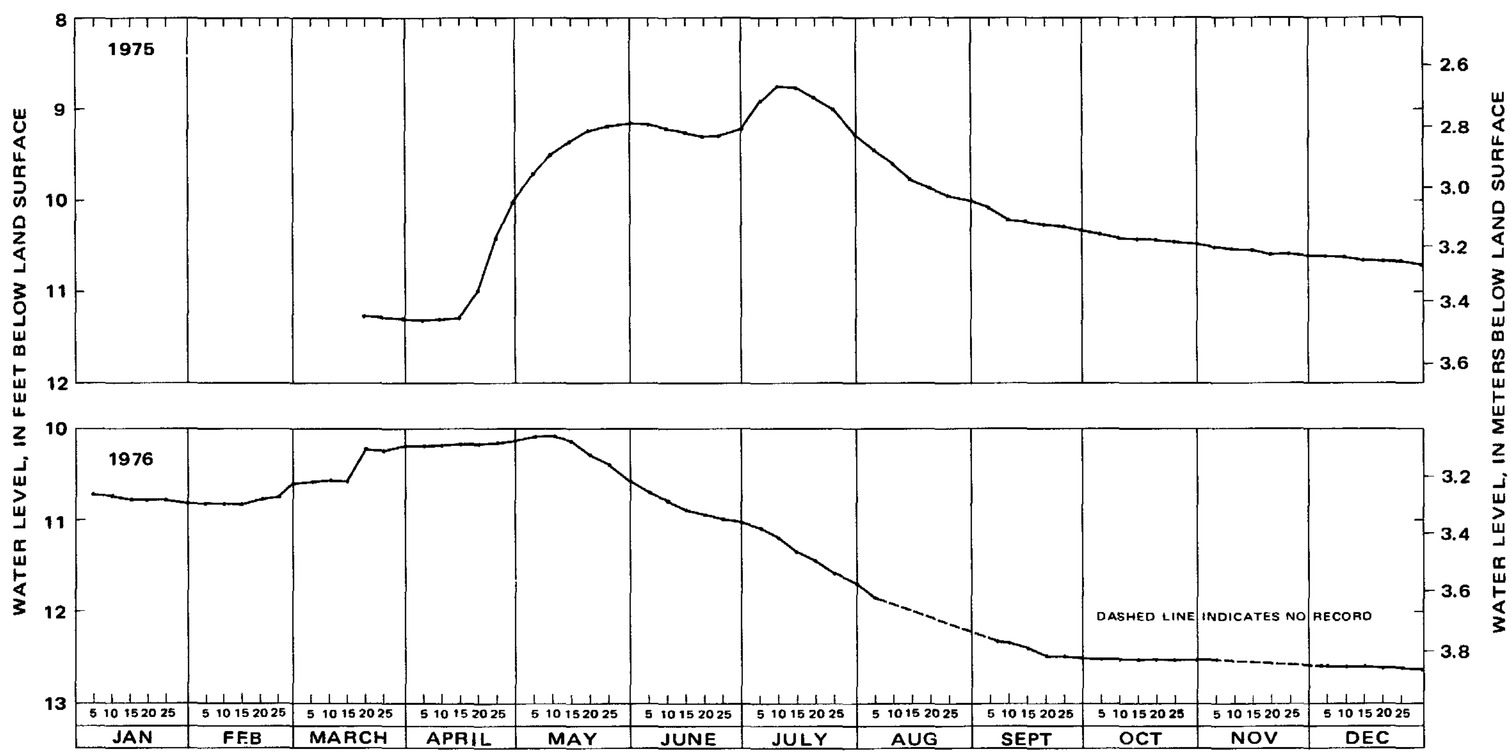


FIGURE 18.—Water levels in observation well 134-064-22BBB2 in the Edgeley aquifer.

Recharge to the undifferentiated glacial-drift aquifers is principally from infiltration of precipitation in areas of sandy soils, lateral movement from adjacent sediments, and surface water that accumulates in ponds and sloughs. Although many of the sloughs and ponds contain water for only a few months in the spring, some are important sources of recharge, depending on hydraulic conductivities and head relationships. The quantity of recharge from each source probably is small, but the total recharge generally is sufficient to replace the water presently being discharged from the aquifers.

Water in the undifferentiated glacial-drift aquifers generally is hard to very hard, but one well, 132-064-23CCC, in the area of thin drift had soft water. Water samples were collected from 12 wells penetrating undifferentiated glacial-drift aquifers. The analyses of the water shows that quality of water varies from place to place. Sodium generally is the predominant cation, but locally calcium may predominate. Generally either sulfate or bicarbonate is the dominant anion, but locally chloride may be the most abundant anion. Dissolved-solids concentrations in the 12 samples ranged from 496 to 2,760 mg/L. Sodium concentrations ranged from 23 to 550 mg/L. The sodium ranged from 9 to 89 percent of the cations. Sulfate ranged from 95 to 1,300 mg/L and exceeded 250 mg/L in eight samples. Chloride concentrations ranged from 5.7 to 630 mg/L and exceeded 250 mg/L in only one sample. Hardness ranged from 49 to 720 mg/L. Iron concentrations exceeded the recommended limit in four of the samples. Manganese concentrations exceeded the recommended limit in nine of 10 samples analyzed for this ion.

The specific conductance ranged from 845 to 3,480 umho/cm; The SAR values ranged from 0.5 to 19 and had a mean value of 8.3. The irrigation classification of the best quality water was C3-S1; the poorest was C4-S4.

USE OF GROUND WATER

The principal uses of ground water in Dickey and LaMoure Counties are for domestic, livestock, public, and irrigation supplies. Practically all of the small industries in the counties use public supplies for their water needs. Dairies and dairy farms throughout the counties use considerable water for cooling and sanitation in addition to livestock use, but no records of water use are kept.

Domestic and Livestock Supplies

Most farm units in the area have at least one well for their domestic and livestock supplies, but no records are available to accurately determine the quantity of water used. The following table shows the approximate quantity of water pumped in 1976.

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

Use	Individual requirements (gal/d)	Population	Estimated pumpage (gal/d rounded)
Domestic (not including cities having public supplies)	a 75	b 7,425	560,000
Cattle	15	c 130,000	1,950,000
Cows with calves	35	c 6,800	240,000
Hogs	2	c 24,000	48,000
Total			2,800,000

a Estimated from average per-person use in smaller cities in Dickey and LaMoure Counties.
b U.S. Bureau of the Census, 1971.
c North Dakota State University, 1976.

Public Supplies

The cities and villages in Dickey and LaMoure Counties all depend on ground water for their water supplies. The cities of Ellendale, Forbes, Fullerton, Ludden, Monango, and Oakes in Dickey County and the cities of Berlin, Edgeley, Jud, Kulm, LaMoure, Marion, and Verona in LaMoure County all have distribution systems. Citizens in other cities and villages in the two counties depend on private wells for their supplies.

Ellendale

The city of Ellendale obtains its water supply from wells 130-062-25CCD2 and 130-062-36BAA completed in the Ellendale aquifer. Each well is capable of producing more than 300 gal/min (19 L/s), or about 430,000 gal/d (1,600 m^3/d). The average daily use in 1976 was reported to be about 219,000 gallons (830 m^3). The annual use is about 80,000,000 gallons (300,000 m^3). A water sample collected from well 130-062-25CCD was analyzed for common and selected minor ions. The concentrations of sulfate (420 mg/L), and manganese (1,500 ug/L) were the only constituents that exceeded the recommended limits.

Should the city of Ellendale require more water, additional wells could be drilled into the Ellendale aquifer in the vicinity of the present wells. However, new wells should be spaced at least several hundred feet from the existing wells in order to decrease interference.

Forbes

The city of Forbes obtains its water supply from a 1,200-foot (366-m) well that is completed in the Newcastle aquifer. The well is capable of producing about 30 gal/min (2 L/s); but it is reported that the city uses only about 5 gal/min (0.32 L/s, or about 2,550,000 gallons (9,700 m^3) annually. A water sample from the municipal supply taken in 1978 had a dissolved-solids concentration of 2,280 mg/L and a chloride concentration of 810 mg/L.

Should the city need another well, they should consider another well to the Newcastle or Lakota-Fall River aquifer. The Pierre aquifer is the only known alternate source of shallow ground water in the area; however, water from wells tapping the Pierre aquifer in the area contains greater quantities of sulfate, chloride, and dissolved solids than their present supply.

Fullerton

The city of Fullerton obtains its water from a 1,090-foot (332-m) well (131-062-15ACB) that is completed in the Newcastle aquifer. The maximum possible well yield has never been determined, but the reported daily use (U.S. Public Health Service, 1964) is about 10,000 gallons (38 m^3), or about 3,650,000 gallons (13,800 m^3) annually. A water sample was collected from the well and analyzed for both common ions and selected minor ions. Chloride (1,200 mg/L) was the only constituent that exceeded the recommended limits.

Should the city of Fullerton desire more water, another well could be drilled either to the Newcastle or Lakota-Fall River aquifer. However, an adequate supply of better quality water could be obtained from the Ellendale aquifer, about 2 miles (3.2 km) east of the city.

Ludden

The city of Ludden obtains its water supply from two wells located at 129-059-07ABB. One of the wells is reported to be between 800 and 900 feet (244 and 274 m) deep and probably is completed in the Newcastle aquifer. The other well is reported to be more than 1,100 feet (335 m) deep and probably is finished in the Lakota-Fall River aquifer. These wells are reported to flow at 10 and 15 gal/min (0.6 and 0.9 L/s), respectively, into a 15,000 gallon (57 m^3) tank. When the tank is full, a valve reduces the flow, which is then bypassed to a pasture south of the city. A water sample taken in 1978 from the deeper well contained 2,610 mg/L dissolved solids and 840 mg/L chloride. No reliable estimates are available concerning the quantity of water used by the city, but based on the population and the poor quality of the water, they probably use about 3,000 gal/d (11 m^3/d).

Should the city of Ludden desire an alternative source of water, an adequate supply of better quality water could be obtained from the Oakes aquifer.

Monango

The city of Monango obtains its water supply from the 48-foot (15-m) well 131-063-08DDB completed in the Pierre aquifer. The well is reported to be pumped at about 10 gal/min (0.6 L/s), but it is not known how long this rate can be sustained. The reported daily use is about 7,000 gallons (26 m^3). A water sample taken in 1978 from the city well contained 1,810 mg/L dissolved solids, 720 mg/L sulfate, 250 mg/L chloride, and 1,200 ug/L iron.

The Pierre aquifer is the only source of water near the city of Monango. The closest alternate source of better quality water is the undifferentiated glacial-drift aquifer near Maple Creek at 132-063-22CCC, about 5 miles (8 km) northeast of the city.

Oakes

The city of Oakes obtains its water supply from two 58-foot (18-m) wells in the Oakes aquifer. Oakes No. 1, at 131-059-29ABC is pumped at a rate of 500 gal/min (32 L/s) and Oakes No. 2 at 131-059-29ADC is pumped at a rate of 400 gal/min (25 L/s). The city reports that their minimum daily use is about 200,000 gallons (757 m^3) and the maximum use is 900,000 gallons (3,400 m^3). The average daily use during 1975 was 274,000 gallons (1,040 m^3), and approximately 100 million gallons (3,785 hm^3) was used during the year.

A water sample collected from well 131-059-29ABC was analyzed for common and selected minor ions. Manganese (770 ug/L) is the only constituent to exceed the recommended limits.

Should the city need more water, other wells could be drilled into the Oakes aquifer for an adequate supply.

Berlin

The city of Berlin obtains its water supply from a 132-foot (40-m) well, 134-062-33BDB, completed in the Nortonville aquifer. The city has a distribution system only to a few commercial establishments and an outlet for hauling water. No records are available as to the quantity of water used. Estimates based on population, however, indicate that about 4,000 gal/d (15 m^3/d) is pumped.

A water sample collected from the city well and analyzed for common and selected minor ions showed that sulfate (470 mg/L) and iron (830 ug/L) are the only constituents that exceeded the recommended limits.

If Berlin needs more water, adequate supplies can be obtained from additional wells in the Nortonville aquifer.

Edgeley

Before 1978, the city of Edgeley obtained its water from seven wells that tapped the Pierre aquifer and aquifers in the undifferentiated glacial drift. These wells were pumped at rates ranging from 15 to 50 gal/min (0.9 to 3 L/s). In 1974, the city used a minimum of 984,000 gallons (3,720 m^3) in January and a maximum of 5,350,000 gallons (20,200 m^3) in July. The total annual use was 24,400,000 gallons (92,400 m^3), or about 67,000 gal/d (254 m^3/d).

A composite sample of water taken from the distribution system was analyzed for both common and selected minor ions. Sulfate (380 mg/L), chloride (330 mg/L), iron (3,300 ug/L), and manganese (850 ug/L) concentrations in the sample all exceeded the recommended limits.

In 1978, after data for this project were collected, the city obtained a new water supply from the Edgeley aquifer.

Jud

The city of Jud obtains its water supply from a 128-foot (39-m) well completed in an undifferentiated glacial-drift aquifer. The well is pumped at 25 gal/min (1.6 L/s) and in 1976 supplied about 7,800 gal/d (30 m^3/d), for a total of 2,880,000 gallons (10,900 m^3) annually. A water sample collected in 1978 contained 1,050 mg/L dissolved solids, 400 mg/L sulfate, and 410 ug/L iron. The Lakota-Fall River and possibly the Newcastle aquifers are alternate sources of water.

Kulm

The city of Kulm obtains its water supply from two wells completed in the undifferentiated glacial drift. Well No. 1, 133-066-26CBA, and well No. 2, 133-066-26CDC, were both reported to be about 290 feet (88 m) deep and were pumped at a rate of 50 gal/min (3 L/s). The reported use in 1975 was about 1.5 million gallons (5,678 m^3) per month, or about 50,000 gal/d (190 L/d).

A sample of water (North Dakota State Dept. of Health, 1964) analyzed for common ions showed that sulfate (298 mg/L) was the only constituent that exceeded the recommended limits.

If Kulm should require more water another well could be drilled into an undifferentiated glacial-drift aquifer near test hole 133-066-23DDD.

LaMoure

The city of LaMoure obtains its water supply from well 133-061-01DBD, which is a 20-foot (6-m) dug well completed in the LaMoure aquifer. About 31 million gallons (117,000 m^3) of water, or about 85,000 gal/d (322 m^3), was withdrawn from the aquifer during 1976.

A sample collected from the well and analyzed for common and selected minor ions showed that iron (850 ug/L) and manganese (570 ug/L) were the only constituents that exceeded the recommended limits.

If LaMoure should need another well, they can obtain one almost anywhere in the LaMoure aquifer. Yields, however, probably would be higher near the James River or about a mile west of the river.

Marion

The city of Marion obtains it water from a 90-foot (27-m) well, 136-061-10CCA, completed in an undifferentiated glacial-drift aquifer. The well is pumped at a rate of 250 gal/min (16 L/s). The reported use in 1976 was 7,340,000 gallons (27,800 m^3). The average use is about 20,000 gal/d (76 m^3/d). The city also uses about 240,000 gallons (910 m^3) per year to flush the iron and manganese from the city mains.

A sample taken from the well in 1975 and analyzed for common and selected minor ions had sulfate (350 mg/L), iron (2,000 ug/L), and manganese (570 ug/L) concentrations that exceeded the recommended limits. This sample, when compared to one collected in 1973, indicates the quality of the water in the well may be slowly deteriorating with use. Dissolved-solids, sulfate, and chloride concentrations have increased from 1,220, 330, and 150 mg/L to 1,270, 350, and 220 mg/L, respectively. The increase in concentrations probably is caused by upward movement of water from the underlying Pierre aquifer. The rate of increase might be reduced by drilling additional wells and spreading the pumpage between wells.

If the city should desire more water, other shallow wells could be drilled. However, if large quantities of water should be needed, a supply could be obtained from the Spiritwood aquifer system about 6 miles (10 km) west of the city.

Verona

The city of Verona obtains its water supply from a 1,223-foot (373-m) well reportedly completed in the Lakota-Fall River aquifer. In 1975 the well flowed about 30 gal/min (1.9 L/s). The water used is not metered, but the mayor, Mr. Pithey (oral commun., 1975), estimated an annual use of about 3,000,000 gallons (11,400 m^3), or about 8,200 gal/d (31 m^3/d).

A sample of water taken from the well and analyzed for both common and selected minor ions showed that sulfate (1,200 mg/L) was the only constituent that exceeded the recommended limits.

If Verona should desire an alternate source of water they could drill a well into the Spiritwood aquifer system about 2.5 to 3 miles (4 to 4.9 km) southwest of the city. By doing so, they could obtain better quality water.

Irrigation Supplies

In 1976 irrigation wells in the Edgeley aquifer pumped approximately 540 acre-feet (0.67 hm^3) of water. Wells in the Ellendale, Guelph, and Nortonville aquifers pumped about 133, 168, and 270 acre-feet (0.16, 0.20, and 0.33 hm^3), respectively. Wells in the LaMoure, Spiritwood, and Oakes aquifers pumped about 2,250 acre-feet (2.75 hm^3), 1,230 acre-feet (1.4 hm^3), and 3,000 acre-feet (3.7 hm^3), respectively.

In addition, about 1,880 acre-feet (2.3 hm^3) of water was pumped from surface sources, principally the James River, for irrigation purposes.

SUMMARY

Ground water in Dickey and LaMoure Counties may be obtained from sandstone beds in the Black Island, Lakota, Fall River, and Newcastle Formations, fractured zones in the shale in the Pierre Formation, and from sand and gravel beds in the glacial deposits.

The Black Island aquifer lies at depths that range from 1,421 feet (433 m) to 3,000 feet (910 m) below land surface. Individual sandstone beds are as much as 18 feet (5.5 m) thick, and aggregate sandstone thicknesses are as much as 57 feet (17 m). Properly constructed wells in the aquifer should be capable of producing about 700 gal/min (44 L/s). Samples from two wells believed to tap the aquifer had sodium sulfate type water containing 2,520 and 3,800 mg/L dissolved solids.

The Lakota-Fall River aquifer underlies the two counties at depths ranging from 1,100 feet (335 m) to 2,200 feet (670 m) below land surface. The aquifer ranges from 35 to 276 feet (11 to 84 m) in thickness and has a mean thickness of about 106 feet (32 m). Well yields generally are small, but locally yields of as much as 1,000 gal/min (63 L/s) should be obtainable. Samples from 20 wells in the aquifer had sodium sulfate, calcium sulfate, or sodium chloride type water containing dissolved-solids concentrations that ranged from 2,030 to 4,850 mg/L.

The Newcastle Formation underlies the area at depths of 790 (240 m) to somewhat more than 2,000 feet (610 m) and is as much as 300 feet (91 m) thick. The formation is considered as one aquifer system that contains two separate aquifers. Well yields generally are less than 80 gal/min (5 L/s). Samples show that water from the upper aquifer generally is a sodium chloride type, and water from the lower aquifer generally is a sodium sulfate type. Dissolved-solids concentrations ranged from 2,060 to 4,590 mg/L.

The Pierre aquifer underlies the glacial drift in the western and northern parts of the two counties. It supplies water for farms in areas where glacial drift is thin and glacial aquifers are missing. Individual well yields are as much as 50 gal/min (3 L/s), but generally yields are less than 5 gal/min (0.3 L/s). Water quality in the Pierre aquifer varies considerably in both type and concentrations; generally sodium is the predominant cation and either chloride or sulfate is the dominant anion. Dissolved-solids concentrations in six samples ranged from 1,400 to 8,630 mg/L.

The glacial-drift aquifers with the greatest potential for development are those associated with buried valleys and outwash deposits. The buried-valley aquifers are the Spiritwood, Nortonville, and Ellendale aquifers; also the southern part of the Guelph aquifer. Those associated with outwash are the Oakes, LaMoure, and Edgeley aquifers, and the northern part of the Guelph aquifer. The Oakes aquifer also is comprised of deltaic and lake deposits. The sediments in the aquifers are lenticular, thus the thickness and hydraulic characteristics of any particular sand or gravel body may vary within a short distance. Undifferentiated glacial-drift aquifers generally yield only small quantities of water. Hydrologic data for the major glacial-drift aquifers are listed in table 3.

The rural population of Dickey and LaMoure Counties is dependent upon ground water for their domestic and most of their livestock needs. In addition, the cities of Ellendale, Forbes, Fullerton, Ludden, Monango, and Oakes in Dickey County and Berlin, Edgeley, Jud, Kulm, LaMoure, Marion, and Verona in LaMoure County obtain their public supplies from wells.

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

Aquifer	Areal extent (square miles)	Average saturated thickness (feet)	Estimated amount of water available from storage (acre-feet)	Water type	Dissolved solids (milligrams per liter)	Sodium-adsorption ratio	Probable maximum well yield (gal/min)
Spiritwood	195	50	936,000	Sodium bicarbonate.	345 to 1,430	0.2 to 13	1,500
Nortonville	42	40	161,000	Sodium sulfate, sodium chloride, or sodium bicarbonate.	944 to 1,890	4.7 to 22	600
Ellendale	125	33	396,000	Sodium-calcium sulfate.	541 to 2,280	.4 to 5.2	500
Guelph	20	35	67,000	Calcium sulfate or sodium sulfate.	710 to 1,440	.5 to 4.9	1,000
Oakes	93	30	268,000	Calcium bicarbonate.	293 to 798	.0 to 3.0	1,500
LaMoure	23	46	102,000	Calcium bicarbonate.	248 to 1,120	.2 to 2.4	1,500
Edgeley	6	10	5,800	Calcium-magnesium bicarbonate.	308 to 945	.5 to 7.6	800

SELECTED REFERENCES

Abbott, G. A., and Voedisch, F. W., 1938, The municipal ground water supplies of North Dakota: North Dakota Geological Survey Bulletin 11, 99 p.

Anderson, S. B., 1953, Summary of the Elmer Heim No. 1 well, LaMoure County, North Dakota: North Dakota Geological Survey Circular no. 29, 6 p.

Armstrong, C. A., and Luttrell, S. P., 1978, Ground-water basic data for Dickey and LaMoure Counties, North Dakota: North Dakota State Water Commission County Ground-Water Studies 28, pt. II, and North Dakota Geological Survey Bulletin 70, pt. II, 557 p.

Bluemle, J. P., 1979, Geology of Dickey and LaMoure Counties, North Dakota: North Dakota State Water Commission County Ground-Water Studies 28, pt. I, and North Dakota Geological Survey Bulletin 70, pt. I.

Clayton, Lee, 1962, Glacial geology of Logan and McIntosh Counties, North Dakota: North Dakota Geological Survey Bulletin 37, 84 p.

Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1963, Preliminary glacial map of North Dakota: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-331.

Croft, M. G., 1971, A method of calculating permeability from electric logs: U.S. Geological Survey Professional Paper 750-B, p. B265-B269.

Darton, N. H., 1909, Geology and underground waters of South Dakota: U.S. Geological Survey Water-Supply Paper 227, 156 p.

Durfor, C. N., and Becker, Edith, 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geological Survey Water-Supply Paper 1812, 364 p.

Fenneman, N. M., 1946, Physiographic divisions of the United States: U.S. Geological Survey map prepared in cooperation with Physiographic Committee, U.S. Geological Survey, scale 1:7,000,000 (reprinted 1964).

Flint, R. F., 1955, Pleistocene geology of eastern South Dakota: U.S. Geological Survey Professional Paper 262, 173 p.

Hansen, D. E., 1955, Subsurface correlations of the Cretaceous Greenhorn-Lakota interval in North Dakota. North Dakota Geological Survey Bulletin 29, 46 p.

Hard, H. A., 1929, Geology and water resources of the Edgeley and LaMoure quadrangles, North Dakota: U.S. Geological Survey Bulletin 801, 90 p.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water (2d ed.): U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Huxel, C. J., Jr., 1961, Artesian water in the Spiritwood buried valley complex, North Dakota: U.S. Geological Survey Professional Paper 424-D, p. D179-D181.

Huxel, C. J., Jr., and Petri, L. R., 1965, Geology and ground-water resources of Stutsman County, North Dakota: North Dakota State Water Commission County Ground-Water Studies 2, pt. III, and North Dakota Geological Survey Bulletin 41, pt. III, 58 p.

Jacob, C. E., 1940, On the flow of water in an elastic artesian aquifer: Transactions of the American Geophysical Union, pt. II, p. 574-586; duplicated as U.S. Geological Survey Ground-Water Note 8, 1953, 24 p.

Johnson, E. E., Inc., 1966, Ground water and wells: St. Paul, Minnesota, Edward E. Johnson, Inc., 440 p.

Koch, N. C., Bradford, Wendell, and Leap, D. I., 1973, Major aquifers and sand and gravel resources in Brown County, South Dakota: South Dakota Geological Survey Information Pamphlet no. 4, Vermillion, South Dakota, 7 p.

Lindvig, M. O., 1965, Ground water in the Ellendale area, Dickey County, North Dakota: North Dakota State Water Commission Ground-Water Studies no. 61, 30 p.

Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Lohman, S. W., and others, 1972, Definitions of selected ground-water terms — revisions and conceptual refinements: U.S. Geological Survey Water-Supply Paper 1988, 21 p.

Meinzer, O. E., and Hard, H. A., 1925, The artesian water supply of the Dakota Sandstone in North Dakota, with special reference to the Edgeley quadrangle: U.S. Geological Survey Water-Supply Paper 520-E, 95 p.

Meyer, R. R., 1963, A chart relating well diameter, specific capacity, and the coefficients of transmissibility and storage, *in* Bentall, Ray, Methods of determining permeability, transmissibility, and drawdown: U.S. Geological Survey Water-Supply Paper 1536-I, p. 338-340.

Naplin, C. E., 1973, Ground-water resources of the Ellendale area, Dickey County, North Dakota: North Dakota State Water Commission Ground-Water Studies no. 75, 128 p.

______ 1976, Ground-water resources of the Edgeley area, LaMoure County, North Dakota: North Dakota State Water Commission Ground-Water Studies no. 82, 56 p.

National Academy of Sciences-National Academy of Engineering, 1972 [1973], Water quality criteria 1972: U.S. Environmental Protection Agency, Ecological Research Series, Report EPA R3-73-033, March 1973, 594 p.

Nettleton, E. S., 1892, Artesian and underflow investigation: 52d Congress, 1st session, Senate Executive Document 41, pt. 2, p. 67-68.

North Dakota State Department of Health, 1964, Chemical analyses of municipal waters in North Dakota: 25 p.

______ 1977, Regulations for public water supply systems of the State of North Dakota: Regulation 61-28.1-02, 18 p.

North Dakota State University, 1977, North Dakota crop and livestock statistics, annual summary for 1976, revisions for 1975: Agricultural Statistics no. 40, 77 p.

Rasmussen, W. C., 1947, Ground water in the deposits of ancient Lake Dakota, Dickey County, North Dakota: North Dakota State Water Commission Ground-Water Studies no. 4, 87 p.

Simpson, H. E., 1929, Geology and ground-water resources of North Dakota, with a discussion of the chemical character of the water by H. B. Riffenburg: U.S. Geological Survey Water-Supply Paper 598, 312 p.

Stallman, R. W., 1963, Type curves for the solution of single-boundary problems, *in* Bentall, Ray, Shortcuts and special problems in aquifer tests: U.S. Geological Survey Water-Supply Paper 1545-C, p. C45-C47.

Strassberg, Morton, 1954, Summary of the Herman Hanson oil syndicate Harold Billey No. 1, Dickey County, North Dakota: North Dakota Geological Survey Circular no. 88, 3 p.

Swenson, F. A., 1968, New theory of recharge to the artesian basin of the Dakotas: Geological Society of America Bulletin, v. 79, p. 163-182.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Transactions of the American Geophysical Union, pt. II, p. 519-524.

——— 1963, Estimating the transmissibility of a water-table aquifer from the specific capacity of a well, *in* Bentall, Ray, Methods of determining permeability, transmissibility, and drawdown: U.S. Geological Survey Water-Supply Paper 1536-I, p. 332-336.

U.S. Army Map Service, 1956, NL 14-5, Jamestown: U.S. Army Map Service, Corps of Engineers.

——— 1964, NL 14-8, Aberdeen: U.S. Army Map Service, Corps of Engineers.

U.S. Bureau of the Census, 1971, 1970 census of population, number of inhabitants, North Dakota: U.S. Bureau of the Census Report PC(1)-A36, 26 p.

U.S. Environmental Data Service, 1963-77, Climatological data, North Dakota; Annual summaries 1962-76: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, v. 71-85, no. 13.

——— 1973, Monthly normals of temperature, precipitation, and heating and cooling degree days 1941-70: U.S. Department of Commerce, National Oceanic and Atmospheric Administration Climatography of the United States, no. 81 (by state), North Dakota.

U.S. Public Health Service, 1962, Public Health Service drinking water standards 1962: Public Health Service Publication no. 956, 61 p.

——— 1964, Municipal water facilities, 1963 inventory, Region VI (North Dakota): Public Health Serivce Publication no. 775 (revised), v. 6, p. 119-127.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Department of Agriculture, Agriculture Handbook no. 60, 160 p.

Wenzel, L. K., and Sand, H. H., 1942, Water supply of the Dakota Sandstone in the Ellendale-Jamestown area, North Dakota, with reference to changes between 1923 and 1938: U.S. Geological Survey Water-Supply Paper 889-A, 81 p.

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 or springs.

Artesian well – A well in which the water level stands above an artesian or confined aquifer. A flowing artesian well is a well in which the water level (artesian head) is above the land surface. See confined ground water.

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

Confining bed – A body of relatively impermeable material adjacent to one or more aquifers. In nature, the hydraulic conductivity of a confining bed may range from near zero to some value distinctly lower than that of the adjacent aquifer.

Confined ground water – Water is under pressure greater than atmospheric, and its upper limit is the bottom of a bed of distinctly lower hydraulic conductivity than that of the material in which the confined water occurs.

Head, static – The height above a standard datum at which the upper surface of a column of water or other liquid can be supported by the static pressure at a given point. The term static head, which is a measure of potential, is sometimes expressed simply as head.

Hydraulic conductivity – A term replacing field coefficient of permeability and expressed as feet per day or meters per day. The ease with which a fluid will pass through a porous material. This is determined by the size and shape of the pore spaces in the rock and their degree of interconnection. Hydraulic conductivity may also be expressed as cubic feet per day per square foot, gallons per day per square foot, or cubic meters per day per square meter. Hydraulic conductivity is measured at the prevailing water temperature.

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.

Porosity – The ratio of the volume of the voids in a rock to the total volume. The ratio may be expressed as a decimal fraction or as a percentage. The term effective porosity refers to the amount of interconnected pore spaces or voids in a rock or soil and is expressed as a percentage of the total volume occupied by the interconnecting pores.

Potentiometric surface – The surface that represents the static head. It may be defined as the level to which water will rise in tightly cased wells. A water table is a potentiometric surface.

Sodium-adsorption ratio – The ratio expressing the relative activity of sodium ions in exchange reaction with soil and is an index of the sodium or alkali hazard to the soil. Sodium-adsorption ratio is expressed by the equation

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

where the concentrations of the ions are expressed in milliequivalents per liter or equivalents per million.

Specific capacity – The rate of discharge of water from a well divided by the drawdown of the water level, normally expressed as gallons per minute per foot of drawdown.

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

Storage coefficient – The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an artesian aquifer the water derived from storage with decline in head comes mainly from compression of the aquifer and to a lesser extent from expansion of the water. In an unconfined, or water-table aquifer, the amount of water derived from the aquifer is from gravity drainage of the voids and is equal to specific yield.

Transmissivity – The rate at which water, at the prevailing temperature, is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity is normally expressed in units of feet squared per day or meters squared per day, but can be expressed as the number of gallons of water that will move in 1 day under a hydraulic gradient of 1 foot per foot through a vertical strip of aquifer 1 foot wide extending the full saturated height of the aquifer.

Water table – Is the upper surface of the zone of saturation in an unconfined aquifer at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the aquifer just far enough to hold standing water.

Zone of saturation – In the saturated zone of an aquifer all voids are ideally filled with water. The water table is the upper limit of this zone. In nature, the saturated zone may depart from the ideal in some respects. A rising water table may trap air in parts of the zone and other natural fluids may occupy voids in the lower part of an aquifer.