GROUND-WATER RESOURCES

OF

LOGAN COUNTY, NORTH DAKOTA

By

Robert L. Klausing

U.S. Geological Survey

COUNTY GROUND-WATER STUDIES 34 — PART III
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

BULLETIN 77 — PART III
North Dakota Geological Survey
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Prepared by the U.S. Geological Survey in cooperation
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Bismarck, North Dakota

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

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

Multiply inch-pound unit	By	To obtain SI unit
Acre	0.4047	hectare (ha)
Acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
Foot (ft)	0.3048	meter (m)
Foot per day (ft/d)	0.3048	meter per day (m/d)
Foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
Foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
Gallon per day (gal/d)	3.785	liter per day (L/d)
Gallon per minute (gal/min)	0.06309	liter per second (L/s)
Gallon per minute per foot [(gal/min)/ft]	0.207	liter per second per meter [(L/s)/m]
Inch (in.)	25.40	millimeter (mm)
Micromho per centimeter at 25 degrees Celsius (umho/cm at 25°C)	1	microsiemens per centimeter at 25 degrees Celsius (uS/cm at 25°C)
Mile (mi)	1.609	kilometer (km)
Million gallon (Mgal)	3,785	cubic meter (m^3)
Square Mile (mi^2)	2.590	square kilometer (km^2)

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ABSTRACT

Ground water in Logan County is obtained from glacial-drift aquifers of Quaternary age and the Fox Hills, Pierre, and Dakota aquifers of Cretaceous age. Glacial-drift aquifers that have the greatest potential for development are the Streeter and Napoleon aquifer systems located in the north-central and northwestern parts of the county. Properly constructed wells in the more permeable parts of these aquifer systems will yield 200 to 1,300 gallons per minute (13 to 82 liters per second). Water from the glacial-drift aquifers is hard to very hard. Dissolved-solids concentrations in water samples from these aquifers ranged from 298 to 2,640 milligrams per liter.

The Fox Hills aquifer underlies the western two-thirds of the county. Yields from this aquifer will range from 0.5 to about 60 gallons per minute (0.03 to 4 liters per second). Dissolved-solids concentrations in water samples from this aquifer ranged from 347 to 2,490 milligrams per liter.

The Pierre aquifer underlies the eastern one-third of the county. Yields from this aquifer will range from 0.25 to 10 gallons per minute (0.02 to 0.6 liters per second). Water is obtained from fractures in the upper part of the aquifer and from hydraulically connected sand and gravel deposits at the base of the overlying glacial till. The water predominantly is a sodium chloride type. Dissolved-solids concentrations in water samples from this aquifer ranged from 1,300 to 6,590 milligrams per liter.

The Dakota aquifer underlies the entire county at depths ranging from 2,100 to 2,400 feet (640 to 730 meters). This aquifer will yield as much as 1,000 gallons per minute (63 liters per second) to properly constructed wells. The water in the aquifer, based on one sample, is a calcium-sodium sulfate type. Dissolved-solids concentration in the sample was 2,220 milligrams per liter.

INTRODUCTION

This investigation was made cooperatively by the U.S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and Logan County Water Management District. The results of the investigation are published in three parts. Part I, published in 1962, is an interpretive report describing the geology of the county; Part II is a compilation of the data collected during the study; and Part III, this report, is an interpretive report describing the ground-water resources of the county. The data used in this report are from Part II (Klausing, 1982) unless otherwise referenced.

Purpose and Objectives

The purpose of this investigation was to determine the quantity and quality of ground water available for municipal, domestic, livestock, and industrial uses. The primary objectives were to: (1) Determine the location, extent, and nature of the major aquifers; (2) evaluate the occurrence and movement of water in the aquifers, including the sources of recharge and discharge; (3) estimate the quantities of water stored in the aquifers; (4) estimate the potential yields of wells tapping the aquifers; (5) evaluate the chemical quality of the water in the aquifers; and (6) estimate the water use.

Geologic and hydrologic data were collected from 523 wells and test holes to determine the location, extent, and nature of the aquifers. Monthly water-level measurements were made in 79 observation wells to determine the effects of precipitation and pumpage on various aquifers. One aquifer test was made to determine the transmissivity and storage coefficient of a specific aquifer for correlation purposes. Chemical analyses of water samples from 224 wells were used to determine the chemical composition of ground water in the county.

Geography

Logan County, located in south-central North Dakota, has an areal extent of 1,015 mi^2 (2,629 km^2; fig. 1). All of the county is in the Coteau du Missouri district of the Great Plains physiographic province except for a small area in the southwestern corner, which is in the Coteau Slope district (Clayton, 1962). Drainage in the Coteau Du Missouri district is to numerous sloughs, potholes, and lakes, which may be intermittently dry. The Coteau Slope district is drained by Beaver Creek, an intermittent stream tributary to the Missouri River.

Maximum topographic relief in the county is about 470 ft (140 m). The highest altitude is 2,280 ft (695 m) on hilltops in the east one-half of sec. 12, T. 133 N., R. 72 W.; the lowest altitude is about 1,810 ft (552 m) on a small lake in the NW¼ sec. 34, T. 136 N., R. 69 W.

The population of Logan County was 3,493 in 1980 (U.S. Bureau of the Census, 1981). Napoleon, which is the county seat and the largest city in the county, had a population of 1,103. Gackle and Fredonia had respective populations of 456 and 82. Lehr, only a part of which is in Logan County, had a population of 57.

The economy of the county is based on agriculture. Small grains (predominantly wheat) and hay are the principal crops. Cattle and dairy products are other sources of farm income.

The climate of the county is cool and semiarid. The mean annual temperature at Napoleon is about 41 °F (5 °C; U.S. Environmental Data Service, 1973). June, July, and August are the warmest months with mean monthly temperatures ranging from about 63 °F to 70 °F (17 °C to 21 °C). January and February are the coldest months with mean monthly temperatures ranging

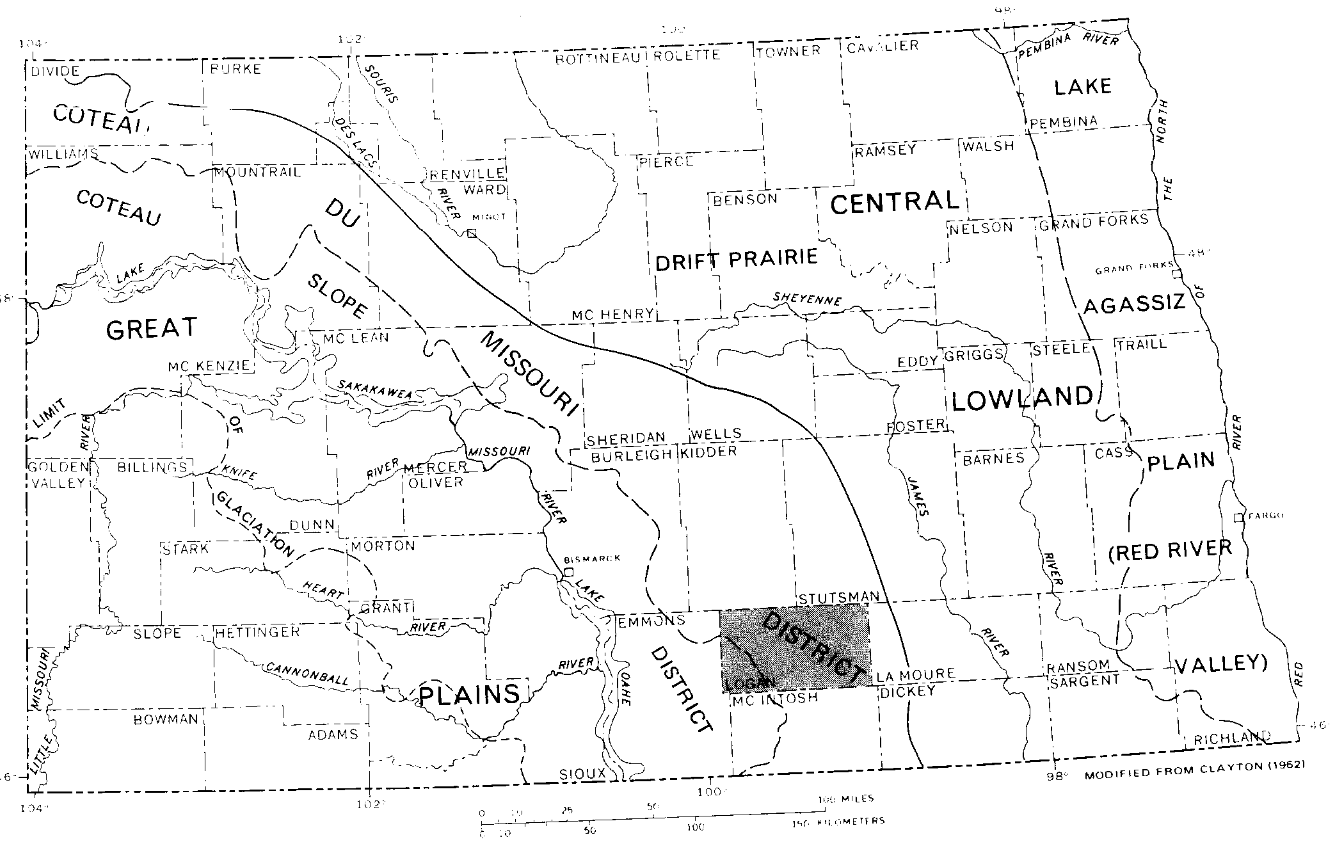


FIGURE 1.—Physiographic divisions in North Dakota and location of study area.

from about 8°F to 12°F (−13°C to −11°C). Mean annual precipitation ranges from 18.02 in. (458 mm) at Napoleon to 19.26 in. (489 mm) at Gackle. Eighty-six percent of the mean annual precipitation occurs during 7 months from April through October.

Location-Numbering System

The location-numbering system used for wells, springs, and test holes in this report is based on the public-land classification system used by the U.S. Bureau of Land Management. The system is illustrated in figure 2. The first numeral denotes the township north of a base line, the second numeral denotes the range west of the fifth principal meridian, and the third numeral 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 tract). For example, well 135-073-15ADC is in the SW¼SE¼NE¼ sec. 15, T. 135 N., R. 73 W. Consecutive terminal numbers are added if more than one well, spring, or test hole is recorded within a 10-acre (4-ha) tract.

Acknowledgments

The collection of data for this report was made possible by the cooperation of the Logan County Water Management District, Logan County Commissioners, city officials, and water-plant operators. Recognition is due the following personnel of the North Dakota State Water Commission: M. O. Lindvig for scheduling the drilling, T. L. Johnson for conducting an aquifer test, and P. A. Burke and A. E. Comeskey for logging test holes. Appreciation is expressed to the well drillers who provided well logs and to the farmers and ranchers of Logan County for allowing access to their lands and for providing records of wells.

Previous Investigations

Todd (1896), who outlined the geology of the Missouri du Coteau from about 25 mi (40 km) north of Logan County to southern South Dakota, was the first to give a detailed description of the glacial land forms in Logan County. Simpson (1929) briefly described the geology and occurrence of water in the glacial drift and the Pierre Shale. Well data and chemical analyses of water from selected wells were included in Simpson's report. Abbott and Voedisch (1938) discussed the municipal ground-water supplies of North Dakota and tabulated chemical analyses of public water supplies in Logan County. Fischer (1952) reported on the geology of Emmons County with emphasis on the Fox Hills Sandstone. Paulson (1952) described the geology and occurrence of ground water in the Streeter area in Stutsman, Logan, and Kidder Counties, N. Dak. Adolphson (1962) reported on artesian water from the glacial drift near Lehr

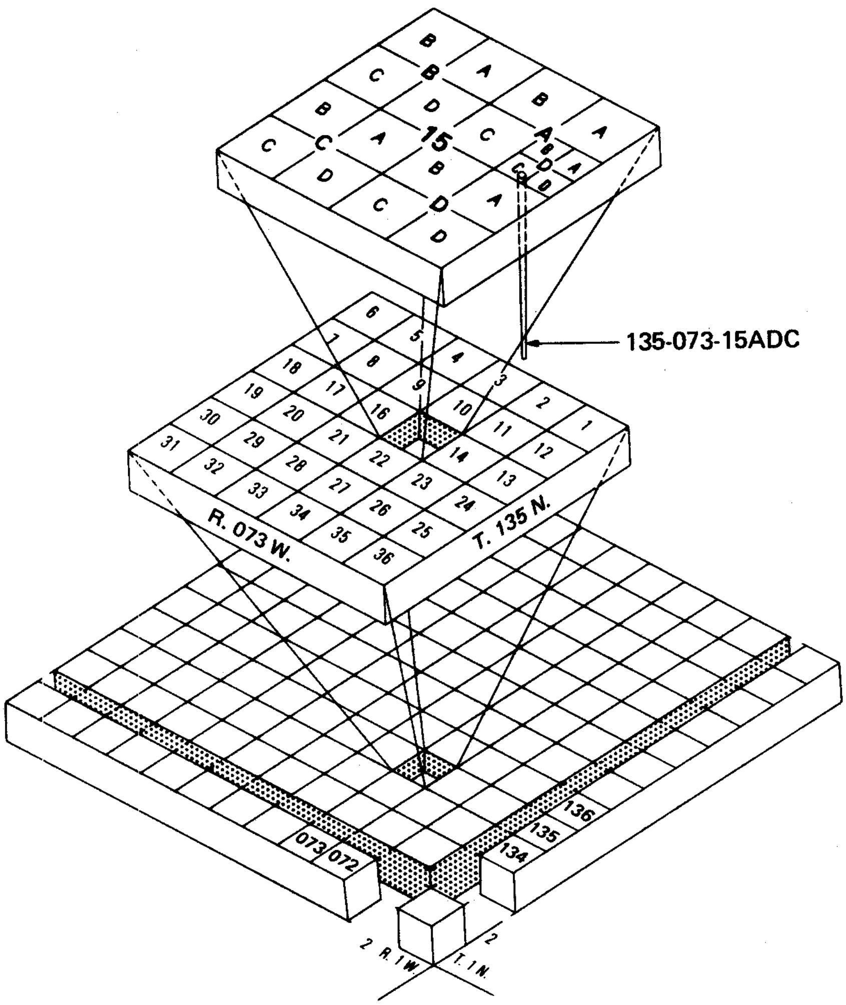


FIGURE 2.—Location-numbering system.

in Logan and McIntosh Counties. Clayton (1962) reported on the glacial geology of Logan and McIntosh Counties, N. Dak.

AVAILABILITY AND QUALITY OF WATER

General Concepts

Most ground water 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 percolates downward until it reaches the zone of saturation. When the water enters the zone of saturation, it becomes ground water and is available to wells.

Ground water moves by gravity from areas of recharge to areas of discharge. Ground-water movement generally is very slow; it may be only a few feet per year. The rate of movement (V) is governed by the hydraulic conductivity (K) of the material through which the water moves, by the effective porosity (θ), and by the hydraulic gradient (dh/dl). The rate can be calculated with the following formula:

$$V = K \frac{-dh/dl}{\theta}$$

The water level in an aquifer fluctuates primarily in response to changes in the rate of recharge to and discharge from an aquifer. Shallow aquifers generally are recharged each spring and early summer by the direct infiltration of precipitation. At the present time (1982), recharge to these aquifers generally is sufficient to replace losses caused by natural processes and by withdrawal from wells, although there may be several consecutive years 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 of precipitation through the fine-grained materials and by percolation from adjacent sediments. 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 aquifers this balance may never be achieved without a curtailment of withdrawals.

Ground water contains dissolved mineral matter in varying quantities. Rain, as it falls, begins to dissolve mineral matter suspended in the air and continues to dissolve mineral matter as the water percolates through the soil. The quantity and kind of dissolved minerals in water depend 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 concentration of dissolved minerals and physical properties. The chemical constituents, physical properties, and characteristics most likely to be of concern in Logan 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 recommended and mandatory concentration limits are given in table 1.

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 chemical analyses and represent the predominant (50 percent or more) cation (sodium, calcium, or magnesium) and anion (bicarbonate, sulfate, or chloride), expressed in milliequivalents per liter (Hem, 1970). A mixed ground-water type is one in which a single kind of cation or anion does not constitute 50 percent or more of the total cations or anions present.

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

Two indices used to show the suitability of water for irrigation are SAR and specific conductance. The SAR is related to the sodium hazard and the specific conductance is related to the salinity hazard. The two indices are combined to make 16 classifications for irrigation water. For additional information the reader is referred to a report by the U.S. Salinity Laboratory Staff (1954).

Aquifer Properties

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

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

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

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

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

Constituents	Major source	Effects upon usability	U.S. Environmental Protection Agency (1976, 1977) recommended and mandatory limits for drinking water
Silica (SiO_2)	Feldspars, quartz, and ferromagnesian and clay minerals.	In presence of calcium and magnesium, silica forms a scale in boilers and on steam turbines that retards heat transfer.	None.
Iron (Fe)	Natural sources: amphiboles, ferromagnesian minerals, ferrous and ferric sulfides, oxides, carbonates, and clay minerals. Man-made sources: well casings, pumps, and storage tanks.	If more than 100 ug/L is present, it will precipitate when exposed to air; causes turbidity, stains plumbing fixtures, laundry, 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 (recommended).
Manganese (Mn)	Soils, micas, amphiboles, and hornblende.	More than 200 ug/L precipitates upon oxidation. Causes undesirable taste and dark-brown or black stains on fabrics and porcelain fixtures. Most industrial uses require water containing less than 200 ug/L.	50 ug/L (recommended).
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, anhydrite, calcite, aragonite, limestone, dolomite, and clay minerals.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate, and silica to form scale in heating equipment. Calcium and magnesium retard the suds-forming action of soap and detergent. Excessive concentrations of magnesium have a laxative effect.	None.
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, magnesite, dolomite, and clay minerals.		
Sodium (Na)	Feldspars, clay minerals, and evaporites.	More than 50 mg/L sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers.	None.
Potassium (K)	Feldspars, feldspathoids, micas, and clay minerals.		
Boron (B)	Tourmaline, biotite, and amphiboles.	Essential to plant nutrition. More than 2 mg/L may damage some plants.	None.
Bicarbonate (HCO_3)	Limestone and dolomite.	Heating water dissociates bicarbonate to carbonate, carbon dioxide, or both. The carbonate can combine with alkaline earths (principally calcium and magnesium) to form scale.	None.
Carbonate (CO_3)			
Sulfate (SO_4)	Gypsum, anhydrite, and oxidation of sulfide minerals.	Combines with calcium to form scale. More than 500 mg/L tastes bitter and may be a laxative.	250 mg/L (recommended).
Chloride (Cl)	Halite and sylvite.	In excess of 250 mg/L may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 mg/L.	250 mg/L (recommended).
Fluoride (F)	Amphiboles, apatite, fluorite, and mica.	Optimum concentration in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. Concentrations in excess of optimum may cause mottling of children's teeth.	Mandatory maximum limits depend on average of maximum daily air temperatures. Maximum limits range from 1.4 mg/L at 32 °C to 2.4 mg/L at 10 °C.
Nitrate (NO_3) as Nitrogen (N)	Organic matter, fertilizers, and sewage.	More than 20 mg/L may cause a bitter taste and may cause physiological distress. Concentrations in excess of 10 mg/L have been reported to cause methemoglobinemia (blue-baby disease) in infants.	10 mg/L (mandatory).
Dissolved solids	Anything that is soluble.	Less than 300 mg/L is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	500 mg/L (recommended).

Material	Hydraulic conductivity [1](feet per day)	(meters per day)
Gravel	267-668	81-204
Sand and gravel	134-267	41-81
Sand, very coarse	120-134	37-41
Sand, coarse	107-120	33-37
Sand, medium to coarse	80-107	24-33
Sand, medium	53-80	16-24
Sand, fine to medium	40-53	12-16
Sand, very fine, silty	13-40	4-12
Clay and silt	0-13	0-4

[1]Modified from Keech, 1964.

The range in values for each material represents various degrees of sorting. Yield estimates were based on the smaller or intermediate values unless the lithologic log indicated that the material was well sorted.

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

Meyer (1963, p. 338-340, fig. 100) published a chart relating well diameter, specific capacity, and coefficients of transmissivity and storage. This chart shows that for coefficients of storage of more than 0.005 and for transmissivities ranging from 270 to 13,500 ft^2/d (25 to 1,250 m^2/d) the ratio of transmissivity to specific capacity is about 270:1, when the specific capacity is given in gallons per minute per foot of drawdown after 24 hours of pumping. The ratio is larger for transmissivities of more than 13,500 ft^2/d (1,250 m^2/d).

Meyer's chart shows that large changes in the storage coefficient in the range of 0.005 to 0.00005 correspond to relatively small changes in specific capacity. In most confined aquifers the storage coefficient is less than 0.005. In those confined aquifers having transmissivities of as much as 13,500 ft^2/d (1,250 m^2/d), the yield, in gallons per minute, for a fully penetrating well with 30 ft (9 m) of drawdown after 24 hours of pumping, may be approximated by dividing the transmissivity by 267. At those sites where 30 ft (9 m) of drawdown was not available, one-half of the available drawdown was used to estimate yield. The diameter of the well also will affect the yield, but this effect is small compared to the inaccuracies caused by estimating transmissivity from lithology.

GEOLOGIC UNITS AND THEIR WATER-YIELDING PROPERTIES

Logan County is underlain by rocks that range from Precambrian through Quaternary in age. The Precambrian rocks are hard, dense, and crystalline, and commonly are referred to as the basement complex. The overlying rocks are sedimentary and were formed by either chemical or sedimentary processes. The sedimentary rocks were deposited on the eastern flank of a large, sporadically subsiding basin now known as the Williston basin, which underlies most of North Dakota and parts of South Dakota, Montana, and Canada.

The sedimentary rocks of pre-Cretaceous age consist principally of limestone, dolomite, and lesser quantities of sandstone, shale, and evaporites. This sequence of sedimentary rocks ranges in thickness from about 1,000 ft (300 m) in the eastern part of the county to about 2,000 ft (600 m) in the western part. The rocks of pre-Cretaceous age are not considered further in this report because of few data and depths of more than 2,300 ft (700 m).

Rocks of Cretaceous age range in thickness from about 2,300 ft (700 m) in the eastern part of the county to about 2,900 ft (880 m) in the western part. The generalized topography of the uppermost rocks of Cretaceous age is shown on plate 1 (in pocket).

Glacial deposits of Quaternary age and alluvial deposits of Holocene age overlie the rocks of Cretaceous age. The glacial and alluvial deposits, which are as much as 450 ft (137 m) thick, have not been differentiated in this report.

Rocks of Cretaceous Age

The sedimentary rocks of Cretaceous age consist largely of shale; however, some thick sandstones are present in the Lower Cretaceous Lakota and Fall River Formations, undifferentiated, and in the Upper Cretaceous Fox Hills Sandstone. Rocks of Cretaceous age that contain aquifers of economic importance in Logan County are: (1) Lakota and Fall River Formations, undifferentiated (herein called the Dakota aquifer); (2) Pierre Shale; and (3) Fox Hills Sandstone (table 2).

Dakota Aquifer

The Dakota aquifer consists of the Lakota and Fall River Formations, undifferentiated, which are composed of very fine to coarse-grained sandstone interbedded with siltstone and shale. The Dakota aquifer underlies all of Logan County. The top of the aquifer ranges in depth from about 2,100 to 2,400 ft (640 to 730 m) below land surface. The aquifer ranges in thickness from 75 to 150 ft (23 to 46 m) and has a mean thickness of about 115 ft (35 m).

Hydraulic conductivities calculated from electric logs (Croft, 1971, p. B265-B269) at eight oil-test sites ranged from 40 to 74 ft/d (12 to 23 m/d). Total transmissivities at these sites ranged from 3,000 to about 6,600 ft^2/d (280 to 610 m^2/d). Twenty-four hour specific capacities should range from about 10 to 32 (gal/min)/ft [2 to 7 (L/s)/m] of drawdown.

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

System and series	Formation	Dominant lithology	Approx. maximum thickness (feet)	Water-yielding characteristics
Quaternary	Glacial drift	Clay, silt, sand, and gravel.	450	Yields as much as 1,300 gallons per minute from thicker and more permeable sand and gravel deposits.
Upper Cretaceous	Fox Hills Sandstone	Claystone, siltstone, and sandstone.	260	Yields as much as 60 gallons per minute from thicker and more permeable sandstone beds.
	Pierre Shale	Shale.	1,100	Relatively impermeable. Yields as much as 10 gallons per minute.
	Niobrara and Carlile Formations, undifferentiated	Shale.	570	Relatively impermeable. Not known to yield water in Logan County.
	Greenhorn Formation and Bell Fourche Shale	Shale.	420	Relatively impermeable except for thin sand beds which may yield small quantities of water.
Lower Cretaceous	Mowry Shale	Shale.	50	Relatively impermeable. Not known to yield water in Logan County.
	Newcastle Sandstone	Sandstone, siltstone, and shale.	—	Not known to yield water to wells in Logan County. Thin sandstone beds may yield small quantities of water.
	Skull Creek Shale	Shale, sandy.	130	Relatively impermeable.
	Fall River and Lakota Formations, undifferentiated (Dakota aquifer)	Sandstone, shale, and siltstone.	150	Yields as much as 1,000 gallons per minute from thicker and more permeable sandstone beds.

Yields of 300 to about 1,000 gal/min (19 to 63 L/s) with about 30 ft (9 m) of drawdown should be obtainable from properly constructed wells in the Dakota aquifer.

Water in the Dakota aquifer occurs under confined conditions. Only one well is known to produce water from the aquifer in Logan County. This well, reported to be 2,400 ft (730 m) deep, is constructed with 2-in. (51-mm) pipe and has an open flow rate of about 43 gal/min (3 L/s). Data from studies in Emmons County (Armstrong, 1978a) and McIntosh County (Klausing, 1981) indicate that wells developed in the aquifer will flow at land-surface altitudes of less than 2,100 ft (640 m).

Recharge to the Dakota aquifer occurs in the Black Hills area of South Dakota (Darton, 1909) and by upward movement of water from the deeper aquifers (Swenson, 1968). Water is discharged from the aquifer in Logan County by flow from one well and by lateral movement to the east.

Chemical analysis of the one water sample collected from the Dakota aquifer indicates that the water is very hard and is a calcium-sodium sulfate type. The dissolved-solids concentration was 2,220 mg/L, the sodium concentration was 270 mg/L, the sulfate concentration was 1,200 mg/L, and the iron concentration was 4,300 ug/L. The sample had an SAR value of 3.8 and an irrigation classification of C4-S1 (fig. 3)

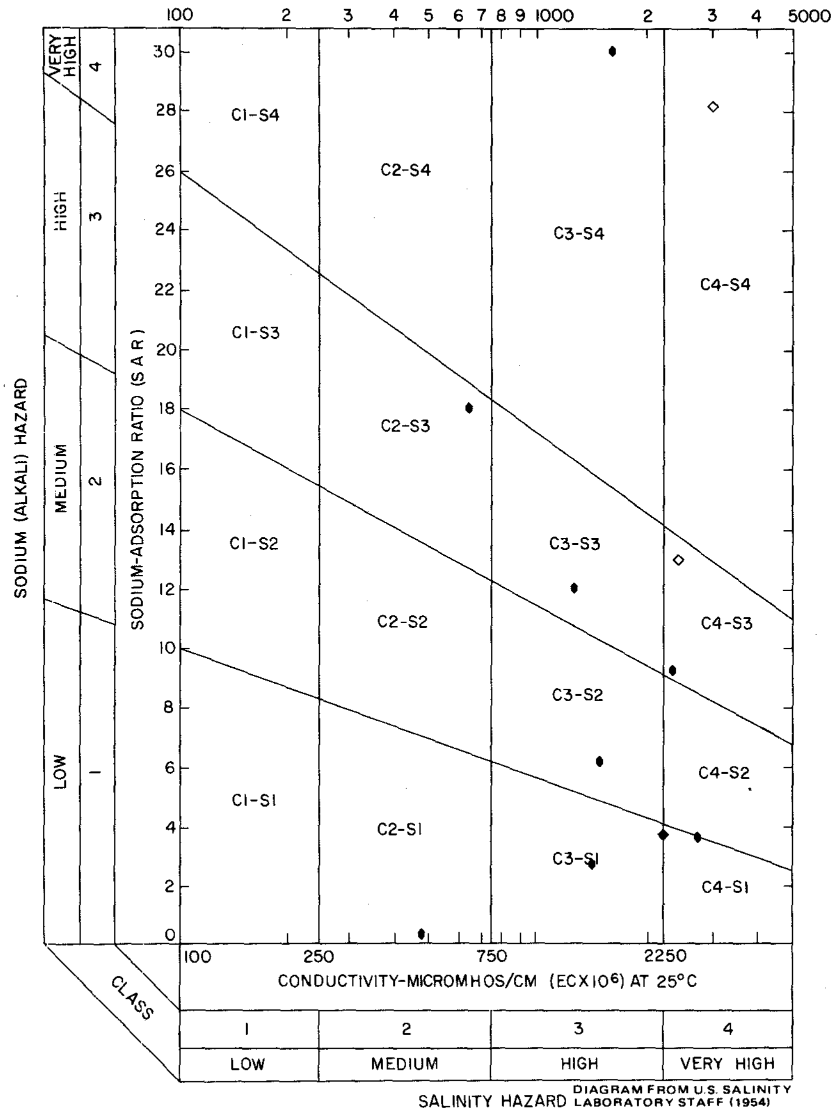
Pierre Aquifer

The Pierre Shale underlies all of Logan County. The Pierre consists of 1,000 to 1,100 ft (300 to 340 m) of dark-gray to black siliceous shale. It underlies the Fox Hills Sandstone in the western two-thirds of the county, and subcrops below the glacial till in the eastern part (pl. 2, sec. A-A′, in pocket). The Pierre will not yield significant quantities of water to wells except where it is fractured. Small quantities of water are generally available from fractured zones in the upper part of the formation. Locally sand or gravel deposits, or both, overlie the fractured zones. Where this occurs the composition of the water in the sand and gravel deposits usually is the same as that in the fractured zones. Therefore, hydraulically connected sand and gravel deposits are considered to be part of the Pierre aquifer in Logan County.

Wells developed in the Pierre aquifer are located in the eastern part of the county. These wells, which range in depth from about 250 to 540 ft (76 to 165 m), will yield from 0.25 to 10 gal/min (0.02 to 0.6 L/s).

Fractured zones in the Pierre aquifer are recharged by downward movement of water through the overlying glacial drift. Discharge is by pumping, flowing wells, and by seepage into topographically low areas where evapotranspiration is effective.

Few water-level data are available because most of the wells are sealed. Reported water levels range from a few feet above land surface in topographically low areas to 180 ft (55 m) below land surface in topographically high areas. The potentiometric head in observation well 135-068-21CDD,



EXPLANATION

◆ DAKOTA AQUIFER

◇ PIERRE AQUIFER

⬧ FOX HILLS AQUIFER

FIGURE 3.—Irrigation classifications of selected water samples from Cretaceous aquifers.

developed in gravel overlying a fractured zone, was 4.5 ft (1.4 m) above land surface.

Chemical analyses of six water samples from the aquifer indicate that the water generally is a sodium chloride type. Dissolved-solids concentrations in the samples ranged from 1,300 to 6,590 mg/L and had a median of 4,405 mg/L. Sulfate concentrations ranged from 0.8 to 200 mg/L and had a median of 12.5 mg/L. Iron and manganese concentrations exceeded the respective recommended limits of 300 ug/L and 50 ug/L in all six samples. Specific conductance ranged from 2,400 to greater than 8,000 umho/cm, and SAR values ranged from 13 to 51 and had a median of 42. The irrigation classification of the best quality water was C4-S3 (fig. 3).

The water is used for domestic and stock purposes. Some residents use the water for drinking and they report no ill effects.

Fox Hills Aquifer

The Fox Hills Sandstone overlies the Pierre Shale in the western two-thirds of the county but is missing in the eastern part (pl. 1). The Fox Hills is overlain by glacial drift except in the southwestern part of the county where it crops out in road cuts and in places along Beaver Creek. The configuration and relation of the Fox Hills Sandstone to the overlying glacial drift is shown on sections A-A' through G-G' (pl. 2).

The Fox Hills Sandstone consists of very fine to medium-grained sandstone interbedded with siltstone and shale. Generally the sandstone, which forms the Fox Hills aquifer, contains considerable quantities of interstitial clay and silt. The aquifer has a maximum known thickness of 135 ft (41 m).

In a study of the ground-water resources of Emmons County (adjacent to Logan County), Armstrong (1978a, p. 14-15) indicated that the hydraulic conductivity of the Fox Hills aquifer ranged from about 3 to 11 ft/d (0.9 to 3 m/d). These values appear to be applicable in Logan County because the lithology of the aquifer is very similar to that in Emmons County.

Estimated transmissivities generally range from 20 to about 300 ft^2/d (1.9 to 28 m^2/d). However, at some localities, such as at 136-073-22AAA where the aquifer consists of 125 ft (38 m) of fine- to medium-grained sandstone, the transmissivity, based on lithology, is estimated to be about 900 ft^2/d (84 m^2/d).

Yields from the Fox Hills aquifer depend on the saturated thickness, well construction, sorting and grain size of the aquifer materials, and on the available drawdown. Assuming that the 24-hour specific capacities would range from 0.05 to 3 (gal/min)/ft [0.01 to 0.62 (L/s)/m] and the available drawdown is 30 ft (9 m), yields to wells should range from 0.5 to 60 gal/min (0.03 to 4 L/s).

The Fox Hills aquifer is recharged by percolation of precipitation through the overlying glacial drift. Discharge from the aquifer is by pumping of stock and domestic wells, by movement into adjacent glacial deposits and westward into Emmons County, and by flowing wells. Discharge from a few flowing wells located in the eastern part of T. 136 N., R. 71 W., ranges from less than 1 to about 10 gal/min (0.06 to 0.6 L/s).

Water levels in the aquifer generally range from about 5 to 120 ft (2 to 36 m) below land surface, except in the lower areas in the central part of the county where there are a few flowing wells. No head measurements were made on the flowing wells; however, it is estimated that the maximum water-level rise in a tightly cased well would be about 20 ft (6 m) above land surface. Water-level fluctuations generally are less than 1 ft (0.3 m); however, fluctuations of as much as 5 ft (2 m) were recorded in observation wells located near pumping wells. The 1.8-ft (0.5-m) water-level rise in well 134-072-10DAA (fig. 4) is attributed in part to recharge derived from the 11 in. (280 mm) of rainfall that occurred between April 3 and July 17. The hydrograph also shows that the lowest water levels occur during the winter and the highest water levels occur during the late spring and early summer. Water-level data indicate that the direction of ground-water movement is controlled by the topography — that is, from areas of higher altitudes to areas of lower altitudes.

The quality of water from the Fox Hills aquifer varies considerably. Analyses of 78 water samples collected from the aquifer indicate that the water generally is very hard. Water in 31 of the samples was a sodium bicarbonate type. In the remaining samples generally either calcium or sodium was the dominant cation and bicarbonate or sulfate was the dominant anion. Dissolved-solids concentrations ranged from 347 to 2,490 mg/L and had a median of 801 mg/L. Sulfate concentrations ranged from 26 to 1,400 mg/L and had a median of 195 mg/L. Iron concentrations exceeded the recommended limit of 300 ug/L in 65 percent of the samples and manganese concentrations exceeded the recommended limit of 50 ug/L in 79 percent of the samples. Specific conductance ranged from 490 to 2,780 umho/cm and SAR values ranged from 0.2 to 33 and had a median of 3.0. Irrigation classifications ranged from C2-S1 to C4-S3 (fig. 3); one sample had a sodium hazard too large to be classified.

Rocks of Quaternary Age

Glacial-drift deposits of Quaternary age cover almost all of Logan County. These deposits unconformably overlie the Pierre Shale in the eastern one-third of the county and the Fox Hills Sandstone in the western two-thirds of the county. The deposits are unconsolidated and consist of fragments of older rocks that have been eroded and transported by glaciers. They range in thickness from 0 to about 450 ft (0 to 137 m). The thickest drift deposits occur in buried valleys, which are delineated on the generalized bedrock contour map (pl. 1). Locally glacial-drift aquifers occur within these buried valleys.

The glacial-drift deposits in Logan County are divided into three main types, based on lithology and inferred origin. The types are till, lake deposits, and glaciofluvial deposits.

Till is a nonsorted, nonstratified sediment that generally consists of a mixture of clay, silt, sand, and gravel. Within a large area, the percentages of material in the till may vary considerably. Till is deposited from glacial ice

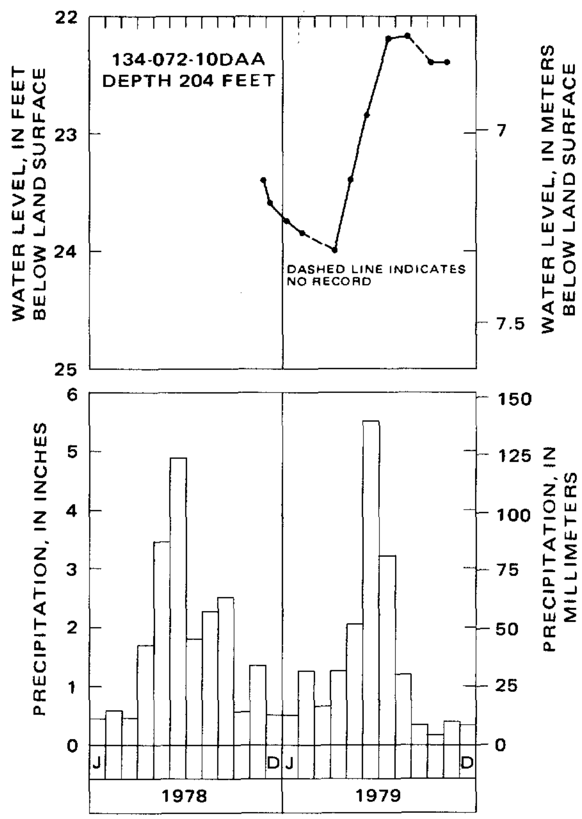


FIGURE 4.—Water-level fluctuations in the Fox Hills aquifer and precipitation at Napoleon.

by dumping, pushing, lodgement, and ablation. In places blocks of locally derived bedrock such as shale or sandstone are incorporated in the till.

Lake deposits consist of clay and silt and occasionally of very fine to medium sand deposited by ponded glacial melt water. These deposits generally are only a few feet thick; however, considerable thicknesses of silt and clay mixed with sand have been penetrated in a few test holes.

Glaciofluvial deposits consist principally of sand and gravel that has been sorted and stratified by glacial melt water. The glaciofluvial deposits occur (1) in preglacial and proglacial stream valleys buried under till, (2) as sediments in melt-water channels, (3) as surficial and buried outwash, and (4) as undifferentiated deposits of sand and gravel. Glaciofluvial deposits form the glacial-drift aquifers in Logan County.

Aquifers in the glacial-drift deposits have the greatest potential for ground-water development in Logan County. Potential yields of the glacial-drift aquifers are shown on plate 3 (in pocket). The aquifers generally are lenticular in cross section and the largest yields are obtainable from the thickest sections. The variations in thickness and material are gradational and the boundaries between the different yield areas are approximate. Wells penetrating aquifers in narrow buried valleys have smaller maximum sustained yields than wells developed in aquifers of comparable thickness that have a large areal extent. Where aquifers are superimposed, the maximum yield is obtainable only by wells open to all aquifers.

The yield map (pl. 3) needs to be used with the understanding that the estimated yields are for fully penetrating, properly screened and developed wells of adequate diameter. The map is intended as a guide to the location of ground water, and not as a map to locate wells with a specific yield. Few if any aquifers are so uniform in extent and physical properties that production wells could be developed in them without preliminary test drilling.

Where sufficient hydrologic data are available, an estimate of ground water available from storage is given in units of acre-feet (cubic hectometers). The volume of water available from an unconfined aquifer is defined by the following formula:

$$V = \overline{m}A\overline{Sy}$$

where V = volume of water available from storage, in acre-feet;

$\overline{m}$ = mean saturated thickness, in feet;

A = areal extent, in acres; and

$\overline{Sy}$ = specific yield of the aquifer, in percent.

The specific yield for glacial-drift aquifer materials may range from 1 to 35 percent. The range for these materials in North Dakota usually is 10 to 20 percent. For purposes of this report, a median value of 15 percent is assumed.

Determination of the volume of water available from storage in a confined aquifer involves a calculation in addition to that shown above owing to expansion of the water, and compressibility of the aquifer. However, the quantity of water gained due to expansion and compression is insignificant when compared to the total volume of water in storage and is not considered in storage estimates for this investigation.

For convenience of discussion and identification and for future reference, the aquifers in the glacial-drift deposits in this report generally are named after nearby prominent geographic features such as lakes and streams or local political entities. However, if an aquifer has been formally named in an adjacent area and the aquifer extends into Logan County, the name applied in the adjacent area takes precedence.

Streeter Aquifer System

The Streeter aquifer system is located in north-central Logan County (pl. 3). It has an areal extent of about 31 mi^2 (80 km^2) and extends northwestward from secs. 20 and 21, T. 135 N., R. 69 W., into Kidder County along the north edge of T. 136 N., R. 70 W.

The aquifer system consists of a small buried-valley aquifer and a surficial-outwash aquifer. The aquifers are separated by glacial till and lacustrine deposits that range in thickness from about 40 to 120 ft (12 to 37 m). The system is bordered on the east by an end moraine that overlies the Pierre Shale (pl. 2, sec. C-C') and on the south and west by glacial till that overlies the Fox Hills Sandstone (pl. 2, sec. D-D').

Streeter buried-valley aquifer

The Streeter buried-valley aquifer underlies an area of about 8 mi^2 (21 km^2) in the northwestern part of T. 136 N., R. 70 W. (pl. 3). The buried valley extends south-southeast from the Kidder-Logan County border to near the northwest corner of sec. 16, T. 136 N., R. 70 W., where it bifurcates. The eastern branch, which at one time was tributary to a larger buried valley to the east, is filled with glacial till that contains lenses of sand and gravel. The southern branch, which appears to terminate about 2 mi (3 km) south, contains sand and gravel deposits.

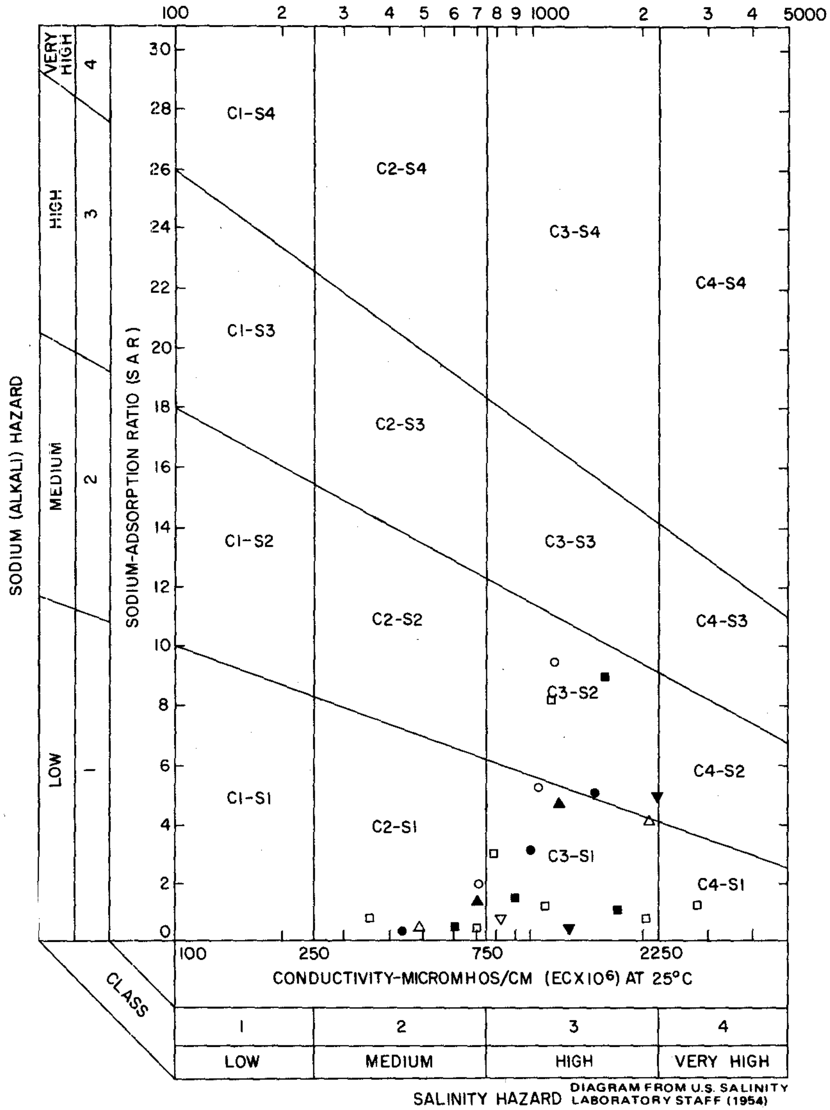
The aquifer is composed of very fine to very coarse sand intermixed with fine to coarse gravel. It ranges in thickness from 5 to 33 ft (2 to 10 m) and has a mean saturated thickness of about 13 ft (4 m).

Estimated yields to wells developed in the buried-valley aquifer range from 50 to 400 gal/min (3 to 25 L/s). However, these yields cannot be verified without additional exploration to adequately determine the areal extent of the aquifer.

Recharge to the aquifer is by vertical, then lateral movement of water from the Fox Hills and glacial drift that underlies the topographically higher areas that border the aquifer on the east, west, and south. Discharge is by pumpage from a few stock and domestic wells and by upward leakage into the overlying till or Streeter outwash aquifer in the topographically low areas.

Water levels in the aquifer range from about 2 to 23 ft (0.6 to 7 m) below land surface. Comparison of the water levels in the buried-valley aquifer with those in the surficial outwash shows that the water levels in the lower aquifer range from 0.6 to 1 ft (0.2 to 0.3 m) higher than those in the surficial aquifer. Water-level data indicate that the hydraulic gradient slopes to the northwest at 3 to 4 ft/mi (0.6 to 0.8 m/km).

Four water samples were collected from wells developed in the buried-valley aquifer and one sample was collected from a well developed in a gravel bed in the till. Analyses of the samples from the buried-valley aquifer indicate that the water is hard to very hard and predominantly is a sodium bicarbonate type. Dissolved-solids concentrations ranged from 842 to 1,220 mg/L. Sulfate concentrations were less than 250 mg/L. Iron concentrations ranged from less than 10 to 320 ug/L and manganese concentrations exceeded the recommended limit of 50 ug/L in all samples. The irrigation classifications of the water were C3-S1 and C3-S2 (fig. 5).



EXPLANATION

■ STREETER AQUIFER SYSTEM

□ HILLSBURG AQUIFER SYSTEM

▲ NAPOLEON BURIED-VALLEY AQUIFER

△ NAPOLEON OUTWASH AQUIFER

● BEAVER LAKE BURIED-OUTWASH AQUIFERS

○ BEAVER LAKE MELT-WATER-CHANNEL AQUIFER

▼ McINTOSH AQUIFER

▽ WISHEK AQUIFER

FIGURE 5.—Irrigation classifications of selected water samples from major glacial-drift aquifers.

Analysis of the sample collected from the gravel bed in the till at 136-070-23AAA1 indicates that the water is very hard and is a calcium bicarbonate type. The dissolved-solids concentration was 547 mg/L, the sulfate concentration was less than 250 mg/L, the iron concentration was less than 300 ug/L, and the manganese concentration exceeded the recommended limit of 50 ug/L. The irrigation classification was C3-S1 (fig. 5).

Based on an areal extent of 8 mi^2 (21 km^2), a mean saturated thickness of 13 ft (5 m), and a specific yield of 15 percent, approximately 10,000 acre-ft (12 hm^3) of water stored in the aquifer would be available to wells.

Streeter outwash aquifer

The Streeter outwash aquifer originally was identified and named by Paulson (1952, p. 43). The outwash generally is composed of intermixed sand and gravel but locally may consist of either sand or gravel. The sand and gravel deposits range in thickness from 0 to about 60 ft (0 to 18 m) and have a mean saturated thickness of about 29 ft (9 m).

Data from test holes penetrating the outwash aquifer indicate that in places silt and clay beds occur in the middle of the aquifer (pl. 2, sec. C-C'). These beds are thicker and more persistent in the northwestern part of the aquifer where they function as confining beds. Thus, in this part of the aquifer the water may be either confined or unconfined.

An aquifer test was made in the outwash aquifer by the North Dakota State Water Commission (T. L. Johnson, written commun., 1979). The test was made using a well constructed by the North Dakota State Water Commission on property owned by Berthold Spitzer. The well was 56 ft (17 m) deep and was screened with 50-slot screen from 31 to 56 ft (9 to 17 m). The well was pumped for 48 hours at a rate of 598 gal/min (38 L/s). Five observation wells equipped with recorders were used to monitor the effects of pumping. Analysis of the early test data indicated that water in the aquifer was confined. However, after 30 minutes of pumping the drawdown plots deviated from the standard type curve. The plots below the standard type curve indicated that the aquifer was being recharged by leakage through the overlying confining bed. The transmissivity was reported to be about 10,000 ft^2/d (929 m^2/d). The storage coefficient ranged from 0.0003 during the early part of the test to about 0.005 during the latter part of the test. The specific capacity after 48 hours of pumping was 32 (gal/min)/ft [6.6 (L/s)/m]. Yields to wells developed in the outwash aquifer should range from less than 50 to about 1,300 gal/min (3 to 82 L/s).

Recharge to the outwash aquifer is by direct infiltration of precipitation and by surface runoff from topographically higher areas. Recharge by infiltration is indicated by the fact that the highest water levels occur after the spring thaw and after significant precipitation. The hydrograph for well 136-070-15CCC2 (fig. 6) shows that from April 3 to July 30, 1979, the water level rose 1.72 (0.5 m). Total precipitation during the 4 months was 13.53 in (344 mm).

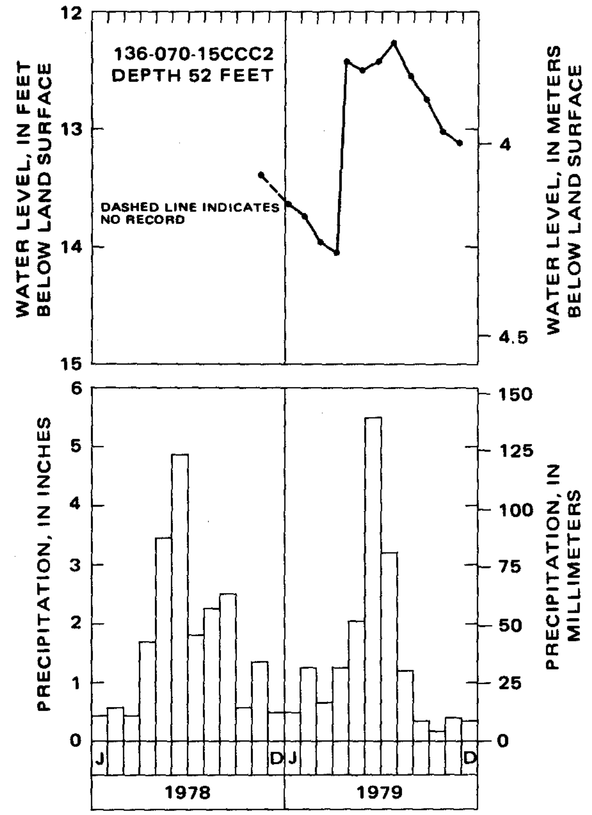
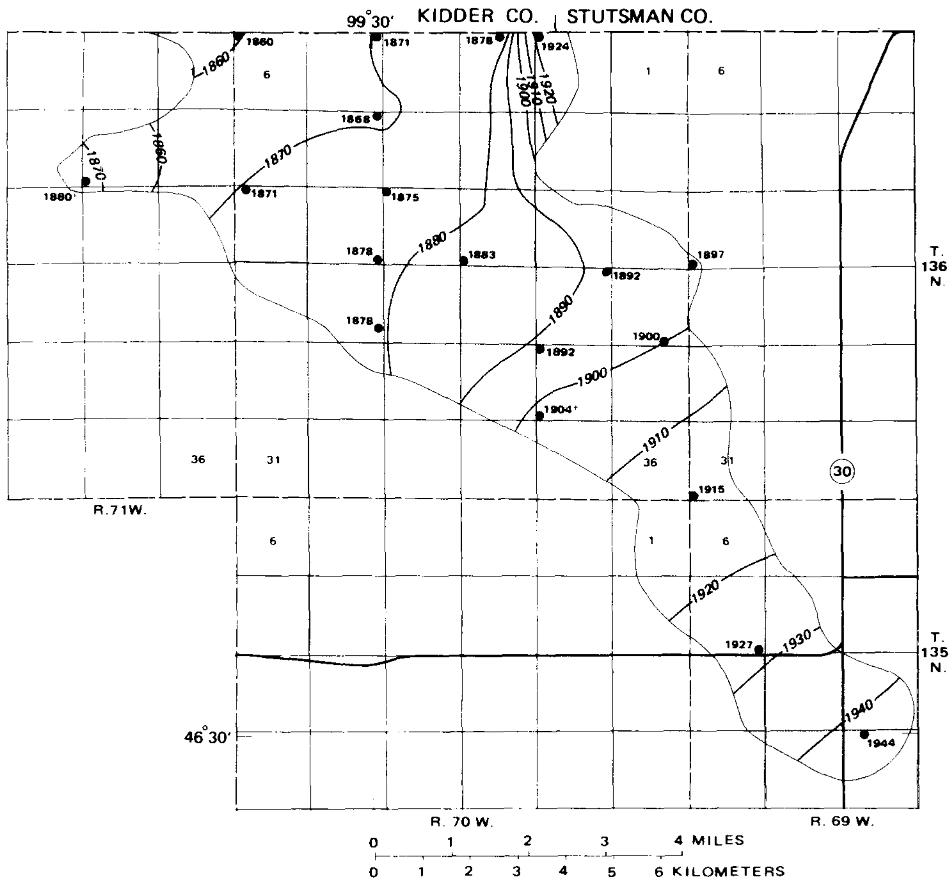


FIGURE 6.—Water-level fluctuations in the Streeter outwash aquifer and precipitation at Napoleon.

Discharge from the outwash aquifer is by pumpage from domestic, irrigation, and stock wells, by evapotranspiration, and by discharge into Alkali Lake, which lies just north of the Kidder-Logan County border. The water table slopes northwestward (fig. 7) at an average rate of about 7 ft/mi (1 m/km).

Water levels in the aquifer range from about 1 to 34 ft. (0.3 to 10 m) below land surface. Long-term water-level data are not available for determination of trends. The available data do, however, indicate that the highest water levels generally occur in April, May, or June. The lowest water levels generally occur in December or January.

Twenty-eight samples were collected from wells developed in the outwash aquifer. Analyses of the samples indicate that the water is hard to very hard and predominantly is a calcium bicarbonate type. Dissolved-solids concentrations ranged from 298 to 1,270 mg/L and had a median of 422 mg/L. Sulfate



EXPLANATION

•1915 OBSERVATION WELL—Number is altitude of water level, in feet above National Geodetic Vertical Datum of 1929

——1910—— WATER-TABLE CONTOUR—Shows altitude of water table. Contour interval 10 feet. National Geodetic Vertical Datum of 1929

——— — — - - AQUIFER BOUNDARY—Includes some areas where well yields are less than 50 gallons per minute

FIGURE 7.—Altitude of water table in the Streeter outwash aquifer, May 6, 1980.

concentrations ranged from 29 to 450 mg/L and had a median of 90 mg/L — four samples had more than 250 mg/L of sulfate. Iron concentrations were less than 300 ug/L in all but four samples and manganese concentrations exceeded the recommended limit of 50 ug/L in all but one sample. Specific conductance ranged from 530 to 1,750 umho/cm and SAR values ranged from 0.3 to 4.2. Five of the samples had irrigation classifications of C3-S1 and the rest were classified as C2-S1 (fig. 5).

Based on an areal extent of 31 mi^2 (80 km^2), a mean saturated thickness of 29 ft (9 m), and a specific yield of 15 percent, approximately 86,000 acre-ft (106 hm^3) of water stored in the Streeter outwash aquifer is available to wells.

Napoleon Aquifer System

The Napoleon aquifer system underlies an area of about 30 mi^2 (78 km^2) in northwestern Logan County. The aquifers comprising the system differ in age of deposition but are hydraulically connected. They consist of clastic material that was deposited in a bedrock valley and as surficial outwash. The aquifers are referred to in the following discussion as the Napoleon buried-valley aquifer and the Napoleon outwash aquifer.

Napoleon buried-valley aquifer

The buried-valley aquifer occupies the northwestern part of a bedrock valley that extends north and west from its origin in T. 134 N., R. 73 W., into Emmons County along the west edge of sec. 18, T. 136 N., R. 73. W. (pl. 1). The aquifer ranges in width from 1 to 2 mi (2 to 3 km) and has an areal extent of about 15 mi^2 (39 km^2). Generally it consists of two sand and gravel beds that are separated by as much as 38 ft (12 m) of till, clay, and silt (pl. 2, sec. B-B'); locally, as in test hole 135-073-01ABB, the two beds coalesce to form one bed about 59 ft (18 m) thick.

Data from seven test holes indicate that the upper bed varies from very fine to very coarse silty clayey sand to sandy medium-sized gravel. The thickness of the upper bed ranges from 6 to 57 ft (2 to 17 m). Data from test holes penetrating the lower bed indicate it varies from very fine to fine silty clayey sand to coarse sandy gravel. The thickness of the lower bed ranges from 7 to 93 ft (2 to 28 m). The aquifer has a mean saturated thickness of 33 ft (10 m).

Data from test holes drilled in the western part of T. 136 N., R. 73 W., show that the deposits in the bedrock valley consist largely of glacial till and that the thicker parts of the aquifer do not extend into adjacent Emmons County.

Yields to wells developed in the buried-valley aquifer will vary depending on the thickness, sorting, and hydraulic conductivity of the material penetrated. Estimated yields from the upper bed range from less than 50 to 700 gal/min (3 to 44 L/s). Yields from the lower bed range from less than 50 to 400 gal/min (3 to 25 L/s). Locally, where the beds coalesce to form a thick aquifer section, yields of as much as 1,000 gal/min (63 L/s) may be possible.

Recharge to the buried-valley aquifer is by infiltration of precipitation, by underflow from a tributary melt-water channel that trends from east of Napoleon to McKenna Lake, and by lateral movement of water from the adjacent Fox Hills aquifer. Discharge from the aquifer is by pumpage from stock and domestic wells, by evapotranspiration, and by some lateral movement into Emmons County.

Water-level measurements made in dual observation wells indicate that the water level in the upper bed generally is 0.5 to 3 ft (0.2 to 0.9 m) higher than in the lower bed. However, the water level in well 136-073-26CBB1, which is completed in the lower bed, is 2 ft (0.6 m) higher than in well 136-073-26CBB2 completed in the upper bed. The fact that the potentiometric head in the lower bed is the same as that in a nearby observation well completed in the Fox Hills aquifer indicates that the lower bed may be hydraulically connected to the Fox Hills aquifer (pl. 2, sec. B-B').

Water-level data indicate that the hydraulic gradient in the upper bed slopes northwestward at about 2 to 3 ft/mi (0.4 to 0.6 m/km). The gradient in the lower bed slopes in the same direction at about 0.5 to 5 ft/mi (0.1 to 0.9 m/km).

Water levels in the aquifer were measured in two wells for about 1 year. The period is too short to define any trends, but the measurements indicate that the annual water-level fluctuations are as much as 1.85 ft (0.6 m). The highest water levels occur during April, May, and June, and the lowest water levels occur during January and February.

Chemical analyses of 10 water samples collected from observation wells developed in the buried-valley aquifer indicate that the water is hard. Four of the samples were a calcium-sodium bicarbonate type water, three were a calcium bicarbonate type, two were a sodium bicarbonate type, and one was a calcium sulfate type. The two wells from which the sodium bicarbonate type waters were obtained are developed in the lower bed, which may be hydraulically connected to the Fox Hills aquifer (pl. 2, sec. B-B'). The calcium-sodium bicarbonate type water in the upper bed, which has no direct contact with the Fox Hills Sandstone, probably is derived from percolation through the overlying till. The wells from which the calcium bicarbonate type water was obtained are relatively shallow and are located near the edges of the aquifer.

Dissolved-solids concentrations ranged from 470 to 769 mg/L and had a median of 532 mg/L. Sulfate concentrations ranged from 84 to 170 mg/L and had a median of 100 mg/L. Iron concentrations were less than the recommended limit of 300 ug/L and manganese concentrations exceeded the recommended limit of 50 ug/L in all samples. Specific conductance ranged from 740 to 1,200 umho/cm and SAR values ranged from 0.7 to 4.7. The irrigation classification of the water was either C2-S1 or C3-S1 (fig. 5).

Based on an areal extent of 15 mi^2 (39 km^2), a mean saturated thickness of 33 ft (10 m), and a specific yield of 15 percent, approximately 48,000 acre-ft (59 hm^3) of water stored in the buried-valley aquifer is available to wells.

Napoleon outwash aquifer

The Napoleon outwash underlies an area of about 15 mi^2 (39 km^2) in the vicinity of the city of Napoleon. The aquifer varies from very fine to very coarse gravelly sand to fine to medium sandy gravel. Locally the sand and gravel deposits contain lenses of sandy clay and silt. The aquifer ranges in thickness from zero at the edges to as much as 66 ft (20 m). The mean saturated thickness is 17 ft (5 m). The thickest part of the aquifer occurs in Napoleon city well 135-072-17CAB2 where the outwash overlies and is hydraulically connected to the buried-valley aquifer.

Estimated yields to properly constructed wells developed in the aquifer generally will range from 50 to 200 gal/min (3 to 13 L/s). Locally, yields of as much as 500 gal/min (33 L/s) may be possible.

Recharge to the aquifer is by infiltration of precipitation and lateral migration of water from the Fox Hills aquifer. Discharge from the outwash aquifer is by pumpage from municipal, domestic, and stock wells, by evapotranspiration, and by discharge into lakes.

Water-level data from observation wells indicate that the hydraulic gradient is toward the two parts of McKenna Lake located just west of Napoleon. The gradient for that part of the aquifer lying east of Napoleon is about 12 ft/mi (2 m/km; pl. 2, sec. E-E'). Water-level data for the northern and western parts of the aquifer are insufficient to establish a gradient.

No long-term water-level records are available; however, measurements made in seven observation wells indicate that water levels range from 3 to 36 ft (1 to 11 m) below land surface, and fluctuate as much as 3 ft (0.9 m). The highest water levels occur after spring snowmelt during April, May, and June and the lowest water levels occur from December to February.

Eleven water samples were collected from wells developed in the aquifer. Analyses of the samples indicate the water is hard to very hard. Seven of the samples were a calcium bicarbonate type water, two samples were a sodium bicarbonate type, one sample was a sodium sulfate type, and one was a sodium-magnesium bicarbonate type. The calcium bicarbonate type water generally occurs in the area of recharge, and the three sodium type waters generally occur in areas where the aquifer is in contact with the Fox Hills Sandstone.

Dissolved-solids concentrations in the samples ranged from 308 to 780 mg/L and had a median of 510 mg/L. Sulfate concentrations ranged from 40 to 160 mg/L and had a median of 72 mg/L. Iron concentrations ranged from 40 to 360 ug/L, but only two of the samples exceeded the recommended limit of 300 ug/L. Manganese concentrations exceeded the recommended limit of 50 ug/L in all samples. Specific conductance ranged from 490 to 945 umho/cm and SAR values ranged from 0.2 to 3.8. The irrigation classification was C2-S1 or C3-S1 (fig. 5).

Based on an areal extent of 15 mi^2 (39 km^2), a mean saturated thickness of 17 ft (5 m), and a specific yield of 15 percent, about 24,000 acre-ft (30 hm^3) of water would be available to wells.

Hillsburg Aquifer System

The Hillsburg aquifer system, located in central Logan County, extends southward from the southwest corner of sec. 27, T. 135 N., R. 69 W., into secs. 3 and 4, T. 133 N., R. 69 W. (pl. 3). The system has an areal extent of about 25 mi^2 (65 km^2).

The aquifer consists of collapsed-outwash deposits composed of intermixed sand and gravel, the predominant material is fine to coarse sandy gravel. The outwash deposits generally are exposed, but locally they are overlain by till. The outwash deposits have a maximum thickness of 29 ft (9 m).

Data from test holes penetrating the outwash deposits indicate that they are underlain by a thick section of till that locally contains lenses and beds of sand and gravel, ranging in thickness from 8 to 34 ft (2 to 10 m). The extent and degree of hydraulic connection of the sand and gravel deposits in the till is unknown, but locally they appear to be hydraulically connected to the outwash deposits. Test hole 134-069-27BBA penetrated gravel from 1 to 30 ft (0.3 to 9 m) and from 256 to 290 ft (78 to 88 m; pl. 2, sec. A-A'). The deeper gravel interval was deposited in a buried valley. The trend of the buried valley is shown on plate 3. The mean saturated thickness of the aquifer system is about 17 ft (5 m).

Yields to wells developed in the collapsed-outwash deposits generally will range from 50 to 200 gal/min (3 to 13 L/s). Wells developed in some of the sand and gravel deposits in the underlying till probably also will yield from 50 to 200 gal/min (3 to 13 L/s). Wells screened in both deposits should yield as much as 500 gal/min (32 L/s). Yields from the buried-valley aquifer should range from 500 to 1,000 gal/min (32 to 63 L/s), provided that the aquifer is areally extensive.

Recharge to the collapsed-outwash aquifer is by infiltration of precipitation. Recharge to the buried sand and gravel deposits is by downward leakage through the till. Downward leakage is indicated by the head differentials in observation wells 134-069-03DDD1,2. The head in well 1, which is 58 ft (18 m) deep, is about 3 ft (0.9 m) greater than the head in well 2, which is 165 ft (50 m) deep. The sand and gravel interval in well 1 probably is connected to the collapsed outwash that occurs north and west of the well site.

Discharge from the Hillsburg aquifer system is by pumping from stock and domestic wells, by evapotranspiration, and by seepage into sloughs and small lakes.

Water levels in the collapsed outwash range from about 6 ft (2 m) above land surface in the topographically low areas to about 22 ft (7 m) below land surface in the topographically high areas. Water levels in the buried sand and gravel deposits range from about 3 ft (0.9 m) above land surface in the topographically low areas to 17 ft (5 m) below land surface in the topographically high areas. The water level in the buried-valley aquifer was about 21 ft (6 m) below land surface in well 134-069-27BBA. Available water-level data indicate that the hydraulic gradient slopes eastward toward a topographic low extending southward from the northeastern edge of T. 134 N., R. 69 W., to near the south line of sec. 4, T. 133 N., R. 69 W.

Analyses of 12 water samples collected from the Hillsburg aquifer system indicate that all but four of the samples are mixed water types. Water from the collapsed-outwash deposits generally had calcium as the dominant cation with nearly equivalent concentrations of either magnesium or sodium. The dominant anion was bicarbonate. Three samples were a calcium bicarbonate type. Dissolved-solids concentrations ranged from 355 to 2,640 mg/L and had a median of 929 mg/L. Sulfate concentrations ranged from 51 to 1,500 mg/L and had a median of 235 mg/L. Iron concentrations were less than 300 ug/L in all but three samples, and manganese concentrations exceeded 50 ug/L in all but one sample. Specific conductance ranged from 575 to 2,800 umho/cm and SAR values ranged from 0.3 to 9.0. Irrigation classifications ranged from C2-S1 to C4-S1 (fig. 5), but most samples had a C3-S1 classification.

Analyses of the two samples collected from the sand and gravel deposits in the till indicate that one sample is a mixed water type and one is a sodium sulfate type. The one sample collected from the buried valley was a sodium chloride-bicarbonate type. The sodium type samples had an irrigation classification of C3-S2 (fig. 5).

Based on an areal extent of 25 mi^2 (65 km^2), a mean saturated thickness of 17 ft (5 m), and a specific yield of about 15 percent, about 41,000 acre-ft (51 hm^3) of water is available from storage in the collapsed-outwashed deposits. Insufficient data prohibit estimation of water available from storage in the sand and gravel deposits underlying the collapsed outwash or from the buried-valley aquifer.

Beaver Lake Aquifer System

The Beaver Lake aquifer system underlies an area of about 16 mi^2 (41 km^2) in southwestern Logan County (pl. 3). The system consists of buried-outwash aquifers and a melt-water-channel aquifer.

Buried-outwash aquifers

The buried-outwash aquifers occur in the northeastern and northwestern parts of T. 134 N., R. 71 W. (pl. 2, sec., F-F'), and have a combined areal extent of about 5 mi^2 (13 km^2). They extend southward to Beaver Lake.

The buried-outwash aquifers are composed largely of very fine to very coarse gravelly sand that locally contains considerable amounts of interstitial clay and silt. The aquifers range in thickness from 10 to 54 ft (3 to 16 m) and have a mean saturated thickness of 28 ft (9 m).

Yields to wells developed in the buried-outwash aquifers generally will range from 50 to 200 gal/min (3 to 13 L/s); however, in places yields of as much as 1,000 gal/min (63 L/s) may be possible.

The aquifers are recharged by infiltration of precipitation and the movement of water from the Fox Hills Sandstone or adjacent glacial drift. Discharge is by evapotranspiration in the topographically low areas where water levels are near land surface, by pumpage from a few domestic and stock wells, and by movement southward into Beaver Lake.

No long-term water-level records are available, but short-term measurements indicate that the water levels in the aquifers range from about 0.4 to about 37 ft (0.1 to 11 m) below land surface. Flowing wells possibly could be constructed in the lowest parts of some depressions. The hydraulic gradient in both the eastern and western buried-outwash aquifers is toward Beaver Lake. The hydraulic gradient in the eastern aquifer is about 6 ft/mi (1 m/km) and the gradient in the western aquifer ranges from 10 to 22 ft/mi (2 to 4 m/km).

Analyses of five water samples collected from the aquifers indicate that the water is very hard. Two samples from the eastern buried-outwash aquifer, where the Fox Hills Sandstone is nearby, were a sodium bicarbonate type water and one sample was a sodium-calcium bicarbonate type. Two samples from the western buried-outwash aquifer were a calcium bicarbonate type. Dissolved-solids concentrations in the five samples ranged from 302 to 981 mg/L and had a median of 706 mg/L. Sulfate concentrations ranged from 14 to 380 mg/L and had a median of 210 mg/L. Four of the five samples had iron concentrations of less than 300 ug/L. Manganese concentrations exceeded 50 ug/L in all samples. Specific conductance ranged from 446 to 1,500 umho/cm and SAR values ranged from 0.1 to 5.4. Irrigation classifications ranged from C2-S1 to C3-S2 (fig. 5).

Based on an areal extent of about 5 mi^2 (13 km^2), a mean saturated thickness of 28 ft (9 m), and a specific yield of 15 percent, approximately 13,000 acre-ft (17 hm^3) of water is available to wells.

Melt-water-channel aquifer

The melt-water-channel aquifer occupies part of a large proglacial drainage that was eroded into the Fox Hills Sandstone (pl. 2, secs. A-A' and B-B'). The channel generally ranges in width from 0.25 to 0.5 mi (0.4 to 0.8 km). It extends from about 2.5 mi (4 km) east of Beaver Lake to the Emmons County border and generally is confined to the Beaver Creek valley (pl. 3). The melt-water-channel aquifer has an areal extent of about 11 mi^2 (28 km^2).

The aquifer consists of undifferentiated fluvial, terrace, and melt-water-channel deposits. These deposits are composed of very fine to very coarse gravelly sand and range in thickness from 9 to 28 ft (3 to 8 m). The mean saturated thickness is about 17 feet (5 m). Well yields from the aquifer will range from less than 50 to 200 gal/min (3 to 13 L/s).

Recharge to the aquifer is by infiltration of precipitation, lateral movement from the adjacent Fox Hills Sandstone and glaciofluvial deposits, runoff from topographically higher areas, and occasional flooding of Beaver Creek. Discharge is by pumping from stock and domestic wells, by evapotranspiration, by discharge into Beaver Creek, and by underflow into Emmons County.

Water levels in the aquifer range from about 2 to 38 ft (0.6 to 12 m) below land surface. The available data indicate that the water level may fluctuate as much as 1.7 ft (0.5 m). The hydraulic gradient slopes toward Beaver Creek and downstream at about 4 ft/mi (0.8 m/km).

Analyses of 10 water samples collected from the aquifer indicate that the water is moderately hard to very hard. Three of the samples were a sodium bicarbonate type water and one sample was a calcium bicarbonate type. The remaining samples were mixed water types. Dissolved-solids concentrations in the samples ranged from 525 to 1,100 mg/L and had a median of 742 mg/L. Sulfate concentrations ranged from 79 to 380 mg/L and had a median of 200 mg/L. Four of the samples had iron concentrations exceeding the recommended limit of 300 ug/L and manganese concentrations exceeded the recommended limit of 50 ug/L in all but one sample. Specific conductance ranged from 740 to 1,320 umho/cm and SAR values ranged from 0.9 to 9.5. Irrigation classifications ranged from C2-S1 to C3-S2 (fig. 5).

Based on an areal extent of 11 mi^2 (28 km^2), a mean saturated thickness of 17 ft (5 m), and a specific yield of 15 percent, about 18,000 acre-ft (22 hm^3) of water stored in the aquifer would be available to wells.

McIntosh Aquifer

An extension of the large McIntosh aquifer located in adjacent McIntosh County (Klausing, 1981, p. 21) underlies an area of about 8 mi^2 (21 km^2) in the southeastern part of Logan County (pl. 3). The northern and western boundaries are not specifically known, but the available data indicate that the aquifer probably does not extend beyond the boundaries shown on plate 3.

The aquifer, which consists of buried- and surficial-outwash deposits, is composed principally of fine to coarse sandy gravel (pl. 2, sec. G-G'). Locally it may be composed of very fine to coarse sand. The deposits range in thickness from 5 to 63 ft (2 to 19 m) and have a mean saturated thickness of about 16 ft (5 m).

Yields to wells developed in the aquifer generally will range from 50 to 100 gal/min (3 to 6 L/s), but locally yields of as much as 1,000 gal/min (63 L/s) may be possible for short periods of time.

Recharge to the aquifer is by infiltration of precipitation. Discharge is by pumpage from a few stock and domestic wells, seepage into sloughs, and movement into McIntosh County where parts of the aquifer occur at lower altitudes.

Two observation wells were completed in the aquifer. Well 133-068-30BCB had a water level of about 24 ft (7 m) below land surface. However, the surficial sand and gravel deposits in observation well 133-068-35BCC, which was drilled on a westward-facing slope, were dry. Any precipitation infiltrating these shallow surficial deposits moves westward and seeps into sloughs.

Water samples were collected from two wells developed in the aquifer. Analyses of the two samples indicate the water is very hard. One sample was a sodium sulfate type water and one was a calcium sulfate type. Dissolved-solids concentrations were 983 and 1,620 mg/L. Sulfate concentrations were 500 and 800 mg/L and iron concentrations were 40 and 530 ug/L. Manganese concentrations exceeded the recommended limit of 50 ug/L in both samples.

Specific conductance was 1,250 and 2,250 umho/cm and SAR values were 0.4 and 5.1. The water had irrigation classifications of C3-S1 and C4-S2 (fig. 5).

Based on an areal extent of 8 mi^2 (21 km^2), a mean saturated thickness of 16 ft (5 m), and a specific yield of 15 percent, about 12,000 acre-ft (15 hm^3) of the water stored in this part of the aquifer is available to wells.

Wishek Aquifer

The Wishek aquifer underlies an area of about 1 mi^2 (3 km^2) in secs. 29, 31, and 32, T. 133 N., R. 70 W. (pl. 3). The aquifer is an extension of the Wishek aquifer system identified in adjacent McIntosh County (Klausing, 1981, p. 22).

Test hole 133-070-31DAA penetrated fine to very coarse sand intermixed with fine to coarse gravel from 1 to 63 ft (0.3 to 19 m), but only the bottom 39 ft (12 m) was saturated.

Potential yields to wells developed in the aquifer probably will range from 250 to 500 gal/min (16 to 32 L/s). However, yields of as much as 500 gal/min (32 L/s) probably could not be sustained for extensive periods because the aquifer is small in areal extent.

The aquifer is recharged by infiltration of precipitation, lateral movement from the Fox Hills Sandstone, and runoff from topographically higher areas. Discharge from the aquifer is by lateral movement to the south into McIntosh County.

Chemical analysis of a water sample from the aquifer indicates that the water is very hard and is a calcium bicarbonate type. Dissolved-solids concentration was 464 mg/L and sulfate concentration was 93 mg/L. Iron and manganese had respective concentrations of 400 and 770 ug/L. Specific conductance was 830 umho/cm and the SAR value was 0.9. The irrigation classification was C3-S1 (fig. 5).

Based on an areal extent of 1 mi^2 (3 km^2), a saturated thickness of 39 ft (12 m), and a specific yield of 15 percent, about 4,000 acre-ft (5 hm^3) of water stored in this part of the aquifer would be available to wells.

Undifferentiated Buried-Glaciofluvial Aquifers

Undifferentiated buried-glaciofluvial aquifers occur throughout Logan County. Most of the aquifers have an areal extent of less than 1 mi^2 (3 km^2); however, some may have areas of 2 to 3 mi^2 (5 to 8 km^2). The aquifers occur as sand or gravel lenses in the till or in narrow channels, which are impossible to delineate without an intensive drilling program. Test holes and wells commonly penetrate one or more beds of sand or gravel at depths of as much as 438 ft (134 m). The aquifers range in thickness from about 5 to 100 ft (2 to 30 m). Generally, aquifer thicknesses of more than 20 feet (6 m) are aggregate thicknesses.

Adolphson (1961) conducted an aquifer test using Gackle city well 136-067-17BCC2. No observation wells were used. The city well, developed in an undifferentiated buried-glaciofluvial aquifer, penetrated 64 ft (20 m) of fine to coarse sandy gravel containing lignite fragments and abundant shale pebbles. The well was pumped for 30 hours at a rate of 55 gal/min (3 L/s). Drawdown in the well was 26.4 ft (8 m), and the specific capacity was 2.1 (gal/min)/ft [0.4 (L/s)/m] of drawdown. The computed transmissivity was 535 ft^2/d (50 m^2/d). Forty hours after pumping stopped, the water level was 5.5 ft (2 m) below the original static level. The slow rate of rise of the water level indicates that recharge to the aquifer is very slow. The small hydraulic conductivity (8 ft/d or 2 m/d) indicates that this aquifer contains substantial quantities of interstitial silt and clay.

Wells developed in the undifferentiated buried-glaciofluvial aquifers generally will yield from 1 to 50 gal/min (0.06 to 3 L/s). The thickness and lithology of some of the aquifers indicate that yields of somewhat more than 500 gal/min (32 L/s) may be possible.

Recharge to the undifferentiated aquifers is from infiltration of precipitation and surface runoff from topographically high areas. Discharge generally is by pumping and by seepage into lakes and sloughs, although some evapotranspiration does occur from shallow aquifers. Water levels in the undifferentiated aquifers range from about 9 to 70 ft (3 to 21 m) below land surface.

Water in 48 samples collected from undifferentiated buried-glaciofluvial aquifers was hard to very hard and differed considerably in quality. Most of the samples were mixed water types. Dissolved-solids concentrations ranged from 339 to 4,320 mg/L and had a median of 1,120 mg/L. Sulfate concentrations ranged from 16 to 2,400 mg/L and had a median of 434 mg/L. Iron concentrations were less than 300 ug/L in 56 percent of the samples. Manganese concentrations exceeded the recommended limit of 50 ug/L in all samples. Specific conductance ranged from 580 to 5,000 umho/cm and SAR values ranged from 0.2 to 6.5. The irrigation classification of the best quality water was C2-S1, and the irrigation classification of the poorest quality water was C4-S2. One-half of the samples were classified as C3-S1.

Undifferentiated Outwash Aquifers

Outwash deposits commonly are penetrated in test holes and wells in Logan County. Some of the outwash deposits are erosional remnants of previous, more extensive deposits; others are associated with potholes, sloughs, and small lakes. Areal extent of the undifferentiated outwash aquifers ranges from 0.5 to 2 mi^2 (1 to 5 km^2). The aquifers are composed of intermixed and interbedded sand and gravel. Saturated thicknesses range from 10 to 73 ft (3 to 22 m).

Wells developed in the outwash aquifers generally will yield 5 to 50 gal/min (0.3 to 3 L/s). Locally yields of as much as 500 gal/min (32 L/s) may be possible. However, this estimate cannot be verified without additional drilling.

The outwash aquifers are recharged by infiltration of precipitation and by surface runoff that accumulates in associated lakes and sloughs. Discharge is by pumping of stock and domestic wells, by evapotranspiration, and by movement into underlying and adjacent deposits. Water levels generally range from 9 to 21 ft (2.7 to 6.4 m) below land surface. In places where the deposits vary topographically, the higher deposits generally are dry.

Analyses of five samples collected from outwash aquifers during this investigation indicate that the water is very hard. Three of the samples were a calcium bicarbonate type water, one was a sodium-calcium bicarbonate type water, and one was a calcium-sodium sulfate type water. Dissolved-solids concentrations in the samples ranged from 354 to 1,300 mg/L and had a median of 461 mg/L. Sulfate concentrations ranged from 40 to 550 mg/L and had a median of 62 mg/L. Iron concentrations ranged from 40 to 850 ug/L and had a median of 100 ug/L. Manganese concentrations ranged from 200 to 3,300 ug/L and had a median of 640 ug/L. The specific conductance ranged from 485 to 1,650 umho/cm and the SAR values ranged from 0.1 to 3.1. The irrigation classifications were C2-S1 and C3-S1.

USE OF GROUND WATER

Ground water in Logan County is used to meet domestic, livestock, public supply, and irrigation needs.

Domestic and Livestock Use

Most of the water used for domestic and livestock purposes in Logan County is obtained from drilled or bored wells ranging in depth from 10 to 2,400 ft (3 to 730 m). Because most domestic and stock wells are equipped with small-capacity pumps, the yields usually range from 5 to 10 gal/min (0.3 to 0.6 L/s).

The majority of the domestic and livestock wells are developed in sand and gravel aquifers in the glacial drift or in the Fox Hills aquifer. A few wells are developed in the Pierre aquifer and in the Dakota aquifer.

Estimates of the quantity of water pumped daily for domestic and livestock use in Logan County are listed in the following table:

Public Supply Use

Gackle

The city of Gackle obtains its water supply from well 136-067-17BCC2. The well is 115 ft (35 m) deep and is developed in an undifferentiated buried-glaciofluvial aquifer about 2 mi (3 km) south of the city. Average annual production from this well from 1977 through 1979 was about 16.1 Mgal (61,000 m^3). The city also has two standby wells, 136-067-05BCB and 136-067-06ADA. These wells are about 80 ft (24 m) deep and also are developed in undifferentiated buried-glaciofluvial aquifers.

Water samples were collected from two of the city wells for chemical analyses. Water from well 136-067-06ADA was a sodium-calcium sulfate type

Use	Individual requirements (gallons per day)	Population	Total pumpage (gallons per day; rounded)
Domestic (not including municipal supplies)	[a]66	[b]1,795	118,500
Cattle	15	[c]50,800	762,000
Milk cows	35	[c]4,200	147,000
Sheep	1.5	[c]2,350	3,500
Hogs	5	[c]1,550	7,800
Total pumpage			1,038,000

[a]Murray and Reeves, 1977.
[b]U.S. Bureau of the Census, 1981.
[c]Mean population for the years 1977 and 1978; North Dakota State University, 1978 and 1979.

and had a dissolved-solids concentration of 998 mg/L. Water from well 136-067-17BCC2 was a calcium-sodium sulfate type and had a dissolved-solids concentration of 1,090 mg/L.

Should the city of Gackle require more water, the city probably could develop one or more wells in the undifferentiated buried-glaciofluvial aquifer located about 3 mi (5 km) southwest of the city.

Lehr

The city of Lehr obtains its water supply from three wells, two of which are in McIntosh County. Well 133-069-33DDD4, in Logan County, is 160 ft (49 m) deep and is developed in an undifferentiated buried-glaciofluvial aquifer. The well is reported to have a pumping rate of 180 gal/min (11 L/s). In 1979 this well produced about 6.8 Mgal (26,000 m^3) of water.

One water sample was collected from well 133-069-33DDD4 for chemical analyses. The water was a calcium-sodium sulfate type and contained 1,590 mg/L of dissolved solids.

Should the city of Lehr require more water, a well developed in the McIntosh aquifer located about 3 mi (5 km) east-northeast of the city should provide an adequate water supply.

Napoleon

Napoleon obtains its water supply from two wells. Well 135-072-17CAB1 is 70 ft (21 m) deep and well 135-072-17CAB2 is 102 ft (31 m) deep. Both wells are developed in the Napoleon outwash aquifer. Pumping rates of the two wells are reported to be 250 and 300 gal/min (16 and 19 L/s). Average annual pumpage from the wells in 1978 and 1979 was about 36 Mgal (136,000 m^3).

Water samples were collected from the two city wells for chemical analyses. Water from well 135-072-17CAB1 was a calcium bicarbonate type and had dissolved-solids concentrations of 316, 334, and 365 mg/L. Water from well 135-072-17CAB2 was a sodium bicarbonate type and had dissolved-solids concentrations of 510, 512, and 526 mg/L.

Should the city of Napoleon require more water, more wells could be drilled into the outwash, wells also could be developed in the Fox Hills aquifer or in the Napoleon buried-valley aquifer northwest of the city. The buried-valley aquifer would have greater yields than the Fox Hills aquifer.

Irrigation Use

As of November 1979, there were three irrigation wells developed in the Streeter outwash aquifer. Wells 136-070-23ACC and 136-070-23BBD are 65 ft (20 m) deep and are reported to have respective pumping rates of 700 and 620 gal/min (44 and 39 L/s). Well 136-070-26BAC2 is 51 ft (16 m) deep and has a reported pumping rate of 850 gal/min (54 L/s). Total pumpage from wells 136-070-23ACC and 136-070-23BBD from 1977 to 1979 was about 166.7 Mgal (631,000 m^3). Pumpage from well 136-070-26BAC2 from 1978 to 1979 totaled about 68.6 Mgal (260,000 m^3). The North Dakota State Water Commission reports that as of the end of 1982 six additional irrigation wells have been developed in the aquifer.

Water samples collected from wells 136-070-23ACC and 136-070-26BAC2 had respective dissolved-solids concentrations of 458 and 365 mg/L. The water was a calcium bicarbonate type.

SUMMARY

Ground water in Logan County is obtained from the Dakota, Pierre, Fox Hills, and glacial-drift aquifers. The Dakota aquifer underlies the county at depths ranging from 2,100 to 2,400 ft (640 to 730 m). It ranges in thickness from 75 to 150 ft (23 to 46 m). Only one well is known to be completed in the Dakota aquifer in Logan County, and this well has a flow rate of about 43 gal/min (3 L/s). Recharge to the Dakota aquifer occurs in the Black Hills area of South Dakota and by upward migration of water from underlying aquifers. Discharge is by pumping and by lateral movement to the east.

Water in the Dakota aquifer is a calcium-sodium sulfate type. The dissolved-solids concentration in the one sample collected from the aquifer was 2,220 mg/L and the sulfate concentration was 1,200 mg/L.

The Pierre Shale underlies all of Logan County. The Pierre will not yield significant quantities of water to wells except where it is fractured in the upper part of the formation. Locally, hydraulically connected sand and gravel deposits overlie the fractured zones and are considered to be part of the Pierre aquifer. Wells developed in the Pierre aquifer range in depth from about 250 to 540 ft (76 to 165 m). These wells generally will yield from 0.25 to 10 gal/min (0.02 to 0.6 L/s). Fractured zones in the Pierre aquifer are recharged by downward movement of water through the overlying glacial drift. Discharge is by pumping and flowing wells and by movement to lower altitudes.

Water in the Pierre aquifer generally is a sodium chloride type. Dissolved-solids concentrations ranged from 1,300 to 6,590 mg/L and sulfate concentrations ranged from 0.8 to 200 mg/L.

The Fox Hills Sandstone underlies the western two-thirds of Logan County. The Fox Hills is overlain by glacial drift except in the southwestern part of the county where it outcrops in road cuts and, in places, along Beaver Creek. Wells developed in the Fox Hills aquifer generally will yield from 0.5 to 60 gal/min (0.03 to 3.4 L/s). Recharge to the aquifer is by percolation of precipitation through the overlying glacial drift and discharge is by pumping of stock and domestic wells, by lateral movement into adjacent glacial deposits, and by flowing wells.

The quality of the water in the Fox Hills aquifer is variable. Water in 31 of the samples was a sodium bicarbonate type. The rest of the samples were mixed water types with either calcium or sodium as the dominant cation and either bicarbonate or sulfate as the dominant anion. Dissolved-solids concentrations in the samples ranged from 347 to 2,490 mg/L and sulfate concentrations ranged from 26 to 1,400 mg/L.

Aquifers in the glacial drift occur as buried-valley deposits, buried- and surficial-outwash deposits, melt-water-channel deposits, undifferentiated buried-glaciofluvial deposits, and undifferentiated outwash deposits. Recharge to these aquifers is by infiltration of precipitation, by infiltration of surface runoff that accumulates in low areas, by leakage, and locally by lateral movement of water from the Fox Hills aquifer. Water is discharged from these aquifers by pumping, evapotranspiration, discharge into lakes and sloughs, and by leakage.

The glacial-drift aquifers in Logan County with the greatest potential for ground-water development are the Streeter and Napoleon aquifer systems. Those with lesser potential are the Hillsburg aquifer system, Beaver Creek aquifer system, McIntosh aquifer, and Wishek aquifer. Hydrologic data for these aquifers are summarized in table 3.

Undifferentiated buried-glaciofluvial aquifers occur throughout the county. Yields from these aquifers generally will not exceed 50 gal/min (3 L/s); however, in places yields of somewhat more than 500 gal/min (32 L/s) may be possible. Water in the undifferentiated buried-glaciofluvial aquifers is hard to very hard. Most of the samples collected were mixed water types. Dissolved-solids concentrations ranged from 339 to 4,320 mg/L and sodium-adsorption ratios ranged from 0.2 to 6.5

Undifferentiated outwash aquifers composed of intermixed and interbedded sand and gravel are scattered throughout the county. Yields from these aquifers generally will range from 5 to 50 gal/min (0.3 to 3 L/s), but locally yields of

TABLE 3. — Summary of data for major aquifers in the glacial drift.

Aquifer or aquifer system	Approximate areal extent (square miles)	Mean saturated thickness (feet)	Estimated volume of water available from storage (acre-feet)	Predominant water type	Dissolved-solids concentration (milligrams per liter)	Sodium-adsorption ratio (SAR)	Probable maximum yield (gallons per minute)
Streeter aquifer system:							
Buried-valley aquifer	8	13	10,000	Sodium bicarbonate.	842-1,220	—	400
Outwash aquifer	31	29	86,000	Calcium bicarbonate.	298-1,270	0.3-4.2	1,300
Napoleon aquifer system:							
Buried-valley aquifer	15	33	48,000	Calcium bicarbonate or sodium bicarbonate.	470-769	0.7-4.7	1,000
Outwash aquifer	15	17	24,000	Calcium bicarbonate.	308-780	0.2-3.8	500
Hillsburg aquifer system	25	17	41,000	Mixed.	355-2,640	0.9-9.0	1,000
Beaver Lake aquifer system:							
Buried-outwash aquifers	5	28	13,000	Sodium or calcium bicarbonate.	302-981	0.1-5.4	1,000
Melt-water-channel aquifer	11	17	18,000	Mixed to sodium bicarbonate.	525-1,100	0.9-9.5	200
McIntosh aquifer	8	16	12,000	Calcium sulfate or sodium sulfate.	983-1,620	0.4-5.1	1,000
Wishek aquifer	1	39	4,000	Calcium bicarbonate.	464	0.9	500

as much as 500 gal/min (32 L/s) may be possible. Water from three of five samples collected from the aquifers was a calcium bicarbonate type. Dissolved-solids concentrations in the five samples ranged from 354 to 1,300 mg/L, and sodium-adsorption ratios ranged from 0.1 to 3.1.

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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. The water level in an artesian well stands above the top of the artesian aquifer the well is completed in.

Confining bed — a body of "impermeable" material stratigraphically adjacent to one or more aquifers. Its hydraulic conductivity may range from nearly zero to some value distinctly less than that of the aquifer.

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

Evapotranspiration — the process by which water is returned to the atmosphere through direct evaporation from water or land surfaces and by transpiration of vegetation.

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

Glaciofluvial — pertaining to material deposited by streams flowing from glaciers.

Ground water — water in the zone of saturation.

Ground water, confined — confined ground water is under pressure greater than atmospheric, and its upper limit is the bottom of a bed with distinctly less hydraulic conductivity than that of the material in which the confined water occurs.

Ground water, unconfined — unconfined ground water is water in an aquifer that has a water table. The pressure at the water table is atmospheric.

Head — the static 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. The static head is the sum of the altitude head and the pressure head. The velocity of ground water is so small that the velocity head is negligible. Head, when used alone is understood to be static head. The head is proportional to the fluid head; therefore, the head is a measure of potential.

Hydraulic conductivity — if a porous medium is isotropic and the fluid is homogeneous, the hydraulic conductivity of the medium is the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of the flow. It replaces the term "field coefficient of permeability," which embodies the inconsistent units gallon, foot, and mile.

Hydraulic gradient — the change in static head per unit distance in a given direction. If not specified, the direction generally is understood to be that of the maximum rate of decrease in head.

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

National Geodetic Vertical Datum of 1929 (NGVD of 1929) — a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

Outwash — stratified detritus (chiefly sand and gravel) removed or "washed out" from a glacier by melt-water streams and deposited in front of or beyond the terminal moraine or the margin of an active glacier.

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 National Geodetic Vertical Datum of 1929.

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

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

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

in which the terms in parentheses are ion concentrations 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 the structure of some soils.

Specific capacity — the rate of discharge of water from a well divided by the drawdown of the water level in the well. It varies slowly with duration of discharge, which should be stated when known. If the specific capacity is constant except for the time variation, it is approximately proportional to the transmissivity.

Specific conductance — electrical conductance, or conductivity, is the ability of a substance to conduct an electrical 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.

Specific yield — the ratio of volume of water which a rock or soil, after being saturated, will yield by gravity to the volume of the medium (including the water drained). Generally expressed as a percentage or decimal fraction.

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 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.

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