GROUND-WATER RESOURCES

OF

RANSOM AND SARGENT COUNTIES, NORTH DAKOTA

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

A dual system of measurements – inch-pound units and the International System (SI) of 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)
Acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
Cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
Foot (ft)	0.3048	meter (m)
Foot per day (ft/d)	0.3048	meter per day (m/d)
Foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
Foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
Gallon (gal)	3.785	liter (L)
	0.003785	cubic meter (m^3)
Gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
Gallon per minute (gal/min)	0.06309	liter per second (L/s)
Gallon per minute per foot [(gal/min)/ft]	0.207	liter per second per meter [(L/s)/m]
Inch (in.)	25.40	millimeter (mm)
Micromho per centimeter (umho/cm)	1	microsiemen per centimeter (us/cm)
Mile (mi)	1.609	kilometer (km)
Million gallons (Mgal)	3,785	cubic meter (m^3)
	0.003785	cubic hectometer (hm^3)
Square mile (mi^2)	2.590	square kilometer (km^2)

To convert degrees Fahrenheit (°F) to degrees Celsius (°C) use the following formula $°C = (°F - 32) \times 5/9$.

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ABSTRACT

Ground water in Ransom and Sargent Counties is available from glacial-drift aquifers of Quaternary age and from the Dakota aquifer system of Cretaceous age. Glacial-drift aquifers with the greatest potential for development are the Spiritwood aquifer system and the Brampton, Elliott, Gwinner, Englevale, Milnor Channel, Oakes, Sheyenne Delta, and Sand Prairie aquifers. Properly constructed wells in the more permeable parts of these aquifers will yield from 500 to 1,500 gallons per minute (32 to 95 liters per second). A total of about 3,000,000 acre-feet (3,700 cubic hectometers) of water is available from storage in the glacial-drift aquifers.

Water from the glacial-drift aquifers varies in chemical quality. Dissolved-solids concentrations in samples from these aquifers range from 203 to 4,670 milligrams per liter.

The top of the Dakota aquifer system underlies Ransom and Sargent Counties at depths that range from about 500 to 1,000 feet (150 to 305 meters) below land surface. Water in the Dakota is under sufficient head to flow at land surface in most parts of the two-county area. Unrestricted flows from wells tapping the aquifer system generally are less than 10 gallons per minute (0.6 liters per second), but may be as much as 50 gallons per minute (3 liters per second). Water in the Dakota aquifer system generally is a sodium sulfate type and has dissolved-solids concentrations ranging from 2,170 to 3,340 milligrams per liter.

INTRODUCTION

Ransom and Sargent Counties are in southeastern North Dakota (fig. 1). They have a combined area of about 1,726 mi^2 (4,470 km^2), in which 863 mi^2 (2,235 km^2) is in Ransom County and 863 mi^2 (2,235 km^2) is in Sargent County. The geology and ground-water resources study of the counties began in July 1974 as a cooperative investigation by the U.S. Geological Survey, the North Dakota State Water Commission, the North Dakota Geological Survey, the Ransom County Water Management District, and the Sargent County Water Management District. The field investigation was completed in December 1977. The results of the study are published in three parts. The North Dakota Geological Survey mapped the geology of the counties and published the results as part I, geology (Bluemle, 1979). The ground-water data collected during the investigation were published as part II, basic data (Armstrong, 1979). This report, part III, is an interpretive report describing the

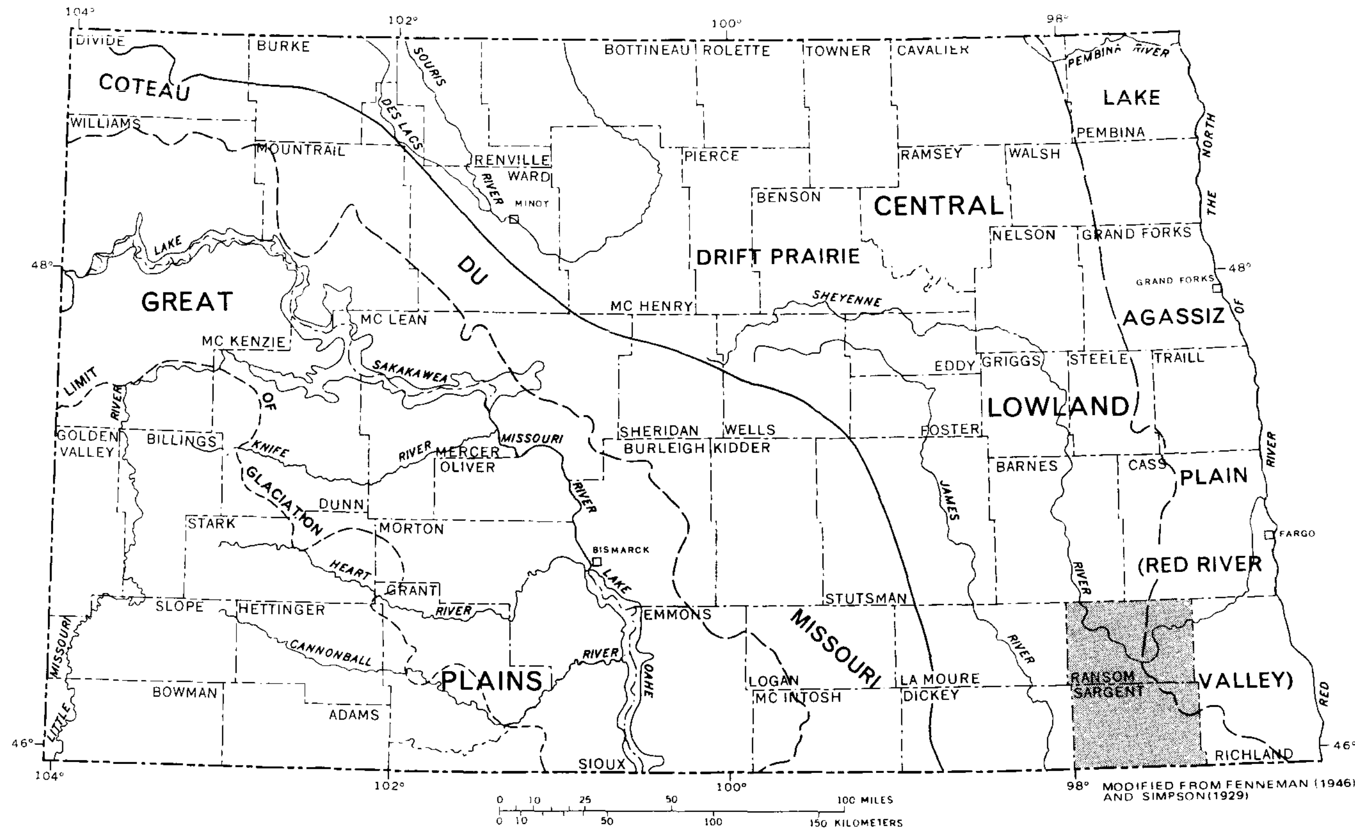


FIGURE 1.—Physiographic divisions in North Dakota and location of study area.

ground-water resources of the two counties. All the data used in this report, unless otherwise referenced, are from part II.

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 Ransom and Sargent Counties, North Dakota. 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 glacial-drift aquifers; (4) estimate the potential yields to wells tapping the major aquifers; (5) determine the chemical quality of the ground water; and (6) estimate water use.

Geologic and hydrologic records were collected from 1,279 wells and test holes to help determine the location and extent of the aquifers. Water levels were measured periodically in 182 observation wells to evaluate patterns of recharge to and discharge from the aquifers. Data from aquifer tests were used to determine the transmissivities and storage coefficients of glacial-drift aquifers in Ransom and Sargent Counties. Physical and chemical properties of ground water were determined from 408 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 section in which a 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 133-057-15DAA would be located in the NE¼NE¼SE¼ sec. 15, T. 133 N., R. 57 W. Consecutive final 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

Ground-water data for Ransom and Sargent 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 Ransom and Sargent 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 southwest Sargent County. Colton, Lemke, and

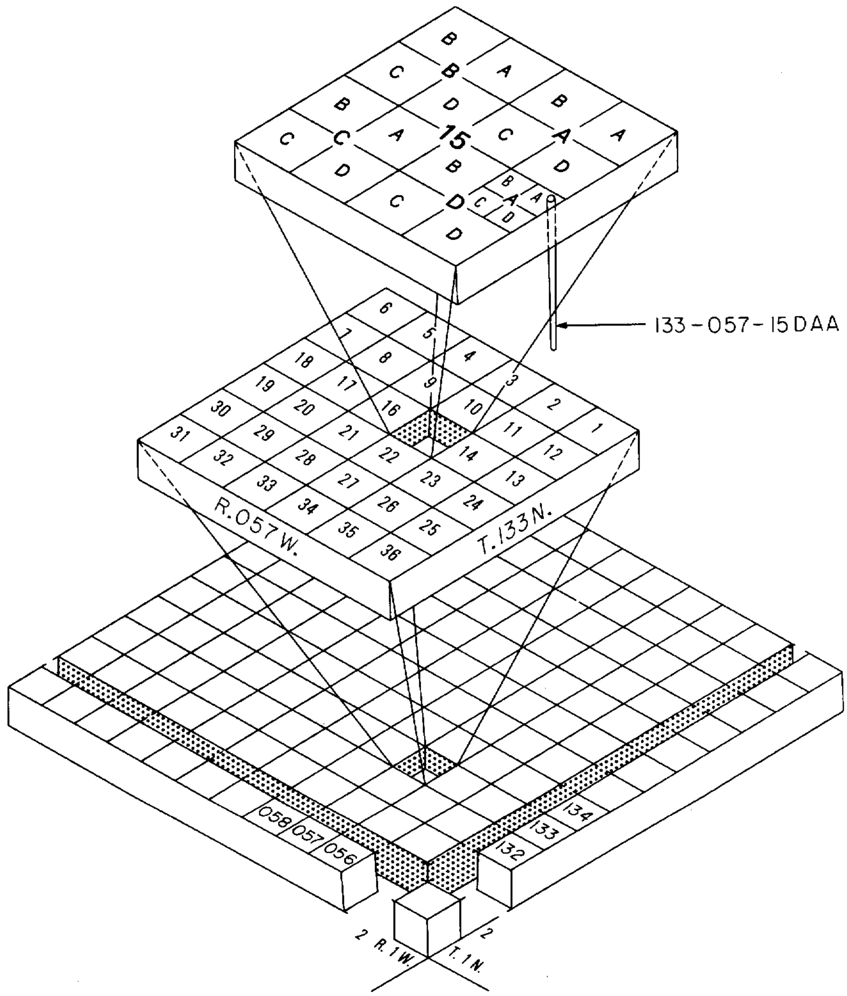


FIGURE 2.—Location-numbering system.

Lindvall (1963) mapped the glacial geology of North Dakota, including Ransom and Sargent Counties.

Ground-water studies completed in adjacent counties have shown the existence of major glacial-drift aquifers, which extend into Ransom or Sargent Counties. The Sheyenne delta was described by Upham (1895), and later described as an aquifer in Richland County by Baker and Paulson (1967) and in Cass County by Klausing (1968). Ground-water and surface-water relationships along the Sheyenne River in Ransom County were described by Paulson (1964). Kelly (1966) traced the Sand Prairie aquifer from Barnes County into Ransom County. The Milnor Channel aquifer in Richland County also was described by Baker and Paulson (1967). Koch and others (1973) described the James aquifer in South Dakota. This aquifer is in part an extension of the Brampton aquifer in North Dakota. Koch (1975) identified the Veblen aquifer in Marshall County, South Dakota. This aquifer is a southern extension of the Spiritwood aquifer system in southeastern Sargent County. Armstrong (1980a) traced the Spiritwood aquifer system through LaMoure and Dickey Counties to the Sargent County border. He also described the Oakes aquifer.

Acknowledgements

Appreciation is expressed to the Ransom and Sargent 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 G. L. Sunderland, L. D. Smith, Jr., and R. L. Cline for their aid in the logging of test holes.

Population and Economy

In 1970, Ransom County had a population of 7,102 and Sargent County had a population of 5,937 (U.S. Bureau of the Census, 1971). The largest cities in Ransom County were Lisbon (county seat), 2,090; Enderlin, 1,343; Sheldon, 192; and Elliott, 50. The largest cities in Sargent County were Milnor, 645; Gwinner, 623; Forman (county seat), 596; Rutland, 225; Cogswell, 203; Havana, 156; and Cayuga, 116.

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 Ransom and Sargent Counties is subhumid. The mean annual precipitation at Lisbon, Ransom County, is 20.19 in. (513 mm) and at Forman, Sargent County, is 20.77 in. (528 mm; U.S. Environmental Data Service, 1973). About 70 percent of the precipitation occurs from April through August. Most of the summer precipitation is from thunderstorms and is extremely variable both in area and in magnitude.

The mean annual temperature is 41.8°F (5.4°C) at Lisbon and is 42.3°F (5.7°C) at Forman. 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. Daily low temperatures commonly are below 0°F (-18°C) during the winter months, especially in January and February.

Physiography and Drainage

About 80 percent of Ransom and Sargent Counties is in the Drift Prairie district of the Central Lowland province and about 20 percent is in the Lake Agassiz Plain (fig. 1). The Drift Prairie is characterized by low topographic relief, except in glacial morainal areas in the southwest and southeast parts of Sargent County and where streams are incised. The Lake Agassiz Plain in Ransom and Sargent Counties consists of the Sheyenne delta. The delta surface is nearly flat in most places, but scattered dunes as much as 85 ft (26 m) high occur locally.

Maximum topographic relief in the two counties is about 790 ft (240 m). The highest altitude is nearly 1,745 ft (532 m) above NGVD of 1929 (National Geodetic Vertical Datum of 1929) on a morainal hill in sec. 19, T. 129 N., R. 54 W. (U.S. Geological Survey, 1958). The lowest altitude is about 959 ft (292 m) in sec. 1, T. 135 N., R. 53 W. where the Sheyenne River flows into Richland County.

Drainage on the Drift Prairie is in a youthful stage and is moderately well developed, except in the delta and morainal areas. Drainage generally is either to the Sheyenne or Wild Rice Rivers. Bear Creek, a tributary of the James River, drains less than 5 percent of the two-county area in western Ransom County. The Maple River drains about 1 percent of the area in north-central Ransom County.

Drainage in the morainal areas of the Drift Prairie 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 Wild Rice River.

Natural surface drainage in the Lake Agassiz Plain is nearly nonexistent except near the Sheyenne and Wild Rice Rivers, which flow through the Sheyenne delta. Short tributaries to these rivers have formed, but they only carry runoff for short periods following large storms.

OCCURRENCE AND QUALITY OF GROUND WATER

General Concepts

All ground water is derived from precipitation. Part of the precipitation that falls on the Earth's surface is returned to the atmosphere by evaporation, part runs off into streams, and the remainder infiltrates into the soil. Some of the water that enters the soil is held by capillary action and evaporates or transpires. The remainder percolates downward to the zone of saturation. When the water enters the zone of saturation it becomes ground water and is available to wells.

Ground water moves, under the effect of gravity, from areas of recharge to areas of discharge. Movement generally is only a few feet per year. The rate of movement is governed by the hydraulic conductivity of the material through which it moves and by the hydraulic gradient. Well-sorted coarse materials such as gravel or coarse sand generally have high conductivities and form good aquifers. Fine-grained materials such as silt, clay, and shale usually have low conductivities 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. In North Dakota, 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. However, 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 contains dissolved solids in varying amounts. Rain dissolves suspended material in the air and continues to dissolve minerals as the water infiltrates through the soil. The amount and type of dissolved chemical constituents 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 type 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 U.S. Environmental Protection Agency (1976,

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

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

[Concentrations are in milligrams per liter, mg/L, or micrograms per liter, ug/L]

Constituents	Major source	Effects upon usability	U.S. Environmental Protection Agency (1976, 1977) recommended and mandatory limits for drinking water
Silica (SiO_2)	Feldspars, quartz, and ferromagnesian and clay minerals.	In presence of calcium and magnesium, silica forms a scale in boilers and on steam turbines that retards heat transfer.	None.
Iron (Fe)	Natural sources: amphiboles, ferromagnesian minerals, ferrous and ferric sulfides, oxides, carbonates, and clay minerals. Man-made sources: well casings, pumps, and storage tanks.	If more than 100 ug/L is present, it will precipitate when exposed to air; causes turbidity, stains plumbing fixtures, laundry, cooking utensils, and imparts tastes and colors to food and drinks. More than 200 ug/L is objectionable for most industrial uses.	300 ug/L (recommended)
Manganese (Mn)	Soils, micas, amphiboles, and hornblende.	More than 200 ug/L precipitates upon oxidation. Causes undesirable taste and dark brown or black stains on fabrics and porcelain fixtures. Most industrial uses require water containing less than 200 ug/L.	50 ug/L (recommended)
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, anhydrite, calcite, aragonite, limestone, dolomite and clay minerals.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate, and silica to form scale in heating equipment. Calcium and magnesium retard the suds-forming action of soap and detergent. Excessive concentrations of magnesium have a laxative effect.	None.
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, magnesite, dolomite, and clay minerals.		
Sodium (Na)	Feldspars, clay minerals, and evaporites.	More than 50 mg/L sodium and potassium may cause foaming, which accelerates scale formation and corrosion in boilers. Large concentrations of sodium may restrict use of water for irrigation.	None.
Potassium (K)	Feldspars, feldspathoids, micas, and clay minerals.		
Boron (B)	Tourmaline, biotite, and amphiboles.	Essential to plant nutrition. More than 2 mg/L may damage some plants.	None.
Bicarbonate (HCO_3)	Limestone and dolomite.	Heating water dissociates bicarbonate to carbonate, carbon dioxide, or both. The carbonate can combine with alkaline earths (principally calcium magnesium) to form scale.	None.
Carbonate (CO_3)			
Sulfate (SO_4)	Gypsum, anhydrite, and oxidation of sulfide minerals.	Combines with calcium to form scale. More than 500 mg/L tastes bitter and may be a laxative.	250 mg/L (recommended).
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 (recommended).
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.	Mandatory maximum limits depend on average of maximum daily air temperatures. Maximum limits range from 1.4 mg/L at 32°C to 2.4 mg/L at 10°C.
Nitrate (NO_3)	Organic matter, fertilizers, and sewage.	More than 100 mg/L may cause a bitter taste and may cause physiological distress. Concentrations in excess of 45 mg/L have been reported to cause methemoglobinemia (blue-baby disease) in infants.	10 mg/L (mandatory).
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.	500 mg/L (recommended).

1977) are given in table 1. The chemical constituents, physical properties, and characteristics most likely to be of concern in Ransom and Sargent Counties are iron, sulfate, nitrate, fluoride, dissolved solids, hardness, temperature, color, odor, taste, specific conductance, SAR (sodium-adsorption ratio), and percent sodium.

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 refer to the predominant cation (sodium, calcium, or magnesium) and anion (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).

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

Hardness in water used for ordinary domestic purposes does not become particularly objectionable until it reaches a level of about 120 mg/L.

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 for irrigation water. For additional information on water quality as related to irrigation, the reader is referred to a report by the 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 aquifer 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:

Material	Hydraulic conductivity (feet per day)	Hydraulic conductivity (meters per day)
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	0.6-6	0.2-2

Where a range is given in the above values, the smaller value was used unless sorting of the sand and gravel was implied by terms such as fine, medium, or coarse, as indicated on the lithologic 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 beds consisting of very fine sand and silt 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 effective well diameter, the coefficient of storage, and the transmissivity are rarely known with sufficient accuracy to determine an actual specific capacity. However, the chart shows that large changes in the storage coefficient correspond to relatively small changes in specific capacity. So, the chart does present a method whereby specific capacities can be estimated. The relation shows that for storage coefficients of less than 0.0005 and for transmissivities greater than 270 ft^2/d (25 m^2/d) the ratio of transmissivity to specific capacity is conservatively estimated to be about 270:1. In most artesian aquifers the storage coefficient falls within the range of 0.00005 to 0.0005. 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 storage coefficients greater than 0.1, which is typical for water-table aquifers, the specific capacity will be greater and the ratio of transmissivity to specific capacity will approach 130:1. The yield of a potential well at a specific site was obtained by multiplying the specific capacity by a drawdown value of 30 ft (9 m). Where 30 ft (9 m) of drawdown was not available, one-half the saturated thickness was used to obtain yield.

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

GEOLOGIC UNITS AND THEIR WATER-BEARING PROPERTIES

Ransom and Sargent Counties are underlain by rocks that range from Precambrian through Quaternary (table 2) in age. The sedimentary rocks of Cretaceous age and older are about 1,400 to 1,500 ft (430 to 460 m) thick in the northwestern part of the area and thin to about 300 ft (90 m) in the eastern part of the area. These rocks dip west-northwest into the Williston basin. Deposits of glacial drift, as much as 410 ft (125 m) thick, overlie the Cretaceous rocks.

Geologic units that contain aquifers of economic importance in Ransom and Sargent Counties are: (1) Dakota Group[1] of Early Cretaceous age; and (2) glacial drift of Quanternary age.

Ground Water in Rocks of Pre-Cretaceous Age

The uppermost sedimentary rocks of pre-Cretaceous age range from about 500 to 650 ft (150 to 200 m) below land surface in the eastern part of the study area and probably are 1,700 to 1,800 ft (520 to 550 m) below land surface in the northwestern part. Pre-Cretaceous sedimentary rocks are missing in about 75 percent of the study area and the Cretaceous sedimentary rocks directly overlie the Precambrian (fig. 3).

Two Cambrian or Ordovician sandstone units that are sufficiently permeable to yield water occur in Dickey and LaMoure Counties. These sandstone units probably extend from LaMoure County eastward into northwestern Ransom County; however, no wells or test holes have been drilled deep enough in the area to confirm the presence of these units in Ransom County.

Ground Water in Rocks of Cretaceous Age

Ground water occurs in aquifers in the Dakota Group, and the Niobrara and Pierre Formations of Cretaceous age. The Dakota aquifer system is composed of fine to coarse sand, and will yield water nearly everywhere in the two-county area. The Niobrara Formation locally contains small lenses of calcareous sand that would yield small quantities of water. Only one well in the Niobrara Formation is known to yield sufficient water for a household supply. The Pierre Formation underlies less than 12 mi^2 (31 km^2) in the extreme northwest part of Ransom County. The formation consists of fissile black shale that contains some water where the shale is fractured.

The stratigaphic 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.

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

Age	Group	Unit name	Description	Thickness (feet)	Water-yielding characteristics
Quaternary		Alluvium and glacial drift, undifferentiated	Till, sand, gravel, silt, and clay.	0 to 410	Yields as much as 1,500 gal/min (95 L/s) to major aquifers.
Tertiary				Absent	
Cretaceous	Montana Group	Pierre Formation	Shale, claystone and bentonite.	150 to 1,000	May yield small quantities of water.
	Colorado Group	Niobrara Formation	Calcareous shale and siltstone.		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.		Does not yield water to wells.
	Dakota Group	Mowry Formation	Shale.	0 to 400	Does not yield water to wells.
		Newcastle Formation	Sandstone, shale, and siltstone.		Yields as much as 50 gal/min (3 L/s).
		Skull Creek Formation	Shale.		
		Fall River Formation and Lakota Formation, undifferentiated	Sandstone and shale.		
Jurassic				Absent	
Triassic					
Permian					
Pennsylvanian					
Mississippian					
Devonian					
Silurian					
Ordovician	Winnipeg Group	Roughlock Formation	Shale, siltstone, and sandstone.	0 to 300	Locally may yield small quantities of water.
		Icebox Formation	Shale.		Not known to yield water.
		Black Island Formation	Sandstone, siltstone, and shale.		Not known to yield water, but may yield as much as 100 gal/min (6 L/s).
Cambrian		Deadwood Formation	Sandstone and limestone.		May yield water from sandstone.
Precambrian basement rocks			Schist and granite.		

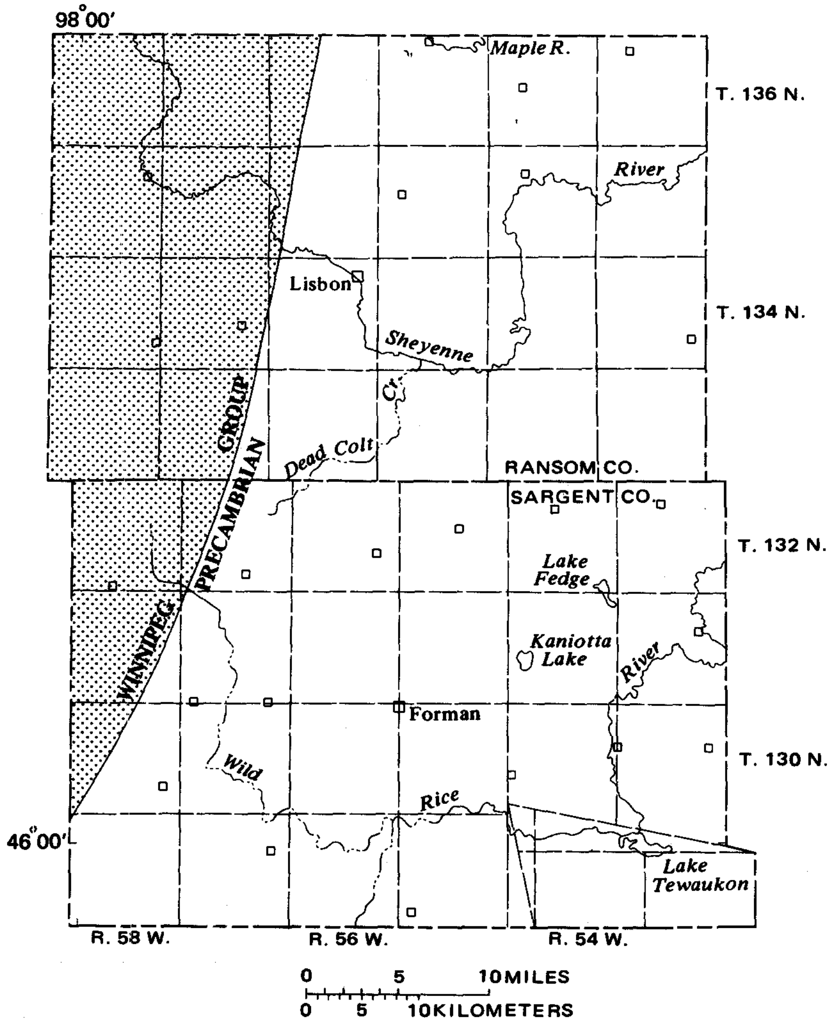


FIGURE 3.—Subcrop map of pre-Cretaceous rocks.

Dakota Aquifer System

The Dakota Group of Cretaceous age underlies all of Ransom and Sargent Counties. The Dakota was deposited on a weathered erosional surface of Precambrian rocks in most of the two-county area, and on formations of the Winnipeg Group in the western parts of the counties. Aquifers in the Dakota Group occur in the Lakota and Fall River Formations undifferentiated, and in the Newcastle Formation. The Newcastle Formation thins in an easterly direction and pinches out or becomes unrecognizable within a few miles of the eastern edge of the Winnipeg Group shown in figure 3. The irregular erosional surface, as well as the pinching out of the Newcastle Formation, cause considerable differences in the thickness of the Dakota interval.

The aquifers in the Dakota Group generally are known as the first, second, or third "flows." However if any of the aquifers are thin or missing, there is uncertainty as to which formation an aquifer might be in. Because sufficient data are not available to adequately differentiate the various formations in the Dakota Group, the Dakota is considered an aquifer system in this report.

The top of the Dakota aquifer system in Ransom and Sargent Counties ranges in depth from about 500 ft (150 m) below land surface in the northeastern part of Ransom County to about 1,000 ft (300 m) in the northwestern part of Ransom County. The aquifer system, although locally missing, generally ranges in thickness from about 10 to 275 ft (3 to 84 m), and has a mean thickness of about 88 ft (27 m). Most of the available drillers logs do not have detailed lithologic descriptions and the thicker sections probably contain considerable clay or shale.

Measurements made during this study indicate water levels in the aquifer system will rise to an altitude of about 1,400 ft (430 m) at well 136-058-30BAB in northwest Ransom County and to at least 1,170 ft (357 m) at Sheldon (some water was leaking around the casing) in northeast Ransom County. These measurements indicate an apparent gradient of about 10 ft/mi (2 m/km) in an easterly direction. Wells completed in the Dakota aquifer system should flow anywhere in Ransom and Sargent Counties unless drilled near the tops of some of the higher hills.

Yields from wells that have been completed in the Dakota aquifer system generally are less than 10 gal/min (0.6 L/s) because the aquifer is thin and transmissivities are low, because the wells are constructed with small-diameter pipe, or have valves that restrict flow. A few wells, however, reportedly will yield as much as 50 gal/min (3 L/s). Potential maximum yields were not estimated because of lack of dependable data.

Recharge to the aquifer system apparently occurs as direct infiltration of precipitation and streamflow on outcrops along the Black Hills uplift in South Dakota (Darton, 1909) and by upward leakage of water from underlying aquifers (Swenson, 1968). The great variations in water quality in the aquifer system also indicate that there is considerable upward leakage from the underlying Ordovician beds in the northwestern part of the area. The only known discharge from the aquifer system is by wells. However, there probably is considerable lateral underflow from Ransom and Sargent Counties northeastward into Richland and Cass Counties and probably northward into Barnes County. Also some upward leakage into overlying aquifers may occur.

Water from the Dakota aquifer system in Ransom and Sargent Counties generally is a sodium sulfate type. However, chloride is the dominant anion in 10 of the 74 samples collected from the Dakota aquifer system.

Dissolved-solids concentrations in 74 water samples ranged from 2,170 to 3,340 mg/L. The mean concentration was 2,680 mg/L. Sodium concentrations ranged from 450 to 1,200 mg/L and had a mean of 880 mg/L. Sodium ranged from 53 to 98 percent of the cations present. Sulfate concentrations ranged from 110 to 1,400 mg/L and had a mean concentration of 1,090 mg/L. Hardness ranged from 46 to 810 mg/L and had a mean of 140 mg/L. Iron concentrations ranged from undetectable to 5,000 ug/L. Most of the large variations in the quantity of iron in the samples probably are due to variations in dissolved iron in the aquifer, but some may be due to electrolytic and biochemical processes within the wells or water systems. Sampling techniques also may have caused some of the variation. The samples had SAR values that ranged from 6.9 to 68; however, only two samples had a value of 10 or less.

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

Ground Water in Rocks of Quaternary Age

Ransom and Sargent Counties are mantled by glacial drift and alluvium of Quaternary age, except locally in the Sheyenne River valley where the Niobrara Formation crops out. Glacial drift ranges in thickness from about 0 ft (0 m) to as much as 406 ft (124 m) in test hole 130-058-22BAB in the southwestern part of Sargent County.

The glacial drift in Ransom and Sargent Counties may be divided into two main types, based on lithology and inferred origin. These are: (1) Till and (2) glacioaqueous deposits, of both fluvial and lake origin. Till is deposited from glacial ice by dumping, pushing, lodgement, 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. The percentages of each type of material in the till vary considerably.

The glacioaqueous deposits are composed largely of fluvial 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) outwash sediments, (3) deltaic and lake sediments, and (4) isolated pockets of sand and gravel surrounded by clay or till.

Alluvial deposits are composed of sand, gravel, silt, and clay that has been sorted and deposited by modern streams. They are similar in composition to outwash deposits. Generally the glacial drift and alluvium have not been differentiated in this report.

The glacial-drift aquifers that have the greatest potential for development of large supplies of water in Ransom and Sargent Counties are those associated with buried valleys, outwash, or 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, estimates of water available to wells from storage are given. These estimates, in acre-feet, are products of areal extent, saturated thickness, and specific yield — which ranges from 10 to 20 percent and averages about 15 percent. The amount of water available to wells from storage is the specific yield, which is approximately half the total amount of water stored in the aquifers. The estimates are based on static conditions and do not take into account effects of ground-water development, 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 aquifer. Yield data are extrapolated from test-hole sites to unexplored sites on plate 1. However, because of the unpredictable variations in glacial-drift aquifers, production wells should not be planned without prior test drilling.

Spiritwood Aquifer System

The Spiritwood aquifer system, originally named by Huxel (1961), is the largest buried glacial-drift aquifer in the two-county area. The system consists of glaciofluvial materials that were deposited in a drainage system that once extended across much of the northern and east-central parts of North Dakota. In Sargent County the Spiritwood aquifer system extends from T. 131 N., R. 58 W. in the western part of the county through T. 129 N., R. 53 W., in the southeastern part of the county (pl. 1), and extends into South Dakota where it is known as the Veblen aquifer (Koch, 1975, p. 42). The aquifer system ranges from about 4 to 7 mi (6 to 10 km) in width, is as much as 283 ft (86 m) deep, and underlies about 175 mi^2 (450 km^2) in Sargent County.

The aquifer materials were deposited in a valley by water flowing in channels and later covered by glacial till. Generally the coarser materials were deposited in the deeper parts of the channels and the finer materials were deposited on the adjacent flood plains. After a channel was filled, water was diverted into a new channel, which in turn was filled. This deposition process continued until the lower parts of the valley were filled. Deposits in individual channels may or may not be hydraulically connected to those in adjacent channels. Water levels shown on plate 2, section A-A′, generally indicate that most channels are connected; however, the water-level gradient between wells 130-056-01ABB and 130-056-02BBB indicates a semipermeable barrier exists somewhere between the two wells. Other barriers probably also exist.

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

After deposition of the till, the Sheyenne River apparently flowed southward from the vicinity of Fort Ransom and eroded through the till in the vicinity of test hole 130-057-05AAA. Aquifer materials deposited in the river valley, known as the Englevale aquifer, are hydraulically connected to the Spiritwood aquifer system. However, even though the Sheyenne River that deposited the Englevale aquifer continued on to the south, the boundary between the Spiritwood and Englevale aquifers is considered, in this report, to be the north edge of the Spiritwood buried valley as shown on plate 1.

A distributary of the Spiritwood drainage flowed southeastward from the principal valley in the vicinity of Lake Taayer and the village of Nicholson. The sediments in this distributary together with the sediments that continue south from the Englevale aquifer form the Brampton aquifer. In this report, the boundary between the Spiritwood aquifer system and the Brampton aquifer is considered to be at the south edge of the Spiritwood buried valley as shown on plate 1.

The Spiritwood aquifer system consists of lenticular deposits of sand and gravel interbedded with clay and silt. The sand and gravel deposits range in thickness from less than 1 ft (0.3 m) at the edges to 124 ft (38 m), and have a mean aggregate thickness of about 50 ft (15 m).

Yields from individual wells in the aquifer system mainly depend upon the thickness and the hydraulic conductivity of the sand and gravel at the well location and on the distance of the well from impermeable boundaries. 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. 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). In the vicinity of Forman and Cogswell, where sand lenses are thinner and have a greater interstitial clay content, well yields generally will be 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 and from the laterally connected Englevale aquifer. Water-level fluctuations in the aquifer are small, and yearly fluctuations generally are less than 3 ft (0.9 m). The spring thaw has a small, nearly immediate effect on the water levels, but the effects of longer term climatic conditions, such as droughts, generally are delayed for a few months (fig. 4). The highest water levels occur following spring snowmelt.

The potentiometric surface slopes from the edges of the aquifer system towards the axis and from west to east, except near the boundary of the Brampton aquifer. The gradient generally varies from near 0 to about 7 ft/mi (0 to 1.3 m/km), but west of Forman the gradient increases to about 70 ft/mi (13 m/km). However, the configuration of the potentiometric surface indicates the geology of the aquifer system is more complex than is shown on section A-A′ (pl. 2). The nearly flat potentiometric surfaces along the axis of the aquifer system indicate areas of higher transmissivity; whereas, the steep surface west of Forman (pl. 2) indicates an area of lower transmissivity.

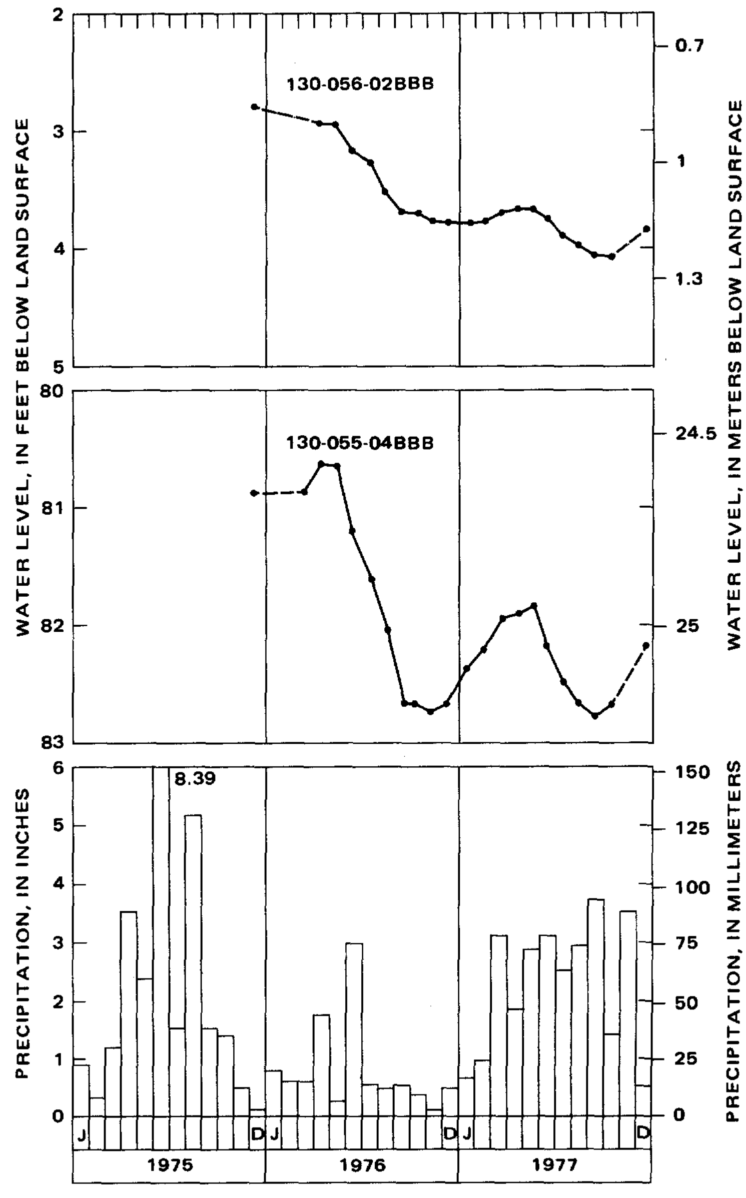


FIGURE 4.—Water-level fluctuations in the Spiritwood aquifer system and precipitation at Forman.

Discharge from the aquifer system is southward into the Brampton aquifer, through wells, and probably southeastward into the Veblen aquifer in South Dakota. Evapotranspiration and upward leakage occur in both the Lake Tewaukon and Lake Taayer areas.

Water from the Spiritwood aquifer system generally is a sodium or sodium-calcium sulfate type. However, locally, calcium, magnesium, or bicarbonate are the predominant ions. Dissolved-solids concentrations in water samples from 25 wells in the aquifer system ranged from 626 to 2,260 mg/L and had a mean of 1,200 mg/L. Sodium concentrations ranged from 30 to 650 mg/L and had a mean of 208 mg/L. Sodium ranged from 13 to 82 percent of the total cations and had a mean of about 48 percent. Sulfate ranged from 73 to 1,100 mg/L and had a mean of 440 mg/L. Sulfate concentrations exceeded 250 mg/L in 17 samples. Chloride concentrations ranged from 4 to 780 mg/L and had a mean of 88 mg/L. Hardness ranged from 220 to 1,000 mg/L. Iron concentrations ranged from 40 to 3,100 ug/L. Three samples were acidized and not filtered, so the iron concentrations of 3,700, 4,400, and 11,000 ug/L were not considered.

SAR values ranged from 0.6 to 17 and specific conductances ranged from 850 to 2,770 umho/cm (us/cm). Irrigation classifications of selected samples are shown in figure 5. Generally the poorest quality water is in the lower yield area from west of Cogswell to east of Forman. The best quality water is in the area west of Nicholson.

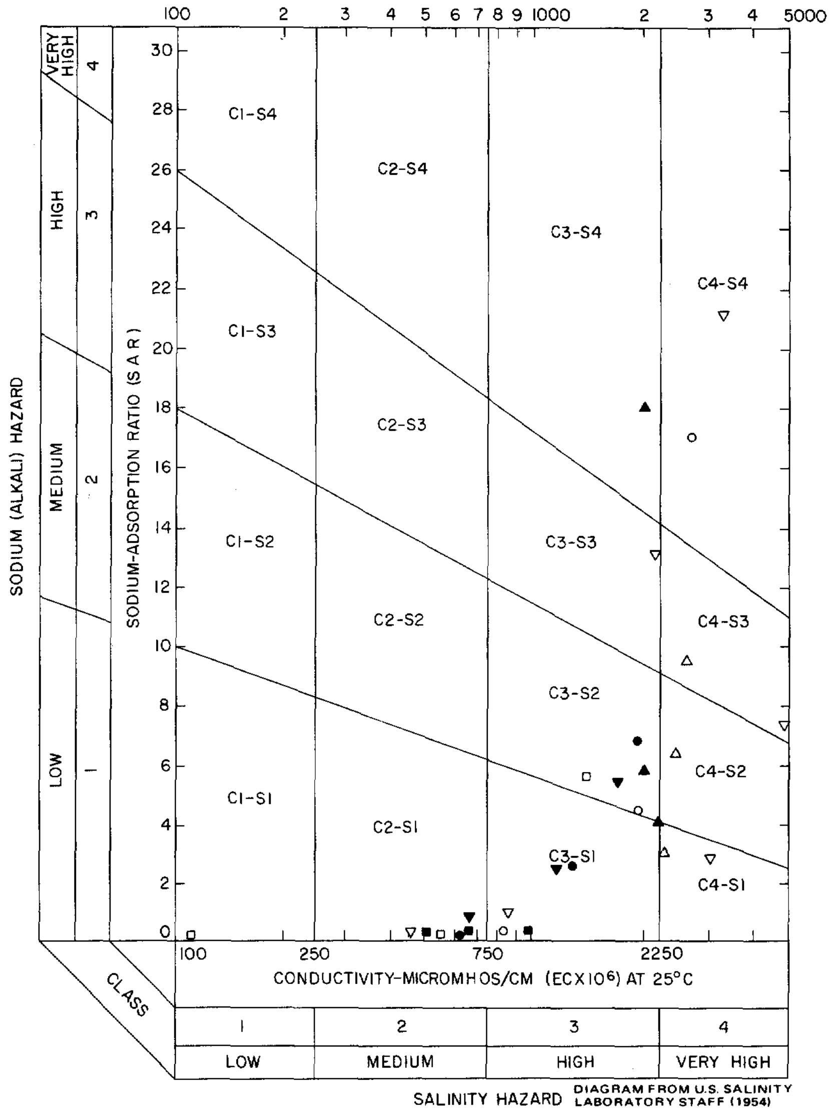
Based on a mean thickness of 50 ft (15 m), an areal extent of 175 mi^2 (450 km^2), and an estimated specific yield of 0.15, about 840,000 acre-ft (1,035 hm^3) of water would be available to wells from storage in the Spiritwood aquifer system. Silts and clays that overlie or are interbedded in the aquifer system also contain considerable water in storage, but the rate of drainage is slow.

Brampton Aquifer

The Brampton aquifer, named for the village of Brampton, was formed during a period when the Spiritwood drainage was blocked and the then existing stream was diverted southward. At a later date when the Sheyenne River flowed southward to form the Englevale aquifer, the river continued southward across the Spiritwood aquifer system and added sediments to the Brampton aquifer. Data are insufficient to determine which ancient stream was the primary source of the Brampton aquifer because all three aquifers are lithologically similar and are hydraulically connected in the area near Nicholson. Therefore, hydrologic boundaries between the aquifers do not exist.

The Brampton aquifer extends southward from the buried valley of the Spiritwood aquifer system in Sargent County in T. 130 N., R. 57 W., to the South Dakota border in T. 129 N., Rs. 56 and 57 W. The Brampton aquifer is equivalent to part of the James aquifer of South Dakota (Koch, 1975).

The Brampton aquifer ranges from about 3.5 to 14 mi (5.6 to 23 km) in width and underlies an area of about 100 mi^2 (260 km^2). The southwestern part of the aquifer consists of lenticular deposits of sand and gravel interbedded



EXPLANATION

- ○ SPIRITWOOD AQUIFER SYSTEM
- ● BRAMPTON AQUIFER
- △ ELLIOTT AQUIFER
- ▲ GWINNER AQUIFER
- ▽ ENGLEVALE AQUIFER
- ▼ MILNOR CHANNEL AQUIFER
- □ SHEYENNE DELTA AND OAKES AQUIFERS
- ■ SAND PRAIRIE AQUIFER

FIGURE 5.—Classifications of selected water samples from glacial-drift aquifers for irrigation use.

with silt and silty clay beds that apparently were deposited in a lake, forming a delta with interbedded lake deposits. There is a buried valley northeast of Straubville, Sargent County, but data are not sufficient to delineate the boundaries. The northwest part of the valley, as indicated by the logs of test holes 130-058-09AAA and 130-058-11BAA, appears to be part of the Spiritwood diversion that became part of the Brampton aquifer.

Locally in T. 129 N., R. 57 W., in the western part of the area of the delta and lake deposits, the aquifer is composed of two sand or gravelly sand zones separated by 75 to 113 ft (23 to 34 m) of silt and sandy silt (pl. 2, sec. B-B′). The upper zone is composed of fine to very fine sand that extends from land surface to as much as 46 ft (14 m) below land surface. The lower zone is composed of fine to very coarse sand with some gravel and clay lenses. The depth to the top of the lower zone of the aquifer in 16 test holes ranged from 92 to 162 ft (28 to 49 m) below land surface. There is a poor hydraulic connection through the silts that separate the upper unconfined aquifer and the lower confined aquifer.

Test drilling indicates that the aggregate aquifer thickness generally ranges from 12 to 111 ft (4 to 34 m) and the mean thickness is about 55 ft (17 m).

An aquifer test was conducted in the Brampton aquifer in October 1977 by R. B. Shaver of the North Dakota State Water Commission. An irrigation well 153 ft (46.6 m) deep at 129-057-07ACA4 was used as the pumped well and 14 observation wells were spaced from 25 to 4,200 ft (7.6 to 1,280 m) from the pumped well. The well was pumped at a rate of 915 gal/min (58 L/s) for 100 hours and then a similar period of recovery was observed. The specific capacity at 24 hours was 36.6 (gal/min)/ft [7.6 (L/s)/m] of drawdown, and at 100 hours was 30.1 (gal/min)/ft [6.2 (L/s)/m] of drawdown. The reduction in specific capacity with time is due to the presence of a semipermeable boundary (valley wall) at the west edge of the aquifer and normal drawdown due to continued pumping. The data collected during the test were analyzed using methods developed by Theis (1935), Jacob (1940), Chow (1952), and Hantush (1964). The analyses using the Theis, Jacob, and Chow methods indicate that the aquifer transmissivity ranges from about 10,000 to 25,000 ft^2/d (930 to 2,300 m^2/d) and storage coefficients range from 0.0003 to 0.0007. All three methods indicated that a significant quantity of leakage occurred during the test, so the calculated transmissivities are too high. The Hantush method, which considers leakage, indicated transmissivities of 5,000 to 7,000 ft^2/d (460 to 650 m^2/d) and storage coefficients that ranged from 0.0001 to 0.0003. Transmissivities calculated using the Hantush method are believed to be more representative of the aquifer at the test site.

The yield from individual wells in the Brampton aquifer should range from about 50 to 1,000 gal/min (3 to 63 L/s), assuming 30 ft (9 m) of drawdown. In 1977, only two large-capacity irrigation wells were pumping water from the aquifer. The wells were reportedly pumped at rates of about 700 and 800 gal/min (44 and 50 L/s). The total pumpage from the aquifer in 1977 was estimated to be about 400 acre-ft (0.49 hm^3).

Recharge to the aquifer is from precipitation and snowmelt that infiltrates through the overlying glacial drift and from the Spiritwood aquifer system. The precipitation record together with water-level fluctuations indicate that most recharge is derived from snowmelt and spring rains (fig. 6).

Water-level fluctuations apparently were less than 3 ft (1 m) before large-scale development took place (1976). After development, water levels in observation well 129-057-08CCC1 fluctuated more than 21 ft (6.4 m). This observation well is in the lower zone and is about 0.25 mi (0.4 km) east-northeast from one irrigation well and about 1 mi (2 km) south of another irrigation well. Water levels in observation well 129-057-08CCC2, in the upper zone, rise and decline with the water levels in the lower zone, but to a lesser extent (fig. 6).

The gradient of the potentiometric surface, as determined from widely scattered water-level measurements, averages about 3 ft/mi (0.6 m/km) in a southeasterly direction, and indicates that the aquifer discharges some water into South Dakota. Some water is lost through evapotranspiration in a few marshy areas. The only other known discharge is by pumpage of wells.

Either sodium or calcium may be the dominant cation and either bicarbonate or sulfate the dominant anion in water in the Brampton aquifer. Water samples were collected from 18 wells finished in the lower zone. Dissolved-solids concentrations ranged from 532 to 1,290 mg/L and had a mean of 948 mg/L. Sodium concentrations ranged from 61 to 230 mg/L and had a mean of 146 mg/L. Sodium constituted 23 to 58 percent of the cations. Sulfate concentrations ranged from 95 to 570 mg/L and had a mean of 356 mg/L. Chloride concentrations ranged from 3.9 to 72 mg/L and had a mean of 24 mg/L. Hardness ranged from 320 to 600 mg/L and had a mean of 440 mg/L. Iron and manganese were analyzed in 13 samples. Concentrations of iron ranged from 80 to 6,300 ug/L and exceeded the recommended limit of 300 ug/L in 11 samples. Concentrations of manganese ranged from 240 to 1,300 ug/L and exceeded the recommended limit of 50 ug/L in all samples. SAR values ranged from 1.4 to 5.1 and specific conductances ranged from 860 to 1,890 umho/cm (us/cm). The irrigation classification generally was C3-S1 (fig. 5).

Water samples were collected from four wells in the upper zone. The water is a calcium bicarbonate type. Dissolved-solids concentrations ranged from 223 to 347 mg/L. Sodium, sulfate, and chloride concentrations were all less than 25 mg/L. Iron and manganese concentrations generally greatly exceeded the recommended limits. The four samples had SAR values of 0.1 and specific conductances of 431, 640, 640, and 650 umho/cm (us/cm). The irrigation classification was C2-S1 (fig. 5).

Based on an area of 100 mi^2 (260 km^2), a mean thickness of 55 ft (17 m), and a specific yield of 0.15, about 530,000 acre-ft (650 hm^3) of water would be available to wells from storage in the Brampton aquifer.

Elliott Aquifer

The Elliott aquifer, named for the city of Elliott, was deposited in a narrow valley and in tributaries to the valley in southwestern Ransom County. A short segment of the valley about 5 mi (8 km) long and one tributary about a mile

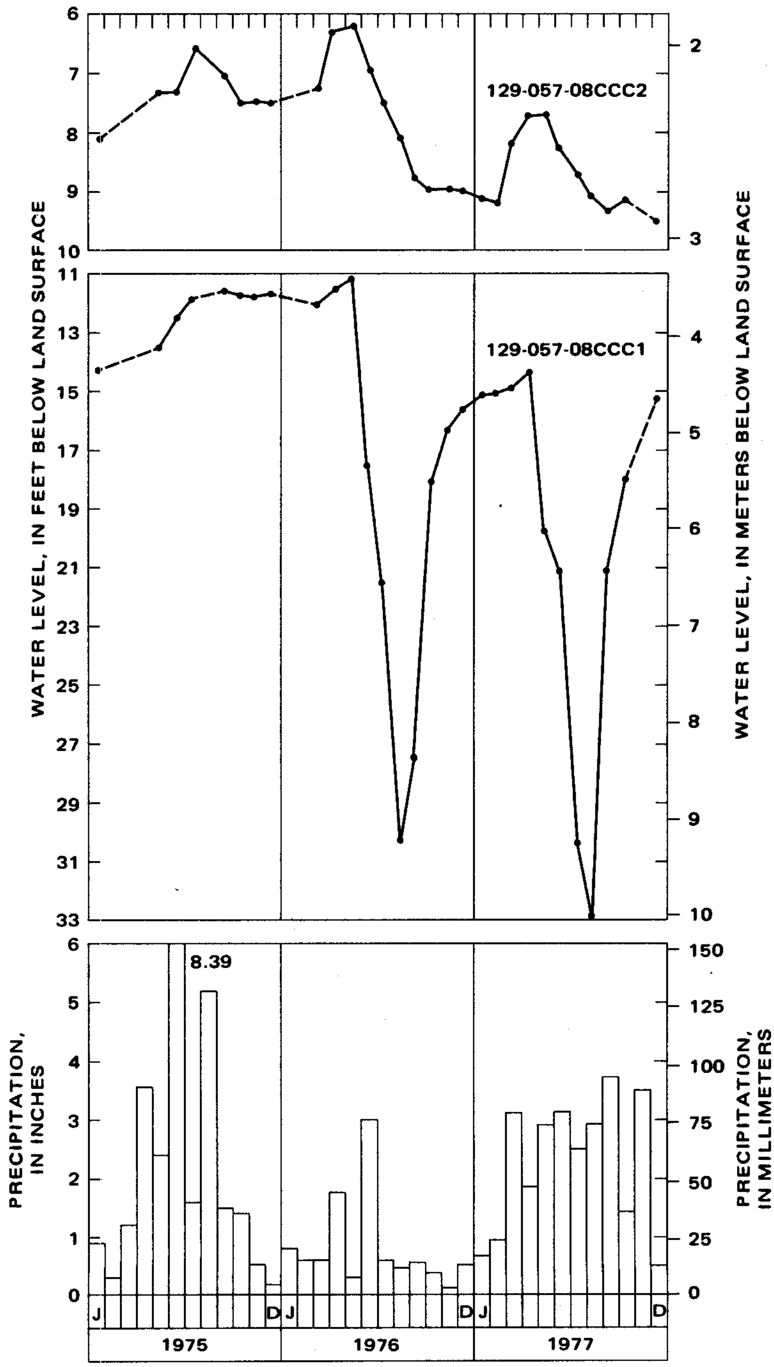


FIGURE 6.—Water-level fluctuations in the Brampton aquifer and precipitation at Forman.

(1.6 km) long were located by test drilling, but the aquifer probably extends much farther than is shown on plate 1. Altitudes and trends of the deposits indicate that the original stream may have been a tributary in the ancient Spiritwood river system.

The Elliott aquifer apparently is about a quarter of a mile (0.4 km) wide. It consists of lenticular deposits of sand and gravel interbedded with silt and silty clay. The top of the aquifer is about 66 to 119 ft (20 to 36 m) below land surface. The aggregate thickness of sand and gravel deposits ranges from 7 to 69 ft (2 to 21 m); mean thickness is 28 ft (9 m).

Yields from individual wells in the Elliott aquifer, assuming 30 ft (9 m) of drawdown, should range from about 25 gal/min (1.6 L/s) near the edges to about 500 gal/min (32 L/s) in the thicker sections of the aquifer. Larger yields may be obtainable for periods of several days, but larger sustained yields will cause considerably greater than 30 ft (9 m) of drawdown. This increased drawdown will cause a faster migration of water from the tributaries and edges of the aquifer to the vicinity of the well.

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 and overlying till.

Water-level measurements made in 1978, after fieldwork for this investigation was completed, show fluctuations in excess of 20 ft (6 m) in observation wells 133-057-10AAB and 133-057-14DCC during the irrigation season. Both of these observation wells are about 0.5 mi (0.8 km) from irrigation wells. The only identified discharge is through pumpage.

Only four water samples were obtained from the Elliott aquifer, one from the main part of the aquifer and three from the tributary. The water sample from the main part of the aquifer was a calcium-sodium sulfate type that contained 1,910 mg/L dissolved solids, 210 mg/L sodium, 950 mg/L sulfate, 21 mg/L chloride, and 870 mg/L hardness. The sample had an SAR value of 3.1, a specific conductance of 2,300 umho/cm (us/cm), and an irrigation classification of C4-S1.

The water samples from the tributary were a sodium sulfate type. Dissolved-solids concentrations were 1,790, 1,850, and 1,890 mg/L. Sodium concentrations were 350, 360, and 460 mg/L. Sodium was 56, 57, and 69 percent of the total cations. Sulfate concentrations were 630, 810, and 820 mg/L; chloride concentrations were 110, 120, and 320 mg/L; hardness concentrations were 440, 570, and 580 mg/L; and iron concentrations were 300, 1,100, and 1,300 ug/L. The samples from the tributary had SAR values of 6.4, 6.5, and 9.5 and specific conductances of 2,400, 2,600, and 2,600 umho/cm (us/cm). The irrigation classifications were C4-S2 and C4-S3 (fig. 5).

The quantity of available water stored in the Elliott aquifer was not determined.

Gwinner Aquifer

The Gwinner aquifer, named for the city of Gwinner, was deposited in a depression in the till that extends from the vicinity of Gwinner in north-central Sargent County to Richland County near Murach Lake (pl. 1). The segment of the aquifer shown on plate 1 is about 22 mi (35 km) long, but the aquifer probably extends farther.

The width of the aquifer may be as little as 0.4 mi (0.6 km) in the northwest part to as much as 4 mi (6 km) wide in the eastern part, where the Gwinner aquifer deposits appear to converge with flood-plain deposits of the Milnor Channel aquifer or are overlain by sand deposits of an ancient glacial lake. The aquifer consists of lenticular deposits of sand and gravel interbedded with silt and silty clay. The top of the aquifer generally is about 52 to 156 ft (16 to 48 m) below land surface. The aggregate thickness of sand and gravel deposits ranges from 9 to 109 ft (3 to 33 m); mean thickness is about 55 ft (17 m).

Yields from individual wells in the Gwinner aquifer, assuming 30 ft (9 m) of drawdown, should range from about 25 gal/min (1.6 L/s) near the edges to 1,000 gal/min (63 L/s) in the thicker sections of the aquifer.

Recharge to the aquifer is from precipitation and snowmelt that infiltrates through the overlying glacial drift in much of the area or the sandy materials in the eastern part of the area near Richland County.

Water-level measurements made in 1976 and 1977 in two observation wells, 131-053-19CCC and 131-054-22BBB, indicate that the water-level change was less than 0.5 ft (0.2 m) from the low in the winter to the high in the spring. The only known discharge is through pumpage by the city of Gwinner and several farms.

Eight water samples were collected from the Gwinner aquifer. Sodium was the dominant cation and sulfate generally was the dominant anion. Dissolved-solids concentrations ranged from 971 to 1,640 mg/L and had a mean of 1,334 mg/L. Sodium concentrations ranged from 180 to 440 mg/L and had a mean of 266 mg/L. Sodium ranged from 44 to 88 percent of the total cations. Sulfate ranged from 350 to 750 mg/L and had a mean of 518 mg/L; chloride concentrations ranged from 34 to 99 mg/L and had a mean of 60 mg/L; hardness ranged from 120 to 640 mg/L and had a mean of 460 mg/L. Iron concentrations ranged from 60 to 800 ug/L.

Water in the samples had SAR values that ranged from 3.9 to 18; however, only one value exceeded 5.7. Specific conductances ranged from 1,470 to 2,200 umho/cm (us/cm). The irrigation classification of five samples was C3-S2, two of the samples were C3-S1, and one sample was C3-S4 (fig. 5).

The quantity of available water stored in the Gwinner aquifer was not determined.

Englevale Aquifer

The Englevale aquifer, named for the village of Englevale, was deposited as glacial outwash deposits in an ancestral course of the Sheyenne River when the river flowed southward. Two, and locally three channels were used by the river during the development of the aquifer. Thus, locally the aquifer consists of two or three sand deposits separated by silty clay or silt. After the channels were filled, most of the area between the channels was covered with sand and gravel deposits. There was, however, a till ridge about 5 mi (8 km) long that was not covered. The ridge is shown as a 0-50 gal/min (0-3 L/s) area on plate

1. The narrow deeper channel on the west side of the aquifer is not considered as part of the aquifer, although a poor hydraulic connection may exist.

The north end of the Englevale aquifer thins as it nears a wind gap that leads into the present Sheyenne River valley near Fort Ransom, northwestern Ransom County. The south end of the aquifer arbitrarily is placed at the north boundary of the Spiritwood buried valley northwest of Cogswell, Sargent County. The aquifer generally is from 1 to 6 mi (2 to 10 km) wide, and underlies an area of about 78 mi^2 (202 km^2).

The Englevale aquifer consists of lenticular deposits of sand and gravel interbedded with silt or silty clay (pl. 2, sec. C-C′). In the north-central part of the aquifer the sand grains and gravel pebbles are composed predominantly of silicate, carbonate, and igneous rocks with about 0 to 30 percent shale pebbles. The percentage of shale pebbles increases toward the south and edges of the aquifer. The southern part of the aquifer near the edges may contain as much as 90 percent shale pebbles.

The depth to water in the Englevale aquifer ranges from land surface near sloughs to as much as 81 ft (25 m) where the shallower channels were never present. The aggregate thickness of saturated sand and gravel deposits ranges from 5 to 129 ft (2 to 39 m) and has a mean of about 40 ft (12 m).

An aquifer test was conducted May 11 to 17, 1977, by R. B. Shaver of the North Dakota State Water Commission. The 75-ft (23-m) deep irrigation well at 134-058-25DCC9 was used as the pumped well. Ten observation wells spaced from 45 to 800 ft (14 to 230 m) from the pumped well were monitored. The well was pumped at a rate of 990 gal/min (62 L/s) for 68 hours, and a similar period of recovery was observed. The analyses, using the Theis time-drawdown method, indicate that the aquifer transmissivity is about 31,600 ft^2/d (2,940 m^2/d). The storage coefficient is about 0.18.

Yields from wells in the channel parts of the aquifer, assuming 30 ft (9 m) of drawdown, generally are between 500 and 1,500 gal/min (32 and 95 L/s). Yields of 50 to 500 gal/min (3 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 directly into the aquifer or percolates into the aquifer from adjacent sediments.

Much of the aquifer is unconfined and water-level fluctuations generally are small when compared to those in confined aquifers. Observation well 134-058-24CDC2 was equipped with a continuous recorder; however, only monthly measurements are shown in figure 7. The missing measurements were either within a few hundredths of a foot or between the successive measurements shown. Water levels generally rise as a result of spring snowmelt and precipitation followed by a decline that is caused by the pumping of irrigation wells and by natural discharge. The rise of about 1.5 ft (0.46 m) between June 15 and July 15, 1975, was caused by more than 12 in. (300 mm) of rain that fell in the last half of June. After these rains, soil moisture was high so pumpage for irrigation for the remainder of the season was less than usual. During the 1976 irrigation season precipitation was low and pumpage high, so water levels declined at an unusually rapid rate. Water levels in a few irrigation wells located in areas with only 20 to 30 ft (6 to 9 m) of saturation declined

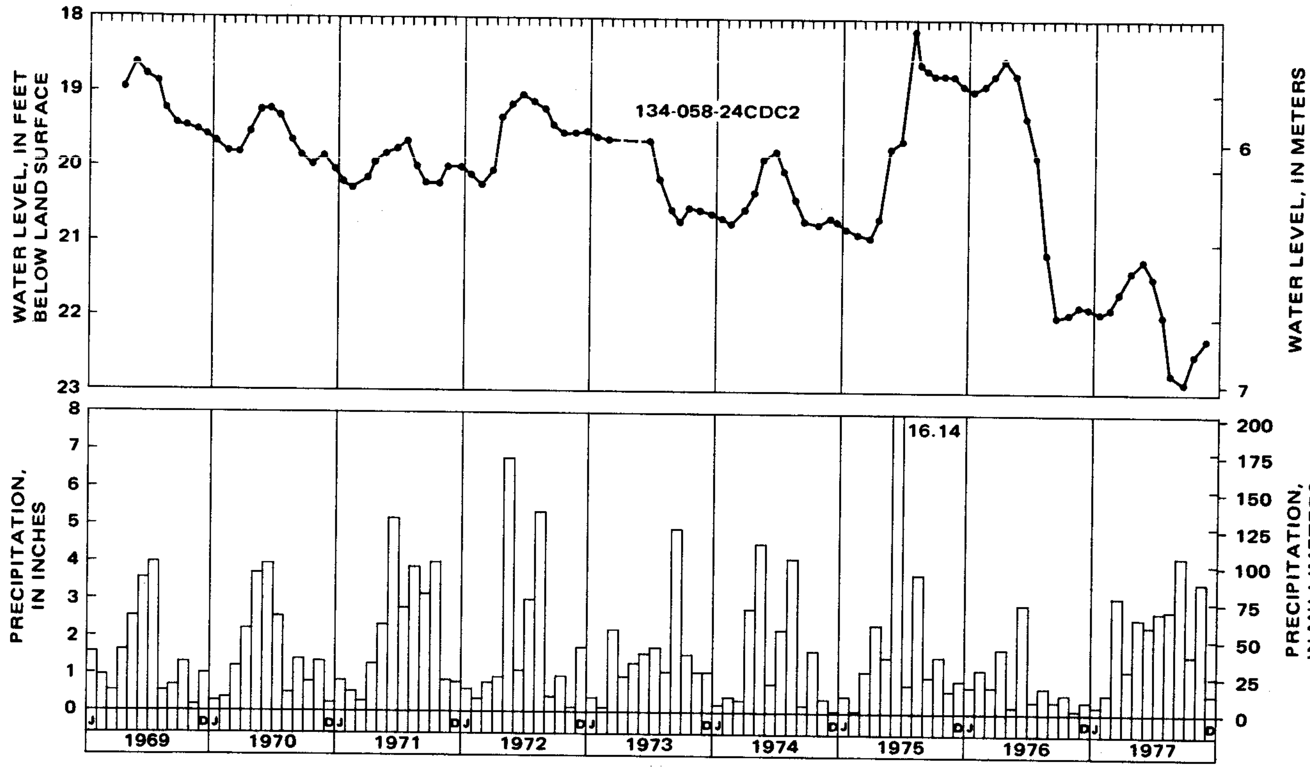


FIGURE 7.—Water-level fluctuations in the Englevale aquifer and precipitation at Lisbon.

to the point where wells that usually produced 700 to 900 gal/min (44 to 57 L/s) yielded less than 500 gal/min (32 L/s).

Discharge from the aquifer is by pumpage and by seepage into sloughs. Some discharge also occurs by evapotranspiration in areas where the water table is near the land surface.

Water in the Englevale aquifer is a calcium bicarbonate type. However, locally sodium may be the dominant cation and either chloride or sulfate may be the dominant anion. The large sodium, chloride, and sulfate concentrations are from the deeper and southern parts of the aquifer. Water samples were obtained from 102 wells in the aquifer. Dissolved-solids concentrations ranged from 255 to 4,670 mg/L and had a mean of 595 mg/L. Sodium concentrations ranged from 1.1 to 840 mg/L and had a mean of 73 mg/L. Sodium was the dominant cation in 13 samples. Sulfate ranged from 1.6 to 2,400 mg/L and had a mean of 138 mg/L. Sulfate concentrations exceeded 250 mg/L in only 8 of the wells. Hardness ranged from 180 to 1,800 mg/L and had a mean of 332 mg/L. Iron and manganese concentrations in the samples generally were larger than the recommended limits. There was no recognizable pattern to the distribution of the iron and manganese concentrations.

The samples from the aquifer had SAR values that ranged from 0.0 to 26 and specific conductances that ranged from 440 to 5,000 umho/cm (us/cm). Water in 65 of the samples had an irrigation classification of C2-S1, 26 were classified C3-S1, 5 were C3-S2, 1 was C3-S3, 1 was C4-S1, 1 was C4-S3, and 3 were C4-S4.

Based on an area of 78 mi^2 (202 km^2), a mean thickness of 40 ft (12 m), and an estimated specific yield of 0.15, about 300,000 acre-ft (370 hm^3) of water would be available to wells from storage in the Englevale aquifer.

Milnor Channel Aquifer

The Milnor Channel aquifer is composed of terrace deposits, abandoned channel deposits, and surficial outwash (Baker, 1966a). The aquifer was formed after the Sheyenne River abandoned the Englevale course and established a new course to the southeast. This new course followed the present Sheyenne River at a higher level than the present course to a point about 4 mi (6 km) south of Lisbon, Ransom County. The new course continued southeastward through the Milnor area and into Richland County. Baker (1966a) described the course of this diversion from the Sheyenne River valley northwest of Milnor to the vicinity of Lake Traverse in South Dakota.

The Milnor Channel aquifer ranges from about 1 to 2 mi (2 to 3 km) in width, is about 20 mi (30 km) long, and underlies an area of about 45 mi^2 (117 km^2) in Ransom and Sargent Counties. It is wider north of Hultman Lake where channel deposits on the eastern side grade into the deposits of the Sheyenne delta. The boundary between the Milnor Channel and Sheyenne Delta aquifers has been arbitrarily located along a line between secs. 4 and 22, T. 133 N., R. 54 W.

The top of the Milnor Channel aquifer generally ranges from 3 to 33 ft (0.9 to 10 m) below land surface. However, northwest of Milnor terrace deposits are buried beneath as much as 77 ft (23 m) of till, clay, and lenses of sand. The aquifer consists of lenticular deposits of sand and gravel interbedded with silt and clay. 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 Sheyenne River. Terraces along the south side of the Sheyenne River in T. 133 N., R. 55 W. and on the southwest side of the aquifer contain considerable coarse gravel and small boulders. The saturated thickness of the sand and gravel deposits ranges from less than a foot at the edges to as much as 58 ft (18 m) in the central part. Test-hole data indicate that the mean saturated thickness of the aquifer is about 35 ft (11 m).

The relationship of the aquifer deposits east to northwest of Milnor to those on the south side of the Sheyenne delta is obscure. The area is nearly level and covered with loam, sandy loam, or fine sand that was derived from lake deposits and perhaps flood-plain deposits; locally, however, till is present. A few miles southeast of the city a section of lake clays and silts separates the Milnor Channel and Sheyenne Delta aquifers (pl. 2, sec. D-D′).

Yields from wells in the Milnor Channel aquifer range from a few gallons per minute from domestic and stock wells to as much as 900 gal/min (57 L/s) from an irrigation well. Potential yields from the aquifer vary considerably within short distances. For example, a properly constructed well at 131-053-03DDD1 should yield about 250 gal/min (16 L/s); the irrigation well at 131-053-10ACC is pumped at 500 gal/min (32 L/s); and at 131-053-10DDD less than 10 gal/min (0.6 L/s) could be obtained.

Several springs discharge from the aquifer along the south side of the Sheyenne River valley. The flows from most of these springs are less than 10 gal/min (0.6 L/s). The combined flow from several springs and seeps along 300 ft (90 m) of a small Sheyenne tributary in the NW¼ sec. 6, T. 133 N., R. 54 W., reportedly is a much as 250 gal/min (16 L/s) in early summer. A combined flow of 175 gal/min (11 L/s) was measured in November 1977.

Recharge to the aquifer is primarily by infiltration of precipitation and snowmelt. Leakage from sloughs also may contribute some recharge, especially in the spring when water levels are high. However, water levels in most sloughs are not higher than the adjacent water table and the sloughs are areas of discharge. The effects of recharge and discharge on the water levels in observation well 131-053-09AAA are shown in figure 8. The water-level rise in 1975 was due to recharge of snowmelt and heavy rains that fell during June. Water-level decline in 1976 was caused primarily by evapotranspiration that was not replaced during the period of low precipitation. Pumping of an irrigation well about three-quarters of a mile (1 km) from the observation well probably caused some of the rapid decline.

Water levels in the Milnor Channel aquifer range from near land surface to about 35 ft (11 m) below land surface. The potentiometric surface slopes to the southeast; however, in the northern part of the aquifer the gradient is to the north toward the Sheyenne River. Locally gradients may be toward nearby lakes, sloughs, or toward the Wild Rice River. The gradients generally are from 1.5 to 10 ft/mi (0.28 to 1.9 m/km).

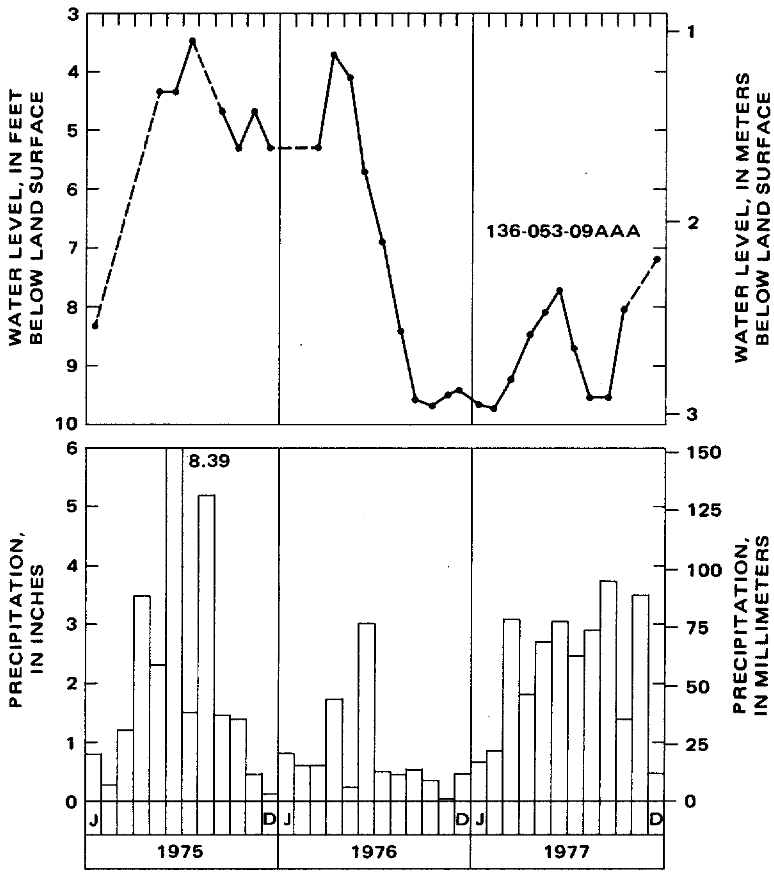


FIGURE 8.—Water-level fluctuations in the Milnor channel aquifer and precipitation at Forman.

Discharge from the aquifer is by evapotranspiration, pumpage, leakage into sloughs, lakes, the Sheyenne and Wild Rice Rivers, and as underflow into Richland County.

Either calcium or sodium may be the major cation and bicarbonate generally is the major anion in water from the Milnor Channel aquifer. Dissolved-solids concentrations in 15 samples from the Milnor Channel aquifer ranged from 325 to 1,120 mg/L and had a mean of 704 mg/L. Sodium concentrations ranged from 3.7 to 200 mg/L and had a mean of 100 mg/L. Sodium ranged from 3 to 65 percent of the cations. Sulfate concentrations ranged from 63 to 400 mg/L and had a mean of 207 mg/L. Samples from 7 of 15 wells exceeded 250 mg/L sulfate. Chloride concentrations ranged from 3.0 to 79 mg/L and had a mean of 35 mg/L. Hardness ranged from 210 to 460 mg/L. Iron concentrations ranged from 0 to 2,800 ug/L, and manganese ranged from 380 to 980 ug/L. The samples had SAR values that ranged from 0.1 to 5.7 and specific conductances that ranged from 540 to 1,690 umho/cm (us/cm). The irrigation classifications of water from 15 samples in the aquifer were C3-S1, C2-S1, or C3-S2 (fig. 5).

Based on an areal extent of 45 mi^2 (117 km^2), a mean saturated thickness of 35 ft (11 m), and an estimated specific yield of 0.15, about 150,000 acre-ft (185 hm^3) of water would be available to wells from storage in the Milnor Channel aquifer.

Sheyenne Delta Aquifer

The Sheyenne delta occupies about 750 mi^2 (1,940 km^2) in Richland, Cass, Ransom, and Sargent Counties in eastern North Dakota. Approximately 230 mi^2 (595 km^2) of the delta is in Ransom and Sargent Counties. The surface area of the delta generally is composed of deltaic materials with thin soils. Shallow depressions from 1 to about 10 ft (0.3 to 3 m) deep and sand dunes as much as 85 ft (26 m) high have been formed by wind action.

The delta deposits in Ransom and Sargent Counties grade from predominantly medium to coarse sand with some lenses of gravelly sand and finer sand and silt in the southwest to predominantly fine to medium sand with a larger proportion of fine sand and silt lenses in the north and east. In the Sheyenne River valley the delta deposits have been removed by erosion and have been replaced by fine-grained alluvial deposits consisting of fine sand, silt, and clay beds. The thickness of the delta deposits ranges from 0 at the edges to as much as 95 ft (29 m) at test hole 136-053-25AAA. The saturated part of the aquifer ranges in thickness from 6 to 87 ft (2 to 27 m) and has a mean saturated thickness of 41 ft (12 m). Downey and Paulson (1974) reported thicknesses as great as 140 ft (43 m) and a mean thickness of 97 ft (30 m); most of their data were from Richland County, so apparently the deposits not only are finer grained in an easterly direction, but also are thicker.

The yields from individual wells should range from a few gallons per minute near the western edge and the alluvial areas to about 1,000 gal/min (63 L/s) in areas where more than 35 ft (11 m) of gravelly sand exists. Variations in yield within short distances may be large, as discovered by a few prospective irrigators who have drilled two to five test holes in the same quarter section before finding a sufficient thickness to yield enough water to supply a pivot system. However, most of the area will yield more than 250 gal/min (16 L/s). The yield range for most of the Sheyenne Delta aquifer as shown on plate 1 is 250 to 1,000 gal/min (16 to 63 L/s) because variations in thickness and transmissivity make closer estimates impractical.

Recharge to the aquifer generally is from precipitation and snowmelt that infiltrates directly through the sandy soil to the aquifer and from flowing wells in the Dakota. Most of the recharge from precipitation occurs in the spring (fig. 9) during the time the frost leaves the ground and before the evapotranspiration loss to maturing crops and high temperatures become significant. Significant recharge also occurs at other times, such as during two storm periods, June 19 and 20, 1975, and June 29 and 30, 1975, when more than 5 in. (127

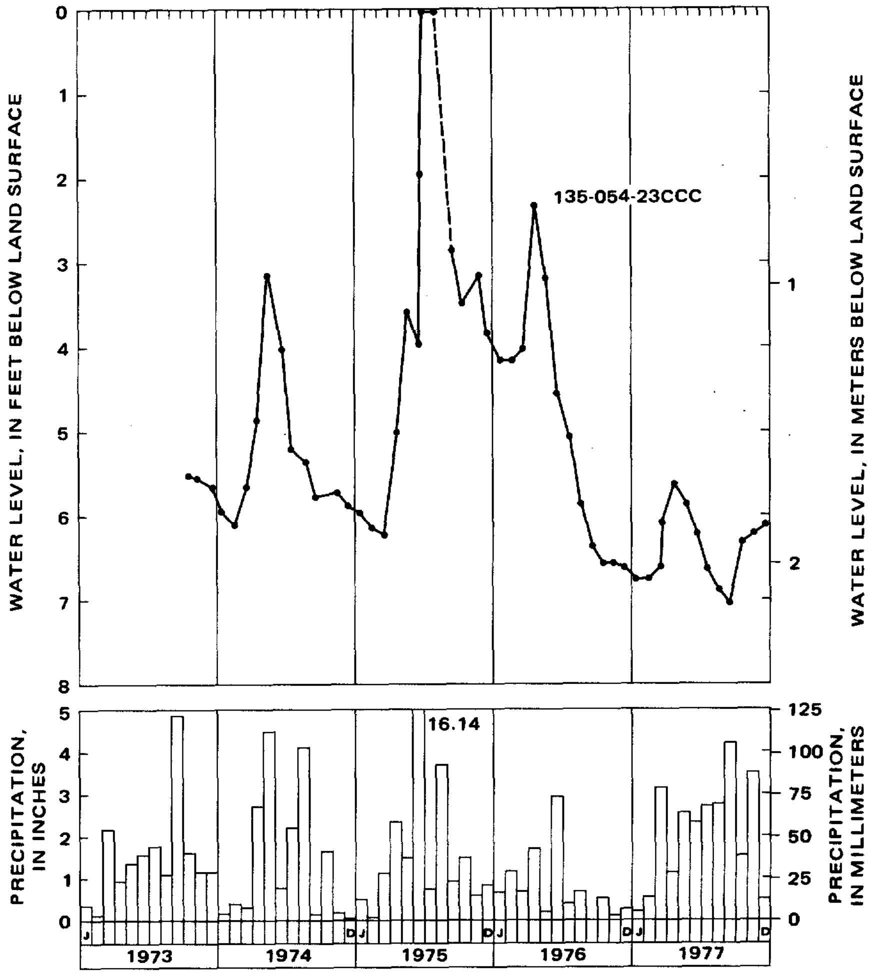


FIGURE 9.—Water-level fluctuations in the Sheyenne delta aquifer and precipitation at Lisbon.

mm) of rain fell during each storm. A digital model of part of the delta area indicates that from 6 to 8 in. (150 to 200 mm) of the precipitation recharges the aquifers.

Water-level fluctuations are shown in figure 9. Water levels rise in the spring due to snowmelt, precipitation, and the release of water from the frost zone. The rise is followed by a sharp decline during the summer months due to evapotranspiration. (This sharp decline may be interrupted by large storms.) The sharp decline is followed by a more gradual decline that occurs during the autumn season when evapotranspiration is lower, and during the winter when capillary water or vapor above the water table is frozen in the soil. Unusual quantities of late fall precipitation can cause water-level rises during the early part of the winter.

The gradient of the potentiometric surface in the Sheyenne Delta aquifer is toward the Sheyenne River in areas within a few miles of the river. The steepest gradients are beneath the bluffs on each side of the river valley. Two to 5 mi (3 to 8 km) beyond the river valley, regional gradients become low and local gradients, which are toward individual low areas where evapotranspiration is greatest, mask regional trends.

Discharge from the aquifer is by evapotranspiration, pumpage, and underflow into the Sheyenne River and its tributaries in the delta. In 1977 about 830 acre-ft (1 hm^3) of water was pumped from the Sheyenne Delta aquifer in Ransom and Sargent Counties.

The Sheyenne River is a gaining stream throughout the delta area of Ransom and Richland Counties (Paulson, 1964, p. 180). The gain in Ransom County was about 14 ft^3/s (400 L/s) in the fall of 1963. Precipitation during 1963 was about 90 percent of normal, so the measured gain probably was lower than could be expected during a year of normal precipitation. Downey and Paulson (1974) reported that measurements made in Ransom and Richland Counties in May and August of 1972 were 109 and 29.4 ft^3/s (3,090 and 833 L/s). If the ratio of gain per mile to total gain remains constant, then the gain in Ransom County would have been 58.6 ft^3/s (1,660 L/s) in May and 15.8 ft^3/s (447 L/s) in August. The discharge in May was due to the high spring water levels caused by recharge from the snowmelt and above normal precipitation in May. These measurements and assumptions, together with the area of delta within the Sheyenne River drainage, indicate that in a year with normal precipitation, between 1 and 3 in. (25 and 76 mm) of the 6 to 8 in. (150 to 200 mm) of precipitation that infiltrates to the aquifer as recharge eventually becomes streamflow. The remainder is lost to evapotranspiration.

Water from the Sheyenne Delta aquifer is a calcium bicarbonate type. Dissolved-solids concentrations in samples from 28 wells tapping the aquifer ranged from 203 to 1,150 mg/L and had a mean of 386 mg/L. Sodium concentrations ranged from 2.2 to 280 mg/L and had a mean of 23 mg/L. Sodium ranged from 3 to 61 percent of the total cations. Sulfate concentrations ranged from 0 to 150 mg/L and had a mean of 37 mg/L. Chloride concentrations generally were low with only one sample from near an abandoned Dakota well containing as much as 210 mg/L. Hardness ranged from 170 to 410 mg/L. Iron concentrations ranged from 40 to 12,000 ug/L, and manganese ranged from 140 to 2,700 ug/L. The samples had SAR values that ranged from 0.1 to 6.4, and specific conductances that ranged from 400 to 1,700 umho/cm (us/cm). The irrigation classification of water from 21 of the samples was C2-S1, four were C3-S1, and one was C3-S2. Irrigation classifications of selected samples are shown in figure 5.

Based on an areal extent of 230 mi^2 (595 km^2), a mean saturated thickness of 41 ft (12 m), and an estimated specific yield of 0.15, about 900,000 acre-ft (1,100 hm^3) of water would be available to wells from storage in the Sheyenne Delta aquifer.

Oakes Aquifer

The Oakes 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 glacial Lake Dakota was formed. The aquifer materials deposited during this stage consist of deltaic and lake deposits, which now form most of the present land surface in the area except along the edge of the moraine where wind-blown deposits cover part of the aquifer and the adjacent moraine. The valley-fill deposits consist of very fine to coarse sand and gravel interbedded with silt and clay. The deltaic deposits generally consist of very fine to medium sand and silt, and the lake deposits generally consist of silt and silty clay. 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 Sargent County the Oakes aquifer extends southward from sec. 30, T. 131 N., R. 58 W., to the South Dakota border. It is bounded on the east by the Oakes moraine. The aquifer generally is about 2 to 3 mi (3 to 5 km) wide, 13 mi (21 km) long, and underlies an area of about 33 mi^2 (85 km^2).

Aquifer thicknesses vary considerably within short distances; as much as 42 ft (13 m) in a distance of half a mile (0.8 km). Drillers logs and test-hole data indicate that the aggregate saturated thickness of sand and gravel in the aquifer ranges from about 18 to 185 ft (5.5 to 56 m) and has a mean thickness of about 80 ft (24 m).

The Science and Education Administration, Federal Research, Mandan, N. Dak. (oral commun., 1978), conducted a 24-hour aquifer test about a mile (1.6 km) west of Sargent County at 130-059-13C, using a 55-ft (17-m) well pumped at varying rates that averaged 270 gal/min (17 L/s). Using their data, R. B. Shaver (North Dakota State Water Commission, oral commun., 1980) estimated that the transmissivity of the aquifer is about 5,000 ft^2/d (465 m^2/d) and the storage coefficient is between 0.05 and 0.2. Much of the aquifer in Sargent County is more than 50 percent thicker and the grain size of the aquifer materials is larger than at the test site in Dickey County. Therefore, the transmissivities in the thicker parts of the aquifer in Sargent County probably range from about 12,000 to 20,000 ft^2/d (1,100 to 1,900 m^2/d).

Yields from wells in the Oakes aquifer range from a few gallons per minute from some domestic and stock wells to as much as 900 gal/min (57 L/s) from irrigation wells. Irrigation wells finished in the aquifer generally yield between 800 and 900 gal/min (50 and 57 L/s), but yields of as much as 1,500 gal/min (95 L/s) could be obtained from wells finished in a few ideal locations. Differences of as much as 500 gal/min (32 L/s) could occur within the same quarter section (65 ha).

Recharge to the aquifer is from infiltration of snowmelt and precipitation. However, some lateral movement of water from the till and glaciofluvial deposits on the eastern edge of the aquifer does occur. Water in the aquifer moves in a westerly direction toward Dickey County in the northern part of the aquifer and southward into South Dakota in the southern part. Discharge from the Oakes aquifer occurs by evapotranspiration, pumpage, and movement into Dickey County and South Dakota. Water-level fluctuations (fig. 10) indicate that responses to recharge events are rapid. A storm that occurred on June 11, 1977, caused a 1.13-ft (0.3-m) water-level rise by June 15. A decline of 1.11 ft (0.3 m) then took place in the following 10 days.

Water from the Oakes aquifer, as determined from 12 samples, is a calcium bicarbonate type. Dissolved solids in the samples ranged from 259 to 819 mg/L and had a mean of 380 mg/L. Sodium concentrations ranged from 3.9 to 210 mg/L and had a mean of 34 mg/L. Sodium ranged from 3 to 63 percent of the total cations. Sulfate concentrations ranged from 6.2 to 82 mg/L and had a mean of 33 mg/L. Chloride concentrations ranged from 0.3 to 160 mg/L and had a mean of 18 mg/L. Hardness ranged from 180 to 320 mg/L. Iron concentrations ranged from 40 to 1,100 ug/L, and manganese ranged from 20 to 760 ug/L. The samples had SAR values that ranged from 0.1 to 5.7 and specific conductances ranged from 420 to 1,350 umho/cm (us/cm). The irrigation classification of water from 11 samples was C2-S1 and from one sample was C3-S2 (fig. 5).

Based on an areal extent of 33 mi^2 (85 km^2), an average saturated thickness of 80 ft (24 m), and an estimated specific yield of 0.15, about 250,000 acre-ft (310 hm^3) of water would be available to wells from storage in the Oakes aquifer in Sargent County.

Sand Prairie Aquifer

The Sand Prairie was formed as an outwash plain by a stream flowing southeastward in the channel now occupied by Stoney Slough. In southern Barnes County the stream left its channel and the deposits were spread over a large area now occupied by the Sand Prairie (Kelly, 1966, p. 51). The stream that deposited the Sand Prairie aquifer was a small stream that flowed southward across a high plain that existed before the Sheyenne River was established; as evidenced by about 30 ft (9 m) of the Sand Prairie deposits exposed in a road cut along Highway 46 on the west side of the Sheyenne River valley. The small stream followed a course that approximates the area indicated as channel in figure 11. As the stream valley filled, the sediments spilled out and

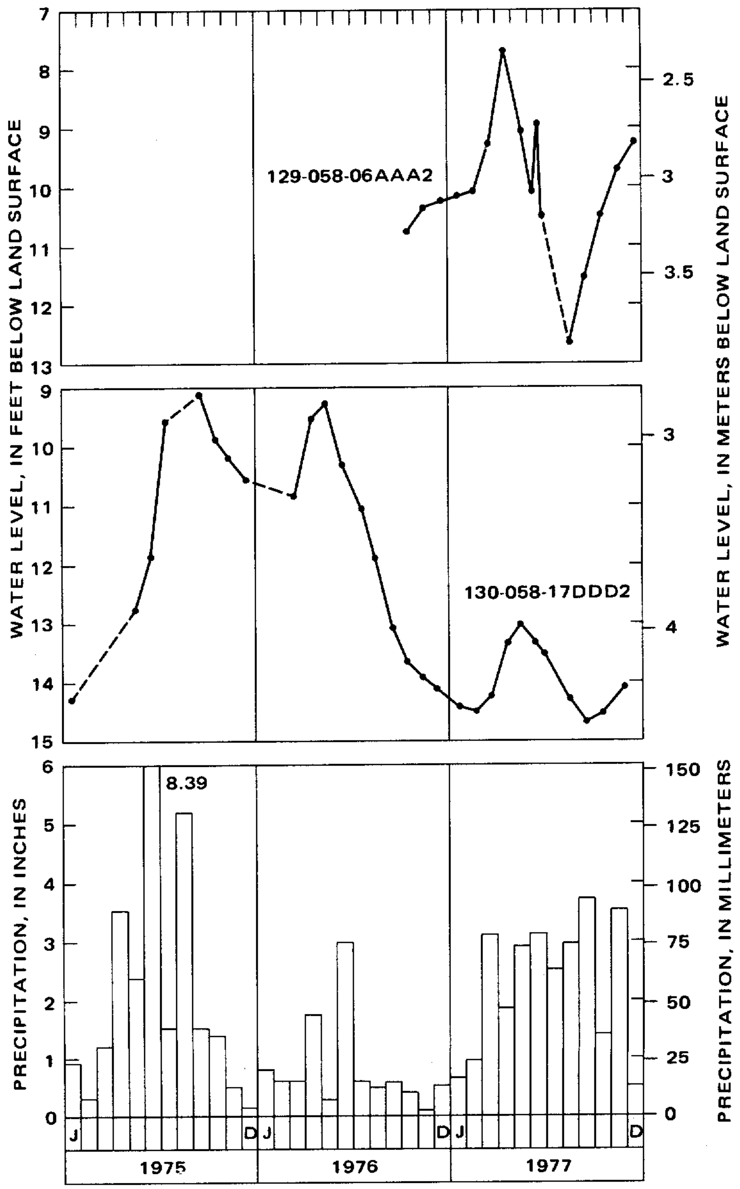


FIGURE 10.—Water-level fluctuations in the Oakes aquifer and precipitation at Forman.

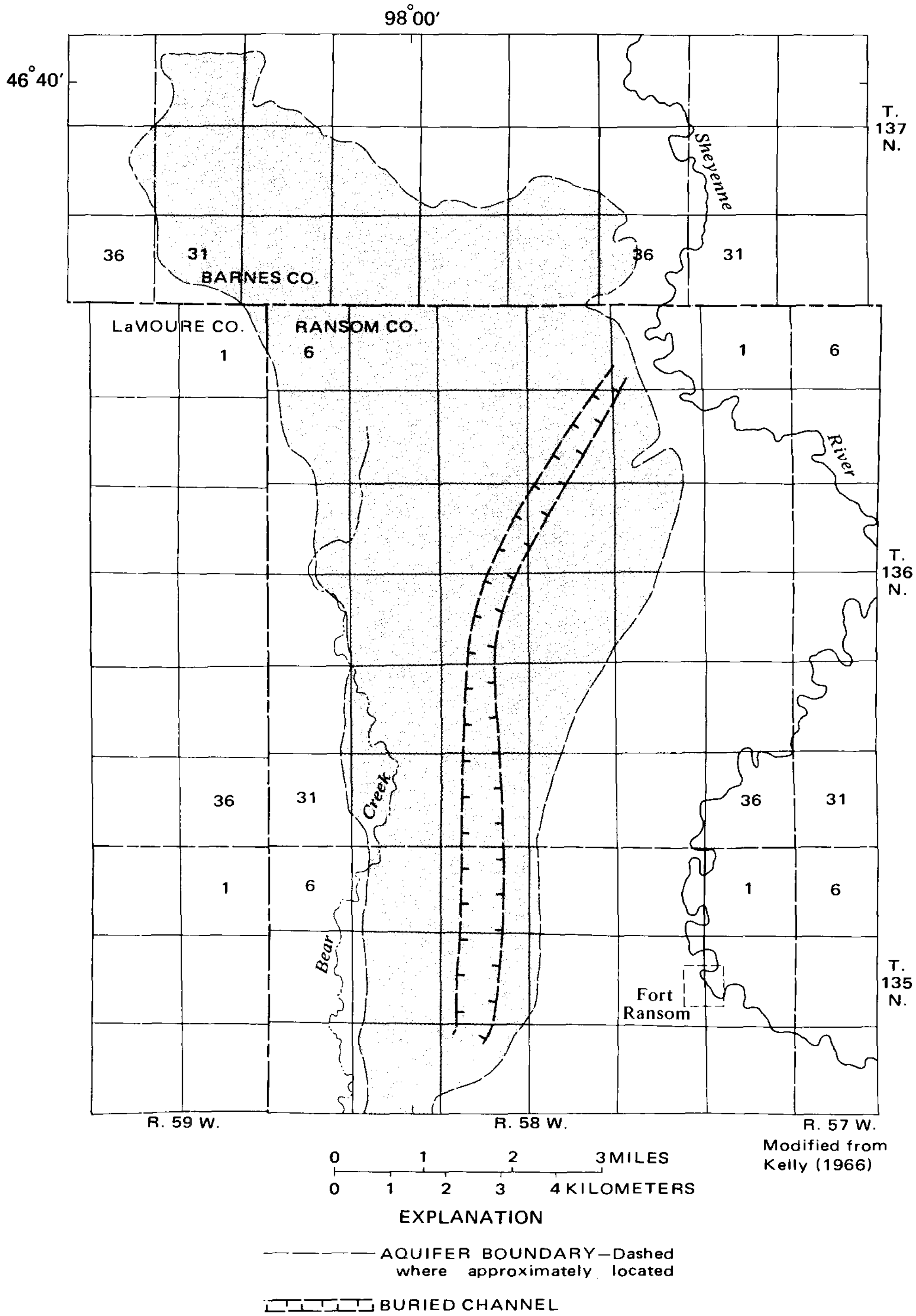


FIGURE 11.—Sand Prairie aquifer in Barnes and Ransom Counties.

formed the Sand Prairie aquifer. The coarser sand and gravel was deposited in the north and the finer sand was carried south. The aquifer in northern Ransom County generally consists of a fine to coarse sand and is a fine to medium sand farther south. However, deposits in the channel also contain very coarse sand and gravel.

The Sand Prairie aquifer underlies about 25 mi^2 (65 km^2) in Ransom County. The aquifer materials range in thickness from near 0 ft (0 m) at the edge to as much as 65 ft (20 m) in the channel. The average saturated thickness throughout most of the Sand Prairie aquifer in Ransom County is about 8 ft (2 m) and about 32 ft (10 m) in the channel areas. The mean saturated thickness is about 14 ft (4 m).

Yields from individual wells in the aquifer depend upon saturated thickness and hydraulic conductivity at the particular well site. In 1977, three irrigation wells located in the channel part of the aquifer were pumped at rates of as much as 900 gal/min (57 L/s). Four other wells drilled near the edge of the channel were pumped as a unit and the yield was about 650 to 700 gal/min (41 to 44 L/s). Yields from domestic and stock wells generally are considerably less than 50 gal/min (3 L/s).

Recharge to the aquifer is by infiltration of rainfall and snowmelt. It is not known how much recharge there is, but the soils are sandy, similar to those in the Sheyenne delta, so as much as 6 to 8 in. (150 to 200 mm) of precipitation may reach the water table in normal years. In dry years the recharge to the aquifer is less because there is less available moisture and soil moisture requirements have to be met before recharge can occur.

Water-level fluctuations in observation well 135-058-04DDD1 are shown in figure 12. Precipitation in 1976 was less than normal; consequently, the water level declined after the spring thaw in 1976.

Discharge from the aquifer is by seepage from springs along the west side of the Sheyenne River valley in Barnes County and in sec. 3, T. 136 N., R. 58 W. in Ransom County and into Bear Creek on the southwest side of the aquifer, by evapotranspiration, and by pumpage.

Water from the Sand Prairie aquifer is a calcium bicarbonate type. Dissolved-solids concentrations in samples from five wells tapping the aquifer ranged from 338 to 624 mg/L and had a mean of 436 mg/L. Sodium ranged from 9.8 to 17 mg/L and had a mean of 14 mg/L. Sodium ranged from 6 to 12 percent of the total cations. Sulfate and chloride concentrations generally were low with maximum concentrations of 100 and 47 mg/L, respectively. Hardness ranged from 260 to 490 mg/L. Iron concentrations ranged from 20 to 650 ug/L, and manganese ranged from 20 to 920 ug/L. The samples had SAR values that ranged from 0.2 to 0.4 and specific conductances that ranged from 535 to 995 umho/cm (us/cm). The irrigation classification of water from the aquifer was C2-S1 or C3-S1 (fig. 5).

Based on an areal extent of 25 mi^2 (65 km^2), a mean saturated thickness of 14 ft (4 m), and an estimated specific yield of 0.15, about 34,000 acre-ft (42 hm^3) of water would be available to wells from storage in the Sand Prairie aquifer in Ransom County.

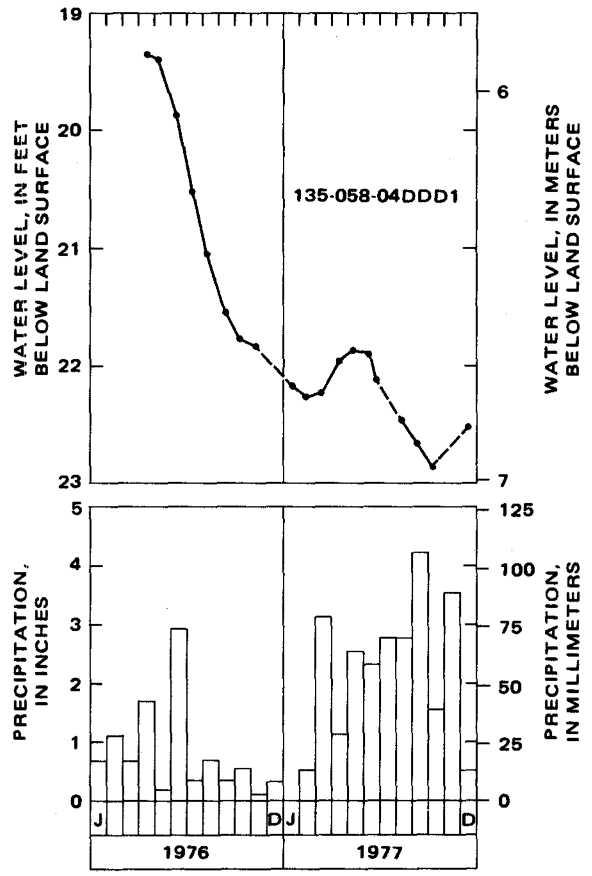


FIGURE 12.—Water-level fluctuations in the Sand Prairie aquifer and precipitation at Lisbon.

Undifferentiated Glacial-Drift Aquifers and Alluvial Aquifers

Undifferentiated glacial-drift aquifers are interspersed within the till in most of Ransom and Sargent 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. Some of the materials may have been deposited in small tributaries of ancient drainage systems. 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 or alluvial 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 water for domestic and stock supplies. Many of the aquifers probably could not sustain yields of a much as 10 gal/min (0.6 L/s), but a few, such as near Enderlin, could yield nearly 500 gal/min (32 L/s). However, the areal extent of these aquifers is not known, but appears to be relatively small, so the time period that large yields could be sustained probably would not be more than a few months (possibly a few weeks). The aquifers most likely to have the greater yields are those associated with elongate surface depressions or chains of sloughs.

Alluvial aquifers in Ransom and Sargent Counties are composed of fine-grained materials. Locally however, sand and gravel lenses are present. Most of these lenses consist of a few feet of fine to medium sand, but as much as 30 ft (9 m) of medium sand to coarse gravel was reported to be present in the Maple River valley near Enderlin. Some of the deeper sand and gravel lenses described as alluvium may be glacial outwash.

Yields from the alluvial aquifers generally are small, less than 30 gal/min (2 L/s), but the city well at Enderlin was tested at 400 gal/min (25 L/s), and a well at Lisbon was tested at 550 gal/min (35 L/s).

Recharge to the undifferentiated glacial-drift aquifers and alluvial aquifers is by infiltration of precipitation in areas of sandy soils, and by lateral movement from adjacent sediments. Surface water that accumulates in ponds and sloughs is an important source of recharge even though many of the sloughs and ponds contain water for only a few months in the spring. 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 samples were collected from 68 wells penetrating undifferentiated glacial-drift aquifers. Analyses of the samples show that the quality of water varies from place to place. Calcium generally is the predominant cation, but sodium predominates in about 44 percent of the samples. Generally either sulfate or bicarbonate is the dominant anion, but locally chloride may be most abundant. Dissolved-solids concentrations in 68 samples ranged from 358 to 4,260 mg/L. Sodium concentrations ranged from 5.0 to 960 mg/L. Sodium ranged from 3 to 97 percent of the cations. Sulfate ranged from 12 to 2,400 mg/L and exceeded 250 mg/L in 54 samples. Chloride concentrations ranged from 2.7 to 710 mg/L and exceeded 250 mg/L in 11 samples. Hardness ranged from 28 to 2,700 mg/L, however only three samples contained less than 180 mg/L. Iron concentrations exceeded the recommended limit in 45 of the samples and manganese concentrations exceeded the recommended limit in 61 samples. The specific conductance ranged from 525 to 4,600 umho/cm (us/cm); SAR values ranged from 0.1 to 54. The irrigation classification of the best quality water was C2-S1; the poorest was C4-S4.

Water samples were collected from six wells penetrating alluvial aquifers. Calcium was the dominant cation in four of the samples and sodium was the dominant cation in two of the samples. Sulfate was the dominant anion in three of the samples, bicarbonate was dominant in two of the samples, and chloride was dominant in one sample. Dissolved-solids concentrations ranged from 773 to 3,620 mg/L. Sodium ranged from 59 to 870 mg/L and comprised 16 to 81 percent of the cations. Sulfate concentrations ranged from 120 to 1,300 mg/L, chloride ranged from 38 to 1,200 mg/L, and hardness ranged from 420 to 2,200 mg/L. Iron concentrations exceeded the recommended limit in five of the samples and manganese concentrations exceeded the recommended limit in all of the samples. Specific conductance ranged from 1,500 to 5,000 umho/cm (us/cm) and SAR values ranged from 1.0 to 19. 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 Ransom and Sargent 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. 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 farms 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.

Use	Individual requirements (gallons per day)	Population	Estimated pumpage, gallons per day, (rounded)
Domestic (not including cities having public supplies)	[a]75	[b]7,800	585,000
Cattle	[c]15	[c]104,000	1,560,000
Cows with calves	[c]35	[c]3,000	105,000
Hogs	[c] 2	[c]29,000	58,000
Total			2,310,000

[a] Estimated from average per-person use in smaller cities in Ransom and Sargent Counties and in adjacent Dickey and LaMoure Counties.
[b] U.S. Bureau of the Census, 1971.
[c] North Dakota State University, 1978.

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.

Public Supplies

The cities and villages in Ransom and Sargent Counties all depend on ground water for at least part of their water supplies. The cities of Elliott, Enderlin, Lisbon, and Sheldon in Ransom County and Cogswell, Forman, Gwinner, and Rutland in Sargent County all have distribution systems. Citizens in other cities and villages in the two counties depend on private wells for their supplies.

Elliott

The city of Elliott obtains its water supply from a 125-ft (38-m) well completed in glaciofluvial deposits that may be connected to the Elliott aquifer. The well is capable of producing about 40 gal/min (3 L/s); but with the present pump the well will yield a maximum of about 10 gal/min (0.6 L/s). No records are kept so the annual use is unknown. A water sample from the municipal supply well taken in 1977 had a dissolved-solids concentration of 1,380 mg/L. Sulfate (590 mg/L), iron (2,200 ug/L), and manganese (140 ug/L) all exceeded the limits recommended for a public supply.

Should the city need more water they could obtain a supply from the Elliot aquifer. However, the quality of the water in the Elliott aquifer may not be as good as that of the present supply.

Enderlin

The city of Enderlin obtains its water supply from well 136-055-04DDB completed in an outwash-alluvial deposit. The well is pumped at a rate of about 300 gal/min (20 L/s), or as much as 430,000 gal/d (1,600 m^3/d). The average daily use in 1977 was reported to be about 141,000 gallons (534 m^3). The annual use is about 51 Mgal (193,000 m^3). A water sample collected in 1977 was analyzed for common and selected minor ions. The concentrations of dissolved solids (1,010 mg/L), sulfate (400 mg/L), iron (620 ug/L), and manganese (1,100 ug/L) were the only constituents that exceeded the recommended limits.

Should the city of Enderlin require more water, additional wells could be drilled in the vicinity of the present well.

Lisbon

The city of Lisbon obtains its water from two wells completed in Sheyenne River alluvium or undifferentiated glacial outwash. The maximum possible well yield was not reported, but one well was tested at 550 gal/min (35 L/s) for 20 hours. Reported daily use in 1976 was about 184,000 gal (696 m^3) or about

67 Mgal (254,000 m^3) annually. In addition to the water used by the city, about 20 percent, or 13 Mgal (49,000 m^3) was used for backwashing sand filters and other treatment and maintenance uses.

A water sample was collected from each well and analyzed for both common ions and selected minor ions. Dissolved solids (1,060 and 773 mg/L), sulfate (330 and 240 mg/L), iron (2,400 and 510 ug/L), and manganese (1,200 and 600 ug/L) exceeded the recommended limits. A sample of the treated water contained 922 mg/L dissolved solids, 268 mg/L sulfate, 20 ug/L manganese, and no detectable iron.

Should the city of Lisbon desire more water, other wells could be drilled in the undifferentiated alluvium and glacial outwash.

Sheldon

The city of Sheldon obtains its water supply from a well located at 136-054-17DDB. The well is reported to be 610 ft (190 m) deep and is completed in the Dakota aquifer. The well is reported to flow at about 40 gal/min (3 L/s) directly into the distribution system with the surplus diverted to waste. A water sample taken in 1977 contained 2,630 mg/L dissolved solids, 1,300 mg/L sulfate, 360 mg/L chloride, 920 ug/L iron, and 60 ug/L manganese. No reliable estimates are available concerning the quantity of water used by the city.

Should the city of Sheldon desire an alternative source of ground water, an adequate supply of better quality water could be obtained from the Sheyenne Delta aquifer to the east.

Cogswell

The city of Cogswell obtains its water supply from three 1,100-ft (335-m) wells in the Dakota aquifer and one 200-ft (60-m) well in the Spiritwood aquifer system. Each of the Dakota wells flows at a rate of about 6 gal/min (0.4 L/s) and each supplies from 20 to 40 homes through separate distribution systems. The 200-ft (60-m) Spiritwood well supplies one home, the park, and the campground. The city does not meter their water use.

A water sample collected from one of the Dakota wells (130-057-02ABC) was analyzed for common ions. Concentrations of dissolved solids (2,430 mg/L) sulfate (1,100 mg/L), chloride (330 mg/L), and iron (990 ug/L) all exceeded the recommended limits.

Should the city need more water, an adequate supply can be obtained from other wells in the Spiritwood aquifer system in or near the city. However, an adequate supply of better quality water could be obtained from the Spiritwood aquifer system in the high yield area to the west.

Forman

The city of Forman obtains its water supply from two wells, 130-056-01AAB1, which is 185 ft (56 m) deep and yields 150 gal/min (9.5 L/s), and

130-056-01AAB2, which is 168 ft (51 m) deep and yields 80 gal/min (5 L/s). Both of these wells are completed in the Spiritwood aquifer system. The city uses an average of about 55,000 gal/d (208 m^3/d) or about 20 Mgal per year (76,000 m^3/yr). Maximum daily use during the summer is as much as 70,000 gal (260 m^3), and in the winter the daily use is as low as 40,000 gal (150 m^3).

A water sample collected from well 130-056-01AAB1 and analyzed for common and selected minor ions showed that the water is a sodium sulfate type. Dissolved solids (1,460 mg/L) and sulfate (810 mg/L) are the only constituents that exceeded the recommended limits.

If Forman needs more water, adequate supplies can be obtained from additional wells in the Spiritwood aquifer system.

Gwinner

The city of Gwinner obtains its water supply from two wells, 132-056-25BBC and 132-056-26ADD, completed in the Gwinner aquifer. About 73 Mgal (0.28 hm^3) of water, or about 200,000 gal/d (760 m^3/d), was withdrawn from the aquifer during 1977.

A sample collected from well 132-056-25BBC and analyzed for common and selected minor ions showed that water is a sodium sulfate type. Dissolved solids (1,460 mg/L), sulfate (640 mg/L), iron (590 ug/L), and manganese (620 ug/L) were the only constituents that exceeded the recommended limits.

If Gwinner should need more water, they probably could obtain it by installing wells in the Gwinner aquifer.

Rutland

The city of Rutland obtains its water from a 170-ft (52-m) well, 130-055-24DDA, that taps the Spiritwood aquifer system. The city used an average of about 28,900 gal/d (109 m^3/d) during 1976. The total use in 1976 was 10,590,000 gal (40,000 m^3).

A water sample taken from the distribution system was analyzed for both common and selected minor ions. Dissolved solids (870 mg/L), sulfate (280 mg/L), iron (11,000 ug/L), and manganese (1,700 ug/L) concentrations all exceeded the recommended limits.

If the city needs more water, other wells could be drilled into the Spiritwood aquifer system.

Irrigation Supplies

The North Dakota State Water Commission (written commun., 1978) reports that in 1977 pumpage from irrigation wells was as follows: Englevale aquifer, 5,620 acre-ft (6.9 hm^3); Milnor Channel aquifer, 1,070 acre-ft (1.3 hm^3); Sheyenne Delta aquifer, 917 acre-ft (1.1 hm^3); Sand Prairie aquifer, 98 acre-ft (0.12 hm^3); Oakes aquifer, 1,350 acre-ft (1.7 hm^3); and Brampton aquifer, 98 acre-ft (0.12 hm^3). In addition, about 11 acre-ft (0.01 hm^3) of water was pumped from two wells in an unnamed glacial-drift aquifer to water the Enderlin golf course.

SUMMARY

Ground water in Ransom and Sargent Counties may be obtained from sandstone beds in the Dakota aquifer system and from sand and gravel beds in the glacial deposits.

The top of the Dakota aquifer system underlies the two counties at depths ranging from about 500 to 1,000 ft (150 to 300 m) below land surface. The aquifer system generally ranges from 10 to 275 ft (3 to 84 m) in thickness and has a mean thickness of about 88 ft (27 m). Well yields generally are less than 10 gal/min (0.6 L/s), but locally yields of as much as 50 gal/min (3 L/s) are obtainable. Water in the aquifer generally is a sodium sulfate type. Dissolved-solids concentrations in 74 samples ranged from 2,170 to 3,340 mg/L.

The glacial-drift aquifers with the greatest potential for development are those associated with buried valleys, outwash, deltaic or terrace deposits. The buried-valley aquifers are the Spiritwood system, Brampton (in part), Gwinner, and Elliott aquifers. Those associated with outwash or terrace deposits are the Englevale, Milnor Channel, Oakes (in part), and Sand Prairie aquifers. The Sheyenne Delta aquifer is the principal deltaic aquifer, although the Oakes aquifer also is composed, in part, of deltaic 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. Hydrologic data for the major glacial-drift aquifers are listed in table 3.

Undifferentiated glacial-drift aquifers are interspersed within the till in most of Ransom and Sargent Counties. They generally are small in size and consequently yield only small quantities of water.

The rural population of Ransom and Sargent Counties is dependent upon ground water for their domestic and most of their livestock needs. In addition, the cities of Elliott, Enderlin, Lisbon, and Sheldon in Ransom County and Cogswell, Forman, Gwinner, and Rutland in Sargent County obtain their public supplies from wells.

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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)	Predominant water type	Dissolved solids (milligrams per liter)	Sodium-adsorption ratio	Probable maximum well yield (gallons per minute)
Spiritwood	175	50	840,000	Sodium sulfate or sodium-calcium sulfate.	626 to 2,260	0.6 to 17	1,000
Brampton	100	55	530,000	—	223 to 1,290	0.1 to 4.5	1,000
Elliott	—	28	—	Calcium-sodium sulfate or sodium sulfate.	1,790 to 1,910	3.1 to 9.5	500
Gwinner	—	55	—	Sodium sulfate or sodium-calcium sulfate.	971 to 1,640	3.9 to 18	1,000
Englevale	78	40	300,000	Calcium bicarbonate.	255 to 4,670	0.0 to 26	1,500
Milnor Channel	45	35	184,000	Calcium or sodium bicarbonate.	325 to 1,120	0.1 to 5.7	900
Sheyenne Delta	230	41	900,000	Calcium bicarbonate.	203 to 1,140	0.1 to 6.4	1,000
Oakes	33	80	250,000	Calcium bicarbonate.	259 to 819	0.1 to 5.7	1,500
Sand Prairie	25	14	34,000	Calcium bicarbonate.	338 to 624	0.2 to 0.4	900
Total (rounded)			3,000,000				

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DEFINITIONS OF SELECTED TERMS

Aquifer — A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells 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 the 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): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

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.

Slough — A depression containing a marshy pond.

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 extended 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.