GROUND-WATER RESOURCES

OF

McINTOSH COUNTY, NORTH DAKOTA

By

Robert L. Klausing

U.S. Geological Survey

COUNTY GROUND-WATER STUDIES 30 — PART III
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

BULLETIN 73 — PART III
North Dakota Geological Survey
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Prepared by the U.S. Geological Survey
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Bismarck, North Dakota

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

A dual system of measurements — inch-pound units and the International System (SI) of metric units — is given in this report. SI is an organized system of units adopted by the 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	0.3048	meter (m)
Foot per day (ft/d)	0.3048	meter per day (m/d)
Foot per mile (ft/mi)	0.18943	meter per kilometer (m/km)
Foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
Gallon	3.785	liter (L)
	0.003785	cubic meter (m^3)
Gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
Gallon per minute (gal/min)	0.06309	liter per second (L/s)
Gallon per minute per foot [(gal/min)/ft]	0.207	liter per second per meter [(L/s)/m]
Inch	25.4	millimeter (mm)
Micromho (umho)	1.000	microsiemens (uS)
Mile	1.609	kilometer (km)
Million gallons (Mgal)	3,785	cubic meter (m^3)
	0.003785	cubic hectometer (hm^3)
Square mile (mi^2)	2.590	square kilometer (km^2)

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ABSTRACT

Ground water in McIntosh County is obtainable from glacial-drift aquifers of Quaternary age and from the Fox Hills and Dakota aquifers of Cretaceous age. Glacial-drift aquifers that have the greatest potential for development are the Spring Creek and Wishek aquifer systems. Properly constructed wells developed in the thicker parts of the Spring Creek aquifer system should yield as much as 1,000 gallons per minute (63 liters per second). Yields of 1,500 gallons per minute (95 liters per second) are available from the Wishek aquifer system. Maximum yields of the McIntosh, Zeeland, Dry Lake, and South Branch Beaver Creek aquifers will be about 500 gallons per minute (32 liters per second). However, yields of as much as 1,000 gallons per minute (63 liters per second) may be obtainable from the northern part of the Zeeland aquifer.

Water from the glacial-drift aquifers is hard to very hard. Dissolved-solids concentrations ranged from 316 to 1,870 milligrams per liter.

The Fox Hills aquifer underlies an area of about 280 square miles (725 square kilometers) in the northwestern part of the county. Yields to wells developed in the aquifer generally will range from 0.5 to 30 gallons per minute (0.03 to 2 liters per second); however, locally yields of as much as 50 gallons per minute (3 liters per second) may be obtainable. The water generally is very hard. Dissolved-solids concentrations in the samples from the aquifer ranged from 227 to 4,220 milligrams per liter.

The top of the Dakota aquifer occurs at depths ranging from about 2,100 to 2,500 feet (640 to 760 meters). Unrestricted flows from wells developed in the aquifer range from 30 to 100 gallons per minute (2 to 6.3 liters per second). Water from the Dakota aquifer generally is hard. Dissolved solids in water samples from the aquifer ranged from 1,930 to 2,380 milligrams per liter and sulfate concentrations ranged from 1,100 to 1,300 milligrams per liter.

INTRODUCTION

The study of the ground-water resources in McIntosh County was started July 1, 1975. The study was made by the U.S. Geological Survey in cooperation with the North Dakota State Water Commission, North Dakota Geological Survey, and the McIntosh County Water Management District. Data collection for the study was completed during October 1977.

Purpose and Scope

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

Geologic and hydrologic data were collected from 747 wells and test holes to help determine the location and extent of the aquifers. Monthly water-level measurements were made in 105 observation wells in order to determine the effects of precipitation and pumpage on various aquifers. Two aquifer tests were made to determine the transmissivity and storage coefficient of specific aquifers. Twenty-four-hour commercial development tests were used to determine the transmissivity of some aquifers. Chemical analyses of water samples from 185 wells were used to determine the chemical composition of ground water in the area.

Location and Physical Geography

McIntosh County has an area of 997 mi^2 (2,580 km^2) in south-central North Dakota (fig. 1). The county is located within the glaciated Missouri Plateau section of the Great Plains physiographic province (Fenneman, 1946). Although the county is in the Missouri River drainage basin, most of the drainage is internal. Numerous lakes and prairie potholes are present and most of them are intermittently wet and dry. The South Branch Beaver Creek, an intermittent stream, drains approximately 180 mi^2 (470 km^2) in the northwestern part of the county.

Climate

The climate of McIntosh County is semiarid. U.S. Environmental Data Service (1973) records show that the mean annual precipitation is 17.96 inches (456 mm) at Ashley and 17.78 inches (452 mm) at Wishek. Most of the precipitation (75-80 percent) occurs from April through September. Much of the summer precipitation is derived from local thunderstorms; consequently, the amount of precipitation received in 1 year varies considerably throughout the county.

The mean annual temperature is 40.5°F (4.7°C) at Ashley and 39.4°F (4.1°C) at Wishek. During June, July, and August, the warmest months, the mean temperatures range from 66.0°F to 68.9°F (16.6°C to 20.5°C). During January, the coldest month, mean temperatures range from 8.2°F (-13.2°C) at Ashley to 6.6°F (-14.1°C) at Wishek.

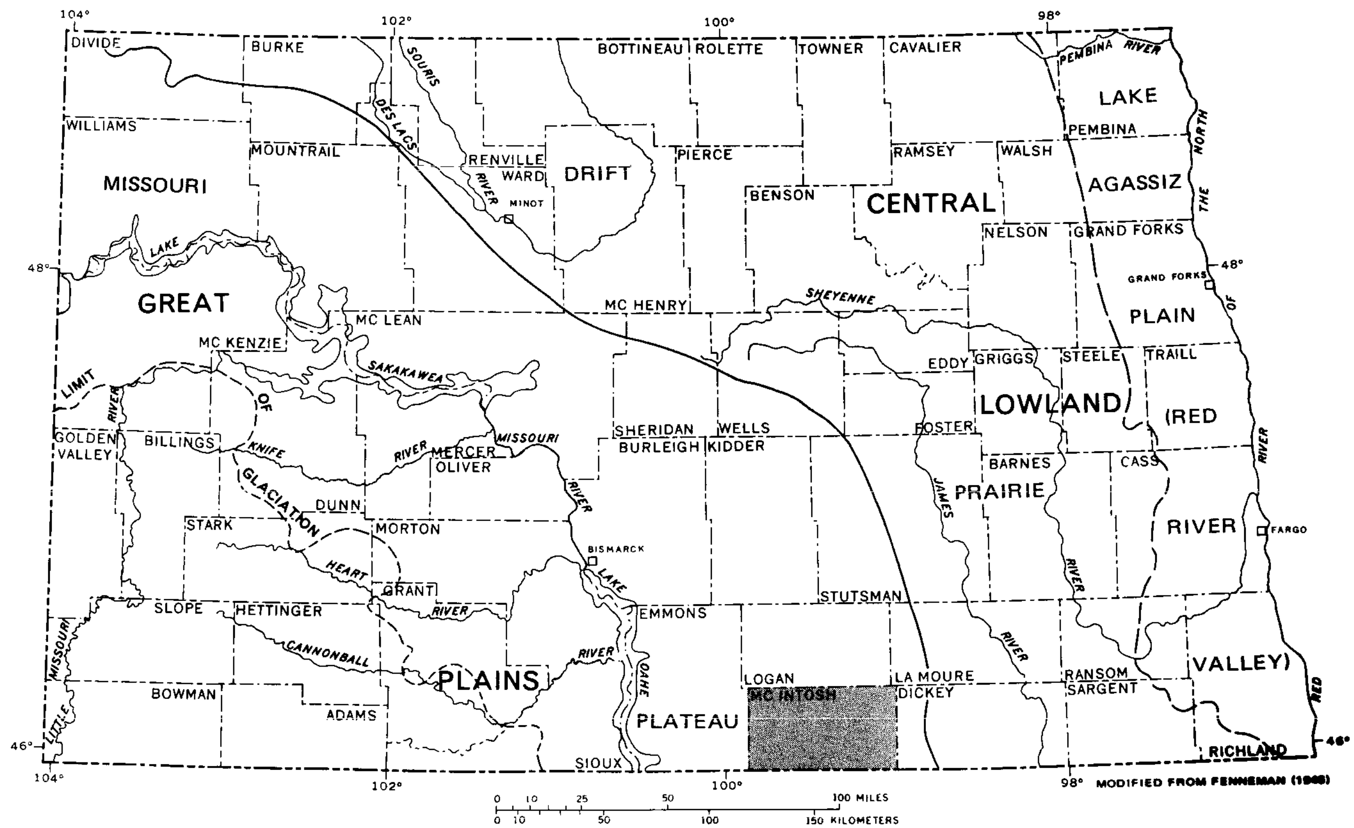

FIGURE 1.—Physiographic divisions in North Dakota and location of study area.

Location-Numbering System

The wells and test holes mentioned in this report are numbered according to a system based on the public land classification of the U.S. Bureau of Land Management. The system is illustrated in figure 2. The first sequence of numerals denotes the township north of a base line, the second series of numbers the range west of the Fifth Principal Meridian, and the third series indicates the section in which the well 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. For example, well 130-073-15ADC is in the SW¼SE¼NE¼ sec. 15, T. 130 N., R. 073 W. Consecutive terminal numbers are added if more than one well or test hole is recorded within a 10-acre (4-ha) tract.

Previous Investigations

Simpson (1929, p. 161-162) briefly described the geology and the occurrence of water in the glacial drift and underlying bedrock. Records of wells and chemical analyses of water from selected wells in McIntosh County are included in Simpson's report. Laird and Akin (1948) described the geology and ground-water resources in the Zeeland area. Their report contains logs of numerous wells, water-quality data, and the results of an aquifer test. A report by Randich (1961) describes the occurrence of ground water in the glacial drift in the vicinity of Ashley, and includes logs of test holes, well records, and water-quality data. Adolphson (1962) described the geology and ground-water resources in the Lehr area. His report contains logs of test holes and a chemical analysis of the water from a flowing well.

Clayton (1962) described the glacial geology of McIntosh County. His report was used as a general guide for the present study.

Acknowledgments

The collection of data for this report was made possible by the cooperation of the McIntosh County Water Management District and by the residents of the county who provided information during the study. Royce Cline and G. L. Sunderland of the North Dakota State Water Commission prepared lithologic logs and electric logs on most of the test holes. R. B. Shaver and T. L. Johnson, also with the North Dakota State Water Commission, did much of the aquifer-test work.

GEOLOGIC SETTING

The preglacial sedimentary rocks underlying McIntosh County were deposited on the eastern flank of a large, sporadically subsiding basin now known as the Williston basin. During Paleozoic time a Precambrian structural high located in Burleigh County was subjected to intermittent uplift (Ballard, 1963).

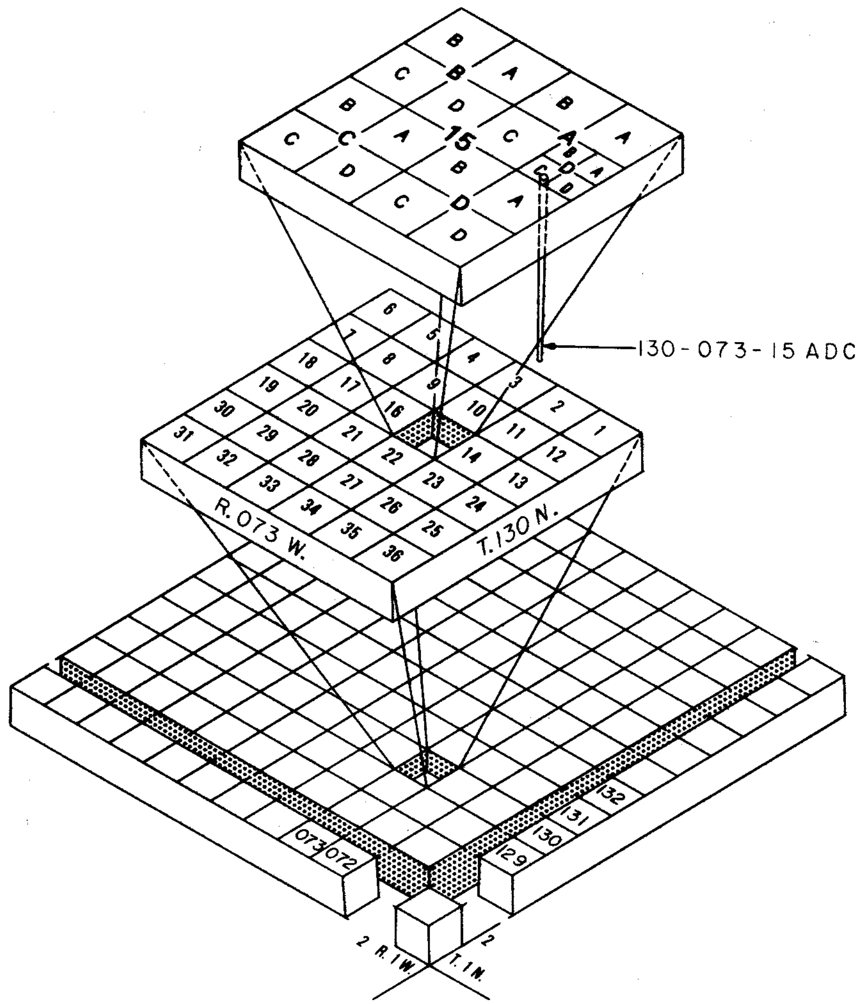

FIGURE 2.—Location-numbering system.

Uplift of this structural feature resulted in thinning and nondeposition of some Paleozoic rocks. Following a period of erosion, deposition was renewed in early Mesozoic time and continued into the Cenozoic Era.

The sedimentary rocks deposited during Paleozoic time consist principally of limestone, dolomite, and lesser amounts of sandstone, shale, and evaporites. This sequence of sedimentary rocks ranges in thickness from about 1,000 feet (300 m) in the eastern part of McIntosh County to about 2,000 feet (600 m) in the western part.

The sedimentary rocks deposited during Mesozoic time consist principally of shale; however, some well-developed sandstones are present in the Lower Cretaceous Dakota Group[1] and in the Upper Cretaceous Fox Hills Formation. The rocks of Mesozoic age range in thickness from about 2,400 feet (730 m) in the eastern part of the county to about 2,900 feet (880 m) in the western part.

The rocks of Cenozoic age that are present in the county are the glacial-drift deposits that were laid down during the Pleistocene Epoch and thin alluvial and fluvial deposits of Holocene age. These deposits have not been differentiated in this report.

Topography of the Pierre Formation

The Pierre Formation underlies all of McIntosh County. It consists of dark-gray to black siliceous shale that is about 1,000 feet (300 m) thick. The topography of the formation (pl. 1, in pocket) indicates that it has been subjected to considerable erosion.

The Fox Hills Formation overlies the Pierre in the northwestern third of the county, and occurs as small outliers in the southern and eastern parts of the county. Where the Fox Hills Formation is missing, the Pierre is overlain by glacial-drift deposits.

The erosional features of the Pierre Formation where it is overlain by the Fox Hills Formation probably were formed prior to or during the deposition of the Fox Hills. The erosional features of the Pierre where it is overlain by glacial-drift deposits are due to both preglacial and proglacial erosion. The topography of the Pierre Formation defines to some extent the location of bedrock valleys and depressions, some of which contain major glacial-drift aquifers.

Glacial-Drift Deposits

Glacial-drift deposits of Quaternary age cover almost all of McIntosh County, and unconformably overlie sedimentary rocks of Late Cretaceous age. The deposits range in thickness from 0 to 420 feet (0 to 130 m). They are

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

unconsolidated and consist of fragments of older rocks that have been eroded and transported by glaciers. In McIntosh County the glacial-drift deposits have been divided into four main types, based on lithology and inferred origin. The types are till, glaciofluvial deposits, ice-contact deposits, and lake deposits.

Till

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 differ considerably. Till is deposited from glacial ice by dumping, pushing, lodgement, and ablation. In places large blocks of locally derived bedrock, such as shale or sandstone, are incorporated in the till.

Glaciofluvial Deposits

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.

Ice-Contact Deposits

Ice-contact deposits consist principally of sand, gravel, and clay deposited in contact with melting glacial ice. These deposits were characterized by abrupt changes in sorting, and by slumped and contorted bedding.

Lake Deposits

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

OCCURRENCE AND QUALITY OF WATER

General Concepts

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

Ground water moves by gravity from areas of recharge to areas of discharge. Ground-water movement generally is very slow; it may be only a few feet per year. The rate of movement is governed by the hydraulic conductivity of the material through which the water moves and by the hydraulic gradient. Well-sorted gravel and coarse sand generally have a relatively large hydraulic conductivity. Deposits of these materials commonly form good aquifers. Fine-grained materials such as silt, clay, and shale usually have a relatively small hydraulic conductivity and are poor aquifers.

The water level in an aquifer fluctuates primarily in response to changes in the rate of recharge to and discharge from the aquifer. Shallow aquifers generally are recharged each spring and early summer by direct infiltration of precipitation. Recharge to these aquifers generally is sufficient to replace losses caused by natural discharge and by pumping of wells, although periods of several years may occur during which there are net gains or losses in ground-water storage. Aquifers that are confined by thick deposits of fine-grained materials such as clay or silt are recharged very slowly. Replenishment of these aquifers is by percolation from adjacent sediments or by infiltration of precipitation through the fine-grained materials. The rate of recharge may increase as heads in the aquifers are lowered by pumping; however, head declines may continue for several years before sufficient recharge is induced to balance the rate of withdrawal. In some aquifers this balance may never be achieved without a curtailment of withdrawals.

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

The suitability of water for various uses is determined largely by the kind and amount of dissolved minerals and by its physical properties. The chemical constituents, physical properties, and characteristics most likely to be of concern in McIntosh 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 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 analyses and represent the predominant cation (sodium, calcium, or magnesium) and anion (bicarbonate, sulfate, or chloride), expressed in milliequivalents per liter (Hem, 1970).

As a general reference, this report uses the following classification of water hardness (Durfor and Becker, 1964, p. 27).

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

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

Constituents	Major source	Effects upon usability	U.S. Environmental Protection Agency (1976,1977) recommended limits for drinking water
Silica (SiO_2)	Feldspars, ferromagnesian, and clay minerals.	In presence of calcium and magnesium, silica forms a scale that retards heat transfer in boilers and on steam turbines.	
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, calcite, aragonite, dolomite, and clay minerals.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate, and silica to form scale in heating equipment. Calcium and magnesium retard the suds-forming action of soap. Excessive concentrations of magnesium have a laxative effect.	
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, dolomite, magnesite, and clay minerals.		
Sodium (Na)	Feldspars, clay minerals, evaporites, and cation exchange with calcium and magnesium on clay minerals.	More than 50 mg/L (milligrams per liter) sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers.	
Potassium (K)	Feldspars, feldspathoids, some micas, and clay minerals.		
Bicarbonate (HCO_3)	Limestone, dolomite, and anaerobic processes.	Upon heating of water to the boiling point, bicarbonate is changed to steam, carbonate, and carbon dioxide. Carbonate combines with alkaline earths (principally calcium and magnesium) to form scale.	
Carbonate (CO_3)			
Sulfate (SO_4)	Gypsum, anhydrite, and oxidation or weathering of sulfide minerals in lignite.	Combines with calcium to form scale. More than 500 mg/L tastes bitter and may be a laxative.	250 mg/L
Chloride (Cl)	Halite and sylvite.	In excess of 250 mg/L may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 mg/L.	250 mg/L
Fluoride (F)	Amphiboles, apatite, fluorite, and mica.	Optimum concentration in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. Concentrations in excess of optimum may cause mottling of children's teeth.	Recommended maximum limits depend on average of maximum daily temperatures. Maximum limits range from 1.4 mg/L at 32°C to 2.4 mg/L at 10°C.
Nitrate (NO_3)	Nitrogeneous fertilizers, animal excrement, legumes, and plant debris.	More than 100 mg/L may cause a bitter taste and may cause physiological distress. Concentrations greatly in excess of 45 mg/L have been reported to cause methemoglobinemia in infants.	10 mg/L
Iron (Fe)	Natural sources: Amphiboles, ferromagnesian minerals, ferrous and ferric sulfides, oxides, carbonates, and clay minerals. Manmade sources: well casings, pump parts, and storage tanks.	If more than 100 ug/L (micrograms per liter) iron is present, it will precipitate when exposed to air causing turbidity, staining plumbing fixtures, laundry, and cooking utensils, and imparting tastes and colors to food and drinks. More than 200 ug/L iron is objectionable for most industrial uses. Excessive concentrations of manganese cause difficulty in water-quality control.	300 ug/L
Manganese (Mn)			50 ug/L
Boron (B)	Tourmaline, biotite, and amphiboles.	Many plants are damaged by concentrations of 2,000 ug/L.	
Dissolved solids	Anything that is soluble.	Less than 300 mg/L is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	500 mg/L

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 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 Staff (1954).

Aquifer Properties

Aquifer properties such as hydraulic conductivity, transmissivity, and specific capacity are used in evaluating the water-yielding properties of aquifers. These properties together with specific yield and saturated volume of the aquifer are used to estimate the yields to wells developed in the aquifer and to estimate the quantity of water available from the aquifer.

Hydraulic conductivities of materials in the glacial-drift aquifers were estimated from the following table. The smaller or an intermediate value was used unless the lithologic log indicated the material was well sorted.

Material	Hydraulic conductivity	
	(feet per day)	(meters) per day)
Gravel	[1]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.

Transmissivities of glacial-drift aquifers were calculated by multiplying the estimated hydraulic conductivity by the saturated thickness of each sand and gravel interval — the total transmissivity is the sum of the individual sand and gravel beds.

Meyer (1963, p. 338-340, fig. 100) published a chart relating well diameter, specific capacity, coefficient of storage, and transmissivity. The relation shows that for coefficients of storage less than 0.005 (generally confined aquifers) and for transmissivities within the range 270 ft^2/d to 13,000 ft^2/d (25 to 1,200 m^2/d) the ratio of transmissivity to specific capacity is about 270:1. The ratio is larger for transmissivities greater than 13,000 ft^2/d (1,200 m^2/d). In most confined aquifers the storage coefficient is within the range of 0.00005 to 0.005, and the chart shows that, within this range, large changes in the storage coefficient correspond to relatively small changes in specific capacity. Therefore, in confined aquifers having transmissivities of as much as 13,000 ft^2/d (1,200 m^2/d) the specific capacity of an efficient, fully penetrating well may be approximated by dividing the transmissivity by 270. The yield of a potential well at a specific site is estimated by multiplying the specific capacity by a drawdown value of 30 feet (9 m). Where 30 feet (9 m) of drawdown was not available, one-half the saturated thickness was used to estimate yield.

The same chart shows that for aquifers having a coefficient of storage larger than 0.005 (unconfined aquifers), the specific capacity will be larger, and the ratio of transmissivity to specific capacity will approach 134:1 for relatively small values of transmissivity and relatively large values of the storage coefficient. For this type of aquifer yields of efficient wells would be as much as twice as great as for similar wells in a confined aquifer with the same transmissivity.

GEOLOGIC UNITS AND THEIR HYDROLOGIC PROPERTIES

Geologic units that contain aquifers of economic importance in McIntosh County are: (1) the Fall River and Lakota Formations of Early Cretaceous age, (2) the Fox Hills Formation of Late Cretaceous age, and (3) the glacial-drift deposits of Quaternary age (table 2).

Aquifers of Cretaceous Age

Dakota Aquifer

The Dakota aquifer, which underlies all of McIntosh County, consists of the Fall River and Lakota Formations. The depth to the top of the aquifer ranges from about 2,100 feet (640 m) in the eastern part of the county to about 2,500 feet (760 m) in the western part; the dip is west-northwest at about 8 ft/mi (1.5 m/km).

The aquifer is composed of very fine to coarse-grained sandstone interbedded with siltstone and shale. The aggregate thickness of the sandstone ranges from 115 feet (35 m) to as much as 160 feet (50 m).

Using a method described by Croft (1971, p. B265-B269), hydraulic conductivity values of the Fall River-Lakota interval were calculated from electric logs of three oil-test holes. The conductivities ranged from 85 to 130 ft/d (26 to 40 m/d). Estimated transmissivities at the three sites ranged from 1,300 to about 20,800 ft^2/d (120 to 1,930 m^2/d).

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

System and Epoch	Formation	Dominant lithology	Approximate maximum thickness (feet)	Water-yielding characteristics
Quaternary	Glacial drift	Clay, silt, sand, and gravel.	420	Yields as much as 1,500 gal/min from thicker and more permeable sand and gravel deposits.
Late Cretaceous	Fox Hills Formation	Claystone, siltstone, and sandstone.	260	Yields as much as 50 gal/min from thicker and more permeable sandstone beds.
	Pierre Formation	Shale.	1,000	Relatively impermeable. Not known to yield water in McIntosh County.
	Niobrara and Carlile Formations, undifferentiated	Shale.	570	Relatively impermeable. Not known to yield water in McIntosh County.
	Greenhorn and Belle Fourche Formations, undifferentiated	Shale.	420	Relatively impermeable, except for thin sand beds which may yield small quantities of water.
Early Cretaceous	Mowry Formation	Shale.	50	Relatively impermeable. Not known to yield water in McIntosh County
	Newcastle Sandstone	Shale and sandstone	100	Not known to yield water to wells in McIntosh County. Thin sandstone beds may yield small quantities of water.
	Skull Creek Formation	Shale, sandy.	120	Relatively impermeable.
	Fall River and Lakota Formations, undifferentiated (Dakota aquifer)	Sandstone, shale, and siltstone.	280	Yields as much as 2,000 gal/min from thicker and more permeable sandstone beds.

Assuming that 24-hour specific capacities would range from 5 to 77 (gal/min)/ft [1 to 16 (L/s)/m] of drawdown, properly constructed wells would yield 150 to as much as 2,300 gal/min (9 to 140 L/s), assuming 30 feet (9 m) of drawdown. These wells would have to be constructed of large-diameter pipe and be screened through the total aquifer thickness in order to reduce head and friction losses. Withdrawals of large quantities of water for an extended period of time will result in a decline of the water level.

Three wells were producing water from the Dakota aquifer during 1977. Two of these wells were drilled to provide water for the cities of Venturia and Zeeland; the third well was drilled to provide water for livestock. The Zeeland well, which is 2,516 feet (767 m) deep, had an initial flow rate of 100 gal/min (6 L/s), and the stock well, which is 2,561 feet (781 m) deep, had an initial flow rate of 30 gal/min (2 L/s). The well at Venturia is reported to be 2,495 feet (761 m) deep and is reported to have a static water level of about 20 feet (6 m) below land surface. A head measurement made on the flowing well at Zeeland indicates that wells developed in the aquifer will flow at land surface altitudes of less than 2,100 feet (640 m).

The Dakota aquifer is recharged by upward migration of water from underlying aquifers that have much higher heads than the Dakota aquifer (Swenson, 1968). Water is discharged from the aquifer by pumping and by lateral movement eastward into adjacent counties. Concentrations of major constituents or physical properties of three samples of water from the Dakota aquifer are listed in the following table.

Constituent or property	Location		
	129-071-15AAB	129-073-03DBC	129-073-21CDB
Calcium (Ca) (mg/L)	93	270	290
Magnesium (Mg) (mg/L)	31	79	76
Sodium (Na) (mg/L)	460	260	330
Potassium (K) (mg/L)	11	17	20
Bicarbonate (HCO_3) (mg/L)	188	185	180
Sulfate (SO_4) (mg/L)	1,100	1,300	1,200
Chloride (Cl) (mg/L)	71	85	180
Fluoride (F) (mg/L)	1.4	2.5	3.0
Nitrate (NO_3) (mg/L)	1	1	—
Boron (B) (ug/L)	1,400	470	360
Iron (Fe) (ug/L)	1,400	6,200	3,600
Manganese (Mn) (ug/L)	60	180	160
Dissolved solids (mg/L)	1,930	2,180	2,380
Hardness	360	1,000	1,000
Percent sodium	73	36	40
Sodium-adsorption ratio (SAR) (units)	11	3.6	4.5

The Newcastle Sandstone, which is part of the Dakota aquifer in the eastern part of the State, consists of siltstone and very fine to medium-grained sandstone. Locally the sandstones in the Newcastle probably will yield some water. However, the Newcastle Sandstone is not considered to be an important source of water in McIntosh County because it is generally thinner and appears to have a much smaller hydraulic conductivity than the underlying Fall River and Lakota Formations.

Fox Hills Aquifer

The Fox Hills Formation occupies an area of about 320 mi^2 (830 km^2) in western McIntosh County. The formation is missing in the eastern and southern parts of the county, except for a few small outliers. The Fox Hills disconformably overlies the Pierre Formation. The Fox Hills crops out locally in the northwestern part, and is unconformably overlain by glacial-drift deposits elsewhere (pl. 2, in pocket). The Fox Hills Formation has a maximum thickness of about 260 feet (79 m).

The Fox Hills aquifer underlies an area of about 280 mi^2 (725 km^2) in the northwestern part of the county (fig. 3). The aquifer is composed predominantly of very fine to fine-grained poorly consolidated clayey glauconitic sandstone. The sandstone beds, which range in thickness from 1 to about 82 feet (0.3 to 25 m), may be interbedded with silt and clay or occur as relatively thick sand bodies.

Yields from the Fox Hills aquifer depend on the thickness and hydraulic conductivity of the sand and sandy clay beds. Yields of as much as 50 gal/min (3 L/s) probably could be obtained from the thicker sand beds provided that the well is screened throughout the entire saturated thickness. However, yields to most wells developed in the sand sections of the aquifer probably will range from 5 to 30 gal/min (0.3 to 2 L/s). Data from driller's logs indicate that locally large-diameter (24-inch or 610-mm) wells developed in the sandy clay will provide small supplies of water. No reliable data are available to indicate what the yields to wells developed in the sandy clay part of the aquifer might be; however, it is presumed that the yields probably would range from about 0.5 to 3 gal/min (0.03 to 0.2 L/s).

The Fox Hills aquifer is recharged by infiltration from precipitation or surface runoff, and by lateral and vertical movement of water from the glacial-drift deposits. Water is discharged from the aquifer by pumping, seepage into intermittent streams, and lateral movement into the glacial-drift deposits.

Comparison of water-level data from observation wells with the well logs indicates that ground water in the Fox Hills aquifer generally is unconfined. The altitude of the water table in the Fox Hills aquifer and associated glacial-drift deposits is shown on sections A-A′ and B-B′ (pl. 2). Water levels in 10 observation wells ranged from about 7 to 69 feet (2 to 21 m) below land surface. Monthly water-level fluctuations generally are less than 1 foot (0.3 m). The highest water levels generally occur during April and May.

Water from the Fox Hills aquifer generally is very hard. Analyses of water samples collected from 21 wells developed in the aquifer indicate that the water is a mixed type. Sodium, calcium, and magnesium are the dominant cations and bicarbonate and sulfate are the dominant anions.

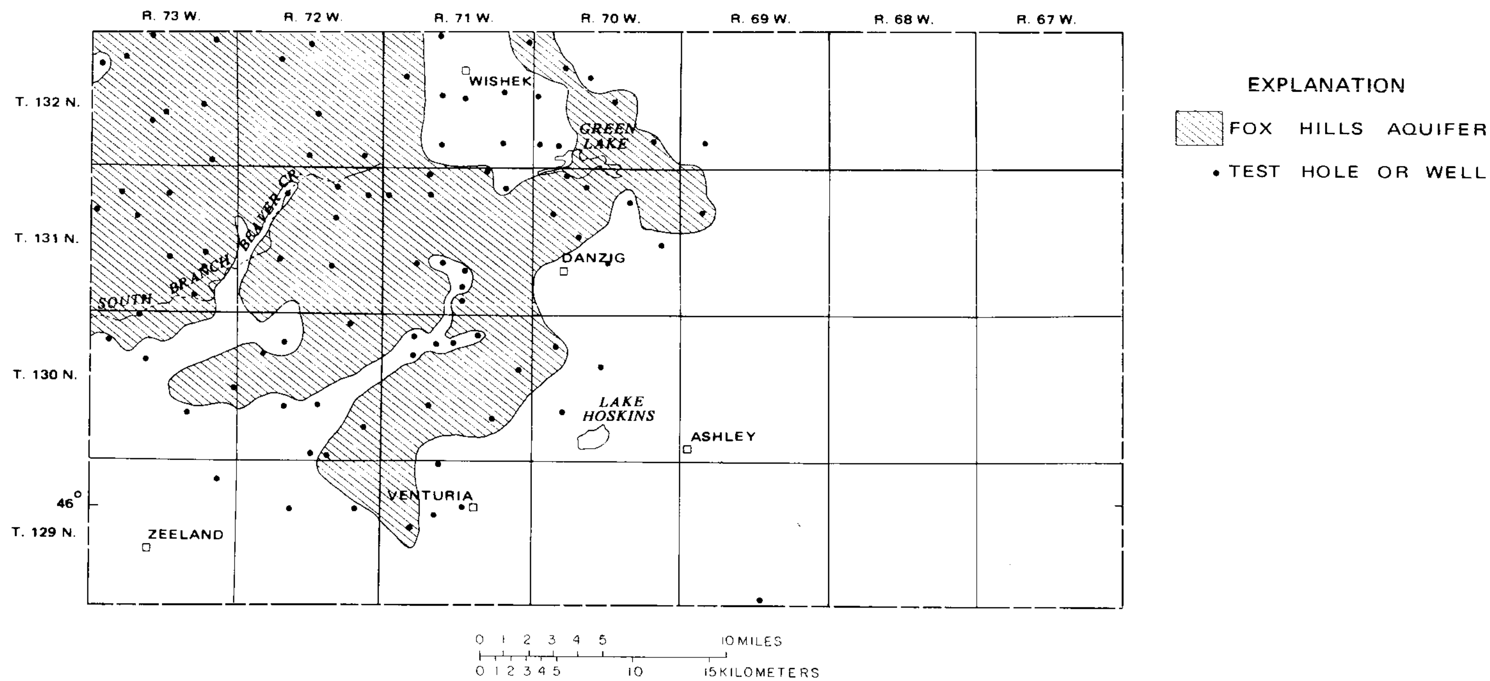

FIGURE 3.—Extent of Fox Hills aquifer.

Dissolved-solids concentrations in the 21 samples ranged from 227 to 4,220 mg/L and had a median of 519 mg/L; however, dissolved-solids concentrations were less than 700 mg/L in 14 samples. Sulfate ranged from 7 to 2,500 mg/L and had a median of 98 mg/L; but sulfate concentrations were less than 250 mg/L in 15 samples. Iron concentrations were less than 300 ug/L in 18 of the samples. Manganese exceeded the recommended limit of 50 ug/L in 17 of the samples. The larger concentrations of dissolved solids and sulfate in the water occur where the aquifer is overlain by oxidized glacial till.

The analyses indicate a low to very high sodium hazard and a medium to very high salinity hazard for irrigation purposes (fig. 4). SAR values ranged from 0.2 to 21; however, 11 of the samples had SAR values of less than 2. Specific conductance ranged from 400 to 5,000 umho/cm, but 12 of the samples had specific conductance values of less than 1,000 umho/cm. Most of the samples had irrigation classifications of C2-S1 or C3-S1.

Aquifers of Quaternary Age

Aquifers in the glacial-drift deposits, particularly those of glaciofluvial origin, have the greatest potential for ground-water development in McIntosh County. The aquifers occur as buried-valley deposits, buried- and surficial-outwash deposits, melt-water-channel deposits, and as undifferentiated sand and gravel deposits.

For convenience of discussion and identification and for future reference, the aquifers in the glacial-drift deposits in this report are named after political entities or geographic features such as lakes and streams. However, if an aquifer has been formally named in an adjacent area and the aquifer extends into McIntosh County, the name applied in the adjacent area takes precedence. The order of discussion of the aquifers is based on areal extent.

Where sufficient test drilling and hydrologic data are available, estimates of ground water available from storage are given for each aquifer. The estimates are products of areal extent, mean saturated thickness, and the specific yield, which is assumed to be about 15 percent. The storage estimates are provided for comparison purposes only, and are based on static conditions. They do not take into account recharge, discharge by evapotranspiration, springs, or ground-water movement between superimposed or adjacent aquifers. The quantitative evaluation of these factors is beyond the scope of the present study.

The estimated potential yields of the aquifers are shown on the ground-water availability map (pl. 3, in pocket). The aquifers are generally 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 valleys generally have smaller maximum sustained yields than wells developed in aquifers of comparable thickness that have a large areal extent. Where aquifers are superimposed, one upon another, the maximum yield is obtainable only by wells open to all aquifers.

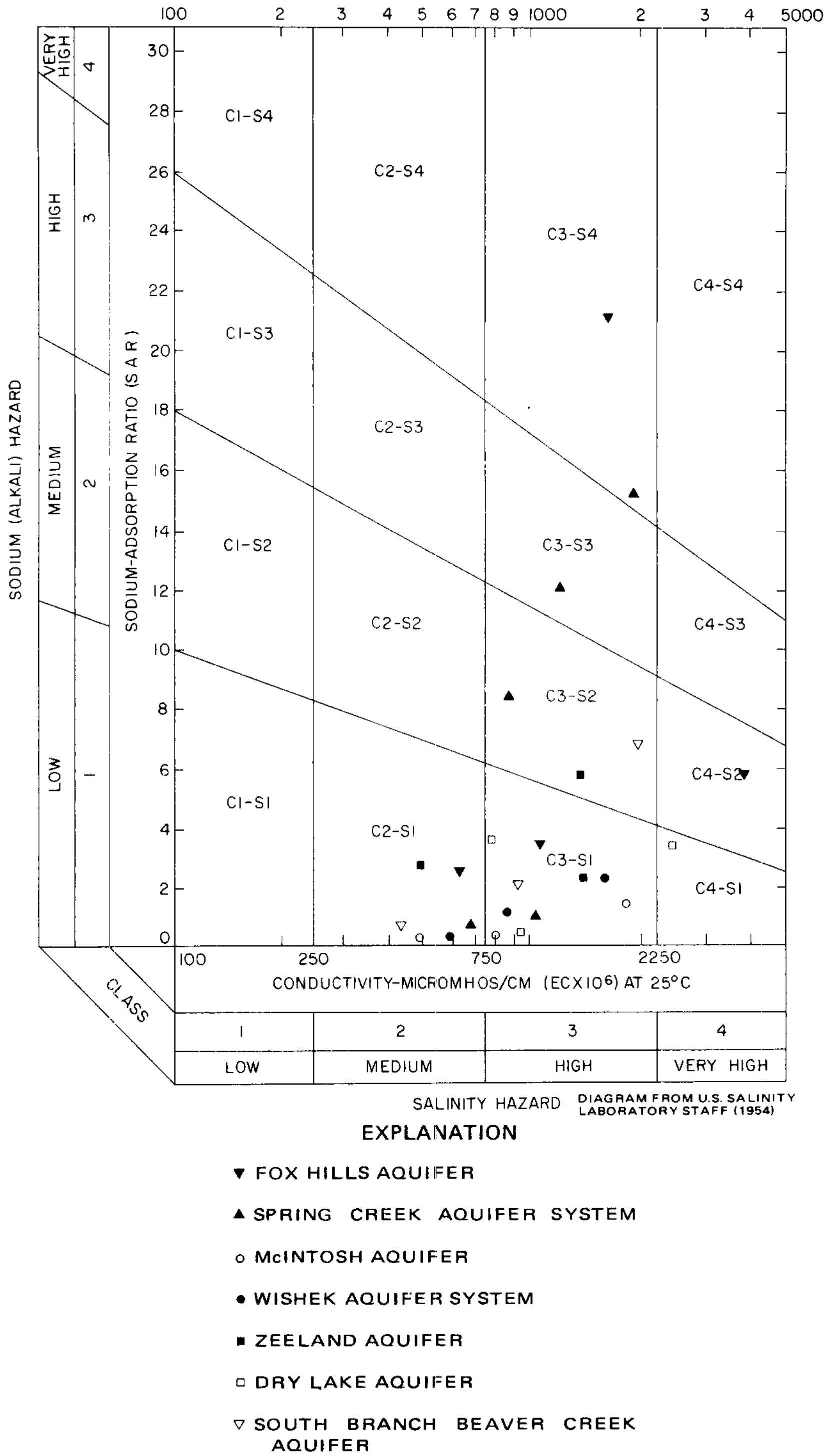

FIGURE 4.—Classifications of selected water samples for irrigation use.

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

Spring Creek Aquifer System

The Spring Creek Aquifer system underlies an area of about 88 mi^2 (230 km^2) in southeastern McIntosh County. The aquifer system extends southward from T. 131 N., Rs. 68 and 69 W. to the South Dakota border, and is part of the Spring Creek aquifer identified by Hamilton (1974) in McPherson County, South Dakota.

The Spring Creek aquifer system is a complex system of buried-valley and buried-outwash aquifers. The aquifers consist of sand and gravel deposits (pl. 4, secs. C-C′, D-D′, and E-E′) that merge near the South Dakota border to form a vertical sequence of four laterally extensive aquifers (pl. 4, sec. E-E′). Locally, late proglacial and postglacial erosion has exposed the uppermost aquifer.

The aquifer materials range in size from very fine sand to coarse gravel; the predominant lithology is coarse to very coarse gravelly sand. The aquifer system has a maximum aggregate thickness of 91 feet (28 m) and a mean saturated aggregate thickness of 39 feet (12 m).

A development test was made on Ashley municipal well 130-069-30DCC, which was drilled in January of 1975. The well penetrated 18 feet (5.5 m) of fine gravel in the interval from 152 to 170 feet (46 to 52 m) and was screened with 10-inch (254-mm) diameter, 40-slot, stainless steel screen from 156 to 170 feet (48 to 52 m). The static water level was reported to be 74 feet (23 m) below land surface. Data from the test indicate that the well was pumped at a rate of 250 gal/min (16 L/s) for 24 hours. Drawdown was 38 feet (12 m) and the calculated specific capacity was about 7 (gal/min)/ft [1 (L/s)/m]. The transmissivity of the aquifer in the vicinity of the well was estimated to be about 1,300 ft^2/d (120 m^2/d).

An aquifer test was made by the North Dakota State Water Commission (T. Johnson, written commun., 1978) in June of 1978. Production well 129-067-28BCB4 penetrated sandy gravel from 136-170 feet (41-52 m). The well was screened with 10-inch (254-mm), 50-slot carbon steel screen from 136-161 feet (41-49 m). The static water level was 42 feet (13 m). The well was pumped at a rate of 893 gal/min (56 L/s) for about 100 hours. Water levels were measured in the production well and in seven observation wells. Data from the test indicated a specific capacity of 26.8 (gal/min)/ft [5.5 (L/s)/m] of drawdown. Calculated transmissivities ranged from about 6,600 ft^2/d to 20,400 ft^2/d (610 to 1,900 m^2/d). The average transmissivity was about 10,000 ft^2/d (930 m^2/d). The smaller transmissivities occurred in wells that were located near impermeable boundaries, and that were developed in areas where the aquifer was only about one-half the maximum thickness. The closest boundary was about 600 feet (180

m) south of the production well. The farthest boundary was about 10,000 feet (3,000 m) west of the production well, but the effects of this boundary were masked by thickening of the aquifer. The storage coefficient was about 1.2×10^{-4}.

Potential yields to wells developed in the Spring Creek aquifer system will vary depending on the saturated thickness and hydraulic conductivity of the materials penetrated. Yields to wells developed in the aquifer system will range from 50 to 1,000 gal/min (3 to 63 L/s). Yields of 500 to 1,000 gal/min (32 to 63 L/s) generally can be obtained where the aquifer system has an aggregate saturated thickness in excess of 30 feet.

Recharge to the Spring Creek aquifer system is from infiltration of precipitation and surface runoff that accumulates in potholes and sloughs. Water-level data from observation wells developed in the different aquifers show that those in the upper part of the system have higher static heads than those in the lower part. This indicates that the potential exists for the downward movement of water through the system.

Water is discharged from the aquifer system by seepage into lakes and sloughs, by evapotranspiration, by pumping, and by lateral movement out of the study area. Water-level data from observation wells indicate that regional movement of ground water in the system is to the south (pl. 3). A ground-water divide occurs in the eastern part of sec. 36, T. 131 N., R. 69 W., and water moves eastward and southwestward from the divide.

Water flowed from a few of the test holes drilled in topographically low areas. Flow rates ranged from about 1 to 20 gal/min (0.06 to 1 L/s). The static head in observation well 129-068-31ADA was 11.1 feet (3.4 m) above land surface in November 1976.

Water in the aquifer system generally is confined; however, water in the uppermost outwash deposit may be unconfined. Generally the uppermost outwash is only partly saturated, and in places may be dry. Water levels in the aquifer system range from 11 feet (3 m) above land surface to 110 feet (30 m) below land surface. Monthly water-level fluctuations are generally less than 1 foot (0.3 m) and reflect changes in storage caused by discharge and recharge to the aquifer. The highest water levels, especially in the shallow aquifers, occur during March, April, and May. However, in the vicinity of Ashley, the water-level fluctuations shown in figure 5 are caused by the pumping of two municipal wells in the city. The hydrographs show that the lowest water level in the wells occurs during the summer months when there is greatest demand for water. The recovery of the water level from September to March was due to a reduction in the amount of water pumped by the city.

Water samples were collected from 41 wells ranging in depth from 20 to 290 feet (6 to 88 m). Analyses of the samples show that the water in the aquifer system consists of mixed types. The analyses also indicate there is no correlation between water type and depth of well. The most common mixed water types are sodium bicarbonate-sulfate and calcium-sodium-magnesium bicarbonate. These water types comprised 36 percent of the samples collected. Twenty percent of the samples were calcium bicarbonate type.

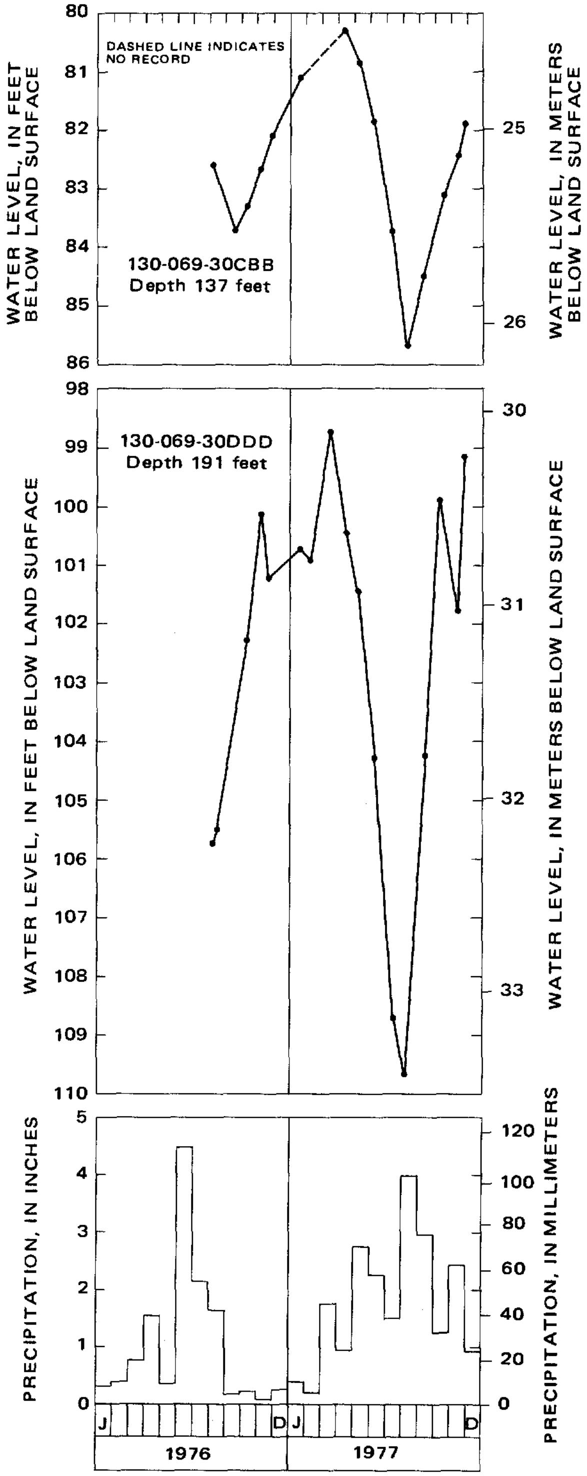

FIGURE 5.–Water-level fluctuations in the Spring Creek aquifer system and precipitation at Ashley.

Dissolved-solids concentrations ranged from 467 to 1,410 mg/L and had a median of 791 mg/L. Sulfate concentrations exceeded 250 mg/L in 22 of the samples, iron concentrations were greater than 300 ug/L in 11 samples, and manganese exceeded the recommended limit of 50 ug/L in 40 samples. The water is hard to very hard.

Analyses indicate a generally low to medium sodium hazard and high salinity hazard for irrigation purposes. SAR values ranged from 0.2 to 15 and specific conductance ranged from 610 to 2,000 umho/cm. Irrigation classifications were C2-S1 to C3-S4 (fig. 4), but were predominantly C3-S1.

Based on an areal extent of 88 mi^2 (230 km^2), a mean thickness of 39 feet (12 m), and a specific yield of 15 percent, about 329,000 acre-feet (406 hm^3) of the water stored in the Spring Creek aquifer system would be available to wells.

McIntosh Aquifer

The McIntosh aquifer underlies an area of about 22 mi^2 (57 km^2) in northeastern McIntosh County. The aquifer extends from sec. 36, T. 132 N., R 69 W., into Logan County along the northern edge of T. 132 N., Rs. 68 and 69 W.

The aquifer consists for the most part of buried outwash (pl. 4, sec. F-F′). However, along the southwestern and western edges, the aquifer occurs as surficial outwash. The outwash deposits are composed of very fine to very coarse gravelly sand. Individual sand and gravel beds range from 5 to as much as 53 feet (2 to 16 m) in thickness. The mean saturated aggregate thickness is 29 feet (8.8 m).

Locally, yields of as much as 500 gal/min (32 L/s) may be sustained for a day or so; however, most yields will range from 50 to 200 gal/min (3 to 13 L/s).

The McIntosh aquifer is recharged by infiltration of precipitation and locally by infiltration from surface runoff. Water is discharged from the aquifer by seepage into sloughs, by evapotranspiration, and by pumping.

Water-level data from observation wells show that ground water in the aquifer may be confined or unconfined. Water levels in the confined part of the aquifer range from about 6 to 46 feet (2 to 14 m) below land surface. Water levels in the unconfined part of the aquifer range from 12 to about 19 feet (3.7 to 5.8 m) below land surface.

Analyses of seven water samples from the aquifer show that four of the samples were a calcium bicarbonate type water, one was a calcium sulfate type, and the rest were a mixed water type. Dissolved solids in the samples ranged from 361 to 1,420 mg/L and had a median of 688 mg/L. Sulfate ranged from 38 to 690 mg/L; however, only two of the samples had sulfate concentrations that exceeded of 250 mg/L. Iron concentrations were less than 300 ug/L in five of the samples. Manganese concentrations exceeded 50 ug/L in all of the samples.

The water has a low sodium hazard and a medium to high salinity hazard for irrigation purposes. SAR values ranged from 0.1 to 1.7 and the specific conductance ranged from 515 to 1,590 umho/cm. Irrigation classifications were C2 -S1 and C3-S1 (fig. 4).

Based on an areal extent of 22 mi^2 (57 km^2), a mean thickness of 29 feet (8.8 m), and a specific yield of 15 percent, about 61,000 acre-feet (75 hm^3) of the water stored in the McIntosh aquifer would be available to wells.

Wishek Aquifer System

The Wishek aquifer system underlies an area of about 21 mi^2 (54 km^2) in north-central McIntosh County. The system extends southward from the county line north of the city of Wishek to about 1 mile (1.6 km) southeast of Green Lake (pl. 3).

The aquifer system consists of two aquifers (pl. 4, sec. G-G′). The upper aquifer is a surficial outwash deposit composed of coarse to very coarse gravelly sand. Locally the outwash is overlain by glacial till. The outwash either abuts or overlies the Fox Hills Formation along the eastern and southern edges of the aquifer system. In the vicinity of test hole 132-070-31AAA the outwash is absent.

The lower aquifer is a buried melt-water channel composed of coarse gravelly sand. It extends from the northern edge of sec. 1, T. 132 N., R. 71 W. to Green Lake in sec. 32, T. 132 N., R. 70 W.

The aquifer system has a maximum aggregate thickness of 80 feet (24 m) and a mean saturated aggregate thickness of about 30 feet (9 m).

The city of Wishek has two public-supply wells developed in the lower aquifer. Well 132-071-10CBD was drilled in June of 1975. The well penetrated 55 feet (17 m) of fine to coarse sand from 63 to 118 feet (19 to 36 m). Twenty-five feet (7.6 m) of 8-inch (203-mm), 60 slot, stainless steel screen was set from 90 to 115 feet (27 to 35 m). Development data show that the static water level in the well was 22 feet (6.7 m) below land surface. The well was pumped for 13 hours at a rate of about 500 gal/min (30 L/s). The drawdown of the water level was about 6 feet (2 m) after 1 hour of pumping, about 15 feet (4.6 m) after 7 hours of pumping, and about 16 feet (4.9 m) after 13 hours of pumping. Assuming that the drawdown would be about 18 feet (5.5 m) after 24 hours of pumping, the specific capacity of the well would be 28 (gal/min)/ft [5.8 (L/s)/m], and the estimated transmissivity would be about 5,300 ft^2/d (490 m^2/d).

City well 132-071-15AAC, which was drilled in 1962, penetrated 32 feet (9.8 m) of fine to medium sand mixed with gravel and boulders from 84 to 116 feet (26 to 35.4 m). The well was cased with 20 feet (6 m) of 12-inch (305-mm) 150-slot screen from 94 to 114 feet (29 to 34.8 m). It was reported that during development the well was pumped at successive rates of 390 to 1,450 gal/min (25 to 91 L/s).

Depending on the thickness and hydraulic conductivity of the aquifer material, yields from the Wishek aquifer system will range from 50 to as much as 1,500 gal/min (3 to 95 L/s; pl. 3). Wells developed in the upper aquifer will yield from 50 to 500 gal/min (3 to 32 L/s) and wells developed in the lower aquifer will yield 50 to 1,500 gal/min (3 to 95 L/s).

The Wishek aquifer system is recharged by infiltration of rain and snowmelt and by lateral movement of water from the Fox Hills aquifer. Ground-water recharge to the system is indicated by differences in static head. The static head in test hole 132-071-01DDD2, developed in the Fox Hills aquifer, is higher than any of the heads in wells developed in the Wishek aquifer system. Most of the recharge to the aquifer system from the Fox Hills aquifer occurs along the eastern edge of the system north of State Highway 13. South of the highway the Fox Hills aquifer occurs at progressively lower altitudes and is overlain by glacial till or part of the Wishek aquifer system. Discharge from the aquifer system is by pumping, seepage into slough areas along the western edge of the aquifer system, and by underflow into Green Lake.

Water in the upper aquifer generally is unconfined, except in areas where the aquifer is overlain by glacial till. Water in the lower aquifer is confined. Water levels in the upper aquifer range from 1 to 26 feet (0.3 to 7.9 m) below land surface; water levels in the lower aquifer range from about 18 to 47 feet (5.5 to 14 m) below land surface. Potentiometric heads for both aquifers show that the head is higher in the upper aquifer, which indicates that the potential exists for leakage into the lower aquifer.

The fluctuations of the water level shown on the hydrograph for observation well 132-071-14BCC1 (fig. 6) are caused by pumping of city well 132-071-10CBD. The hydrograph shows that the lowest water levels occur during the summer months (June to September) when there is a greater demand for water.

Water samples were collected from 16 wells developed in the Wishek aquifer system. Analyses of the samples indicate that the water is predominantly a calcium bicarbonate type. The water is very hard. Dissolved-solids concentrations ranged from 362 to 1,160 mg/L and had a median of 468 mg/L. Sulfate concentrations ranged from 44 to 530 mg/L, but only one sample contained more than the recommended limit of 250 mg/L. Iron concentrations were less than the recommended limit of 300 ug/L in 14 samples. Manganese concentrations exceeded the recommended limit of 50 ug/L in 15 samples.

Analyses indicate a low sodium hazard and a medium to high salinity hazard for irrigation purposes. SAR values ranged from 0.1 to 2.5, and specific conductance ranged from 600 to 1,620 umho/cm. The samples had irrigation classifications of either C2-S1 or C3-S1 (fig. 4).

Based on an areal extent of 21 mi^2 (54 km^2), a mean thickness of 30 feet (9 m), and a specific yield of 15 percent, approximately 60,000 acre-feet (74 hm^3) of the water stored in the Wishek aquifer system would be available to wells.

Zeeland Aquifer

The Zeeland aquifer underlies an area of about 16 mi^2 (41 km^2) about 3 miles (5 km) east of the city of Zeeland in Tps. 129 and 130 N., Rs. 72 and 73 W. (pl. 3). The aquifer consists of buried outwash that was laid down on an erosional surface. The western part of the aquifer is confined to a buried valley; whereas, the eastern part overlies a bedrock high. The two parts extend southward and

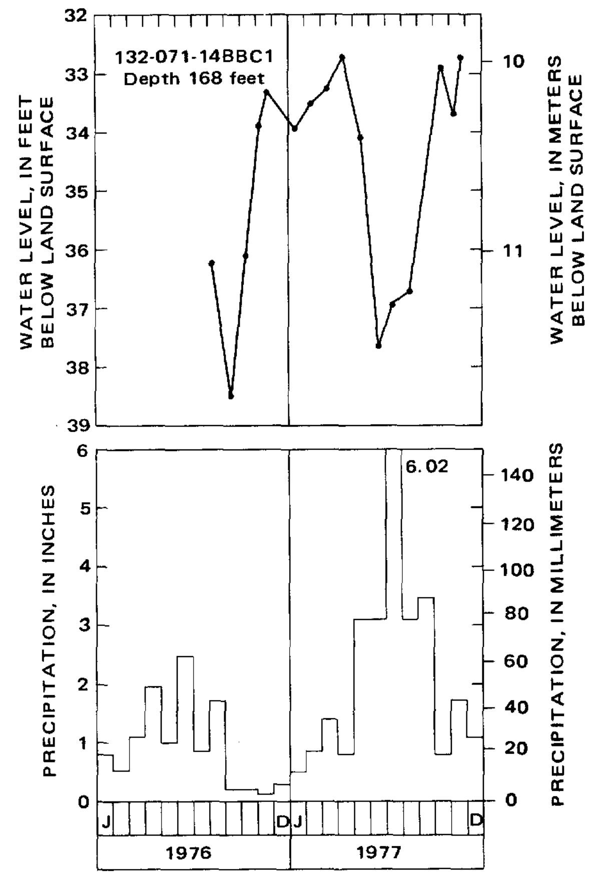

FIGURE 6.—Water-level fluctuations in the Wishek aquifer system and precipitation at Wishek.

converge to form an aquifer that is about 5 miles (8 km) wide along the south edge of T. 129 N., R. 72 W. (pl. 4, sec. E-E′).

The aquifer is composed of very fine to very coarse sand intermixed with gravel; the predominant lithology is coarse to very coarse gravelly sand. Maximum aquifer thickness is 56 feet (17 m) and mean saturated thickness is about 20 feet (6 m).

An aquifer test was made by the North Dakota State Water Commission (R. B. Shaver, written commun., 1976) to determine if the aquifer would provide an adequate supply of water for the city of Zeeland. Production well 129-073-24DDD5 was screened from 117 to 134 feet (36 to 41 m) with 12-inch (305-mm), 50-slot, stainless steel screen. The well was pumped at a rate of 352 gal/min (22 L/s) for about 95 hours. Water levels were measured in the production well and in 13 observation wells. Data from the test indicate a specific capacity of 7.7 (gal/min)/ft [1.6 (L/s)/m] of drawdown, a transmissivity of about 3,800 ft^2/d (350 m^2/d), and a storage coefficient of $1x10^{-4}$.

The aquifer should yield from 50 to 500 gal/min (3 to 32 L/s). It is possible that yields of as much as 1,000 gal/min (63 L/s) could be obtained from the northern part of the aquifer, where the aquifer is as much as 56 feet (17 m) thick.

The aquifer is recharged by infiltration of precipitation and surface runoff. Water is discharged by pumping of wells and by lateral movement to areas outside the study area.

A comparison of water-level data with lithologic and electric logs shows that the water in the western part of the aquifer is confined and water in the eastern part is unconfined. The unconfined water in the eastern part probably becomes confined as it moves downgradient to the southwest. The potentiometric surface in the western part of the aquifer slopes from north to south. Available water-level data for the eastern part of the aquifer indicate that the potentiometric surface slopes to the southwest. Water levels range from about 7 feet (2 m) above land surface in the extreme southern part of the aquifer to about 147 feet (45 m) below land surface in the northern part.

Analyses of water samples collected from 22 wells show that the water in the Zeeland aquifer consists largely of mixed types. Ten of the samples were a sodium-calcium-magnesium bicarbonate type, and two samples were sodium-magnesium-calcium bicarbonate type. Six samples were a calcium-sodium-magnesium bicarbonate type, one was a calcium-magnesium-sodium bicarbonate type, and three were sodium bicarbonate type. The water is very hard. Dissolved-solids concentrations ranged from 490 to 1,020 mg/L and had a median of 685 mg/L. Sulfate ranged from 72 to 440 mg/L, but only seven samples had concentrations greater than 250 mg/L. Iron generally was less than the recommended limit of 300 ug/L, but manganese exceeded the recommended limit of 50 ug/L in all samples.

All analyses except one indicate a low sodium hazard and all analyses indicate a high salinity hazard for irrigation. SAR values ranged from 1.5 to 5.6 and specific conductance ranged from 730 to 1,660 umho/cm. Twenty-one of the samples had an irrigation classification of C3-S1, and one sample had an irrigation classification of C3-S2 (fig. 4).

Based on an areal extent of 16 mi^2 (41 km^2), a mean thickness of 20 feet (6 m), and a specific yield of 15 percent, approximately 31,000 acre-feet (38 hm^3) of the water stored in the Zeeland aquifer would be available to wells.

Dry Lake Aquifer

Dry Lake aquifer underlies an area of about 14 mi^2 (36 km^2) in the northern part of T. 130 N., R. 70 W. and the southern part of T. 131 N., R. 70 W. (pl. 3). About 6 mi^2 (16 km^2) of the aquifer underlies a topographic low that locally is known as Dry Lake. Small valleys on the northwest, northeast, and east sides of the aquifer slope toward the topographic low.

The aquifer consists of buried and surficial outwash. The buried outwash occurs in the topographic low and on the valley floors. The surficial outwash generally occurs as a mantle overlying the higher till areas between the valleys. Locally, the surficial outwash is connected to the buried outwash.

The aquifer material consists of very fine to very coarse sand that is intermixed and interbedded with very fine to coarse gravel. The aquifer has a maximum aggregate thickness of 54 feet (16 m) and a mean saturated aggregate thickness of 25 feet (7.6 m).

Yields to properly developed wells in the aquifer probably will range from 50 to 250 gal/min (3 to 16 L/s); but locally yields ranging from 250 to 500 gal/min (16 to 32 L/s) may be possible.

The aquifer is recharged by rain and snowmelt infiltrating the surficial outwash. The water moves downgradient and recharges the buried outwash. The general direction of water movement in the aquifer is shown on plate 3. Water is discharged from the aquifer by leakage into the glacial till and by pumping from a few stock and domestic wells.

Water in the aquifer may be either confined or unconfined. Generally water in the buried outwash is confined; however, in the upper reaches of some of the small valleys it may be unconfined. The surficial outwash deposits generally are not saturated to the extent that they will yield any significant amounts of water. Water levels in the aquifer range from about 23 feet (7 m) above land surface in well 130-070-02CCC to an estimated depth of about 50 feet ((15 m) below land surface in 131-070-25AAB.

Analyses of seven water samples from the aquifer indicate that one sample was a sodium bicarbonate type and six of the samples were mixed water types. Five of the samples were mixed calcium-sodium or calcium-magnesium bicarbonate or sulfate types and one sample was a sodium-calcium-magnesium sulfate-bicarbonate type. The water is very hard. Dissolved-solids concentrations ranged from 568 to 1,790 mg/L and had a median of 851 mg/L. Sulfate concentrations ranged from 120 to 530 mg/L. Sulfate exceeded the recommended limit of 250 mg/L in four samples. Nitrate exceeded the recommended limit of 45 mg/L in three samples. The fact that these three samples were taken from shallow stock or domestic wells indicates that the wells and perhaps the aquifer are being polluted by animal wastes. Iron ranged from 20 to 1,500 ug/L, and exceeded the recommended limit of 300 ug/L in three samples. Manganese exceeded the recommended limit of 50 ug/L in six samples.

Analyses indicate a low sodium hazard and a generally high salinity hazard for irrigation purposes. SAR values ranged from 0.4 to 3.5, and specific conductance ranged from 700 to 2,010 umho/cm. The irrigation indices were C3-S1, except for one that was C4-S1 (fig. 4).

Based on an areal extent of 14 mi^2 (36 km^2), a mean thickness of 25 feet (7.6 m), and a specific yield of 15 percent, about 34,000 acre-feet (42 hm^3) of the water stored in the Dry Lake aquifer would be available to wells.

South Branch Beaver Creek Aquifer

The South Branch Beaver Creek aquifer underlies about 10 mi^2 (26 km^2) in western McIntosh County (pl. 3). The aquifer occupies a shallow glacial meltwater channel that extends southwestward from the center of sec. 4, T. 131 N., R. 72 W. to the northwest corner of sec. 6, T. 130 N., R. 73 W., where it enters Emmons County.

Data from five test holes show that the aquifer may consist either of very fine to very coarse gravelly sand or fine to very coarse sandy gravel. The aquifer has a maximum thickness of 58 feet (18 m), and a mean saturated thickness of about 27 feet (8.2 m).

Yields to properly constructed wells developed in the aquifer generally will range from 50 to 250 gal/min (3 to 16 L/s). Locally short-term yields of as much as 500 gal/min (32 L/s) may be possible.

The aquifer is recharged by infiltration of water from precipitation or from surface runoff, by lateral movement of water from the Fox Hills aquifer, and by underflow from numerous small tributary aquifers. Water is discharged from the aquifer by seepage into Beaver Creek, by pumping, and by evapotranspiration. Water-level data from the four observation wells developed in the aquifer indicate that the hydraulic gradient slopes southward at about 8 ft/mi (2 m/km).

A comparison of water-level data with test-hole logs indicates that the water in the aquifer is unconfined. Water levels range from about 3 to 12 feet (0.9 to 3.7 m) below land surface. The maximum monthly fluctuation is about 1 foot (0.3 m).

Analyses of 10 water samples collected from wells developed in the aquifer show that most of the samples are mixed water type. Calcium, magnesium, and sodium are the dominant cations in the water and bicarbonate is the dominant anion. The water is very hard. Dissolved-solids concentrations ranged from 232 to 1,870 mg/L and had a median of 588 mg/L. Sulfate ranged from 13 to 590 mg/L; seven of the samples had sulfate concentrations of less than 250 mg/L. Iron concentrations were less than 300 ug/L in nine of the samples. Concentrations of manganese exceeded 50 ug/L in eight samples.

All analyses except one indicate a low sodium hazard and all show medium or high salinity hazard for irrigation purposes. SAR values ranged from 0.8 to 7.0, and specific conductance ranged from 440 to 2,000 umho/cm. Irrigation indices were C2-S1 and C3-S1 (fig. 4), except for one index at C3-S2.

Based on an areal extent of 10 mi^2 (26 km^2), a mean thickness of 27 feet (8.1 m), and a specific yield of 15 percent, about 26,000 acre-feet (32 hm^3) of the water stored in the South Branch Beaver Creek aquifer would be available to wells.

Undifferentiated Sand and Gravel Aquifers

Undifferentiated sand and gravel deposits occur throughout McIntosh County. Test holes and wells commonly penetrate one or more deposits of sand or gravel at depths as great as 383 feet (117 m) below land surface. The deposits range in thickness from about 5 to 59 feet (2 to 16 m). The fact that most of the sand and gravel deposits are buried and are not laterally extensive suggests that they may be remnants of an earlier period of glacial deposition that occur as small lenses or narrow channels that are impossible to delineate without an intensive drilling program. Most of the undifferentiated sand and gravel aquifers have an areal extent of less than 1 mi^2 (3 km^2); however, some have areal extents of 2 to 3 mi^2 (5 to 8 km^2).

An aquifer test was made in August 1947 (Laird and Akin, 1948) in a small undifferentiated aquifer located in parts of secs. 19, 29, and 30 in T. 129 N., R. 73 W. The test was made using a public supply well owned by the city of Zeeland. The well was cased to 26 feet (7.9 m) with 8-inch (203-mm) galvanized casing and was screened in fine- to coarse-grained sand in the interval from 26 to 41 feet (7.9 to 12 m). The well was pumped for 43 hours at a rate of 107 gal/min (6.8 L/s). The calculated transmissivity was about 1,200 ft^2/d (110 m^2/d). The storage coefficient was 0.19 near the end of the test. The specific capacity was about 11 (gal/min)/ft [2.3 (L/s)/m]. Eight days after pumping had stopped the water level was still 0.63 foot (0.19 m) below the original static level. The fact that the water level had not recovered to the static level indicates that the aquifer is small in areal extent and that recharge to it is very slow.

Comparison of the aquifer-test data with the thicknesses and estimated hydraulic conductivities of other undifferentiated sand and gravel aquifers indicates that yields from these aquifers probably will range from about 1 to 100 gal/min (0.06 to 6.3 L/s). However, long-term yields greater than 50 gal/min (3 L/s) cannot be verified without additional test drilling to determine the extent of the aquifers.

Recharge to the undifferentiated aquifers is from infiltration of water from precipitation or from surface runoff, and locally by lateral movement of water from the Fox Hills aquifer. Water is discharged from the aquifers by pumping, by evapotranspiration, and locally by discharge into small lakes and sloughs.

Water levels in the undifferentiated sand and gravel aquifers range from about 5 feet (2 m) above land surface to about 90 feet (27 m) below land surface. The flowing wells represent local flow systems associated with topographic lows of small areal extent.

Water from the undifferentiated sand and gravel aquifers generally is very hard but differs considerably in quality. The dissolved solids in 41 samples ranged from 329 to 6,450 mg/L. Sulfate ranged from 29 to 4,220 mg/L and 27 of the samples had concentrations greater than 250 mg/L. Twenty-four of the samples had iron concentrations less than the recommended 300-ug/L limit. Manganese exceeded the recommended limit of 50 ug/L in 35 samples. Analyses show that 42 percent of the samples were mixed water types. The remaining samples consisted of the following types: calcium bicarbonate, sodium sulfate, calcium sulfate, sodium bicarbonate, and sodium chloride.

SAR values ranged from 0.1 to 11 and specific conductance ranged from 485 to 5,300 umho/cm. The irrigation classification of the best quality water was C2-S1 and the poorest quality water was greater than the classification range. Most of the samples were in the C3-S1 classification.

USE OF GROUND WATER

The entire population of McIntosh County is dependent upon ground water for municipal, domestic, and livestock needs. The use of ground water for irrigation is now of minor importance, but it will probably increase in the future.

Domestic and Livestock Use

Most of the wells that provide water for domestic and livestock use in the county are either drilled or bored wells. They range in depth from 6 to about 2,561 feet (2 to 781 m) and most yield less than 10 gal/min (0.6 L/s). However, the yields are usually sufficient for domestic use and for small herds of livestock. Estimates of the quantity of water pumped daily from domestic and livestock wells in McIntosh County are listed in the following table.

Use	Individual requirements (gallons per day)	Population or number	Estimated pumpage (gallons per day; rounded)
Domestic (not including communities having municipal water supplies)	[a] 66	[b] 2,429	160,000
Cattle	15	[c] 50,333	755,000
Milk cows	35	[c] 4,000	140,000
Hogs	5	[c] 3,900	19,500
Total			1,074,500

a Murray and Reeves, 1977.
b U.S. Bureau of the Census, 1971.
c Mean population 1974-76; North Dakota State University, 1976, 1977.

Public Supply Use

Ashley

The city of Ashley obtains its water supply from two wells that are developed in the Spring Creek aquifer system. Well 130-069-31BAB is 182 feet (56 m) deep and was reported to have been put into operation in 1948. Well 130-069-30DCC is 170 feet (52 m) deep and was completed January 30, 1975.

Total pumpage from January 1966 to January 1977 was about 519.3 Mgal (2 hm^3). Mean daily usage during 1975 was 124,000 gal/d (469 m^3/d), during 1976 it was 117,000 gal/d (443 m^3/d), and during 1977 it was 122,000 gal/d (462 m^3/d).

The water from the two city wells is hard to very hard and is a sodium bicarbonate type. Dissolved-solids concentrations were 732 and 755 mg/L.

At the present time the existing wells provide adequate supplies of water for the city's needs. Any increase in demand can be met by expansion of the existing well field.

Lehr

The city of Lehr obtains its municipal water supply from two wells that tap undifferentiated sand and gravel aquifers. Well 132-069-05BCD is 240 feet (73 m) deep and is located within the city limits. Well 132-070-01DDA, which is about 80 feet (24 m) deep, is located about 1 mile (2 km) west of the city on the north edge of a large slough.

No pumpage data are available for the public supply wells; however, it is estimated that the daily per capita use is about 100 gallons (380 L). Based on a population of 287, the daily pumpage would be 28,700 gal/d (109 m^3/d).

The water from both wells is very hard. Water from well 132-069-05BCD is a sodium bicarbonate-sulfate type that had a dissolved-solids concentration of 1,120 mg/L. The water from well 132-070-01DDA is a calcium-sodium bicarbonate type that had a dissolved-solids concentration of 916 mg/L.

Because the undifferentiated sand and gravel aquifers are limited in areal extent, expansion of the present well field may not be feasible. However, additional supplies of water possibly could be obtained from the McIntosh aquifer about 2 miles (3 km) east of the city.

Venturia

The city of Venturia obtains its water supply from a 2,495-foot (760-m) well (129-071-15AAB) developed in the Dakota aquifer. From July 1, 1968, to June 1, 1977, approximately 13.7 Mgal (51,900 m^3) of water was withdrawn from the aquifer. About 11.3 Mgal (42,800 m^3) was used for municipal purposes and about 2.4 Mgal (9,100 m^3) was used by adjacent farmsteads. The mean daily withdrawal in 1976 was about 3,500 gal/d (13 m^3/d).

Analysis of a water sample collected from the city well shows that the water is very hard and is a sodium sulfate type. Dissolved-solids concentration in the sample was 1,930 mg/L.

The existing well provides adequate amounts of water for the residents of the city. Any increase in demand could be met by completing additional wells in the Dakota aquifer.

Wishek

The city of Wishek obtains its municipal water supply from three wells, 132-071-10CBD (depth 115 feet or 35 m), 132-071-15AAC (depth 116 feet or 35 m), and 132-071-15ACA (depth 46 feet or 14 m) developed in the Wishek aquifer. Total pumpage from these wells from January 1, 1968, to July 4, 1977, was about 559.2 Mgal (2 hm^3). Daily withdrawals from the aquifer in 1976 amounted to about 237,700 gal/d (900 m^3/d).

Analyses of water samples collected from wells 132-071-10CBD and 132-071-15ACA show that the water is very hard and is a calcium bicarbonate type. Dissolved-solids concentrations were 544 and 482 mg/L.

The city of Wishek has an adequate supply of very good quality water. Any increase in demand can be met by expansion of the existing well field.

Zeeland

Prior to May 1975 the city of Zeeland obtained its water supply from a well (129-073-30BAA) tapping an undifferentiated sand and gravel aquifer located about 1.5 miles (2.4 km) west of Zeeland. This well is 40 feet (12 m) deep and is reported to yield about 38 gal/min (2 L/s). Due to increased usage and a declining water level caused by a lengthy drought, the yield of the well was not adequate to meet the demand. In order to alleviate the water shortage the city had a 2,516-foot (767-m) well (129-073-21CDB) drilled into the Dakota aquifer. Upon completion, the well was reported to flow 100 gal/min (6.3 L/s) through a 2-inch (51-mm) casing. The flow was later reduced to 60 gal/min (4 L/s). The hydraulic head at the well site was about 92 feet (28 m) above land surface.

Because the yield of the shallow well west of Zeeland was inadequate and because the water from the Dakota well contained objectionable concentrations of sulfate and iron, the city still did not have an adequate supply of water suitable for municipal use.

Test holes drilled as part of this study indicated the presence of a north-south trending buried-valley aquifer located about 3.5 miles (5.6 km) east of Zeeland. A 134-foot (41-m) well (129-073-24DDD5) developed in the Zeeland aquifer during the fall of 1976 now provides water for the city of Zeeland. This well, which was not put into operation until January 1978, is screened from 119 to 134 feet (36 to 41 m) and is capable of yielding 350 gal/min (22 L/s).

Pumpage from well 129-073-30BAA from January 1953 through December 1974 was about 109.8 Mgal (415,600 m^3). From January 1975 to January 1978 the combined withdrawal of ground water from the undifferentiated aquifer west of Zeeland and from the Dakota aquifer was about 20.4 Mgal (77,200 m^3). Daily pumpage during 1977 was about 18,000 gal/d (68 m^3/d). No pumpage data are available for well 129-073-24DDD5, but it is estimated that the mean daily pumpage from January through April 1978 was about 17,000 gal/d (64 m^3/d).

The water from well 129-073-30BAA, tapping the undifferentiated sand and gravel aquifer, is very hard and is a calcium bicarbonate type; dissolved-solids concentration was 576 mg/L. The water from well 129-073-21CDB, completed in the Dakota aquifer, is very hard and is a sodium-calcium sulfate type. Dissolved-solids concentration was 2,380 mg/L.

The water from well 129-073-24DDD5, completed in the Zeeland aquifer, is very hard and is a sodium-calcium bicarbonate type. Dissolved-solids concentration was 518 mg/L.

The city of Zeeland has an adequate supply of water suitable for municipal use. Any increase in demand could be met by completing more wells in the Zeeland aquifer or by using the Dakota aquifer.

SUMMARY

Ground water in McIntosh County is obtained from the Dakota and Fox Hills aquifers and from aquifers in the glacial-drift deposits. The Dakota aquifer underlies all of the county at depths ranging from about 2,100 to 2,500 feet (640 to 760 m), and has an aggregate sandstone thickness of about 115 feet (35 m). Wells developed in the Dakota aquifer will flow at land surface altitudes of less than 2,100 feet (640 m). Flow rates of 30 to 100 gal/min (2 to 6.3 L/s) have been obtained. Recharge to the Dakota aquifer is by upward migration of water from underlying aquifers. Discharge is from wells and by lateral movement to the east.

Water in the Dakota aquifer may be either a sodium sulfate, sodium-calcium sulfate, or calcium-sodium sulfate type. Dissolved solids in three samples ranged from 1,930 to 2,380 mg/L and sulfate ranged from 1,100 to 1,300 mg/L.

The Fox Hills aquifer underlies an area of about 280 mi^2 (725 km^2) in the northwestern part of the county. Well yields can be expected to range from 0.5 to 30 gal/min (0.03 to 2 L/s); however, yields of as much as 50 gal/min (3 L/s) may be obtained from the thicker sand beds provided that the well is screened throughout the entire saturated thickness. Recharge to the aquifer is principally from infiltration of precipitation, and by lateral and vertical movement of water from the glacial drift. Water is discharged by pumping, seepage into intermittent streams, and lateral movement into the glacial drift.

Dissolved solids in 21 water samples from the Fox Hills aquifer ranged from 227 to 4,220 mg/L, but only seven of the samples had dissolved-solids concentrations of more than 700 mg/L.

Aquifers in the glacial-drift deposits, particularly those of glaciofluvial origin, have the greatest potential for ground-water development. The aquifers occur as buried-valley deposits, buried- and surficial-outwash deposits, melt-water-channel deposits, and undifferentiated sand and gravel deposits. Recharge to these aquifers is from infiltration of precipitation and surface runoff. Water is discharged from these aquifers by pumping, evapotranspiration, and discharge into lakes and sloughs.

The glacial-drift aquifers in McIntosh County are the Spring Creek and Wishek aquifer systems and the McIntosh, Zeeland, Dry Lake, and South Branch Beaver Creek aquifers. Hydrologic data for these aquifers are summarized in table 3.

Undifferentiated sand and gravel aquifers in the glacial-drift deposits are scattered throughout the county. Yields from these aquifers generally will range from 1 to 100 gal/min (0.06 to 6.3 L/s); however, in places yields may be greater than 100 gal/min (6.3 L/s). The water in the undifferentiated glacial-drift aquifers varies in quality but is generally very hard.

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

Aquifer or aquifer system	Areal extent (square miles)	Mean saturated thickness (feet)	Estimated amount of water available to wells (acre-feet)	Dissolved-solids concentrations (milligrams per liter)	Sodium-adsorption ratio	Estimated maximum well yield (gallons per minute)
Spring Creek	88	39	329,000	467-1,410	0.2-15	1,000
McIntosh	22	29	61,000	361-1,420	.1-1.7	500
Wishek	21	30	60,000	362-1,160	.1-2.5	1,500
Zeeland	16	20	31,000	490-1,020	1.5-5.6	1,000
Dry Lake	14	25	34,000	568-1,790	.4-3.5	500
South Branch Beaver Creek	10	27	26,000	232-1,870	.8-7.0	500

SELECTED REFERENCES

Adolphson, D. G., 1962, Artesian water from glacial drift near Lehr, Logan and McIntosh Counties, North Dakota: North Dakota State Water Commission Ground-Water Studies no. 38, 21 p.

Armstrong, C. A., 1975, Ground-water basic data for Emmons County, North Dakota: North Dakota Geological Survey Bulletin 66, part II, and North Dakota State Water Commission County Ground-Water Studies 23, part II, 375 p.

—— 1978, Ground-water resources of Emmons County, North Dakota: North Dakota Geological Survey Bulletin 66, part III, and North Dakota State Water Commission County Ground-Water Studies 23, part III, 43 p.

Ballard, F. V., 1963, Structural and stratigraphic relationships in the Paleozoic rocks of eastern North Dakota: North Dakota Geological Survey Bulletin 29, 46 p.

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

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

Doering, E. F., and Berg, L. C., 1972, Pumping an artesian source for water table control: Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, p. 275-286.

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

Fischer, S. P., 1952, The geology of Emmons County, North Dakota: North Dakota Geological Survey Bulletin 26, 47 p.

Feldman, R. M., 1972, Stratigraphy and paleoecology of the Fox Hills Formation (Upper Cretaceous) of North Dakota: North Dakota Geological Survey Bulletin 65, 65 p.

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

Hamilton, L. J., 1974, Major aquifers in McPherson, Edmunds, and Faulk Counties, South Dakota: Department of Natural Resource Development, South Dakota Geological Survey, Information Pamphlet no. 8, 11 p.

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

Keech, C. F., 1964, Ground water conditions in the proposed waterfowl refuge area near Chapman, Nebraska, *with a section on* chemical quality of the water by P. G. Rosene: U.S. Geological Survey Water-Supply Paper 1779-E, 55 p.

Klausing, R. L., 1979, Ground-water basic data for McIntosh County, North Dakota: North Dakota Geological Survey Bulletin 73, part II, and North Dakota State Water Commission County Ground-Water Studies 30, part II, 458 p.

Laird, W. M., and Akin, P.D., 1948, Ground water in the Zeeland area, North Dakota: North Dakota State Water Commission Ground-Water Studies no. 12, 38 p.

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

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

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

Murray C. R., and Reeves, E. B., 1977, Estimated use of water in the United States in 1975: U.S. Geological Survey Circular 765, 39 p.

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

—— 1976, North Dakota crop and livestock statistics, annual summary for 1975, revisions for 1974: Agricultural Statistics no. 38, 76 p.

Randich, P. G., 1961, Ground water conditions in the vicinity of Ashley, McIntosh County, North Dakota: North Dakota State Water Commission Ground-Water Studies no. 37, 20 p.

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

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

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

U.S. Environmental Data Service, 1977-78, Climatological data, North Dakota; Annual summaries 1976-77: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, v. 85-86, no. 13.

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

U.S. Environmental Protection Agency, 1976 [1978], National interim primary drinking water regulations: Office of Water Supply, U.S. Environmental Protection Agency, Report EPA-570/9-76-003, 159 p.

—— 1977, National secondary drinking water regulations: Federal Register, v. 42, no. 62, Thursday, March 31, 1977, Part I, p. 17143-17147.

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

DEFINITIONS OF SELECTED TERMS

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

Aquifer system — a system of interconnected permeable water-bearing rocks.

Artesian — artesian is synonymous with confined. An artesian well is a well deriving its water from an artesian or confined water body. The water level in an artesian well stands above the top of the water body it taps.

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

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

Glacial till — unsorted and unstratified drift, generally unconsolidated, deposited directly by and underneath a glacier without subsequent reworking by water from the glacier, and consisting of a heterogeneous mixture of clay, sand, gravel, and boulders.

Glaciofluvial — pertaining to streams flowing from glaciers.

Ground water — water in the zone of saturation.

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

Ground water, unconfined — water in an aquifer that has a water table.

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

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

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

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

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

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 NGVD 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:

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

Ion concentrations are expressed in milliequivalents per liter. Experiments cited by the U.S. Salinity 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 within the well.

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 (umho/cm) at 25°C (Celsius). The electrical conductivity of water is related to the concentration of ions in the water. Distilled water normally will have a conductance of about 1.0 micromho per centimeter, whereas sea water may have a conductance of about 50,000 micromhos per centimeter.

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

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

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.

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

Zone, unsaturated — is the zone between the land surface and the water table. Characteristically this zone contains liquid water under less than atmospheric pressure, and water vapor and air or other gases generally at atmospheric pressure.