GROUND-WATER RESOURCES

OF

EMMONS COUNTY, NORTH DAKOTA

by

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COUNTY GROUND-WATER STUDIES 23 — PART III
North Dakota State Water Commission
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BULLETIN 66 — PART III
North Dakota Geological Survey
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Prepared by the U.S. Geological Survey
in cooperation with the North Dakota Geological Survey,
North Dakota State Water Commission,
and Emmons County Board
of Commissioners

1978

Bismarck, North Dakota

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SELECTED FACTORS FOR CONVERTING ENGLISH UNITS TO THE INTERNATIONAL SYSTEM (SI) OF METRIC UNITS

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

Multiply English units	**By**	**To obtain SI units**
Acres	0.4047	hectares (ha)
	.004047	square kilometers (km^2)
Acre-feet	1,233	cubic meters (m^3)
	.001233	cubic hectometers (hm^3)
Cubic feet per second (ft^3/s)	28.32	liters per second (L/s)
Feet	.3048	meters (m)
Feet per day (ft/d)	.3048	meters per day (m/d)
Feet squared per day (ft^2/d)	.0929	meters squared per day (m^2/d)
Feet per mile (ft/mi)	.1894	meters per kilometer (m/km)
Gallons	3.785	liters
	.003785	cubic meters (m^3)
Gallons per day (gal/d)	.003785	cubic meters per day (m^3/d)
Gallons per minute (gal/min)	.06309	liters per second (L/s)
Gallons per minute per foot [(gal/min)/ft]	.207	liters per second per meter [(L/s)/m]
Inches	25.40	millimeters (mm)
Miles	1.609	kilometers (km)
Million gallons (Mgal)	3,785	cubic meters (m^3)
Million gallons per day (Mgal/d)	3,785	cubic meters per day (m^3/d)
Pounds per square inch (lb/in^2)	.0703	kilograms per square centimeter (kg/cm^2)
Square miles (mi^2)	2.590	square kilometers (km^2)

GROUND-WATER RESOURCES OF EMMONS COUNTY, NORTH DAKOTA

By

C. A. Armstrong

ABSTRACT

Ground water in Emmons County generally is obtained from glacial-drift aquifers of Quaternary age and the Fox Hills and Dakota aquifers of Cretaceous age. Glacial-drift aquifers with the greatest potential for development are the Strasburg, Long Lake, Braddock, and Winona. Properly constructed wells in the more permeable parts of these aquifers will yield from 500 to 1,000 gallons per minute (32 to 63 liters per second).

Water from these glacial-drift aquifers differs in chemical quality depending on sources of recharge. Dissolved-solids concentrations in samples from these aquifers ranged from 269 to 2,150 milligrams per liter.

The Fox Hills aquifer underlies about 80 percent of the county and supplies water to about 75 percent of the wells. Yields from wells tapping the Fox Hills aquifer range from 0.5 to 40 gallons per minute (0.03 to 2.5 liters per second). The water generally is a sodium bicarbonate type that commonly contains less than 1,000 milligrams per liter dissolved solids in areas where sandstone crops out. It contains less than 1,500 milligrams per liter in areas where siltstone and silty shale crop out.

The Dakota aquifer underlies Emmons County at depths that range from 2,200 to 2,530 feet (670 to 770 meters). Unrestricted flows from wells in the aquifer range from 30 to 60 gallons per minute (2 to 4 liters per second). Water in the Dakota aquifer is a sodium sulfate type. Dissolved-solids concentrations in the samples from the aquifer ranged from 2,220 to 2,640 milligrams per liter and sulfate concentrations ranged from 1,140 to 1,440 milligrams per liter.

INTRODUCTION

Emmons County has an area of 1,559 mi² (4,038 km²) in south-central North Dakota (fig. 1). This study of the geology and ground-water resources of the county began in July 1971 and is a cooperative investigation by the U.S. Geological Survey, the North Dakota State Water Commission, the North Dakota Geological Survey, and the Emmons County Board of Commissioners. The field investigation was completed in November 1973. The North Dakota Geological Survey mapped the geology of the county and will publish the results as part I of this series. The data used in this report, unless otherwise referenced, were published in part II of this series (Armstrong, 1975).

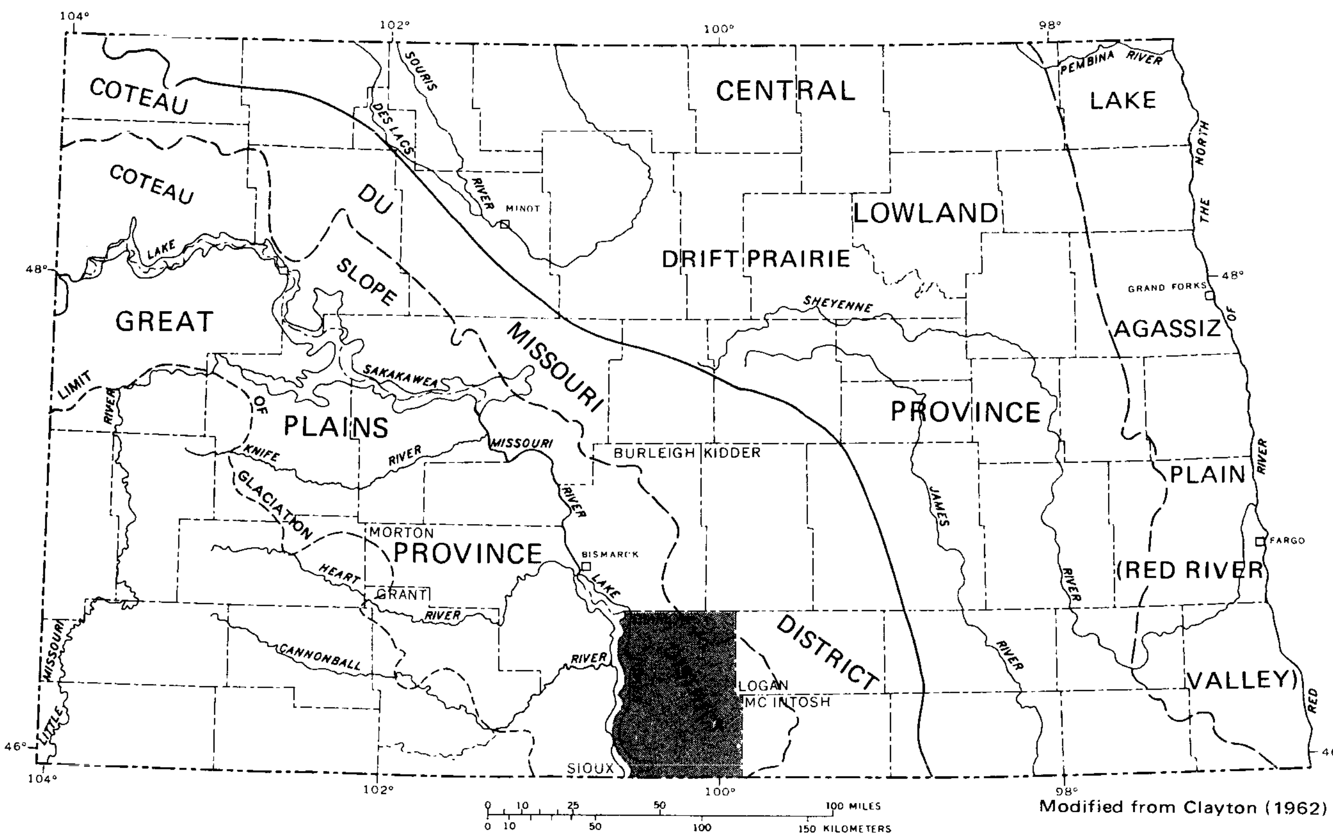


FIGURE 1.— Physiographic divisions in North Dakota and location of study area.

Purpose and Scope

The purpose of the investigation was to determine the quantity and quality of ground water potentially available for municipal, domestic, irrigation, livestock, and industrial purposes in Emmons County, 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 major glacial-drift aquifers; (4) estimate the potential yields to wells tapping the major aquifers; and (5) determine the chemical quality of the ground water.

The geology of the county was mapped to help determine the location and extent of the aquifers. Geologic and hydrologic data were collected from 1,193 wells and test holes to help determine the location and extent of the aquifers. Water levels were measured periodically in 76 observation wells to evaluate patterns of recharge to and discharge from the aquifers. Three aquifer tests were made to determine the transmissivities and storage coefficients of aquifers at specific sites and to establish a basis for estimating transmissivities of glacial-drift aquifers elsewhere in the study area. Water samples were obtained from selected wells. Of these, 265 samples were analyzed to determine the chemical composition of water in the county.

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 the well, spring, or test hole is located. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre or 4-ha tract); thus well 132-076-15DAA would be located in the NE¼NE¼SE¼ sec. 15, T. 132 N., R. 76 W. Consecutive terminal numbers are added if more than one well or test hole is recorded within a 10-acre (4-ha) tract. This numbering system also is used in this report for the location of small areas.

Previous Investigations

Ground-water data for Emmons County were included in a report by Simpson (1929) on the ground-water resources of North Dakota. Abbott and Voedisch (1938) discussed the municipal ground-water supplies of North Dakota, including those supplies from Emmons County, and tabulated chemical analyses of ground water used by the cities and villages. The geology and ground-water resources of the Zeeland area were studied by Laird and Akin (1948). Their study included a small part of southeastern Emmons County. Fischer (1952) reported on the geology of Emmons County with emphasis on the Fox Hills Formation. Randich (1963) reported on a study of the geology and ground-water resources of the Linton-Strasburg area.

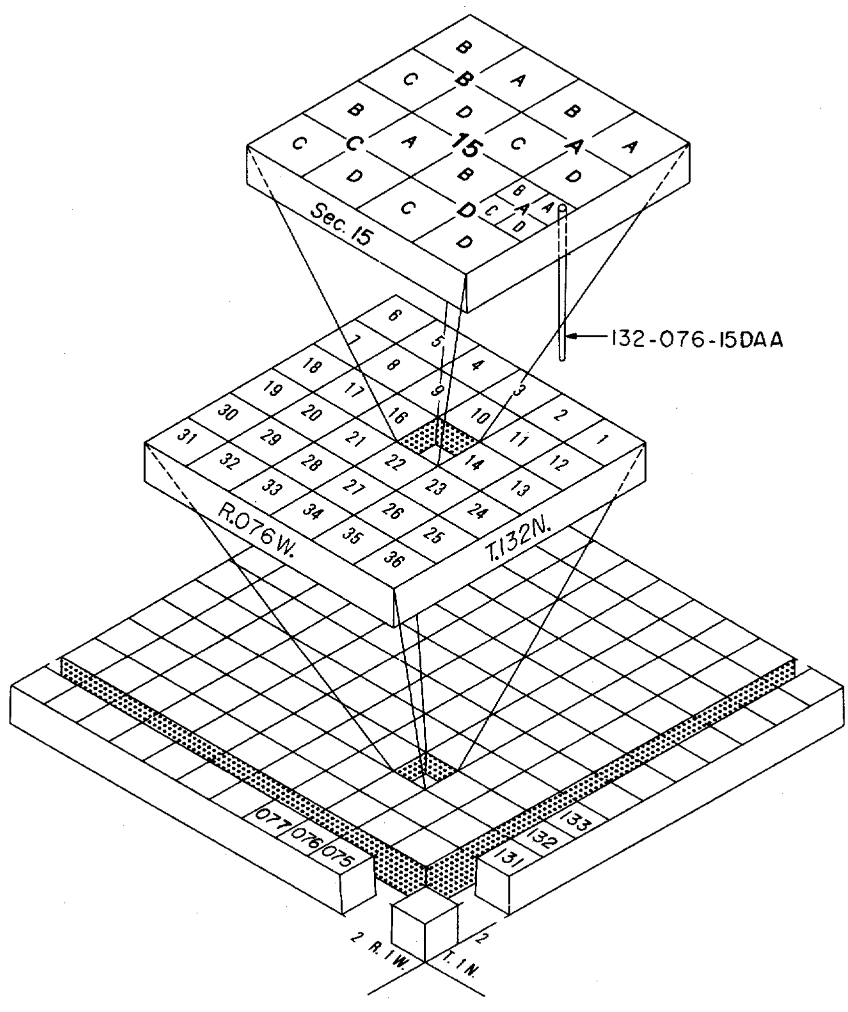


FIGURE 2.— Location-numbering system.

Acknowledgments

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

Particular recognition is due M. O. Lindvig and R. W. Schmid of the North Dakota State Water Commission for their aid during aquifer tests and L. L. Froelich and C. E. Naplin, also of the State Water Commission, for the logging of test holes. Appreciation is expressed to the well drillers who furnished well logs and to the farmers and ranchers of Emmons County for allowing access to their lands and for providing records of wells.

Population and Economy

The population of Emmons County was 7,200 in 1970 (U.S. Bureau of the Census, 1971). The largest cities are Linton (county seat), Strasburg, and Hazelton; with populations of 1,695, 642, and 374, respectively. The economy of the county is based largely on agriculture. Small grains, flax, and hay are the principal crops. Cattle and dairy products are other important sources of farm income.

Climate

The climate of Emmons County is semiarid. U.S. Environmental Data Service (1962-74) records show that the mean annual precipitation at Linton is 16.75 inches (425 mm). About 70 percent of the precipitation generally falls from April through August when it is most needed for the germination and growth of crops. Most of the summer precipitation is from thunderstorms and is extremely variable. Parts of the county may receive more than an inch (25.4 mm) of rain during a thunderstorm while other parts, within a few miles, may receive very little or none.

The average annual temperature in the area is 42.5°F (6°C). Summer daytime temperatures are usually warm, ranging from 75°F to 85°F (24°C to 29°C). However, temperatures exceeding 90°F (32°C) commonly occur each summer. The maximum recorded temperature since 1962 was 108°F (42°C) on August 8, 1972. The minimum temperature recorded since 1962 was −44°F (−42°C) on January 18, 1970. The average number of days between the last freeze (32°F or 0°C) in the spring and the first freeze in the fall is 117.

Physiography and Drainage

Emmons County lies, for the most part, in the Coteau Slope district of the Great Plains province (fig. 1). A small area in the northeast part of the county is in the Coteau du Missouri district.

Maximum topographic relief in the county is greater than 600 feet (183 m). The highest altitude is 2,225 feet (678 m) above msl (mean sea level) on the top of a broad hill in 134-075-28 (U.S. Army Map Service, 1954). The lowest altitude is 1,608 feet (490 m) above msl — the normal pool level of Lake Oahe, which was formed behind a dam on the Missouri River.

Drainage on the Coteau Slope is westward into Lake Oahe and generally is well developed. Locally, however, there are poorly drained areas. The principal tributaries that drain into Lake Oahe are Badger Creek, Horsehead Creek, Beaver Creek, Little Beaver Creek, and Cat Tail Creek. Long Lake Creek, in the northeast part of the county, flows northwestward into Long Lake in Burleigh County.

Drainage on the Coteau du Missouri is poorly developed — surface runoff is toward undrained or poorly drained depressions. However some of these depressions fill up and overflow into lower ones or drain into tributaries, which eventually lead to Lake Oahe.

OCCURRENCE AND QUALITY OF GROUND WATER

General Concepts

All ground water of economic importance in Emmons County is derived from precipitation. Part of the precipitation that falls on the earth's surface is returned directly to the atmosphere by evaporation, part runs off into streams, and the remainder infiltrates into the ground. Some of the water that enters the soil is held by capillarity and is evaporated from the soil or transpired by plants. The excess water infiltrates downward until it reaches the zone of saturation. When the water enters the zone of saturation, it becomes ground water and is available to wells.

Ground water moves by gravity from areas of recharge to areas of discharge. Ground-water movement is generally very slow; it may be only a few feet per year. The rate of movement is governed by the hydraulic conductivity of the material through which the water moves and by the hydraulic gradient. Well-sorted gravel and coarse sand generally have a high hydraulic conductivity. Deposits of these materials commonly form good aquifers. Fine-grained materials such as silt, clay, and shale usually have a low hydraulic conductivity and are poor aquifers. Fractures also contribute to the hydraulic conductivity of 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 primarily in response to changes in the rate of recharge to and discharge from the aquifer. Shallow aquifers generally are recharged each spring and early summer by direct infiltration of precipitation. At the present time, recharge to these aquifers generally is sufficient to replace losses caused 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 such as clay or silt are recharged very slowly. Replenishment of these aquifers is by percolation from adjacent sediments or by infiltration of precipitation through the fine-grained materials. The rate of recharge may increase as heads in the aquifers are lowered by pumping; however, head declines may continue for several years before sufficient recharge is induced to balance the rate of withdrawal. In some cases this balance may never be achieved without a curtailment of withdrawals.

Ground water in Emmons County contains dissolved mineral matter in varying amounts. Rain, as it falls, begins to dissolve mineral matter suspended in the air and continues to dissolve mineral matter as the water infiltrates through the soil. The amount and kind of dissolved minerals in water depends upon the solubility and types of rocks encountered, the length of time the water is in contact with the rocks, the temperature, the pressure, and the pH of the water.

The suitability of water for various uses is determined largely by the kind and amount of dissolved minerals and by its physical properties. The chemical constituents, physical properties, and characteristics most likely to be of concern in Emmons County are: iron, sulfate, nitrate, fluoride, dissolved solids, hardness, temperature, color, odor, taste, specific conductance, sodium-adsorption ratio (SAR), and percent sodium. The sources of the major chemical constituents, their effects on usability, and the limits recommended by the U.S. Public Health Service are given in table 1. Additional information may be found in "Drinking Water Standards" published by the U.S. Public Health Service (1962).

Numerous references are made in this report to ground-water types, such as sodium bicarbonate type or calcium bicarbonate type. These types are derived from inspection of the analyses and represent the predominant cation (sodium, calcium, or magnesium) and anion (bicarbonate, sulfate, or chloride), expressed in milliequivalents per liter (Hem, 1959).

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 description
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

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

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

Constituents	Major source	Effects upon usability	U.S. Public Health Service (1962) recommended limits for drinking water.
Silica (SiO_2)	Feldspars, ferromagnesian and clay minerals.	In presence of calcium and magnesium, silica forms a scale in boilers and on steam turbines that retards heat transfer.	
Iron (Fe)	Natural sources: amphiboles, ferromagnesian minerals, ferrous and ferric sulfides, oxides, carbonates, and clay minerals. Manmade sources: well casings, pumps, and storage tanks.	If more than 100 ug/L[1] iron is present, it will precipitate when exposed to air; causes turbidity, stains plumbing fixtures, laundry, and cooking utensils, and imparts tastes and colors to food and drinks. More than 200 ug/L is objectionable for most industrial uses.	300 ug/L
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
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, calcite, aragonite, limestone, dolomite, and clay minerals.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate, and silica to form scale in heating equipment. Calcium and magnesium retard the suds-forming action of soap and detergent. High concentrations of magnesium have a laxative effect.	
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, magnesite, dolomite, and clay minerals.		
Sodium (Na)	Feldspars, clay minerals, and evaporites.	More than 50 mg/L[2] sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers.	
Potassium (K)	Feldspars, feldspathoids, some micas, and clay minerals.		
Boron (B)	Tourmaline, biotite, and amphiboles.	Essential to plant nutrition. More than 2,000 ug/L may damage some plants.	
Bicarbonate (HCO_3)	Limestone and dolomite.	Upon heating of water to the boiling point, bicarbonate is changed to steam, carbonate, and carbon dioxide. Carbonate combines with alkaline earths (principally calcium and magnesium) to form scale.	
Carbonate (CO_3)			
Sulfate (SO_4)	Gypsum, anhydrite, and oxidation of sulfide minerals.	Combines with calcium to form scale. More than 500 mg/L tastes bitter and may be a laxative.	250 mg/L
Chloride (Cl)	Halite and sylvite.	In excess of 250 mg/L may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 mg/L.	250 mg/L
Fluoride (F)	Amphiboles, apatite, fluorite, and mica.	Optimum concentration in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. Concentrations in excess of optimum may cause mottling of children's teeth.	Recommended limits depend on annual average of maximum daily air temperatures. Limits range from 0.6 mg/L at 32°C to 1.7 mg/L at 10°C.[3]
Nitrate (NO_3)	Organic matter, fertilizers, and sewage.	More than 100 mg/L may cause a bitter taste and may cause physiological distress. Concentrations in excess of 45 mg/L have been reported to cause methemoglobinemia in infants.	45 mg/L
Dissolved solids	Anything that is soluble.	More than 500 mg/L is not desirable if better water is available. Less than 300 mg/L is desirable for some manufacturing processes.	500 mg/L

[1] Micrograms per liter.
[2] Milligrams per liter.
[3] Based on a 40-year record, the average maximum daily air temperature at Bismarck, Burleigh County, is 11.5°C (U.S. Environmental Service, oral commun., 1974).

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 the 16 classifications shown in figure 3. For further information the reader is referred to "Diagnosis and Improvement of Saline and Alkali Soils" (U.S. Salinity Laboratory Staff, 1954).

Aquifer Properties

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

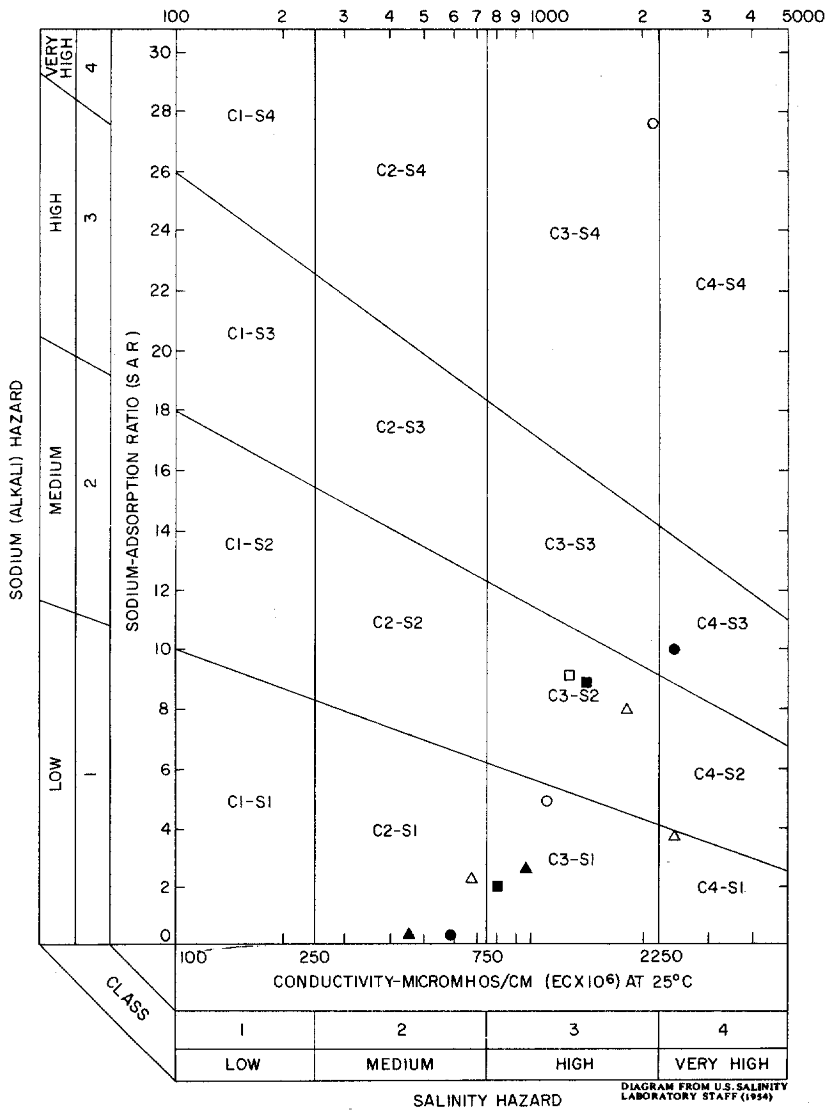
Hydraulic conductivities of materials in the glacial-drift aquifers were estimated from lithologic logs using the following empirical values:

Material	Hydraulic conductivity (ft/d)	Hydraulic conductivity (m/d)
Gravel	330-530	100-160
Sand and gravel	260-330	80-100
Coarse sand	200	60
Medium sand	100	30
Fine sand	50	15
Very fine sand	10	3
Silt	0.6-6	0.2-2

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

Transmissivities of glacial-drift aquifers were estimated by multiplying the hydraulic conductivity by the saturated thickness of each lithologic unit — the total transmissivity is the sum of the transmissivities of the separate units. Generally very fine sand and silt beds were omitted from estimates if they did not contribute more than 5 percent of the total transmissivity.

Estimates of transmissivity of an aquifer also were made from specific-capacity data and from charts devised by Meyer (1963, p. 339) and Theis (1963, p. 334). The charts by Meyer (1963) and Theis (1963), however, were based on a pumping period of 1 day and transmissivities determined by this method or from specific capacities determined from shorter pumping periods, will result in transmissivities that are high. Specific capacities determined from wells that partially penetrate aquifers will result in transmissivities that are low unless data are corrected for partial penetration. Specific capacities of wells that are known to be inefficient should not be used for this purpose as they also will result in low estimates of transmissivity.



EXPLANATION

- ● **STRASBURG AQUIFER**
- ○ **LONG LAKE AQUIFER**
- ▲ **BRADDOCK AQUIFER**
- △ **CAT TAIL AQUIFER**
- ■ **WINONA AQUIFER**
- □ **GLENCO CHANNEL AQUIFER**

FIGURE 3.— Classifications of selected water samples from glacial-drift aquifers for irrigation use.

GEOLOGIC UNITS AND THEIR HYDROLOGIC PROPERTIES

Geologic units that contain aquifers of economic importance in Emmons County are: (1) the Fall River and Lakota Formations[1] of Early Cretaceous age, (2) the Pierre, Fox Hills, and Hell Creek Formations of Late Cretaceous age; and (3) the glacial drift of Quaternary age (table 2).

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

Rocks of pre-Cretaceous age generally are more than 2,550 feet (777 m) below land surface in Emmons County. Electric and sample logs from four oil-test holes indicate that the rocks are composed principally of limestone, sandstone, and shale with lesser amounts of dolostone and evaporites. Some of the limestone is reported to be porous or cavernous and probably would yield large quantities of poor-quality water. The sandstones generally are reported to be very fine, fine, or medium grained and probably would yield small, but dependable, supplies of water. The quality of the water, however, probably would make it unsuitable for most uses.

Ground Water in Rocks of Cretaceous Age

Dakota Aquifer

The Dakota aquifer underlies all of Emmons County. It consists of the Lakota and Fall River Formations, which are composed of fine- to coarse-grained sandstone interbedded with siltstone and shale. The Newcastle Formation, which is part of the Dakota aquifer in the eastern part of the State, contains very fine grained sandstone that probably would yield some water. However, the Newcastle Formation will not be an important source of water and is not considered as part of the Dakota aquifer in Emmons County because of low yields and the difficulties that would be encountered in developing wells in the very fine grained sandstone.

Section A-A′ (pl. 1, in pocket) shows the Dakota aquifer in relation to the overlying formations. Locally in Emmons County, principally in the southeastern part, where the Fox Hills and(or) the glacial-drift aquifers are thin or missing, the Dakota is the shallowest aquifer that will yield significant quantities of water to wells.

The top of the Dakota aquifer in the county ranges in depth from 2,200 to 2,530 feet (670 to 770 m) below lsd (land surface datum). The aquifer ranges from about 60 to 175 feet (18 to 53 m) in thickness with a mean of about 125 feet (38 m). It generally increases in thickness toward the east. The aquifer dips in a northwesterly direction at about 20 ft/mi (4 m/km).

The transmissivity of the Dakota aquifer apparently increases toward the southeast, because of the increase in aquifer thickness or an increase in the average hydraulic conductivity. Using a method described by Croft (1971, p. B265-B269), the mean hydraulic conductivities were calculated from electric

TABLE 2. — Generalized stratigraphy and water-yielding characteristics of geologic units in Emmons County

System	Formation	Dominant lithology	Maximum thickness (feet)	Water-yielding characteristics
Quaternary	Glacial drift	Clay, silt, sand, and gravel.	536	Yields as much as 1,000 gal/min from thicker and more permeable sand and gravel deposits.
Late Cretaceous	Hell Creek Formation	Siltstone, claystone, and sandstone.	250	Yields as much as 4 gal/min from basal sandstone.
	Fox Hills Formation	Shale, siltstone, and sandstone.	232+	Yields as much as 100 gal/min from thicker and more permeable sandstone beds.
	Pierre Formation	Shale.	1,100	Yields about 1 gal/min from fractures. Low hydraulic conductivity except where fractured.
	Niobrara Formation	Calcareous shale.	270	Very low hydraulic conductivity except for sandstone units, which may yield small quantities of water.
	Carlile Formation	Shale.	360	
	Greenhorn Formation	Calcareous shale.	195	
	Belle Fourche Formation	Shale.	290	
Early Cretaceous	Mowry Formation	Shale.	75	
	Newcastle Formation	Shale and sandstone.	105	
	Skull Creek Formation	Sandy shale.	140	
	Fall River Formation, Lakota Formation (Dakota aquifer)	Sandstone, shale, and siltstone.	175	Yields from 500 to 1,500 gal/min from thicker and more permeable sandstone units.

logs at three oil-test sites; the conductivities ranged from 80 to 130 ft/d (24 to 40 m/d). Estimated transmissivities for these sites ranged from about 7,500 to 21,000 ft^2/d (700 to 1,950 m^2/d). Therefore, the 24-hour specific capacities of properly constructed wells should range from about 25 to 75 (gal/min)/ft [5.2 to 16 (L/s)/m] of drawdown.

Yields of 500 to 1,500 gal/min (32 to 95 L/s) with about 20 feet (6 m) of drawdown should be obtainable from wells in the Dakota aquifer. Such wells would have to be constructed of at least 10-inch-diameter pipe and screened through the entire aquifer thickness to reduce head and friction losses. Large withdrawals of water over a long period would result in a decline of head.

Eighteen flowing wells were producing water from the Dakota aquifer in 1973. These wells were completed with 2-inch (51-mm) steel pipe perforated from near the top of the aquifer to near the bottom. The wells flowed at rates ranging from 30 to 60 gal/min (2 to 4 L/s) when they were initially developed; however, to conserve water, present flows are restricted to only a few gallons per minute. Estimates indicate that Dakota wells will flow at land-surface altitudes of less than 2,100 feet (640 m).

Recharge to the Dakota aquifer apparently occurs in the Black Hills area of South Dakota (Darton, 1909) and by upward migration of water from underlying aquifers (Swenson, 1968). The only known discharge from the Dakota aquifer is from wells. However, there probably is considerable lateral discharge of water from Emmons County eastward into Logan and McIntosh Counties.

Water from the Dakota aquifer in Emmons County generally is a sodium sulfate type. Dissolved solids in 16 samples ranged from 2,220 to 2,640 mg/L, with a mean of about 2,400 mg/L. Sodium ranged from 343 to 852 mg/L with a mean of 640 mg/L and sulfate ranged from 1,140 to 1,440 mg/L with a mean of about 1,300 mg/L. Only two samples had less than 70 percent sodium. Hardness ranged from 19 to 862 mg/L with a mean of 260 mg/L. Iron ranged from undetectable to 4,700 ug/L. The large variation in the quantity of iron in the samples probably was due to variations in dissolved iron in the formation, but some may have been due to electrolytic and chemical reactions of the water with the steel pipe in the wells. Sampling techniques also may have caused some of the variation.

The samples had SAR values that ranged from 5.0 to 74 and irrigation classifications that ranged from C4-S2 to C4-S4.

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.

Pierre Aquifer

The Pierre Formation underlies all of Emmons County, and crops out in low areas in the southwestern part of the county and along Beaver Creek. It consists of 1,000 to 1,100 feet (300 to 340 m) of dark-gray to black siliceous shale, siltstone, and a few thin layers of yellowish-white to white bentonite. In most places the formation is practically impermeable and will not yield sufficient water for even a small domestic supply. Locally, however, small quantities of water are available from fracture zones in the upper few feet of the formation. The fracture zones constitute the Pierre aquifer in Emmons County.

Well 130-075-07AAB is reported to be completed in shale, probably the Pierre aquifer, at a depth of 180 feet (55 m). The well is pumped at rates of between 1.5 and 2 gal/min (0.09 to 0.1 L/s) and is reported to go dry within an hour or two; however, it recovers and can be pumped again after about half an hour. It is possible that small supplies of water could be obtained from fracture zones in the Pierre Formation elsewhere in the county, but yields of more than 1 gal/min (0.06 L/s) should not be expected.

The sample of water from well 130-075-07AAB was soft and of a sodium bicarbonate-sulfate type containing 1,750 mg/L dissolved solids. The only ion present in excessive concentrations was sulfate at 611 mg/L. The water had a SAR value of 38, a specific conductance of 2,630 umho/cm (micromhos per centimeter at 25°C), and an irrigation classification of C4-S4.

Fox Hills Aquifer

The Fox Hills Formation overlies the Pierre Formation in most of Emmons County, but locally it is missing in the southern part of the county. It crops out or underlies either the Hell Creek Formation or the glacial drift. Fischer (1952) has divided the Fox Hills Formation in Emmons County into four members. The members are, in ascending order: Trail City, Timber Lake, Bullhead, and Colgate. Plate 1 (sec. B-B′) shows the relationships of the various Fox Hills members north of Temvik.

The Trail City Member is composed predominantly of shale; the Timber Lake Member is composed of very fine to fine-grained sandstone with some interstitial clay or silt; the Bullhead Member is composed of siltstone and shale; and the Colgate Member generally is composed of fine-grained sandstone with some interstitial silt or clay. Locally the Colgate sandstone is fractured.

The Timber Lake and Colgate Members form the Fox Hills aquifer. Generally the Bullhead Member separates the aquifer into an upper (Colgate Member) and lower (Timber Lake Member) zone.

The Fox Hills aquifer underlies about 80 percent of the county, and provides water to about 75 percent of the wells. It is thin or missing southeast of Strasburg, in the Strasburg buried-valley system, and in the valleys of Beaver, lower Cat Tail, and Badger Creeks. South of Beaver Creek the aquifer generally is only a few feet thick; the lower zone is the only part of the aquifer that yields water to wells because the upper zone, where present, is unsaturated. North of Beaver Creek the combined aquifer thickness is as much as 118 feet (36 m); both zones may be present and both may yield water to wells.

One aquifer test was made in the Fox Hills aquifer using well 135-076-19CCC5. The test well was completed in a 28-foot (8.5-m) sandstone bed overlain, in ascending order, by 12 feet (3.7 m) of sandy siltstone and 45 feet (14 m) of saturated sandstone. The well was pumped at a rate of 7.7 gal/min (0.49 L/s) for 2,000 minutes. Water levels were measured in the test well and five observation wells. The transmissivity and the storage coefficient were calculated to be about 80 ft^2/d (7 m^2/d) and 0.007, respectively. The calculated transmissivity may be slightly high because the test was affected by leakage from the overlying sandy siltstone. The specific capacity after 24 hours was 0.2 (gal/min)/ft [0.04 (L/s)/m] of drawdown.

Based on the aquifer-test data and the lithologic log of test hole 135-076-19CCC1, the transmissivity of both sandstone beds at the site of the aquifer test is estimated to be about 300 ft^2/d (28 m^2/d). The specific capacity of a well completed in both sandstone beds at the site should be nearly 1.6 (gal/min)/ft [0.33 (L/s)/m] of drawdown. If the drawdown is limited to 25 feet (7.6 m), the yield at the end of 1 day would be about 40 gal/min (2.5 L/s).

Transmissivities generally should range from 20 to 300 ft^2/d (2 to 28 m^2/d), assuming mean hydraulic conductivities of 7 ft/d (2 m/d). At some localities, such as at 136-077-16ADD, where there is as much as 85 feet (26 m) of fine- to medium-grained sandstone, the transmissivity could be as high as 900 ft^2/d (80 m^2/d). Specific capacities of wells should range from 0.07 to 1.6 (gal/min)/ft [0.01 to 0.33 (L/s)/m] of drawdown, but could be as high as 3.4 (gal/min)/ft [0.7 (L/s)/m] of drawdown.

Yields from the Fox Hills aquifer depend on the thickness, sorting, and grain size of the sandstone beds, and the available drawdown. In localities where the sandstone is fractured, well yields will also depend on the distribution, size, and interconnection of the fractures. Well yields generally range from 0.5 to 40 gal/min (0.03 to 2.5 L/s). Locally, in the northern part of the area, the aquifer could yield as much as 100 gal/min (6 L/s) to wells. However, in areas of low transmissivity, such as near Temvik, well yields of 0.5 to 3 gal/min (0.03 to 0.2 L/s) are all that can be expected.

Recharge to the Fox Hills aquifer generally is from infiltration of precipitation and snowmelt. Thus, water levels respond, with some delay, to precipitation.

Water-level fluctuations generally are very small, but may be as much as a foot after prolonged storms. The 0.91-foot (0.28-m) water-level rise in well 134-078-15DDD in October 1973 (fig. 4) occurred 3 days after a 4-day rainstorm of 1.8 inches (44 mm). Near Lake Oahe, where the aquifer and the lake are hydraulically connected, ground-water levels are affected by and vary with the lake level. The effect of the lake on ground-water levels decreases with increased distance from the lake. Water levels in observation well 136-078-07BDB, which is approximately half a mile (0.8 km) from Lake Oahe fluctuated as much as 6 feet (1.8 m; fig. 5) in 1971-73. The ground-water-level fluctuations correspond to fluctuations of the lake level.

Water levels indicate that the direction of ground-water movement is similar to that of surface water — that is, from the higher elevations toward the low areas in adjacent stream valleys, thence toward Lake Oahe.

Discharge of water from the aquifer generally is by pumpage from wells and by lateral movement into adjacent valley deposits or into Lake Oahe. Locally where water tables are high some water is discharged by evapotranspiration.

The quality of water in the Fox Hills aquifer varies with location. In areas where sandstone outcrops are present and till is absent within a quarter of a mile, the water is either a sodium bicarbonate or calcium bicarbonate type and

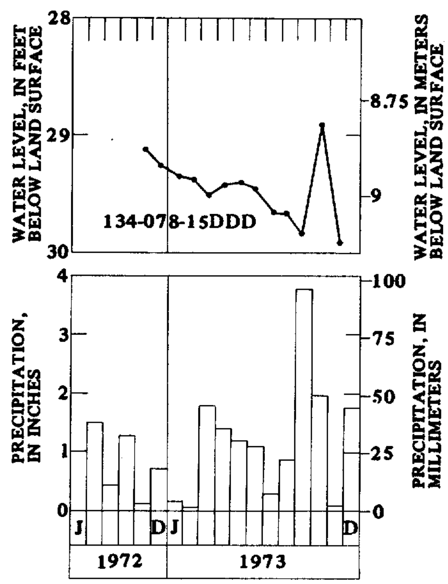


FIGURE 4.— Water-level fluctuations in the Fox Hills aquifer and precipitation at Linton.

dissolved solids generally are less than 1,000 mg/L. Such an area occurs in Tps. 133 and 134 N., Rs. 74 and 75 W. In areas where siltstone, silty shale, or till overlie the aquifer, the water is a sodium bicarbonate type. Dissolved-solids concentrations generally are less than 1,500 mg/L, but locally are as high as 3,660 mg/L.

Water samples were collected from 68 wells in the Fox Hills aquifer. Dissolved solids ranged from 183 mg/L to 3,660 mg/L with a mean of about 1,000 mg/L. Sulfate ranged from 0.8 to 2,140 mg/L with a mean of 318 mg/L. Sulfate exceeded 250 mg/L in samples from 35 wells. Percent sodium ranged from 2 to 98 with a mean of 64. Locally iron and manganese were excessive.

SAR values ranged from 0.1 to 59 with a mean of 13.6. Irrigation classifications were C2-S1 and C3-S1 to C4-S4, with some of the samples having sodium or salinity hazards too high to be classified.

Hell Creek Aquifer

The Hell Creek Formation overlies the Fox Hills Formation in much of the northern part of Emmons County. The formation crops out in much of its area of occurrence. It consists of as much as 250 feet (76 m) of siltstone, claystone, and sandstone in some of the higher hills, but in most places is much thinner.

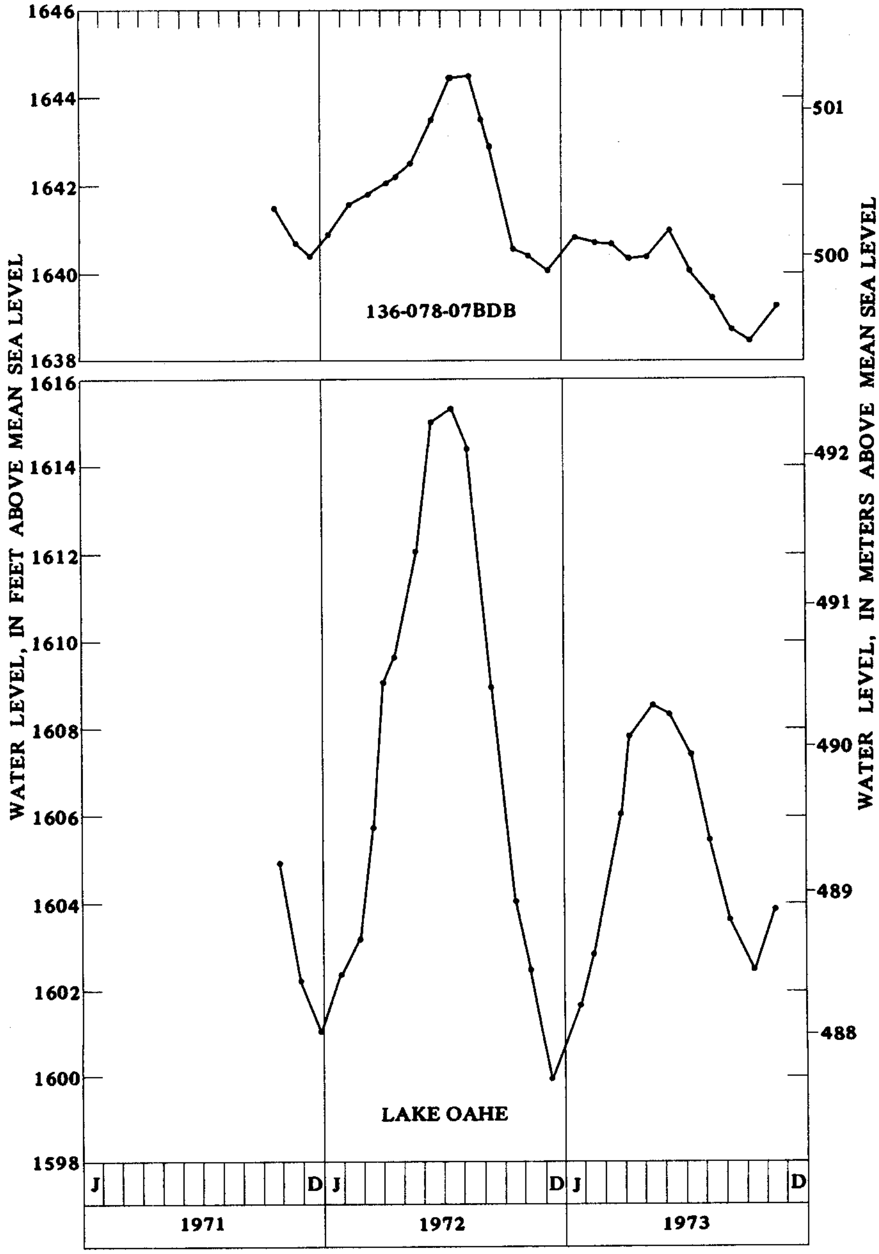


FIGURE 5.— Water-level fluctuations in the Fox Hills aquifer and Lake Oahe.

Generally the formation is unsaturated, but locally saturated sandstone lenses form an aquifer in the lower part of the formation. This aquifer yields water to small springs that discharge on the lower slopes of the broader hills and in small ravines. Most of the springs are seasonal, but a few are perennial. Only a few springs were visited during this investigation and only one was recorded. This spring, at 136-077-10DCD1, generally flows from 3 to 4 gal/min (0.2 to 0.3 L/s), but is reported to flow at somewhat higher rates after about a year of above-average precipitation.

A sample of water from the spring was a sodium bicarbonate type with 623 mg/L of dissolved solids. Manganese at 150 ug/L was the only constituent that exceeded the recommended limit. The water had a SAR value of 5.7 and an irrigation classification of C3-S2.

Ground Water in Glacial Drift

Glacial drift occurs in ancient valleys and on some of the uplands in Emmons County. The thickest deposits of glacial drift generally are in the ancient valleys, which are now either buried or partly filled. The deposits in the valleys are as much as 536 feet (163 m) thick. The thickest and most extensive deposits of glacial drift on the uplands are located in the northeastern and southern parts of the county, where the drift may be as much as 200 feet (60 m) thick. Elsewhere, deposits of glacial drift 1 to 20 feet (0.3 to 6 m) thick mantle many of the hills and buttes.

Aquifers in the glacial drift occur in (1) buried-valley deposits, (2) undifferentiated glacial drift, and (3) outwash deposits. The individual aquifers are named after nearby cities, streams, and topographic features. The aquifers are discussed by type of deposit, and from most productive to least productive. The glacial-drift aquifers with the greatest potential for large-scale ground-water development are the Strasburg, Long Lake, Braddock, and Winona (pl. 2, in pocket). Those with lesser potential for development are the Glenco Channel, Cat Tail, undifferentiated glacial-drift, and outwash aquifers.

Estimates of ground-water storage are given for localities where sufficient test-drilling and hydrologic data are available. The estimates, in acre-feet, are the volume of ground water available from storage. Ground-water storage is the product of the area, the average saturated thickness, and the specific yield of the aquifer — which is assumed to be about 20 percent. The storage estimates are provided for comparison purposes only and are based on static conditions. They do not take into account recharge, natural discharge, or ground-water movement between adjacent aquifers. The quantitative evaluation of these factors is beyond the scope of the present study.

The potential well yields of the aquifers are shown on the ground-water availability map (pl. 2). The aquifers generally are lenticular in cross section, and the largest yields are obtainable from the thickest sections. The variations in thickness and materials are gradational, and the boundaries between each of the different yield areas are approximate. Wells penetrating aquifers in narrow valleys have lower maximum sustained yields than wells tapping glacial aquifers of comparable thickness but having larger areal extent.

The ground-water availability map (pl. 2) should be used with the understanding that the estimated yields are for fully penetrating, properly screened and developed wells of adequate diameter. The map is intended to be used only as a general guide to exploration and development of ground water, and not for location of specific wells. Few, if any, aquifers are so uniform in extent and physical properties that production wells may be drilled in them without preliminary test drilling.

Aquifers in Buried-Valley Deposits

Strasburg aquifer

The Strasburg aquifer includes all of the sediments that were deposited in the ancient Strasburg valley and its tributaries. The valley extends from the mouth of Horsehead Creek southeastward for about 14 miles (22 km), where it is divided by a topographic high near Baumgartner Lake. The two valleys rejoin south of the high and trend southward into Campbell County, S. Dak. The river that formed the valley probably was a tributary to the ancient Grand River (Flint, 1955, p. 148) through the Mound City channel in South Dakota (Hedges, 1972, p. 21). The valley in Emmons County is about 41 miles (66 km) long. It generally ranges in width from 1 to 2 miles (1.6 to 3 km), but near junctions with tributary valleys is considerably wider; the average width is about 2.4 miles (3.9 km).

The lower part of the Strasburg valley, which probably is a few hundred feet wide, consists of a stream channel that is filled with at least 55 feet (17 m) of sand and gravel. The gradient of the stream channel apparently is to the southeast at about 4 to 5 ft/mi (0.8 to 0.9 m/km). The middle part consists predominantly of silt and silty clay, but some sand was encountered in nearly every test hole. South of Beaver Creek the upper part is composed of till overlain by outwash; north of Beaver Creek it is composed of alternating lenses of sand, silt, and clay.

Sediments in the tributary valleys on the west side of the Strasburg valley were derived from the Pierre, Fox Hills, and Hell Creek Formations. The deposits in these valleys, therefore, are composed predominantly of silt and clay, but some sand is present in scattered beds or lenses along the sides of the valleys. Only two large tributary valleys were located on the east side of the Strasburg valley. They are filled with reworked till, clay, silt, sand, and gravel derived from the glacial drift.

The Strasburg aquifer underlies an area of about 98 mi^2 (250 km^2) in Emmons County. It is divided into three — lower, middle, and upper — sand and gravel zones, which are separated by till, silt, and clay. Locally the middle zone is subdivided into as many as five separate deposits, but as some of these deposits are known to coalesce, all have been designated as part of the middle zone (fig. 6). The three zones appear to be separate aquifers; however, heavy pumpage may show that the middle and lower zones are hydraulically connected.

The thickness of the sand and gravel in the aquifer varies considerably. It ranges from near 0 feet at the edges of the aquifer to as much as 275 feet (83.8 m) in the thickest part. Available data indicate that the mean thickness of the aquifer is about 60 feet (18 m).

Test holes drilled into the central part and western side of the aquifer northwest of Strasburg (fig. 7) generally penetrated thicker and more numerous sand and gravel lenses than those drilled in the eastern side. A few farmers have reported drilling "dry holes" near the northeastern side of the aquifer about 2 to 4 miles (3 to 6 km) southeast of Beaver Creek.

Two aquifer tests were made near Hull to determine the aquifer coefficients and to help determine the yield estimates shown on plate 2. The first test was made on the upper zone at well 130-075-31BAA7. The test well was completed with 6-inch (152-mm) diameter 0.025-inch (0.635-mm) slot screen set from 20 to 30 feet (6 to 9 m). The well was pumped at a rate of 70.5 gal/min (4.4 L/s) for 75 hours. Water levels were measured in the test well and in three observation wells. Data from this test indicate the specific capacity of the test well is 8.7 (gal/min)/ft [1.8 (L/s)/m] of drawdown, the aquifer transmissivity is about 4,000 ft^2/d (400 m^2/d), and the average hydraulic conductivity is 400 ft/d (100 m/d). The storage coefficient is 0.001 — indicating leaky artesian conditions. The data also indicate a boundary of low permeability at a distance of about 2,000 feet (600 m). The leakage, however, counteracted and delayed some of the hydraulic effect of the boundary, so the actual distance probably is somewhat less.

The second test was made in sand lenses in the upper part of the middle zone at the same site as the first test. The test well, 130-075-31BAA5, was completed with 10 feet (3 m) of 8-inch (203-mm) diameter 0.016-inch (0.41-mm) slot screen set from 127 to 137 feet (39 to 42 m) and 40 feet (12 m) of 6-inch (152-mm) diameter 0.012-inch (0.30-mm) slot screen set from 139 to 179 feet (42 to 55 m). The test well was pumped at a rate of 86 gal/min (5.4 L/s) for a period of 3,000 minutes. Recovery was observed for a similar period. Water levels were measured in the test well and in nine observation wells. The cone of depression in the aquifer extended for at least a mile (1.6 km) south of the test well. No water-level fluctuations were noted in observation wells completed in the upper zone or in sand lenses below a depth of 200 feet (61 m) in the middle zone. Data from the observation wells indicate that the transmissivity of the upper sand lenses in the middle zone generally is about 5,500 ft^2/d (510 m^2/d) and the storage coefficient is about 0.0005. The transmissivity determined at the test well, however, is only about 2,400 ft^2/d (220 m^2/d). The difference probably is due to the generally finer grain size of the aquifer materials at the test-well site. The transmissivity values obtained from the aquifer test agree with those based on thickness and values of hydraulic conductivity estimated

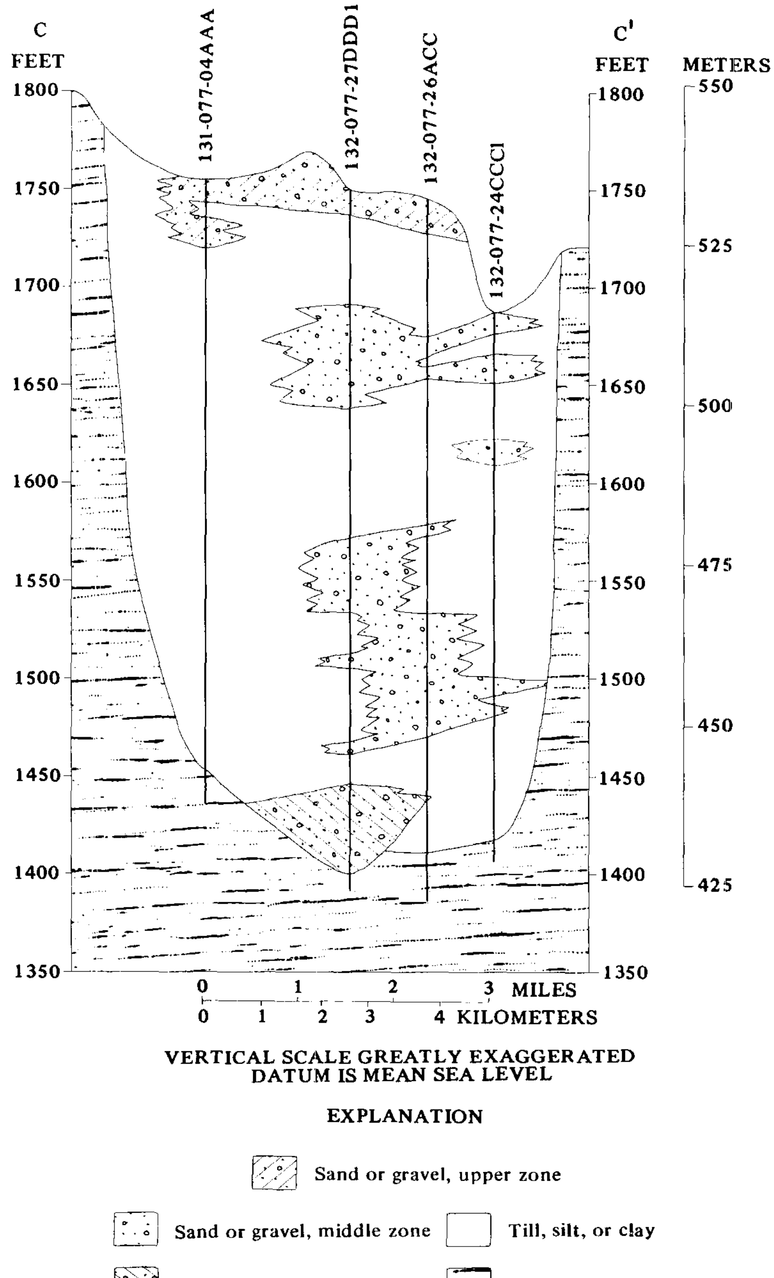


FIGURE 6.— Geohydrologic section C-C′ through the Strasburg aquifer.

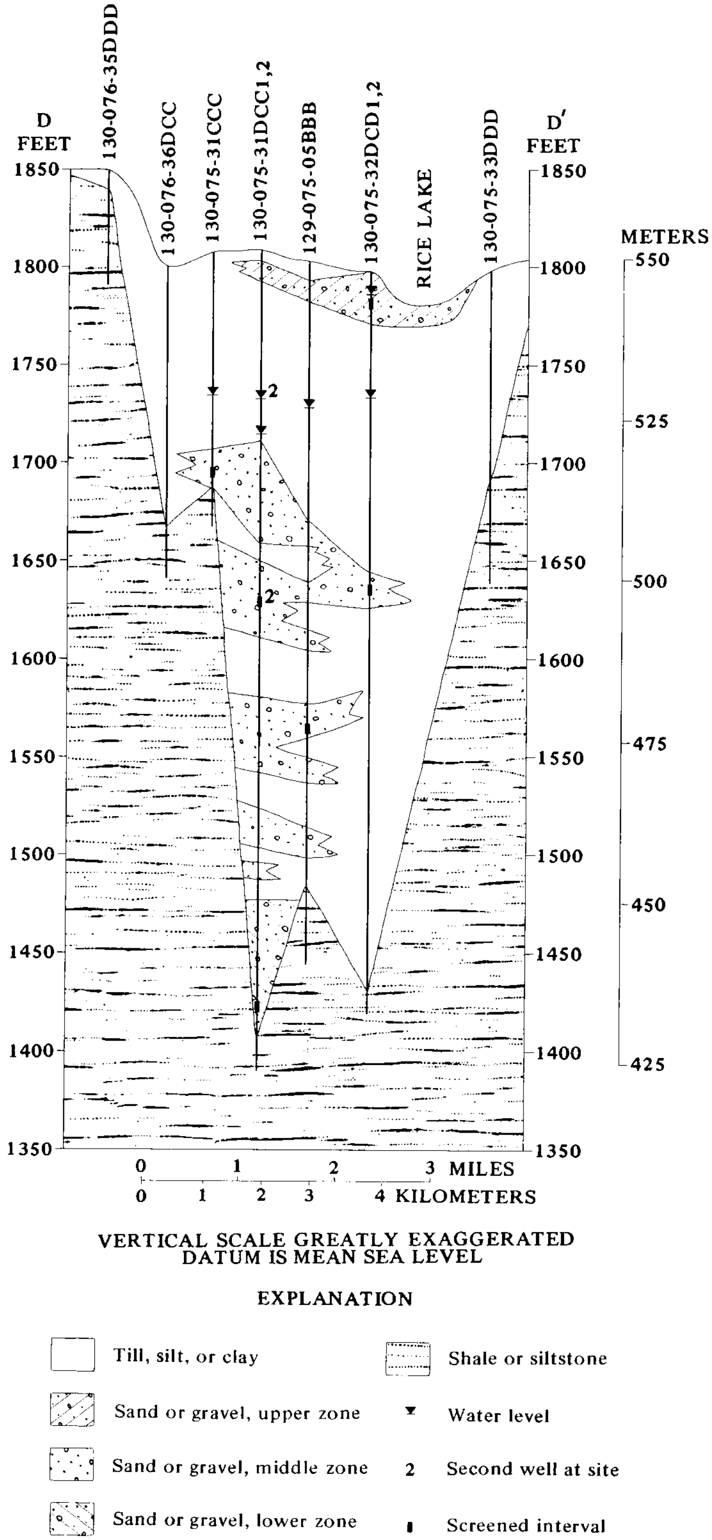


FIGURE 7.— Geohydrologic section D-D′ through the Strasburg aquifer.

from grain sizes shown in well logs. The specific capacity of the test well, which was 2.3 gal/min (0.15 L/s) per foot of drawdown, was not used to estimate transmissivity because the well was only about 25 percent efficient.

Yields from the thicker part of the lower zone of the Strasburg aquifer should range from 500 to 1,000 gal/min (32 to 63 L/s). Rates higher than 1,000 gal/min (63 L/s) probably could be obtained locally, but they could not be maintained for more than a few weeks because of the effects of nearby low-permeability boundaries.

Yields from the middle zone of the Strasburg aquifer will vary considerably within short distances because of abrupt changes in lithology and thickness. For example, the yield at test well 130-075-31BAA5 was 86 gal/min (5.4 L/s) with 37 feet (11 m) of drawdown; the yield at test hole 130-075-31BAA3, 100 feet (30 m) northeast, would be about 300 gal/min (20 L/s) with about 30 feet (9 m) of drawdown. One mile (1.6 km) south, at 130-075-31DCC1, the aquifer materials are much coarser and thicker and yields of about 600 gal/min (40 L/s) should be possible. At sites where more than one sand lens is present, larger yields could be obtained by screening wells in each lens. In localities where the middle zone is composed of very fine silty or clayey sand the yields would be low.

Yields from the upper zone generally will be less than 100 gal/min (6 L/s) because of the small amount of available drawdown. Larger yields probably would cause water levels to drop below the tops of well screens.

Yield from a well finished in all three zones of the Strasburg aquifer probably would not exceed about 1,000 gal/min (63 L/s). This amount is less than the combined maximum yield from each of the zones because the areas suitable for optimum development for each zone do not coincide.

Recharge to the Strasburg aquifer is principally from precipitation and surface runoff that infiltrates into the aquifer. Some recharge is from the Fox Hills aquifer in the area north of Beaver Creek. Water levels are higher and fluctuations greater in the shallow parts of the aquifer than they are in the deep parts (fig. 8), indicating that ground water moves downward as well as laterally in the Strasburg aquifer.

Most of the discharge from the Strasburg aquifer is by wells and evapotranspiration. Water-level gradients indicate there also is some discharge into Lake Oahe and Beaver Creek in the northern part of the aquifer, and percolation into Rice Lake and South Dakota in the southern part. The ground-water divide, although not located precisely, is in the vicinity of Baumgartner Lake.

Analyses of water from wells in the Strasburg aquifer indicate that the water quality differs both areally and vertically. The areal differences probably are associated with the types of material near the edges of the aquifer and in the formations adjacent to the aquifer. Generally the water is very hard and is a calcium bicarbonate type; however, in the northern part of the aquifer and in other areas where the aquifer is bounded by the Fox Hills aquifer, the water generally is a sodium bicarbonate type. Sulfate concentrations are higher in

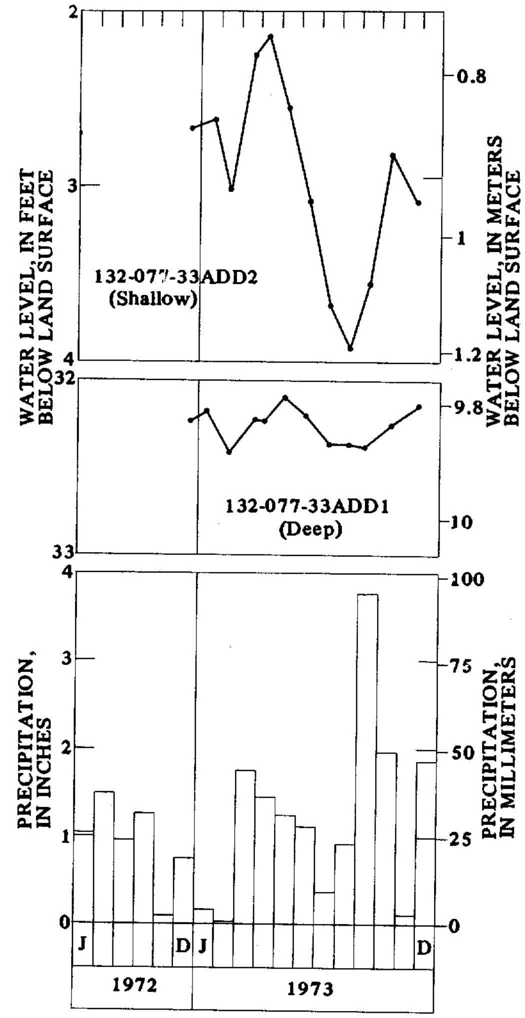


FIGURE 8.— Water-level fluctuations in the Strasburg aquifer and precipitation at Linton.

wells completed near the contact with the Pierre Formation, or in localities where the aquifer contains large quantities of shale grains and pebbles derived from the Pierre Formation.

Water samples were collected from 56 wells completed in the Strasburg aquifer. Dissolved solids ranged from 362 mg/L to 1,720 mg/L with a mean of about 1,030 mg/L. Sulfate ranged from 21 to 890 mg/L, but only 17 of the 56 samples contained sulfate in excess of 250 mg/L. Iron and manganese generally exceeded the recommended limits of 300 and 50 ug/L, respectively.

The SAR values ranged from 0.2 to 15 with a mean of 4.0. The higher SAR values were from wells with sodium bicarbonate type water. The specific conductance ranged from 597 to 2,470 umho/cm with a mean of 1,550 umho/cm. Irrigation indices ranged from C2-S1 to C4-S3 (fig. 3), but the indices of most water samples were either C3-S1 or C3-S2.

Based on an areal extent of about 98 mi^2 (250 km^2), a mean thickness of 60 feet (18 m), and a specific yield of 20 percent, about 750,000 acre-feet (920 hm^3) of the water stored in the Strasburg aquifer is available to wells.

Long Lake Aquifer

The Long Lake aquifer occurs in an ancient southwest-trending valley in northern Emmons County (pl. 2). The valley extends from Long Lake in Burleigh County (Randich, 1966, p. 45) to the mouth of Badger Creek — a distance of about 19 miles (31 km). The drift in the valley is as much as 295 feet (90 m) thick, and at the top varies in width from about 0.2 to 0.35 mile (0.3 to 0.56 km).

The Long Lake aquifer underlies an area of about 4 mi^2 (10 km^2). It is composed of lenses of sand and fine gravel interbedded with silt and clay. The thicker lenses of sand and gravel occur in the deeper, narrower part of the aquifer. Sand and gravel thicknesses in seven test holes ranged from 11 to 167 feet (3.4 to 50.9 m) with a mean of 68 feet (21 m).

Test holes drilled into the aquifer northeast of well 135-078-11CCD generally penetrated thicker, coarser, and better sorted material with less silt and clay than those drilled to the southwest. An exception to this is near the aquifer's junction with Lake Oahe where the materials are coarse and little clay is present.

One large-capacity well, 136-077-29BBB1, taps the Long Lake aquifer. In 1964, M. O. Lindvig of the North Dakota State Water Commission (written commun., 1964) used the well and two nearby observation wells for an aquifer test. The test well was pumped for 40 hours at a rate of 1,080 gal/min (68 L/s).

Analysis of the test using the Theis (1935) formula indicated an aquifer transmissivity of about 8,700 ft^2/d (810 m^2/d) and a storage coefficient of about 0.0002. Specific capacity of the test well after 24 hours was 18 (gal/min)/ft [3.7 (L/s)/m] of drawdown, indicating a transmissivity of about 6,000 ft^2/d (560 m^2/d). The low transmissivity indicated by the specific capacity of the well is the result of nearby impermeable boundaries — the valley walls. The quality of the data was not good enough to determine the exact distance from the test well to the valley walls but one impermeable boundary appears to be about 400 feet (120 m) northwest of the test well and the other somewhat less than 400 feet (120 m) in an easterly direction.

Well yields generally should be greatest in the northeastern and the extreme southwestern parts of the aquifer, where yields ranging from 500 to 1,000 gal/min (32 to 63 L/s) should be obtainable (pl. 2). Yields greater than 1,000 gal/min (63 L/s) could be obtained locally, but probably could not be maintained for a long period because the aquifer is narrow. Yields of 200 to 500 gal/min (13 to 32 L/s) should be available elsewhere in the aquifer.

Recharge to the Long Lake aquifer is from direct infiltration of precipitation and lateral movement of water from the Fox Hills aquifer. The hydrograph of observation well 136-077-29BBB2 (fig. 9) generally shows a rapid seasonal rise following spring thaws and a long-term rising trend. Above-normal precipitation between 1965 and 1971 increased the storage in the Long Lake and Fox Hills aquifers and the result was a gradual regional rise in the water table.

A ground-water divide occurs in the Long Lake aquifer between observation wells 136-076-07CBC and 136-077-16AAD. The crest of the divide probably is about three-fourths of a mile (1.2 km) west of U.S. Highway 83. The ground water moves northeastward and southwestward from the crest.

Discharge from the aquifer southwest of the divide is by wells, evapotranspiration, seepage to Badger Creek, underflow down Badger Creek valley, and infiltration directly to Lake Oahe. Discharge from wells was about 63 acre-feet (78,000 m^3) in 1972 and about 77 acre-feet (95,000 m^3) in 1973. Low-flow measurements made on Badger Creek indicate that an average of about 270 acre-feet of water per year (330,000 m^3/yr) is discharged from the aquifer into Badger Creek. Discharge by evapotranspiration and underflow could not be measured. Discharge from the aquifer northeast of the divide is principally by underflow to Burleigh County.

The slope of the potentiometric surface from the divide southwest to observation well 135-078-14CDC is between 5 and 8 ft/mi (0.9 and 1.5 m/km). From this observation well to Lake Oahe the slope is about 15 ft/mi (3 m/km). Northeast of the divide the slope of the potentiometric surface is about 5 ft/mi (0.9 m/km) toward the northeast. The slope was determined from water-level measurements in observation well 136-076-07CBC and measurements made in Burleigh County (Randich, 1966, p. 45).

Water in the Long Lake aquifer generally is very hard and of a sodium bicarbonate type. Water samples were collected from six wells tapping the aquifer. Dissolved solids ranged from 702 mg/L to 1,260 mg/L with a mean of 987 mg/L. Sulfate ranged from 136 to 383 mg/L with a mean of 220 mg/L — one sample had more than 250 mg/L of sulfate. Iron and manganese commonly exceeded the recommended limits of 300 and 50 ug/L, respectively. The SAR values ranged from 4.7 to 28 with a mean value of 12; the lower SAR values occurred within a few miles of the ground-water divide. The specific conductance ranged from 1,110 to 2,020 umho/cm and the irrigation classifications ranged from C3-S1 to C3-S4.

About 35,000 acre-feet (43 hm^3) of the water stored in the Long Lake aquifer in Emmons County is available to wells — based on an area of 4 mi^2 (10 km^2), a mean thickness of 68 feet (21 m), and a specific yield of 20 percent. If the potentiometric surface of the Long Lake aquifer is lowered, some recharge probably will be induced from the Fox Hills aquifer.

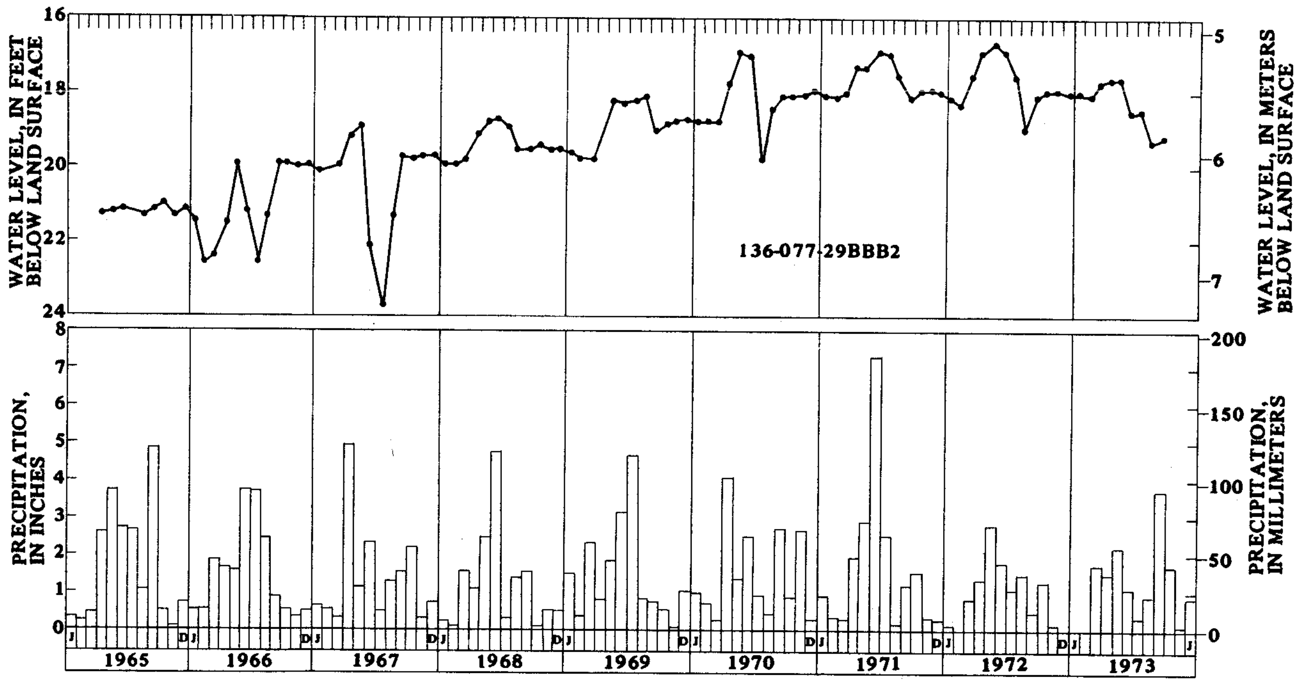


FIGURE 9.— Water-level fluctuations in the Long Lake aquifer and precipitation at Linton.

Braddock aquifer

The Braddock aquifer was deposited in a small glacial lake basin and in valleys tributary to the glacial lake. The principal tributary valley, which underlies the southeast reach of Long Lake Creek, is as much as a quarter of a mile (0.4 km) wide and contains as much as 109 feet (33 m) of drift. Other tributary valleys generally are narrower and shallower. No deep outlet from the lake was found; however, during the last stages of the lake's existence the overflow probably was to Long Lake Creek.

The Braddock aquifer underlies about 10 mi^2 (26 km^2). It extends from near land surface to a depth of as much as 110 feet (34 m) and is composed of sand and gravel interbedded with lenses of silt, clay, and till. The sand and gravel ranges in thickness from 9 to 81 feet (3 to 25 m) with a mean thickness of 36 feet (11 m). Locally the aquifer is separated into two parts by silt and till. The lower part generally contains the coarsest sand and gravel.

As no large-capacity wells and only a few domestic and stock wells have been drilled in the Braddock aquifer, yields can be estimated only from lithologic data from test holes. Test hole 135-074-20BAA penetrated 81 feet (25 m) of aquifer material ranging in size from very fine sand to gravel. The transmissivity of the aquifer at this test hole is estimated to be about 7,000 ft^2/d (650 m^2/d); thus, a properly constructed well would have a specific capacity of about 25 (gal/min)/ft [5.2 (L/s)/m] of drawdown and an initial yield of about 750 gal/min (47 L/s) with about 30 feet (9 m) of drawdown. Such a yield probably could not be sustained , however, because of the narrowness of the aquifer. At test hole 135-075-22ABB the aquifer materials are thin and fine grained and only about 100 gal/min (6 L/s) could be obtained. The aquifer probably will yield less than 200 gal/min (13 L/s) in most places.

Recharge to the Braddock aquifer is from precipitation, runoff, lateral movement of water from the Fox Hills aquifer, and possibly by seepage from Goose Lake. Discharge is by evapotranspiration in areas of high water levels, possibly by seepage into Goose Lake, and by underflow down Long Lake Creek.

Water-level measurements indicate the hydraulic gradient in the aquifer generally ranges from 7 to 11 ft/mi (1 to 2 m/km) from the peripheral areas of the aquifer toward Long Lake Creek.

Water in the Braddock aquifer is hard to very hard. In the southern and eastern parts of the aquifer water is a calcium bicarbonate type; elsewhere the water contains a larger proportion of sodium and locally is a sodium bicarbonate type. Water samples were collected from five wells tapping the Braddock aquifer. Dissolved solids ranged from 269 to 662 mg/L with a mean of 338 mg/L. Sulfate ranged from 19 to 234 mg/L with a mean of 81 mg/L. Iron and manganese commonly exceeded the recommended limits of 300 and 50 ug/L, respectively. The SAR values ranged from 0.2 to 3.0 with a mean value of 1.4. The specific conductance ranged from 483 to 981 umho/cm. The irrigation classification was C2-S1 or C3-S1.

Based on an areal extent of 10 mi^2 (26 km^2), a mean thickness of 36 feet (11 m), and a specific yield of 20 percent, about 46,000 acre-feet (57 hm^3) of the water stored in the Braddock aquifer is available to wells.

Cat Tail aquifer

The Cat Tail aquifer is located in an ancient valley that underlies much of the present Cat Tail Creek and extends about 19 miles (31 km) southeastward from Cat Tail Creek to the South Dakota border. The valley is as much as 0.5 mile (0.8 km) wide and 405 feet (123 m) deep. The floor of the valley slopes about 4 ft/mi (0.8 m/km) toward the southeast. The stream that formed the valley probably was a part of the ancient Grand River system and a tributary to the river that formed the ancient Strasburg valley.

Logs of seven test holes show that the lower part of the valley generally is filled with till but locally contains cemented sandstone, gravel, boulders, and clay deposits overlain by till or silt. The upper part of the valley is composed of silt, silty clay, and thin sand beds. These beds are overlain by till, outwash, and alluvium.

The alluvium generally has not been differentiated from the outwash, but a wood sample from 20 to 30 feet (6 to 9 m) below land surface was radiocarbon dated (U.S. Geological Survey laboratory sample No. W2899) and determined to have been $6{,}850 \pm 250$ years old. Therefore, the upper 20 to 30 feet (6 to 9 m) of sediments probably was deposited after the glaciers had disappeared from the area.

The Cat Tail aquifer is composed of lenses of sand and gravel interbedded with silt and clay. It lies from near the surface to a depth of as much as 196 feet (59.7 m). The thickness of sand and gravel ranges from 0 to 93 feet (0 to 28 m) with a mean of about 40 feet (12 m). The upper part of the aquifer is as much as half a mile wide (0.8 km), but generally is about a quarter of a mile (0.4 km) wide. It underlies about 5 mi^2 (13 km^2). The sand and gravel in the upper part has a mean thickness of 34 feet (10 m) and contains only small quantities of clay. The lower part of the aquifer probably is not more than a few hundred feet wide. This part generally contains considerable clay and may be cemented in places.

In 1973, there were 15 domestic and stock wells producing water from the upper part of the Cat Tail aquifer. Six of the wells flowed. Yields generally were from 2 to 6 gal/min (0.1 to 0.4 L/s), but one well was reported to yield only 0.5 gal/min (0.03 L/s). The lower part of the aquifer probably will not yield more than a few gallons per minute to wells. Properly constructed wells in the thicker, more permeable upper part of the aquifer should have a specific capacity of about 6 (gal/min)/ft [1 (L/s)/m] of drawdown. Therefore, maximum yields with 30 feet (9 m) of drawdown would be about 180 gal/min (11 L/s).

Recharge to the Cat Tail aquifer is from precipitation and lateral migration of water from the Fox Hills aquifer. Discharge is by evapotranspiration, wells, percolation to South Dakota, seepage into Cat Tail Creek, and percolation into the Winona aquifer or Lake Oahe. Discharge measurements indicate that the average base flow in the creek is about 0.8 ft^3/s (23 L/s).

The movement of water within the aquifer generally is northwestward toward Lake Oahe. However, a surface divide and probably a ground-water divide are located in the east half of 129-077-17. Southeast of this divide, ground-water movement is southeastward toward South Dakota, as indicated by reported water levels.

Water levels in the aquifer were measured in two observation wells for 1 year. This period was too short to define any trends, but the measurements indicate that the annual water-level fluctuations are as much as 1.75 feet (0.5 m).

Water samples were collected from three wells in the northwestern part of the aquifer and three wells in the southeastern part. Analyses of these samples indicate there is a considerable difference in water quality. Water in the northwestern part is very hard and of a sodium bicarbonate type. Dissolved solids in the samples were 396, 1,050, and 1,250 mg/L. Sulfate concentrations were 47, 277, and 362 mg/L. Iron and manganese in all the samples exceeded the recommended limits of 300 and 50 ug/L.

Water in the southeastern part of the aquifer also is very hard, but is a sodium sulfate type containing higher concentrations of dissolved solids and sulfate. Dissolved solids in the samples were 1,930, 2,040, and 2,150 mg/L. Sulfate concentrations were 758, 795, and 825 mg/L. The sulfate probably is higher in this part of the aquifer because a large proportion of the drift was derived from the Pierre Formation.

The SAR values ranged from 2.4 to 8.3 with a mean value of 4.5, and the specific conductance ranged from 687 to 2,650 umho/cm. The irrigation classifications of the water in the northwestern part of the aquifer were either C2-S1 or C3-S2, and in the southeastern part the classification was C4-S1.

The upper part of the aquifer covers an area of about 5 mi^2 (13 km^2), has a mean thickness of about 34 feet (10 m), and a specific yield of about 20 percent; thus, the upper part of the aquifer should contain about 22,000 acre-feet (27 hm^3) of water that is available to wells. The quantity of ground water in storage in the lower part of the Cat Tail aquifer cannot be estimated reasonably with available data.

Glenco Channel aquifer

The Glenco Channel aquifer in Emmons County is a small part of a much larger aquifer located principally in Burleigh County (Randich, 1966, p. 51-53). The aquifer underlies about 0.5 mi^2 (1 km^2) in 136-078-06 and 136-079-01 (pl. 2). One test hole in Emmons County showed that the aquifer is present between 100 and 167 feet (30 and 50.9 m) below land surface. It is composed of about 54 feet (16 m) of sand and gravel with about 13 feet (4 m) of interbedded silt and clay.

Randich (1966, fig. 7) showed the aquifer in Burleigh County would generally yield from 250 to 500 gal/min (16 to 32 L/s). Calculations based on the test hole in Emmons County show that the specific capacity of a properly constructed well at the test site should be about 15 (gal/min)/ft [3.1 (L/s)/m] of drawdown; therefore, a yield of about 450 gal/min (28 L/s) with 30 feet (9 m) of drawdown is possible.

Recharge to the aquifer in Emmons County is apparently from direct infiltration of precipitation, surface runoff, and percolation through the aquifer from Burleigh County. Based on Randich's statement (1966, p. 53) that ground-water movement in the Glenco Channel aquifer is to the west and south, discharge from the aquifer is into Lake Oahe.

A water sample was collected from observation well 136-078-06BCB. The water was very hard and of a sodium bicarbonate type. The sample contained 1,240 mg/L dissolved solids and 342 mg/L sulfate. Iron and manganese concentrations greatly exceeded the recommended limits of 300 and 50 ug/L, respectively. The water had a SAR value of 9.3 and an irrigation classification of C3-S2.

Based on an area of 0.5 mi^2 (1 km^2), a mean thickness of about 50 feet (15 m), and a specific yield of 20 percent, there is approximately 3,200 acre-feet (3.9 hm^3) of water available from storage in the Glenco Channel aquifer in Emmons County.

Winona aquifer

The Winona aquifer underlies an area of about 8 mi^2 (21 km) near the mouth of Cat Tail Creek in southwestern Emmons County (pl. 2). The major part of the aquifer is a buried terrace deposit of the Missouri River. The Winona aquifer occurs from 108 to 160 feet (33 to 49 m) below land surface and is overlain by silt and clay. The aquifer generally is composed of sand and gravel but near its eastern edge it includes much clay and silt, both as lenses and interstitially. The aquifer ranges in thickness from 12 to 37 feet (3.7 to 11 m) and has a mean thickness of about 22 feet (6.7 m).

A surficial sand and gravel deposit overlies the principal part of the Winona aquifer near test hole 131-079-28DDD. It occurs from land surface to a depth of 48 feet (15 m). Test drilling and surficial mapping indicate this deposit is somewhat more than a mile (1.6 km) long and about a mile (1.6 km) wide. The hydraulic connection, if any, between the surficial deposit and the Winona aquifer probably is poor.

There are no large-capacity wells in the Winona aquifer, therefore yields can be estimated only from lithologic data. Well yields should range from about 100 to 800 gal/min (6 to 50 L/s) with 30 feet (9 m) of drawdown (pl. 2). The surficial sand and gravel deposit may yield as much as 400 gal/min (25 L/s).

Recharge to the Winona aquifer is from precipitation, Lake Oahe, surface runoff, the Fox Hills aquifer, and the Cat Tail aquifer. When Lake Oahe is high, the lake recharges the aquifer; however, when the lake level is low, the aquifer discharges into the lake.

Water-level fluctuations in observation well 130-079-04BBB correlate closely with the fluctuations in Lake Oahe (fig. 10). Three other observation wells also show this correlation.

Water samples collected from four wells showed some variation in water quality in the aquifer. A water sample collected from well 130-079-03CCC, which apparently receives some recharge from the Cat Tail aquifer, was very hard and of a sodium-calcium bicarbonate type. The sample contained 513 mg/L dissolved solids. Iron and manganese concentrations greatly exceeded the

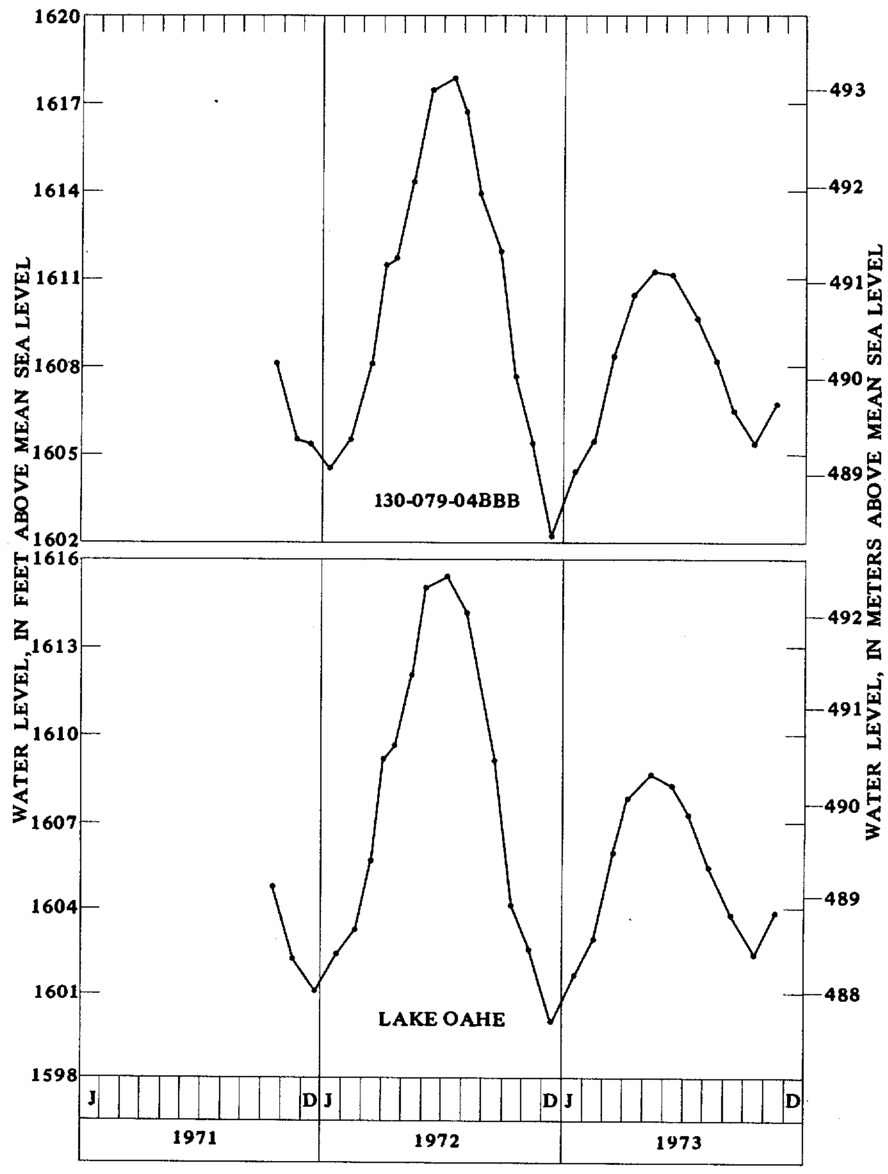


FIGURE 10.—Water-level fluctuations in the Winona aquifer and Lake Oahe.

recommended limits of 300 and 50 ug/L, respectively. Water from the other wells was hard to very hard and of a sodium bicarbonate type. Dissolved solids in the samples were 914, 1,280, and 1,320 mg/L and sulfate concentrations were 183, 379, and 403 mg/L. The iron concentrations exceeded the recommended limit. The SAR values of the four samples ranged from 2.2 to 9.1, and the specific conductance ranged from 848 to 1,940 umho/cm. The irrigation classification was either C3-S1 or C3-S2.

A sample of water collected from a well 45 feet (14 m) deep in the surficial sand and gravel was a sodium bicarbonate type that had 555 mg/L dissolved solids. Iron and manganese greatly exceeded the recommended limits. The SAR value was 3.8 and the irrigation classification was C3-S1.

Based on an areal extent of 8 mi^2 (20 km^2), a mean thickness of about 22 feet (6.7 m), and a specific yield of 20 percent, about 23,000 acre-feet (28 hm^3) of water is available from storage in the Winona aquifer. However, any significant decrease of water in storage, at least in the high-yield area (pl. 2), would soon induce recharge from Lake Oahe. Some recharge also would be induced from the adjacent Fox Hills aquifer.

Aquifers in Undifferentiated Glacial Drift

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

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

Recharge to the undifferentiated glacial-drift aquifers is principally from infiltration of precipitation in areas of sandy soils and surface runoff that accumulates in ponds and sloughs. Although many of the sloughs or ponds contain water for only a few months in the spring, their bottoms are covered by materials having low hydraulic conductivity and the water is available long enough for some to leak through the bottoms and recharge the aquifers. The quantity of recharge from each slough probably is small, but the total recharge from the sloughs is significant and generally is sufficient to replace the water presently being discharged from the aquifers.

Water in the undifferentiated glacial-drift aquifers generally is very hard, but otherwise differs considerably in quality. Water samples were collected from nine wells penetrating undifferentiated glacial-drift aquifers. Water that contained less than 1,000 mg/L dissolved solids was a calcium bicarbonate type. Water that had more than 1,000 mg/L dissolved solids was either a calcium or a sodium sulfate type. Dissolved solids in the nine samples ranged from 373 to 4,780 mg/L with a mean of 2,060 mg/L. Hardness ranged from 242 to 1,900 mg/L with a mean of 770 mg/L. Sulfate ranged from 92 to 2,210 mg/L and exceeded 250 mg/L in seven samples. Iron or manganese concentrations exceeded the recommended limits in six of the nine samples.

The specific conductance ranged from 602 to 5,970 umho/cm; the SAR values ranged from 0.1 to 16 with a mean value of 7.1. The irrigation classification of the best quality water was C2-S1; the poorest quality water exceeded the classification range.

Aquifers in Outwash Deposits

Because the location, the stratigraphic position, and the lithology of the outwash and the alluvial deposits in Emmons County are similar, they are not differentiated in this report. Outwash deposits large enough to be considered hydrologically significant are present only in valleys of present-day streams. They generally are not more than a few hundred feet wide, they are thin in the upper reaches of the valleys, and they gradually thicken downstream. The deposits are composed of gravel, sand, silt, and minor amounts of clay. The saturated thickness of these deposits generally ranges from near 0 to about 50 feet (15 m), but commonly is less than 25 feet (7.6 m).

Wells tapping the outwash deposits commonly yield less than 10 gal/min (0.6 L/s), largely because of their small-capacity pumps; locally, larger yields could be obtained. For example, the city wells at Linton yield as much as 300 gal/min (19 L/s). A properly constructed well at the site of test hole 133-077-15BAA in the valley of Sand Creek probably could yield as much as 450 gal/min (28 L/s). Other favorable outwash deposits probably are present but were not located during this investigaton.

Most of the recharge to the outwash deposits is from surface runoff and precipitation, but some lateral movement of water from the Fox Hills aquifer also occurs.

Water in the outwash aquifers generally is hard to very hard and is of a sodium bicarbonate or sodium-calcium bicarbonate type. In four water samples collected during this investigation dissolved-solids concentrations ranged from 644 to 1,020 mg/L and sulfate from 218 to 346 mg/L. Iron ranged from 220 to 1,600 ug/L and manganese from 10 to 560 ug/L. The specific conductance ranged from 934 to 1,550 umho/cm and the SAR values ranged from 3.5 to 6.2. The irrigation classification was either C3-S1 or C3-S2.

USE OF GROUND WATER

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

Domestic and Livestock Supplies

Most farm units in the area have at least one well for their domestic and livestock supplies, but no records are available to accurately determine the quantity of water used. The following table shows the approximate quantity of water used in 1973.

	Individual requirements (gal/d)	Population	Pumpage (gal/d) (rounded)
Domestic (not including cities having public supplies)	a 60	b 4,343	260,000
Cattle	15	c 73,000	1,100,000
Cows with calves	35	c 6,600	230,000
Hogs	2	c 7,500	15,000
Sheep	1.5	c 1,340	2,000
Poultry	.04	c 27,000	1,000
Total (rounded)			1,600,000

a Average per-person use in cities in Emmons County.
b U.S. Bureau of the Census, 1971.
c North Dakota State University, 1973.

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 Emmons County all depend on ground water for their water supplies. The cities of Hague, Hazelton, Linton, and Strasburg have distribution systems. Citizens in other cities and villages in the county depend on private wells for their supplies.

Hague

The city of Hague obtains its water supply from well 129-074-06BBD finished in the Dakota aquifer. The well reportedly is capable of producing 60 gal/min (4 L/s) or about 86,000 gal/d (330 m^3/d). The mean daily use was reported to be about 18,000 gallons (68 m^3) in 1974. In addition, an estimated 14,000 gallons (53 m^3) per day flows to waste. The water is supplied through a closed distribution system with the pressure maintained in a 2,500-gallon (9.5-m^3) storage tank at about 90 lbs/in^2 (6 kg/cm^2) by the aquifer. A water sample from the municipal supply contained 2,330 mg/L dissolved solids and

1,290 mg/L sulfate — these greatly exceed the recommended limits. The water had a specific conductance of 3,410 umho/cm and a SAR value of 37. The principal use of the water in the city is for sanitation and lawn watering. Some inhabitants drink the water but others haul water of better quality for drinking purposes.

Should the city of Hague desire an alternate water source, an adequate supply of water of much better quality probably could be obtained from Rice Lake about 3 miles (5 km) west of the city or from the Strasburg aquifer about 4 miles (6 km) west of the city.

Hazelton

The city of Hazelton obtains its water supply from two wells (135-076-29BCB and 135-076-30ADA), about 150 feet (46 m) apart, that are finished in the Fox Hills aquifer. Each well reportedly is capable of yielding 40 gal/min (2.5 L/s); their maximum daily yield is about 115,000 gallons (435 m^3). In 1963, the mean use was 25,000 gal/d (95 m^3/d).

A water sample from the municipal supply contained 1,010 mg/L dissolved solids and 42 mg/L hardness. The sulfate concentration was high (309 mg/L) and iron and manganese concentrations were low. The water had a specific conductance of 1,450 umho/cm, a SAR value of 22, and an irrigation classification of C3-S4.

Should the city of Hazelton require more water, more wells could be drilled into the Fox Hills aquifer. However, a new well should be spaced at least several hundred feet from the present wells in order to decrease interference between wells.

Linton

The city of Linton obtains its water supply from three wells finished in outwash deposits. City well 1, 132-076-07DAD, reportedly yields 200 gal/min (13 L/s). City wells 2 and 3, 132-076-08CCB1 and 8CCB2, reportedly yield 300 gal/min (19 L/s) each. These maximum rates cannot be maintained for more than a few hours. The mean daily use by the city is about 120,000 gallons (450 m^3). The maximum daily pumpage in 1974 was about 400,000 gallons (1,500 m^3), but as much as 750,000 gal/d (2,800 m^3/d) could be pumped if necessary.

Water from the city wells is very hard. Manganese, sulfate, and dissolved-solids concentrations generally are slightly higher than the recommended limits. Water from the wells differs somewhat in quality; however, there is sufficient mixing in the lines and storage tanks so that the differences are not noticeable.

Should Linton require more water, the city probably could develop one or two new wells in the outwash deposits in or near the city. However, in times of prolonged or severe drought, water levels in the outwash deposits would decline and Linton could have a water shortage. A more dependable source of water could be developed in the Strasburg aquifer about 3 miles (5 km) south (or southwest) of the city.

Strasburg

The city of Strasburg obtains its water supply from two wells finished in the Strasburg aquifer. The daily capacity of the wells is about 134,000 gallons (507 m^3); only about 9,000 gallons (30 m^3) more than their mean summer use of 125,000 gal/d (473 m^3/d). The mean use during the remainder of the year is about 50,000 gal/d (190 m^3/d).

Water from the city of Strasburg's wells is very hard and is a calcium bicarbonate type. Water samples collected from city wells 131-076-26CBD and 131-076-26CDA had dissolved-solids concentrations of 527 and 704 mg/L, hardness of 408 and 502 mg/L, specific conductances of 820 and 986 umho/cm, SAR values of 0.5 and 0.6, respectively, and an irrigation classification of C3-S1. The only ions present in objectionable quantities were iron and manganese.

The city does not treat the water, but many of the homes and businesses use water conditioners to reduce the hardness and the iron and manganese concentrations.

Should Strasburg require more water, the city could drill new wells either at new sites or to a deeper part of the aquifer at the present sites.

Irrigation Supplies

As of 1973 only one well in the county, 136-077-29BBB1, produced water for irrigation. The well, which is finished in the Long Lake aquifer, was pumped for 555 hours in 1973. Part of the time the irrigation water was pumped through a sprinkler system at a reported rate of about 700 gal/min (44 L/s). During the remainder of the time the water was pumped directly into ditches at a reported rate of about 850 gal/min (54 L/s). The average rate is estimated to be about 750 gal/min (47 L/s). The total water pumped was about 25,000,000 gallons (77 acre-feet; 95,000 m^3).

SUMMARY

Ground water in Emmons County is obtained mainly from the Dakota, Fox Hills, and glacial-drift aquifers. The Dakota aquifer occurs at depths that range from 2,200 to 2,530 feet (670 to 770 m). It ranges in thickness from about 60 to 175 feet (18 to 53 m) and generally increases in thickness toward the east. Wells finished in the Dakota aquifer will flow at altitudes of less than 2,100 feet (640 m). Flow rates of 30 to 60 gal/min (2 to 4 L/s) could be obtained, but generally the rates of flow are restricted to conserve water and pressure head. Recharge to the Dakota aquifer apparently occurs in the Black Hills area of South Dakota. Discharge is from wells and probably by lateral discharge of water eastward into Logan and McIntosh Counties.

Water in the Dakota aquifer generally is a sodium sulfate type. Dissolved solids in sixteen samples ranged from 2,220 to 2,640 mg/L and sulfate ranged from 1,140 to 1,440 mg/L.

The Fox Hills aquifer underlies about 80 percent of the county and provides water for about 75 percent of the wells. Well yields generally range from 0.5 to

40 gal/min (0.03 to 2.5 L/s); however, in the northern part of the county, as much as 100 gal/min (6 L/s) could be obtained locally. Recharge to the aquifer generally is from infiltration of precipitation and snowmelt. Discharge of water generally is by pumpage from wells and by lateral movement into adjacent valley deposits or into Lake Oahe.

The quality of the water is variable. In areas where sandstone crops out or sandy soils overlie the aquifer the water is either a sodium bicarbonate or a calcium bicarbonate type, generally with less than 1,000 mg/L of dissolved solids. Water in areas where siltstone, silty shale, or till overlie the aquifer generally is a sodium bicarbonate type with less than 1,500 mg/L dissolved solids.

Glacial-drift aquifers occur in buried-valley deposits, undifferentiated glacial drift, and outwash deposits. Most of Emmons County is a recharge area so recharge to these aquifers generally is from precipitation, runoff, and lateral percolation of water from adjacent sediments. Locally, there may be some recharge from Lake Oahe when water levels in the lake are high. Discharge from the glacial aquifers generally is by pumpage from wells, evapotranspiration, underflow and surface flow in the creeks that overlie the various aquifers, and percolation into Lake Oahe and other smaller lakes in the county.

The glacial-drift aquifers in Emmons County with the greatest potential for large-scale ground-water development are the Strasburg, Long Lake, Braddock, and Winona; those with lesser potential for development include the Glenco Channel and Cat Tail aquifers. Hydrologic data for the glacial-drift aquifers are summarized in table 3.

Undifferentiated glacial-drift aquifers are interspersed within the till in the southeastern and northeastern parts of the county. Yields from these aquifers generally are small (less than 10 gal/min or 0.6 L/s). The water in the undifferentiated glacial-drift aquifers varies in quality, but generally is very hard. Water that has less than 1,000 mg/L dissolved solids generally is a calcium bicarbonate type. Water that has more than 1,000 mg/L dissolved solids generally is either a calcium sulfate or a sodium sulfate type. Dissolved solids in samples ranged from 373 to 4,780 mg/L, and hardness ranged from 242 to 1,900 mg/L. Sulfate ranged from 92 mg/L to 2,210 mg/L and generally exceeded 250 mg/L. Sodium-adsorption ratios ranged from 0.1 to 16.

Outwash aquifers generally are present only in valleys of present-day streams. These aquifers commonly contain less than 25 feet (7.6 m) of saturated thickness. Yields from wells in the outwash generally are less than 10 gal/min (0.6 L/s), but locally could be as much as 450 gal/min (28 L/s). Water in the outwash aquifers is either a sodium bicarbonate or sodium-calcium bicarbonate type. Water samples from four wells indicated that the water quality may differ within each aquifer. Dissolved solids in the samples ranged from 644 mg/L to 1,020 mg/L. Sulfate in one sample exceeded 250 mg/L — the limit recommended by the U.S. Public Health Service (1962). Sodium-adsorption ratios ranged from 3.5 to 6.2.

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

Aquifer	Areal extent (square miles)	Average saturated thickness (feet)	Estimated amount of water available from storage (acre-feet)	Water type	Dissolved solids (milligrams per liter)	Sodium-adsorption ratio	Probable maximum well yield (gal/min)
Strasburg	98	60	750,000	Calcium bicarbonate to sodium bicarbonate.	362 to 1,720	0.2 to 15	1,000
Long Lake	4	68	35,000	Sodium bicarbonate.	702 to 1,260	4.7 to 28	1,000
Braddock	10	36	46,000	Calcium bicarbonate to sodium bicarbonate.	269 to 662	.2 to 3.0	750
Cat Tail	5	34	22,000	Sodium bicarbonate to sodium sulfate.	396 to 2,150	2.4 to 8.3	180
Glenco Channel	.5	50	3,200	Sodium bicarbonate.	1,240	9.3	450
Winona	8	22	23,000	Sodium bicarbonate to sodium-calcium bicarbonate.	513 to 1,320	2.2 to 9.1	800

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DEFINITIONS OF SELECTED TERMS

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

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

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

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

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

Fluvial – of or pertaining to streams.

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

Glaciofluvial – pertaining to streams flowing from glaciers.

Ground water – water in the zone of saturation.

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

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

Hydraulic conductivity – the capacity of a rock to transmit water — usually described as the rate of flow in cubic feet per day through 1 ft^2 (0.09 m^2) of the aquifer under unit hydraulic gradient, at existing kinematic viscosity.

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

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

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

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

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

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

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

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

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

Specific capacity – the rate of discharge of water from a well divided by the drawdown of the water level within the well.

Specific conductance – electrical conductance, or conductivity, is the ability of a substance to conduct an electric current. Standard laboratory measurements report the conductivity of water in micromhos (reciprocal of ohms) per centimeter at 25°C (Celsius). The electrical conductivity of water is related to the concentration of ions in the water. Distilled water normally will have a conductance of about 1.0 micromho per centimeter, whereas sea water may have a conductance of about 50,000 micromhos per centimeter.

Storage coefficient – the volume of water an aquifer releases or takes into storage per unit surface area of the aquifer per unit change in head.

Surface runoff – that part of the runoff which travels over the soil surface to the nearest stream channel.

Till – nonsorted and nonstratified sediment deposited by a glacier. Generally composed of clay or silt with varying amounts of sand, pebbles, and boulders.

Transmissivity – the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths.

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

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

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