GROUND-WATER RESOURCES

of

MC HENRY COUNTY, NORTH DAKOTA

by

P. G. Randich

U.S. Geological Survey

COUNTY GROUND-WATER STUDIES 33 — PART III
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

BULLETIN 74 — PART III
North Dakota Geological Survey
Lee Gerhard, *State Geologist*

Prepared by the U.S. Geological Survey
in cooperation with the North Dakota State Water Commission,
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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 11th General Conference of Weights and Measures in 1960. Selected factors for converting inch-pound units to SI units are given below.

Multiply inch-pound unit	By	To obtain SI unit
Acre	0.4047	hectare (ha)
Acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
Cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
Foot (ft)	0.3048	meter (m)
Foot per day (ft/d)	0.3048	meter per day (m/d)
Foot per year (ft/yr)	0.3048	meter per year (m/yr)
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)	0.003785	cubic meter per day (m^3/d)
Gallon per minute (gal/min)	0.06309	liter per second (L/s)
Gallon per minute per foot [(gal/min)/ft]	0.207	liter per second per meter [(L/s)/m]
Inch (in.)	25.4	millimeter (mm)
Mile (mi)	1.609	kilometer (km)
Square mile (mi^2)	2.590	square kilometer (km^2)

GROUND-WATER RESOURCES OF McHENRY COUNTY, NORTH DAKOTA

By
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ABSTRACT

Large quantities of water can be obtained from glacial-drift aquifers in McHenry County. Bedrock aquifers also are a source of water in most of the county, but yields are much less and the water contains more sodium and dissolved solids than water from glacial-drift aquifers.

Glacial-drift aquifers occur in sand and gravel deposits associated with buried valleys and glacioaqueous deposits in McHenry County. These aquifers underlie about 430 square miles (1,114 square kilometers) and contain approximately 1,748,000 acre-feet (2,155 cubic hectometers) of available ground water. Potential well yields range from 50 to 2,000 gallons per minute (3 to 130 liters per second) from the major glacial-drift aquifers. The water generally is hard and is a calcium or sodium bicarbonate type. Dissolved solids in samples collected from these aquifers ranged from 229 to 4,590 milligrams per liter.

The Hell Creek and Fox Hills aquifers, which consist of very fine to medium-grained sandstone beds, are the major bedrock aquifers. Wells developed in these aquifers generally do not yield more than 50 gallons per minute (3 liters per second). The water generally is soft and is a sodium bicarbonate, sodium chloride, or sodium sulfate type. Dissolved solids in samples collected from these aquifers ranged from 410 to 3,180 milligrams per liter.

The rural population and all communities in McHenry County depend on ground water as a source of supply. The use of ground water from glacial-drift aquifers for irrigation exceeds that used for all other purposes, including rural, municipal, or industrial.

INTRODUCTION

The ground-water resources investigation of McHenry County (fig. 1) was made cooperatively by the U.S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and McHenry County Water Management District. The results of the investigation are published in three parts. Part I is an interpretive report describing the geology of the study area and is being prepared by the North Dakota Geological Survey. Part II (Randich, 1981) is a compilation of the geologic and hydrologic data collected during the investigation, and is a reference for the other two parts. Part III is this interpretive report describing the ground-water resources. The reports are prepared and written to assist state and county water managers, consultants to water users, and

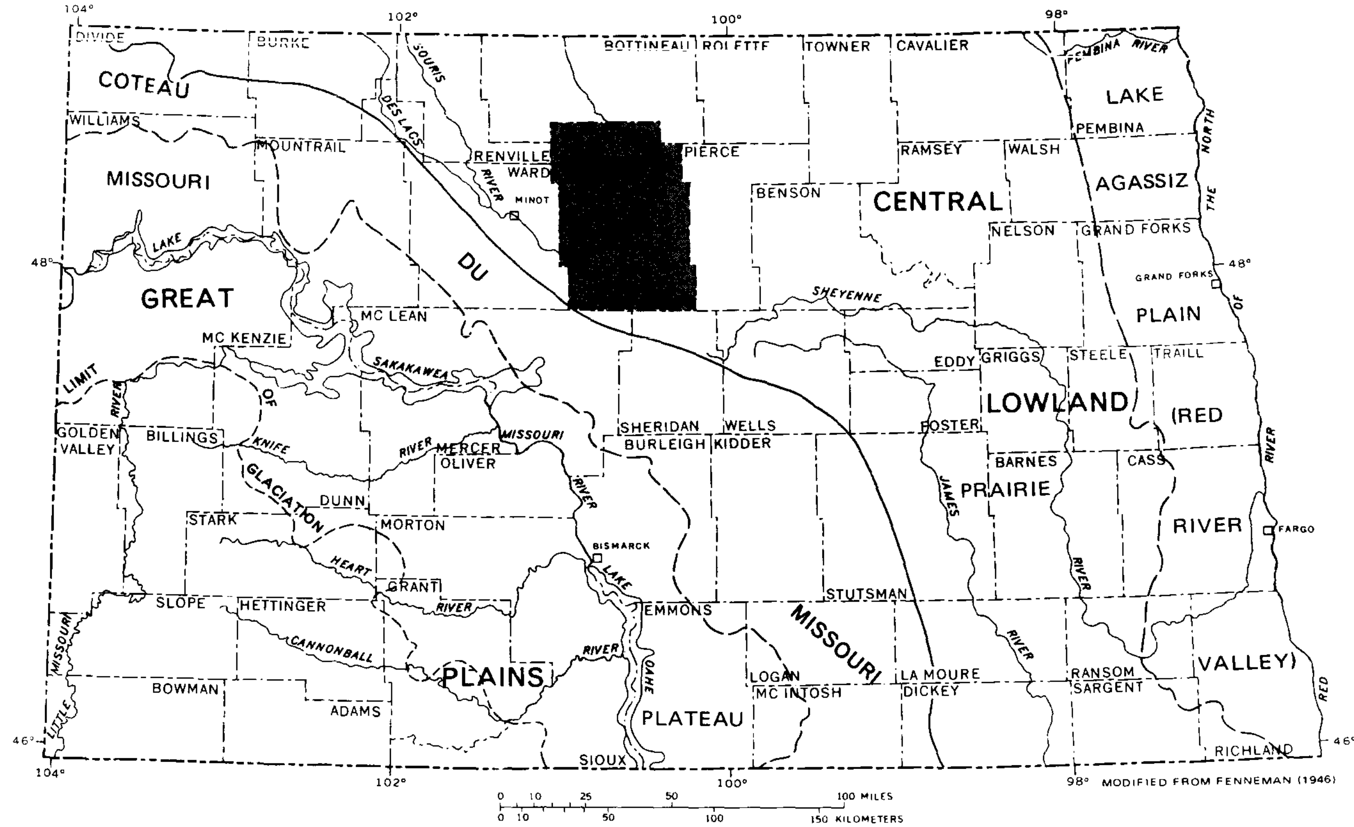


FIGURE 1.—Physiographic divisions in North Dakota and location of study area.

local water users in the development of ground-water supplies for municipal, domestic, livestock, irrigation, industrial, and other uses.

Objectives and Scope

The objectives of the geohydrologic investigation in McHenry County were to: (1) Determine the location, extent, and characteristics of the major aquifers; (2) evaluate the occurrence, movement, recharge, and discharge of ground water; (3) estimate the quantities of water stored in glacial and alluvial aquifers; (4) estimate potential yields to wells penetrating major aquifers; and (5) describe the chemical quality of the ground water.

Interpretations contained in this report are based on data from 861 wells and test holes. These data include lithologic and geophysical logs of 781 wells and test holes; periodic water-level measurements in 135 observation wells; chemical analyses of 229 samples of ground water; 14 laboratory tests of core samples to determine hydrologic properties and particle sizes; 9 heavy mineral analyses; and results of 5 aquifer tests to determine aquifer characteristics. Also included in the data base of this study were chemical analyses of 21 water samples from the Souris and Wintering Rivers and 19 stream-discharge measurements during periods of low flow.

Water-level measurements in selected observation wells will be continued as part of a statewide program to monitor ground-water resources. The purpose of the statewide program is to provide data to governmental agencies responsible for managing the water resources of the State.

Previous Investigations

The first worker concerned with the geology of the area was Upham (1895), who described the surface features of the glacial Lake Souris basin. Simpson (1929) included a brief description of the geology and ground-water resources of McHenry County in his report on the geology and ground-water resources of North Dakota. Abbott and Voedisch (1938) listed chemical constituents of a few water samples from the area. Andrews (1939) mapped the geology and coal resources of the Minot, Sawyer, Benedict, Kongsberg, and Balfour quadrangles. Paulson and Powell (1957) reported on the geology and ground-water resources of the Upham area. Lemke (1960) described the geology of the Souris River area, including most of McHenry County. Adolphson (1961) reported on the geology and ground-water resources of the Drake area. LaRocque and others (1963a) compiled tables of hydrologic data and an interpretive report (1963b) on the area north of the Souris River.

Acknowledgments

Collection of the data on which this report is based was made possible by the cooperation of residents and officials of McHenry County. M. O. Lindvig, G. L.

Sunderland, R. B. Shaver, and T. L. Johnson of the North Dakota State Water Commission contributed to the interpretation of the geohydrology of the area.

Location-Numbering System

The location-numbering system used 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 is located. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre or 4-ha tract). For example, well 151-076-15ADC is in the SW¼SE¼NE¼ sec. 15, T. 151 N., R. 76 W. Consecutive final numerals are added if more than one well or test hole is recorded within a 10-acre (4-ha) tract.

Geography

McHenry County has an area of 1,904 mi^2 (4,930 km^2) in north-central North Dakota (fig. 1). All of the county is in the Drift Prairie section of the Central Lowland physiographic province.

The area generally is of moderate to low relief. The highest point has an altitude of 2,140 ft (652 m) NGVD of 1929 and is in the southwestern corner of McHenry County. The lowest point is 1,420 ft (433 m) NGVD of 1929 in the Souris River valley at the county line in north-central McHenry County. Local relief is generally less than 30 ft (9 m).

Most of McHenry County is in the Souris River drainage basin. About three townships along the east side of the county are in the Sheyenne River drainage basin. The Souris River is an underfit stream in a large valley that has a channel gradient of 0.5 ft/mi (0.09 m/km) through McHenry County. Major tributaries to the Souris River in this area are the Wintering River, Deep River, Bonnes Coulee, Spring Creek, Willow Creek, and Oak Creek. These tributaries are perennial streams.

McHenry County is in a region of cool-temperature continental climate. The mean annual temperature ranges from 39.0°F (Fahrenheit) or 3.9°C (Celsius) at Towner, to 40.6°F (4.9°C) at Velva (U.S. Environmental Data Service, 1973). The average number of days in the growing season (temperatures greater than 32°F or 0°C) ranges from 114 at Towner to 119 at Granville (U.S. Department of Agriculture, 1979). The mean annual precipitation ranges from 16.52 in. (420 mm) at Granville to 17.81 in. (452 mm) at Velva. Most of the precipitation falls during the growing season, which is April through September (U.S. Environmental Data Service, 1973).

During the winter, frost forms to a depth of 4 to 6 ft (1 to 2 m) below land surface in most parts of the area (U.S. Department of Agriculture, 1979). Spring thaw usually starts during March and peak flows in streams occur during April.

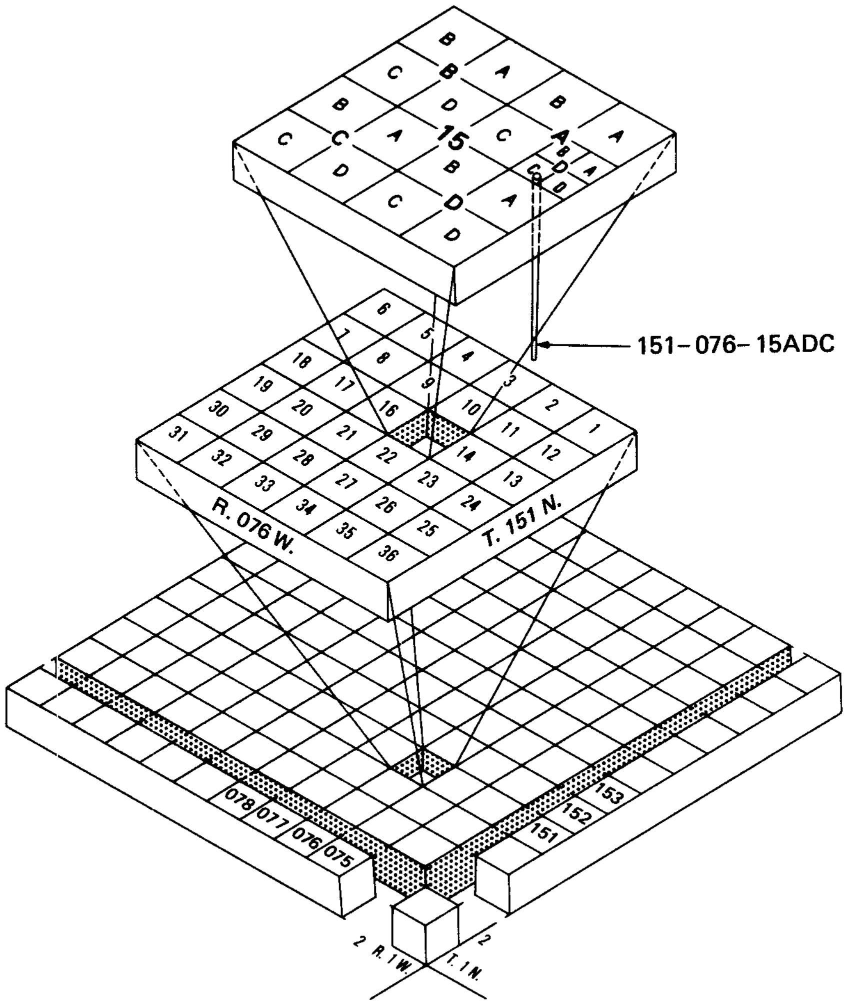


FIGURE 2.—Location-numbering system.

The population of North Dakota decreased about 2.3 percent from 1960 to 1970 (U.S. Bureau of the Census, 1971). Comparatively, the population of McHenry County decreased 19.1 percent for the same period. During 1970 McHenry County had a total population of 8,977, of which 4,538, or 50.5 percent, were rural residents.

Farming and stock raising are the two primary industries. The principal crops are hay, barley, oats, flax, corn, and durum spring and winter wheat. Livestock production includes cattle, hogs, sheep, and chickens.

Geohydrologic Setting

Deposits of Quaternary age cover all of McHenry County except for small isolated outcrops of Tertiary age in the southwestern part of the county. The Quaternary deposits consist of eolian materials, alluvium, and glacial drift that in places form major aquifers. The generalized locations of the bedrock formations underlying the Quaternary deposits are shown in figure 3. Most of the usable ground water in McHenry County is in rocks of Late Cretaceous and Tertiary age and in unconsolidated deposits of Quaternary age. Therefore, these deposits were studied in detail with special reference to their water-bearing properties. The stratigraphy of the geologic units of Late Cretaceous, Tertiary, and Quaternary age is summarized in table 1. Rocks older than Late Cretaceous age generally occur at depths greater than 1,900 ft (580 m) and contain saline water.

The generalized bedrock topography of McHenry County is shown on plate 1 (in pocket). Test-hole and surficial geologic data were used in constructing the map. Glacial advances during the Pleistocene Epoch altered the bedrock topography before subsequent deposition of glacial deposits occurred. The most prominent features are northwest trending buried valleys, which at one time contained glacial ice-front streams, incised into the bedrock. The thickest glacial-drift deposits are found in these valleys; consequently, the valleys contain most of the major glacial-drift aquifers in McHenry County.

The Dakota Sandstone of Early Cretaceous age underlies the entire area. Depth to the Dakota Sandstone is shown in figure 4. The Dakota contains water that generally is saline and undesirable for domestic or irrigation use. Although the Dakota is not used in McHenry County, it has been used in adjoining counties for livestock watering where no other water is available. When an economical desalinization process is developed, the Dakota may be an important source of water.

AVAILABILITY AND QUALITY OF GROUND WATER

General Concepts

All water is derived ultimately from precipitation. After precipitation falls on the Earth's surface, part is returned to the atmosphere by evaporation, part runs off into streams, and the remainder infiltrates into the ground. Some of the water

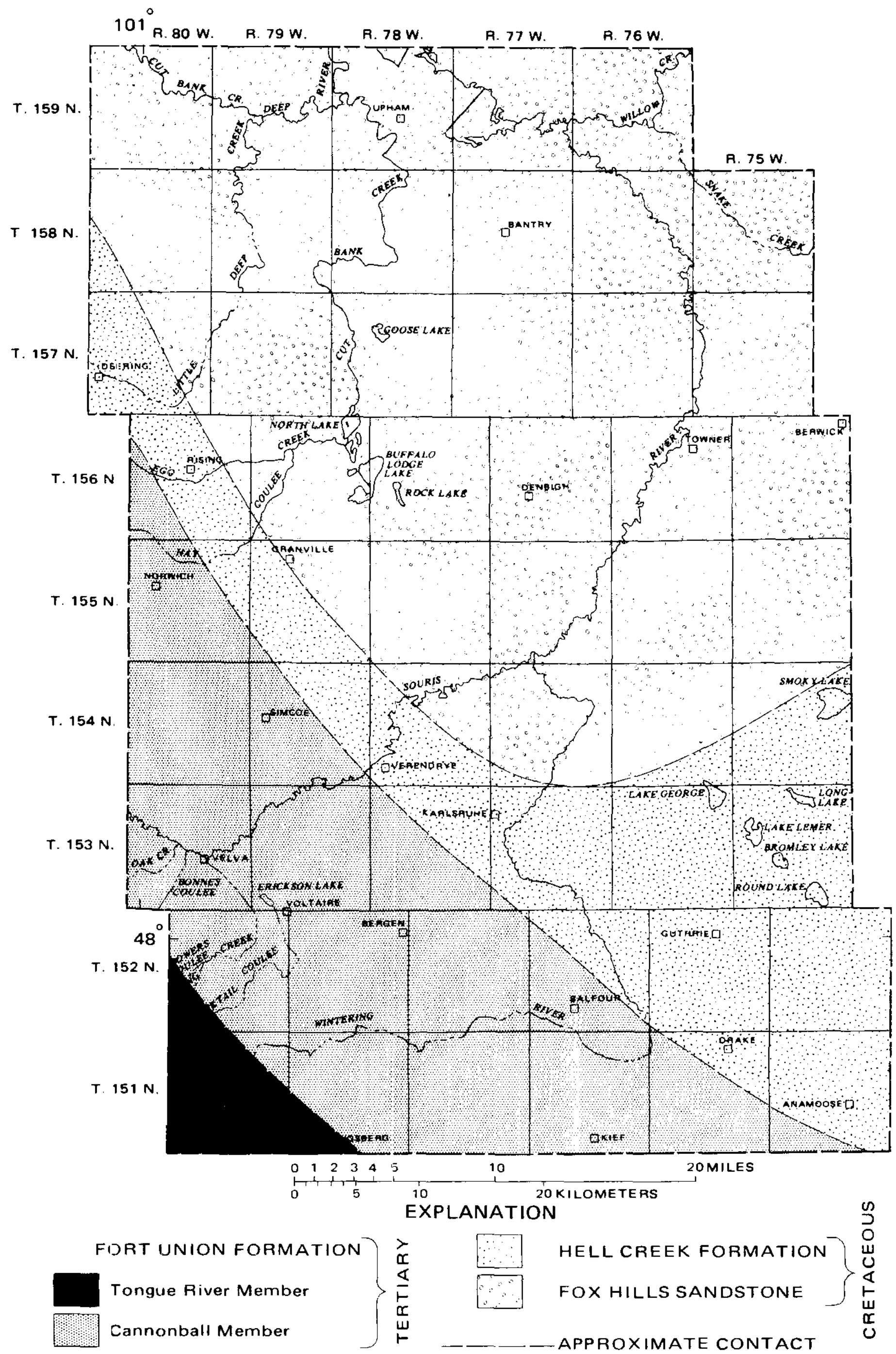
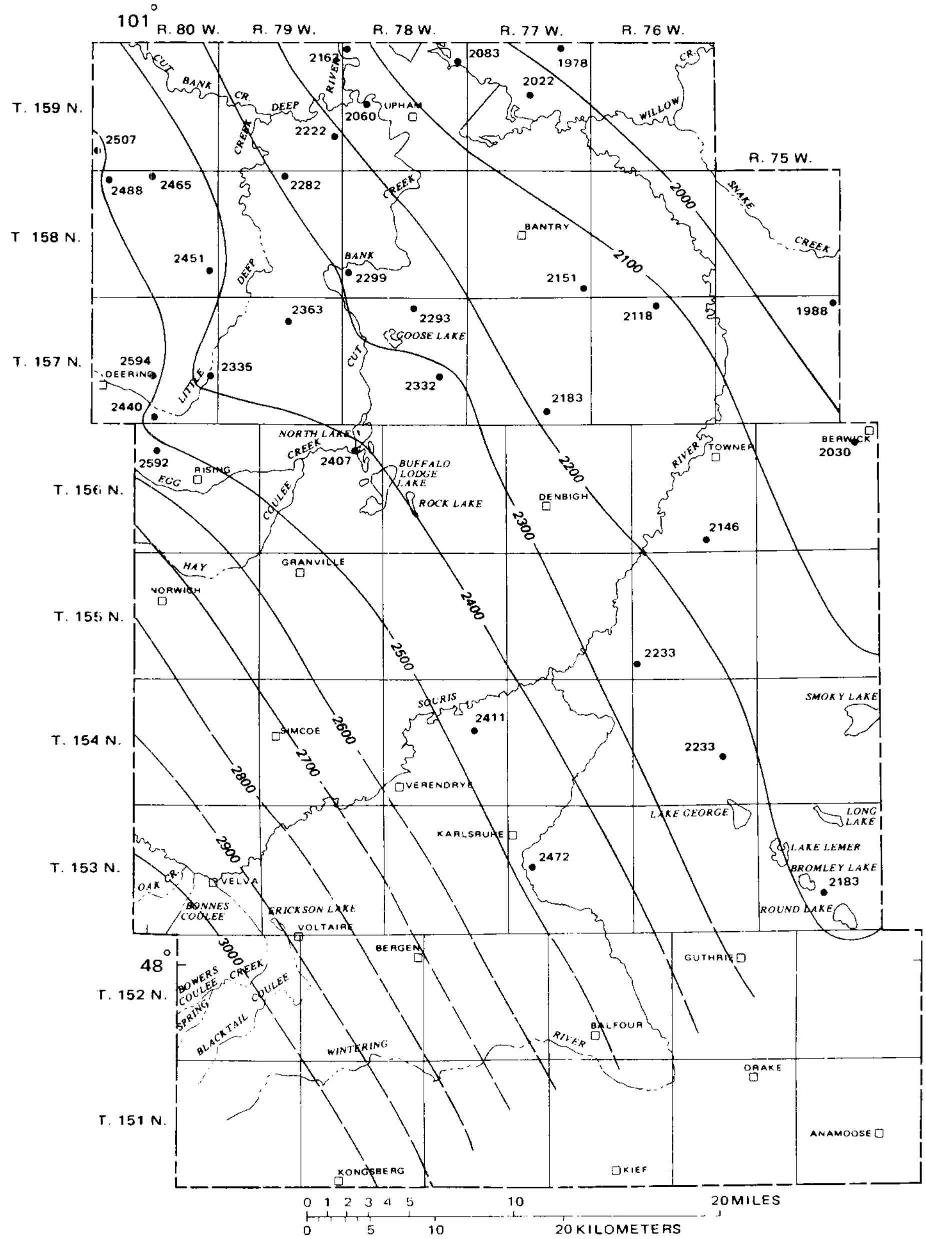


FIGURE 3.—Generalized map of bedrock formations underlying the glacial drift in McHenry County.

TABLE 1. — Generalized stratigraphy and water-yielding characteristics of geologic formations in McHenry County

System	Series	Formation, member, or deposit	General lithology	Average thickness (feet)	Water-yielding characteristics
Quaternary	Holocene	Eolian	Very fine to medium sand, silt, and clayey silt.	20	Yields as much as 50 gal/min from Lake Souris sand deposits.
	Holocene	Alluvium	Silt, clay, and sand.	10	Yields as much as 20 gal/min from sand deposits.
	Pleistocene	Glacial drift	Boulders, cobbles, gravel, sand, silt, clay, and till.	130	Yields as much as 2,000 gal/min from thick sand and gravel deposits in buried valleys.
Tertiary	Paleocene	Fort Union Formation: Tongue River Member	Sandstone, siltstone, claystone, shale, and lignite.	Unknown	Yields 5 to 50 gal/min from sandstone and lignite.
	Paleocene	Fort Union Formation: Cannonball Member	Sandstone, siltstone, and shale, with fossiliferous or limestone concretions.	100	Yields 2 to 20 gal/min from sandstone.
Cretaceous	Upper Cretaceous	Hell Creek Formation	Very fine sandstone, siltstone, claystone, and lignite; bentonitic in places; siderite nodules.	200	Yields 0.5 to 10 gal/min from sandstone.
	Upper Cretaceous	Fox Hills Standstone	Very fine to medium sandstone, siltstone, claystone and shale; fossil zones and limonitic concretions; in places the basal part consists of very dense bentonitic shale.	250	Yields 0.5 to 50 gal/min from sandstone.
	Upper Cretaceous	Pierre Shale	Shale, very thin lenses of bentonite and occasional fossils.	—	Only the upper few feet were examined during this study. Has minimal hydraulic conductivity and yields little or no water.



EXPLANATION

——2200—— LINE OF EQUAL DEPTH TO TOP OF DAKOTA SANDSTONE--Dashed where approximately located. Interval 100 feet (30 meters). Datum is land surface

•2233 TEST HOLE OR WELL--Number is depth to top of Dakota Sandstone, in feet below land surface. (Data from oil-test logs)

FIGURE 4.--Depth to the top of the Dakota Sandstone.

that enters the ground is held within the upper few feet by capillary attraction and evaporates or is transpired. The water in excess of the moisture-holding capacity of the soil infiltrates downward to the water table and becomes available to wells.

Ground water moves under the effect of gravity from areas of recharge to areas of discharge. Ground-water movement generally is only a few feet per year. The rate of movement is governed by the hydraulic conductivity of the material through which it moves and by the hydraulic gradient. Gravel, well-sorted sand, and fractured rocks have large conductivities. Deposits of these materials form aquifers. Cemented deposits and fine-grained materials such as silt, claystone, and shale usually have minimal conductivities and restrict ground-water movement.

Aquifer properties — especially hydraulic conductivity, transmissivity, and storage coefficient or specific yield — are used in evaluating the water-yielding properties of aquifers. These properties together with saturated volume of the aquifer are used to estimate the quantity of water available from the aquifer and the yields to wells penetrating the aquifer. Aquifer properties were determined from aquifer tests using methods developed by Theis (1935), Jacob (1946), and Stallman (1963).

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

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

Where a range is given in the above values, the smaller value was used unless sorting, such as fine, medium, or coarse, was indicated on the lithologic log.

The ability of the glacial-drift aquifers to yield water (transmissivity) was estimated by multiplying hydraulic conductivity by the thickness of each saturated bed of sand or gravel — the total transmissivity of the aquifer is the sum of the transmissivities of the separate units. Generally very fine sand and silt were omitted from estimates if they did not contribute more than 5 percent of the total transmissivity.

Estimates of transmissivity of an aquifer also were made from specific-capacity data and from charts devised by Meyer (1963, p. 339) and Theis and others (1963, p. 334). The charts by Meyer (1963) and Theis and others (1963), however, were based on a pumping period of 1 day and transmissivities determined by this method or from specific capacities determined from shorter pumping periods result in transmissivities that are larger than actual. Specific capacities determined from wells that partly penetrate aquifers will result in transmissivities that are smaller than actual unless data are corrected for partial penetration.

The water level in an aquifer fluctuates in response to recharge to and discharge from the aquifer, usually indicating a change in the amount of water stored in the aquifer. In confined aquifers, however, changes in atmospheric pressure and in surface load also cause fluctuations in water level. Aquifers exposed at land surface are recharged each spring, summer, and early fall by direct infiltration of precipitation. Aquifers that are confined by thick deposits of fine-grained materials are recharged by seepage from the fine-grained materials or by lateral movement downgradient from a recharge area exposed at land surface. The rate of recharge may increase as water levels in the aquifer are lowered by pumping. However, water levels may decline for several years before sufficient recharge is induced to balance the rate of withdrawal. In some places this balance may never be achieved without curtailment of withdrawal.

In parts of McHenry County, surface-water sources such as the Souris and Wintering Rivers, lakes, and potholes, generally are in hydraulic connection with aquifers. The aquifer may either receive recharge from the surface-water sources or discharge ground water into them, depending on the water level in streams, lakes, and potholes in relation to the water level in the aquifers.

The ground water in McHenry County contains varying concentrations of dissolved mineral matter. Rainfall begins to dissolve mineral matter as it falls and continues to dissolve mineral matter as the water infiltrates through the soil. The amount and kind of dissolved mineral matter in water depends upon the kinds and proportions of minerals that make up the soil and rocks, the pressure and temperature of the water and rock formations, and the concentration of carbon dioxide and soil acids in the water. Ground water that has been in storage a long time (that has moved a long distance from a recharge area) generally is more mineralized than water that has been in transit only a short time.

The suitability of water for various uses usually is determined by the kind and amount of dissolved mineral matter. The chemical constituents, physical properties, and indices most likely to be of concern are: iron, sulfate, nitrate, fluoride, boron, chloride, dissolved solids, hardness, temperature, odor, taste, specific conductance, sodium-adsorption ratio (SAR), and percent sodium. The sources of the major chemical constituents, their effects upon usability, and the recommended limits are given in table 2. Additional information regarding drinking-water standards may be found in reports published by the U.S. Environmental Protection Agency (1976, 1977).

In this report numerous references are made to ground-water types, such as sodium bicarbonate type and calcium bicarbonate type. These terms are assigned based on inspection of the water analyses and refer to the predominant cation (sodium, calcium, or magnesium) and anion (bicarbonate, sulfate, or chloride), as expressed in milliequivalents per liter.

TABLE 2.—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. Manmade sources: well casings, pumps, and storage tanks.	If more than 100 ug/L iron is present, it will precipitate when exposed to air; causes turbidity, stains plumbing fixtures, laundry, and cooking utensils, and imparts tastes and colors to food and drinks. More than 200 ug/L is objectionable for most industrial uses.	300 ug/L (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, and 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)	Organic matter, fertilizers, and sewage.	More than 100 mg/L may cause a bitter taste and may cause physiological distress. Concentrations in excess of 45 mg/L have been reported to cause methemoglobinemia (blue-baby disease) in infants.	10 mg/L (mandatory).
Dissolved solids	Anything that is soluble.	Less than 300 mg/L is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	500 mg/L (recommended).

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

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

Hardness in water used for ordinary domestic purposes does not become particularly objectionable until concentrations of about 100 mg/L.

The quality of water used for irrigation is an important factor in productivity and in quality of the irrigated crops. Two indices used to show suitability of water for irrigation are SAR and specific conductance. The SAR is related to the sodium hazard, the specific conductance is related to the salinity hazard. These two indices are combined to make the classifications of selected water samples from aquifers in McHenry County (fig. 5). For further information the reader is referred to a report by the U.S. Salinity Laboratory Staff (1954).

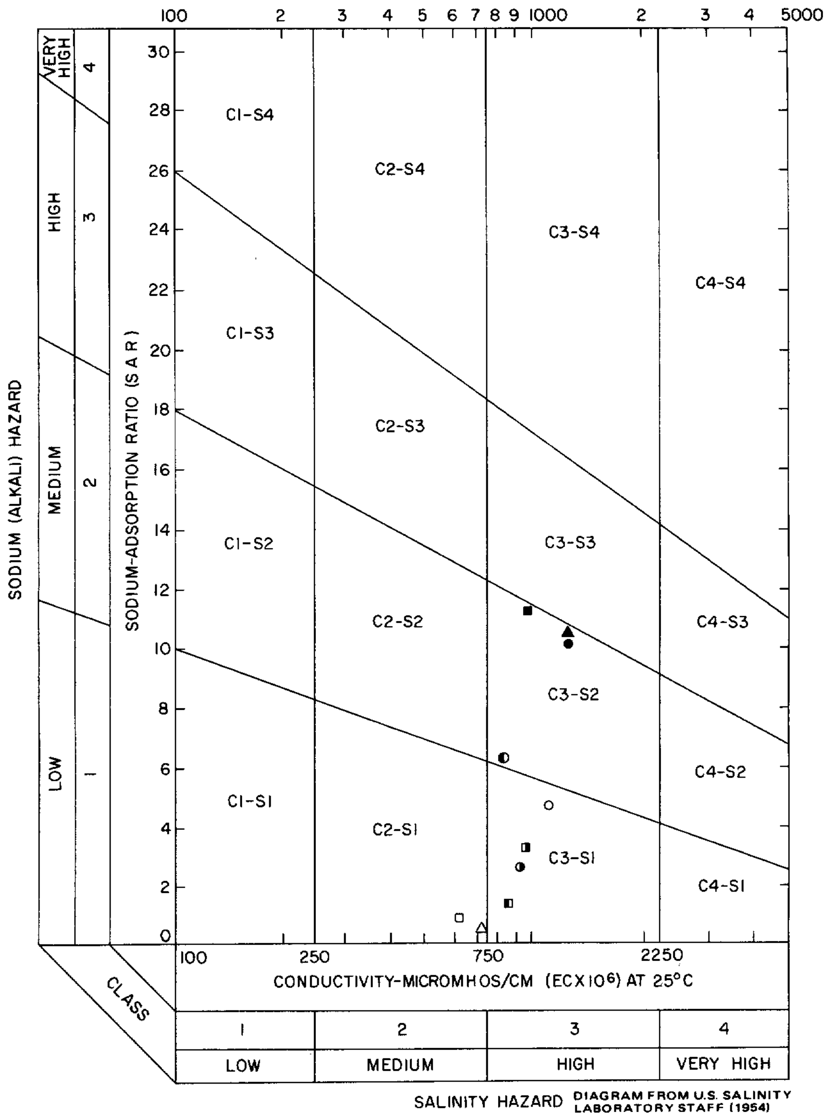
Water in Rocks of Late Cretaceous Age

Fox Hills Aquifer

The Fox Hills Sandstone underlies all of McHenry County. Structure contours of the base of the Fox Hills (fig. 6) show a generalized dip of about 10 ft/mi (1.9 m/km) west toward the center of the Williston basin. Extensive beds of sandstone, which form the Fox Hills aquifer, occur in the upper and middle parts of the Fox Hills (pl. 2, secs. A-A′ and B-B′, in pocket). However, in the northern one-half of the county, the upper part of the Fox Hills, including most of the sandstone beds, was eroded during Pleistocene glaciation. The sandstone beds range in thickness from less than 10 ft (3 m) in the northern part of the county to about 100 ft (30 m) in the southern and southeastern parts of the county. Lithologic samples of the sandstone beds indicate that they consist predominantly of very fine to medium-grained sand, but in places include as much as 45 percent silt and clay.

Data from test holes and geophysical logs indicate the porosities range from 30 to 45 percent and hydraulic conductivities from less than 1 to about 100 ft/d (0.3 to 30 m/d). Potential yields of wells completed in the aquifer should range from 0.5 to 50 gal/min (0.03 to 3 L/s); the larger potential yields occur in the southern part of the county where the sandstone is thickest.

Recharge to the Fox Hills aquifer is derived from precipitation infiltrating through overlying deposits or outcrops in the topographically high areas.

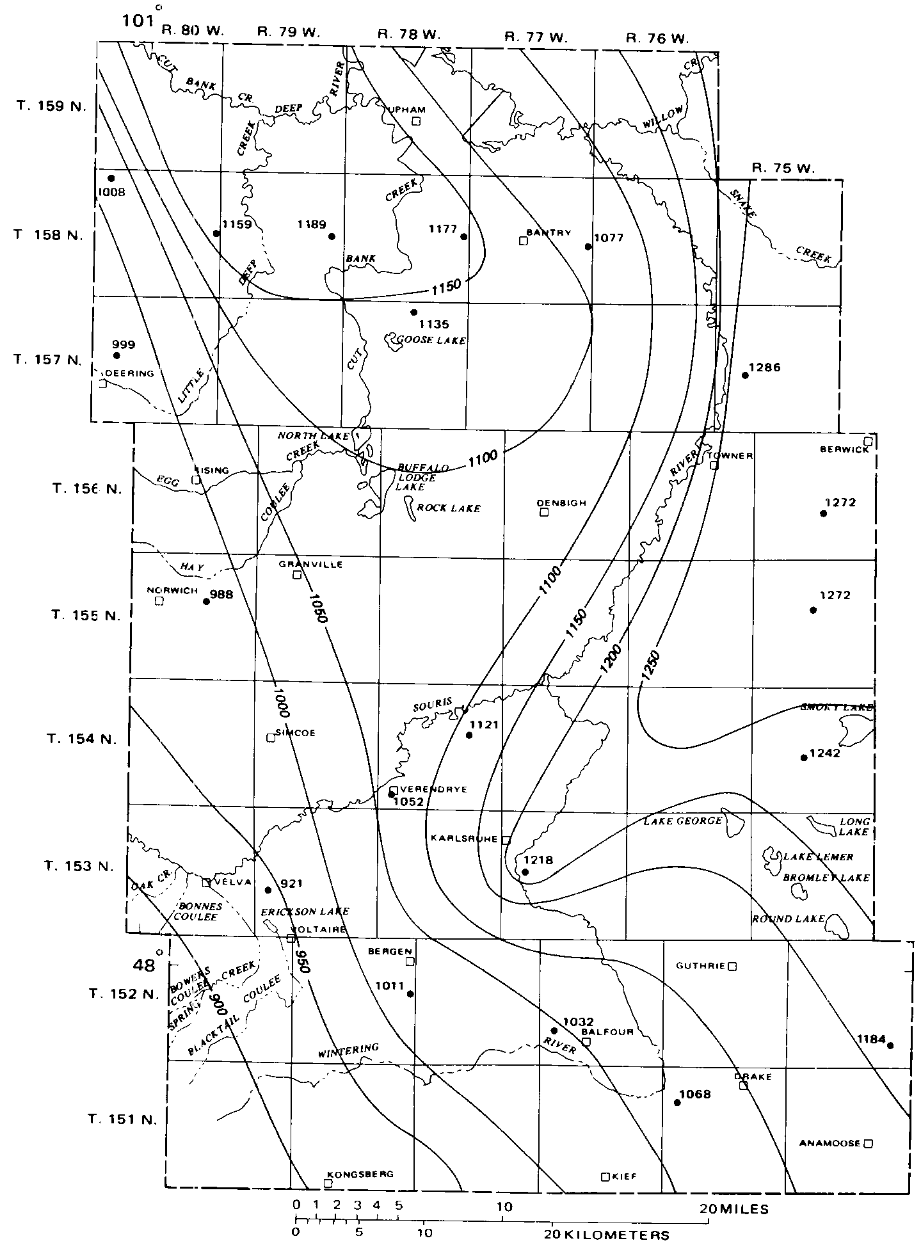


EXPLANATION

MEAN PLOTS FOR ALL AVAILABLE WATER SAMPLES FROM MAJOR AQUIFERS IN McHENRY COUNTY

○ NEW ROCKFORD	▲ BUTTE
● VOLTAIRE	◐ MARTIN
□ DENBIGH	◧ LAKE SOURIS
■ CUT BANK CREEK	◑ KARLSRUHE
△ OUTWASH	◨ SOURIS VALLEY

FIGURE 5.—Mean classifications of ground water for irrigation use.



EXPLANATION

——1250—— STRUCTURE CONTOUR—Shows altitude of base of Fox Hills Sandstone. Contour interval 50 feet (15 meters). National Geodetic Vertical Datum of 1929

•1184 TEST HOLE OR WELL—Number is altitude at base of Fox Hills Sandstone, in feet. National Geodetic Vertical Datum of 1929

FIGURE 6.—Structure contours of base of Fox Hills Sandstone.

The potentiometric surface of the Fox Hills aquifer for July 1977 is shown in figure 7. Water in the aquifer generally moves northeasterly under a hydraulic gradient ranging from 2 to 8 ft/mi (0.4 to 1.5 m/km). Local deviations to the general gradient occur in the vicinity of the Souris River valley. The hydraulic gradient is less in the north-central part of the county where the upper materials were eroded away and replaced with glacial drift.

In most of the area the hydraulic head in the Fox Hills aquifer is higher than hydraulic heads in overlying aquifers — indicating the Fox Hills discharges to the overlying aquifers. Large ground-water withdrawals from overlying aquifers cause a decline in hydraulic head in the Fox Hills aquifer. The water level in the Fox Hills aquifer has declined about 3 ft (1 m) in 2 years as a result of pumping from an irrigation development in the overlying Denbigh aquifer system (fig. 8).

Twenty-four water samples were collected for chemical analyses from 23 wells developed in the Fox Hills aquifer. Examination of the results of these analyses indicates that the water generally is soft and is a sodium bicarbonate or sodium chloride type. Dissolved-solids concentrations in the 24 samples ranged from 410 to 3,180 mg/L, and had a mean of 1,880 mg/L. Dissolved sodium ranged from 120 to 1,200 mg/L, and had a mean of 750 mg/L. Dissolved chloride ranged from 1.4 to 1,600 mg/L, and had a mean of 740 mg/L.

Water from the Fox Hills aquifer has predominantly very high sodium and salinity hazards for irrigation use. Chloride concentrations appear to increase with depth in the southern and western parts of the county where overburden restricts recharge. In the southwestern part of the area, hydrogen sulfide odor was detected in wells developed in the Fox Hills aquifer.

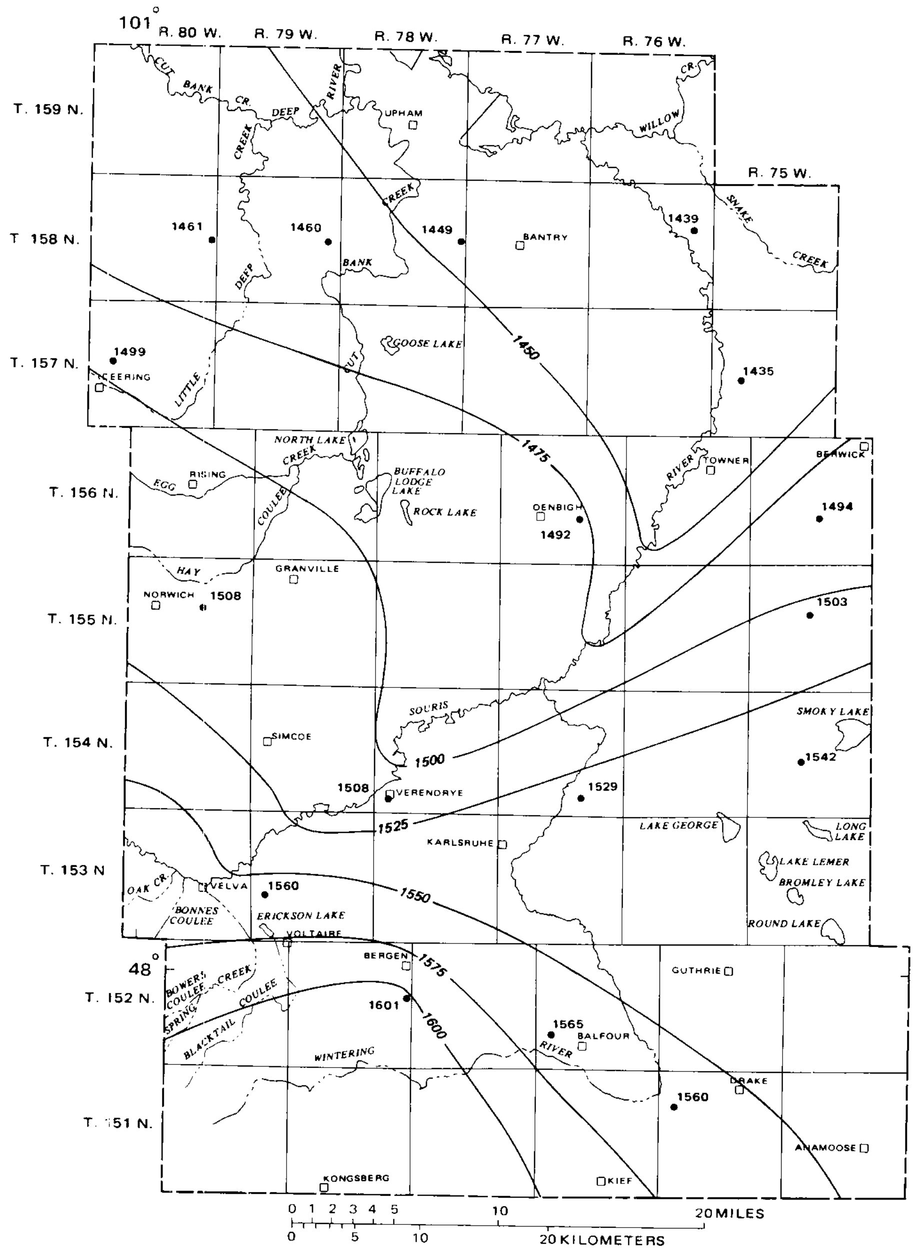
The water is satisfactory for most domestic and livestock uses, but caution may be advisable for people on a sodium-restricted diet (North Dakota State Health Department, 1962).

Hell Creek Aquifer System

The Hell Creek Formation underlies approximately the southern one-half of McHenry County. Beds of sandstone generally occur in the lower and middle parts of the formation (pl. 2, sec. B-B′). These sandstone beds, which form the Hell Creek aquifer system, range in thickness from about 10 to 70 ft (3 to 20 m). Lithologic samples of the sandstone beds indicate the material consists predominantly of very fine to medium-grained sand with about 40 percent silt and clay.

Data from test holes and geophysical logs indicate the porosity ranges from 30 to 45 percent, and hydraulic conductivities range from less than 1 to about 20 ft/d (0.3 to 6 m/d). Potential yields to wells completed in the aquifer system should range from 0.5 to 10 gal/min (0.03 to 0.6 L/s); the largest potential yields would occur in the southwestern part of the county where the sandstone is thickest.

Recharge is derived from precipitation infiltrating through glacial deposits, and from the underlying Fox Hills aquifer. Water movement through the aquifer system is northward toward the discharge area of the Souris River valley. The general hydraulic gradient is about 7 ft/mi (1.3 m/km). Water levels in eight observation wells ranged from 11 to 62 ft (3.4 to 19 m) and averaged 30 ft (9 m) below land surface.



EXPLANATION

—— *1450* —— POTENTIOMETRIC CONTOUR—Shows altitude of potentiometric surface. Contour interval 25 feet (8 meters). National Geodetic Vertical Datum of 1929

• 1439 TEST HOLE OR WELL—Number is altitude of potentiometric surface, in feet. National Geodetic Vertical Datum of 1929

FIGURE 7.—Potentiometric surface of the Fox Hills aquifer, July 1977.

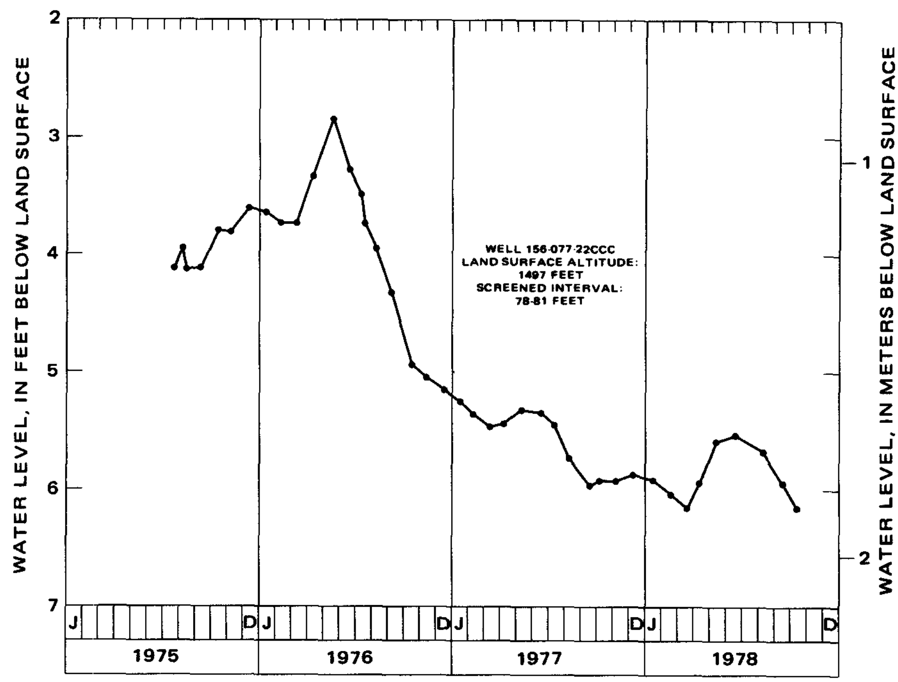


FIGURE 8.—Water-level fluctuations in the Fox Hills aquifer affected by pumping of an irrigation development in the Denbigh aquifer system.

Twenty-four water samples were collected for chemical analyses from wells developed in the Hell Creek aquifer system. Examination of the analyses indicates that the water generally is soft and is a sodium bicarbonate or sodium chloride type. Dissolved-solids concentrations in the samples ranged from 987 to 2,400 mg/L, and had a mean of 1,670 mg/L. Dissolved sodium ranged from 230 to 890 mg/L, and had a mean of 630 mg/L. Dissolved chloride ranged from 44 to 910 mg/L, and had a mean of 430 mg/L.

Water from the Hell Creek aquifer system generally has very high sodium and salinity hazards for irrigation use. The mean chloride concentration is about one-half as much as that in water from the underlying Fox Hills aquifer, dissolved solids and sodium are in about the same range, and sulfate increases slightly. The water is satisfactory for most domestic and livestock uses, but caution may be advisable for people on a sodium-restricted diet.

Ground Water in Rocks of Tertiary Age

Cannonball Aquifer

The Cannonball Member of the Fort Union Formation underlies the glacial drift or Tongue River Member of the Fort Union Formation in approximately the southwestern one-third of McHenry County. Sandstone beds, which form the

Cannonball aquifer, generally occur randomly throughout the member (pl. 2, sec. B-B'). The sandstone beds range in thickness from about 15 to 40 ft (5 to 13 m). The sandstone generally is very fine to medium grained and commonly contains fossiliferous or limonitic concretions.

Data from test holes and geophysical logs indicate porosity ranges from about 35 to 45 percent, and hydraulic conductivities from 2 to about 40 ft/d (0.6 to 12 m/d). Potential yields to wells completed in the aquifer should range from 2 to about 20 gal/min (0.1 to 1 L/s); the largest yields would occur where the sandstone is thickest.

Recharge to the Cannonball aquifer is derived from precipitation infiltrating through surface formations in the southwestern part of the outcrop area in the vicinity of the Souris River. Water in the aquifer generally moves north under a hydraulic gradient of 3 to 4 ft/mi (0.6 to 0.8 m/km). Local deviations to the general gradient occur due to localized recharge or discharge relationships. Seasonal and long-term water-level fluctuations in a well completed in the Cannonball aquifer near Verendrye are shown in figure 9. Annual flooding conditions during 1975-78 in the Souris River valley have resulted in a rise of water levels in the Cannonball aquifer. Flow measurements made during the winter months show the reach of the Souris River from Velva northeast toward Verendrye generally receives some ground-water discharge from the Cannonball aquifer.

Three water samples were collected for chemical analysis from wells completed in the Cannonball aquifer. Two of the samples were a sodium bicarbonate type and one sample was a sodium-magnesium sulfate type. Dissolved solids in the samples were 475, 852, and 1,290 mg/L. Sulfate (51, 100, and 530 mg/L) and iron (150, 480, and 1,800 ug/L) concentrations in places make the water undesirable to unusable for domestic purposes.

Tongue River Aquifer

The Tongue River Member of the Fort Union Formation underlies approximately one township in southwestern McHenry County (fig. 3). Beds of very fine to medium-grained sandstone generally occur at the base of the member. These sandstone beds and lignite beds within the upper and middle parts of the member form the Tongue River aquifer. The sandstone and lignite beds range in thickness from 5 to 30 ft (2 to 9 m). Estimated potential yields to wells completed in the Tongue River aquifer range from 5 to about 50 gal/min (0.3 to 3 L/s).

Three water samples were collected for chemical analysis from wells developed in the Tongue River aquifer. The water was a sodium or calcium bicarbonate type. Dissolved solids in the samples were 824, 1,830, and 1,920 mg/L. The large sulfate (270, 380, and 490 mg/L) and iron (1,100, 1,300, and 2,000 ug/L) concentrations make the water undesirable to unusable for domestic purposes.

Water in Deposits of Quaternary Age

Aquifers with the largest potential for development in the glacial deposits are those associated with buried-valley and glacioaqueous deposits in McHenry

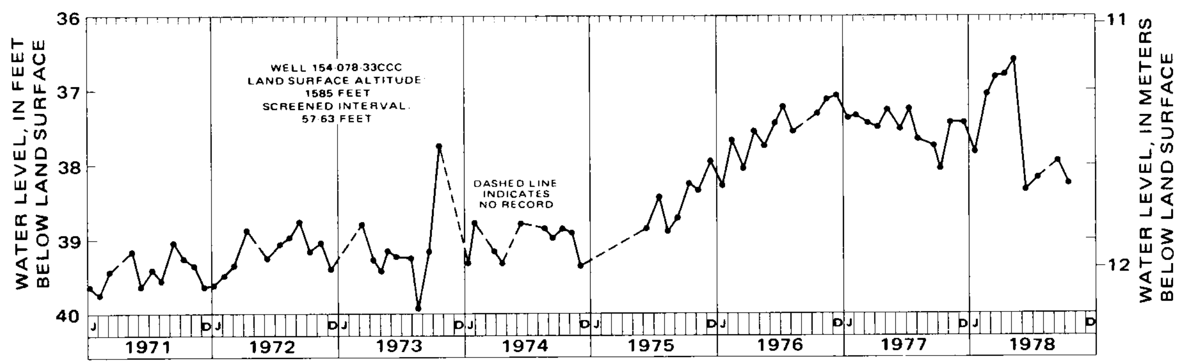


FIGURE 9.—Water-level fluctuations in the Cannonball aquifer near Verendrye.

County. Where appropriate, aquifer names are continued from adjacent areas — New Rockford, Martin, Butte, and Kilgore aquifers (pl. 3, in pocket). Newly recognized aquifers are named after local geographic features, such as streams or cities — Voltaire, Denbigh, Cut Bank Creek, Karlsruhe, Lake Souris, and Souris Valley aquifers (pl. 3).

Estimates of water available to wells from storage are given for aquifers where sufficient geohydrologic data are available. These estimates, in acre-feet, are products of areal extent, saturated thickness, and specific yield — which ranges from 10 to 20 percent and averages about 15 percent — of the aquifer. The storage estimates are provided for comparison purposes only and are based on static conditions. They do not take into account effects of ground-water development, recharge, natural discharge, or ground-water movement. The quantitative evaluation of these factors is beyond the scope of this study.

The potential yields of wells in these aquifers are shown on the ground-water availability map (pl. 3). The yield values are based on transmissivities calculated according to methods described by Keech (1964) and Meyer (1963, p. 339), and from results of aquifer tests. The aquifers are lenticular in cross section; thus, the largest well yields are obtainable only by developing the thickest sections. The variations in thickness and lithology are gradational, and the yield boundaries are approximate.

The ground-water availability map (pl. 3) should be used with the understanding that the estimated yields are for fully penetrating, properly spaced, screened, and developed wells of adequate diameter. The map is intended as a guide in the location of ground-water resources, and not as a map to locate specific production wells. Few if any glacial aquifers are so uniform in areal extent and composition that production wells could be constructed in them without additional test drilling.

New Rockford Aquifer System

The New Rockford aquifer system occupies a buried valley in southern McHenry County (pl. 3). The aquifer system extends from southwestern Pierce County northwest toward Verendrye, beneath the Souris River valley (where its width narrows), continues to the west, and thence into Ward County. The New Rockford aquifer system has an areal extent of about 104 mi^2 (270 km^2) in McHenry County.

The aquifer system generally consists of several sand and gravel beds (pl. 2, secs. C-C′ and D-D′). Data from 60 test holes show that the aquifer system ranges in thickness from 4 to 226 ft (1 to 69 m) and has a mean thickness of about 90 ft (30 m). Test-hole data indicate that the coarsest, most permeable material generally is found along the central axis of the buried valley.

Water levels in the New Rockford aquifer system range from less than 1 to 90 ft (0.3 to 30 m) below land surface. The aquifer system is confined, except in the Karlsruhe area. In the confined eastern part of the aquifer system not affected by pumping, yearly water-level fluctuations average about 2 ft (0.6 m; fig. 10). These

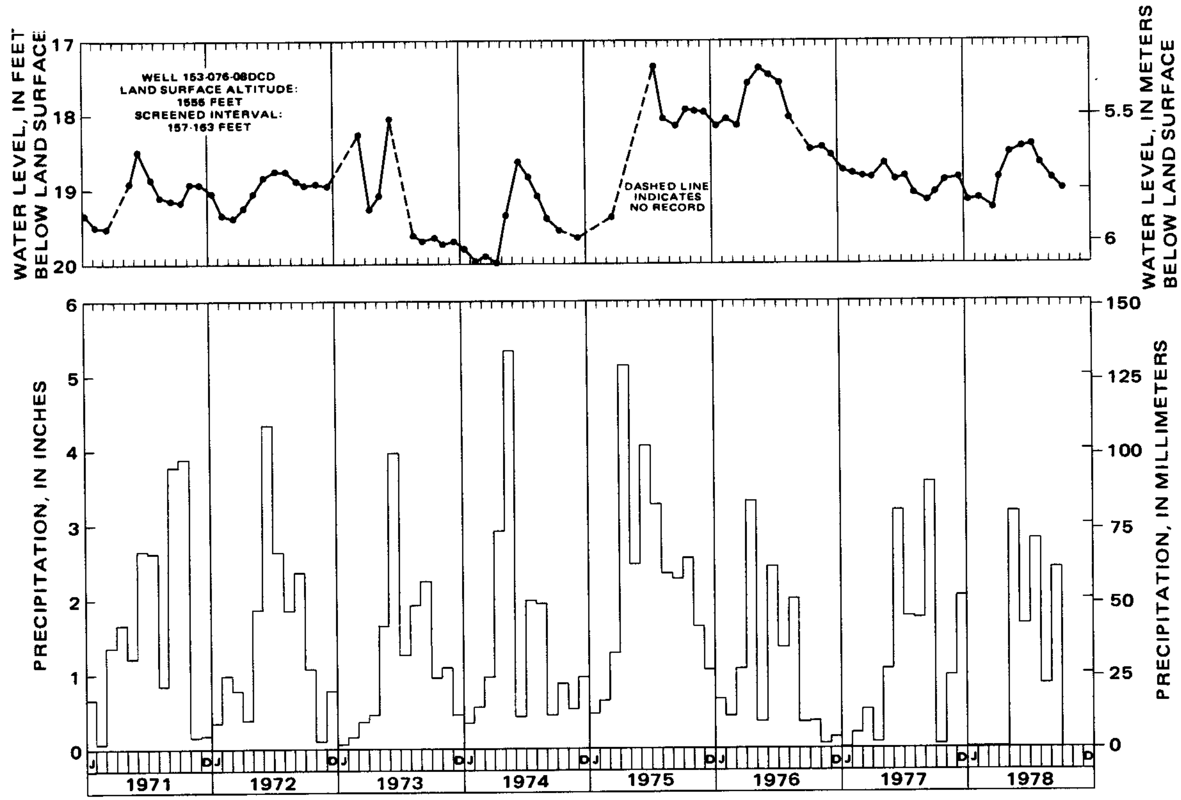


FIGURE 10.—Water-level fluctuations in the eastern part of the New Rockford aquifer system not affected by pumping, and precipitation at Velva.

fluctuations reflect gradual changes in storage — controlled largely by precipitation infiltrating through surface deposits, and by leakage from hydraulically connected adjacent and underlying aquifers.

In the confined western part of the system, which is affected by pumping by the city of Minot, in Ward County, a drawdown of about 5 ft/yr (2 m/yr) has occurred since pumping started during 1976 (fig. 11). Before pumping began, a ground-water divide was located approximately 5 mi (8 km) west of the Ward-McHenry county line. As a result of pumping since 1976, this divide has shifted east about 10 mi (16 km). The rate of drawdown should decrease when an unconfined condition is reached in the western part of the New Rockford aquifer system.

The effects of irrigation development during 1976-78 in the New Rockford aquifer system north of Karlsruhe are shown in figure 12. Effects of pumping on water levels generally are gradual in well 154-078-26BBB because it is in the unconfined part of the aquifer system. Well 154-077-35BBB is on the northern flank of the aquifer system under confined conditions. Effects of pumping are substantially more pronounced here than in the unconfined part of the aquifer system.

Municipal and irrigation pumping is causing water levels to decline in the New Rockford aquifer system. The rate of decline is gradual, but may become of concern to water managers in the future if the decline continues or the rate of decline increases.

Recharge is from underlying and adjacent bedrock aquifers, from overlying or adjacent glacial aquifers, and from infiltration of precipitation.

Altitude of the potentiometric surface in the New Rockford aquifer system ranges from 1,568 ft (478 m) northeast of Anamoose to about 1,520 ft (463 m) in the vicinity of the Souris and Wintering Rivers. Ground-water movement is northwest toward the rivers, under a hydraulic gradient of about 2 ft/mi (0.4 m/km). However, in the west-central part of the county near North Dakota State Highway 41, the potentiometric surface slopes east toward the Souris River valley, and indicates there is a ground-water divide in the aquifer (pl. 3).

Low-flow measurements made during February and November 1977 on the Souris River show an increase in discharge of 25 percent downstream from the New Rockford aquifer system, indicating gains to the stream where it flows across the underlying aquifer. Water samples collected from the Souris River for chemical analyses at the same time and place that low-flow measurements were made indicate an increase in silica and manganese, and a decrease in potassium. Other dissolved constituents remained relatively constant.

The hydraulic properties of the New Rockford aquifer system are based on analyses of three aquifer tests; the test results are summarized in table 3. These tests show that storage coefficients range from 0.0005 to 0.12. The aquifer is unconfined at well 154-077-32CDB and confined at wells 154-077-28ABD and 154-077-35BCA2. Analyses of the tests show confining beds of varying degrees exist at all three sites. These confining beds restrict recharge and cause smaller sustained well yields.

FIGURE 11.—Water-level fluctuations in the western part of the New Rockford aquifer system affected by pumping of the Minot well field.

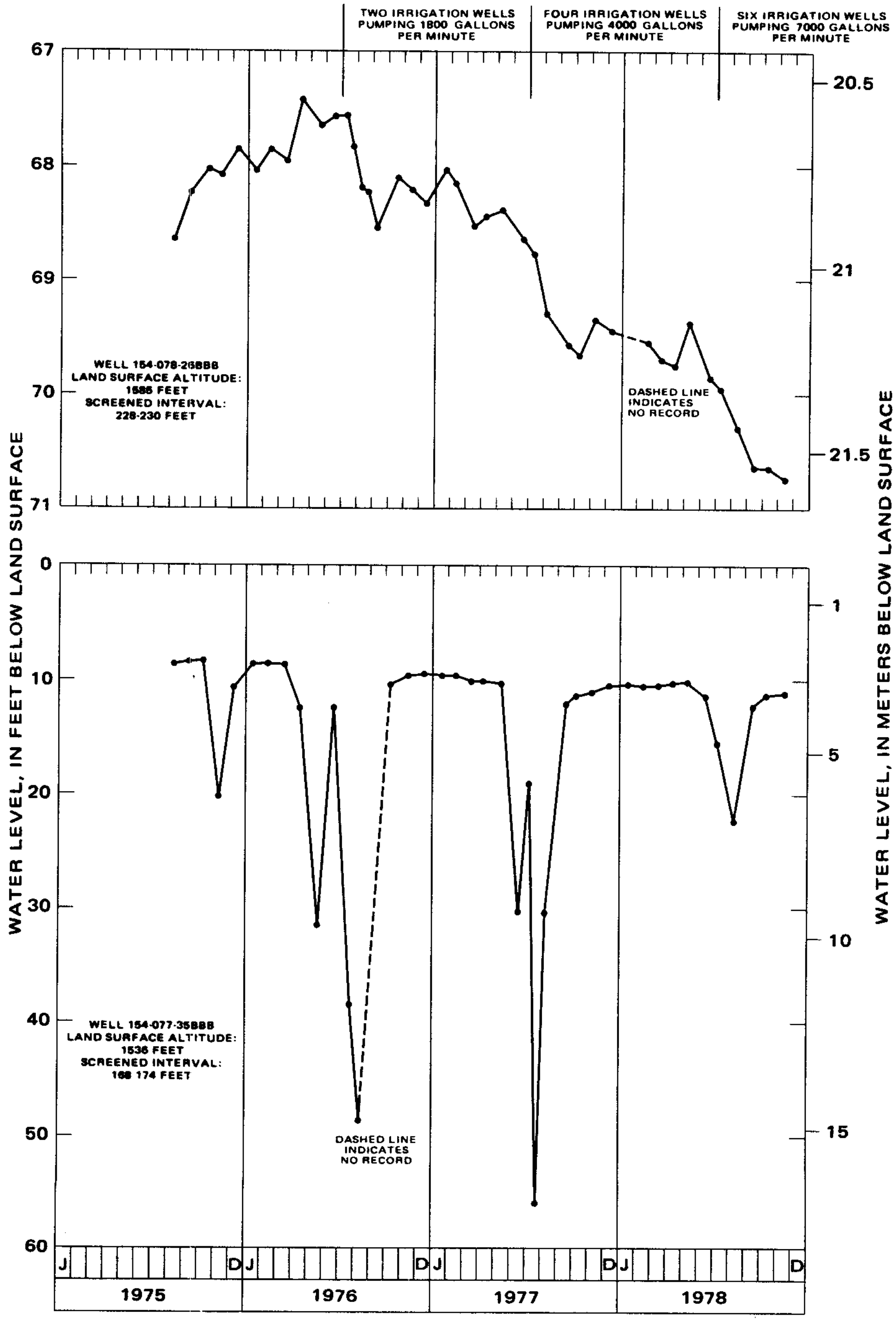


FIGURE 12.—Water-level fluctuations in the New Rockford aquifer system north of Karlsruhe affected by pumping of irrigation wells.

TABLE 3. — **Summary of data obtained from aquifer tests in the New Rockford aquifer system**

	Test wells		
	154-077-28ABD[1]	154-077-32CDB[1]	154-077-32CDB[2]
Date of test	11/14/79-11/17/79	04/20/76-04/23/76	01/12/72-01/15/72
Well depth (feet)	215	148	100
Well screen diameter (inches)	12/12	12/12	16/12
Screened interval (feet)	195-215	118-148	60-100
Discharge (gallons per minute)	1,122	754	803
Duration of test (days)	3	2.7	3
Static water level (feet below lsd)	16.13	18.10	15.85
Drawdown (feet)	27.27	56.77	15.2
Specific capacity (gallons per minute per foot)	40.6	13.3	52
Number of observation wells	26	9	14
Transmissivity (feet squared per day)	39,000	2,500	36,000
Storage coefficient	0.0005	0.0009	0.12

[1]North Dakota State Water Commission test results.
[2]U.S. Bureau of Reclamation test results.

Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the New Rockford aquifer system in McHenry County could yield from 50 to 2,000 gal/min (3 to 130 L/s; pl. 3). Based on an areal extent of 104 mi^2 (270 km^2), a mean thickness of 90 ft (30 m) and an estimated specific yield of 15 percent, about 900,000 acre-ft (1,110 hm^3) of water is available from storage in the McHenry County part of the New Rockford aquifer system.

Analyses of 67 water samples from 52 wells completed in the New Rockford aquifer system indicate that the water predominantly is very hard and generally is a calcium bicarbonate or a sodium bicarbonate type. Dissolved-solids concentrations in the samples ranged from 235 to 2,340 mg/L, and had a mean of 760 mg/L. Calcium ranged from 2.3 to 270 mg/L, and had a mean of 84; sodium ranged from 3.1 to 470 mg/L, and had a mean of 154; bicarbonate ranged from 202 to 956 mg/L, and had a mean of 492; and sulfate ranged from 0.8 to 1,100 mg/L, and had a mean of 180. The SAR ranged from 0.1 to 21, and had a mean of 4.5.

The irrigation classification of the water ranged from a low to very high sodium hazard and a medium to very high salinity hazard, with a mean of C3-S1 (fig. 5).

At present (1979), nine irrigation wells are completed in the aquifer system in McHenry County. These wells yield from 800 to 2,000 gal/min (50 to 126 L/s). Most of these wells are in use for 30 to 60 days during the growing season (May-October). The quantity of water pumped from these nine irrigation wells during the 1979 growing season was estimated to be about 1,800 acre-ft (2.2 hm^3).

Voltaire Aquifer

The Voltaire aquifer occupies a narrow surficial glacial-diversion stream channel that extends from Velva to Balfour in southern McHenry County (pl. 3). The aquifer is named after the city of Voltaire, which it underlies. The Voltaire aquifer has an areal extent of about 32 mi^2 (83 km^2).

The aquifer consists of sand and gravel beds (pl. 3, sec. E-E′). Data from 40 test holes show that the aquifer ranges in thickness from 4 to 71 ft (1.2 to 22 m) and has a mean thickness of 25 ft (8 m). Test-hole data indicate the most productive areas in the Voltaire aquifer are near Voltaire and Bergen (pl. 3).

Water levels in the Voltaire aquifer range from 3 to 25 ft (0.9 to 8 m) below land surface. The aquifer is under unconfined conditions. Recharge to the aquifer is derived from adjacent or underlying bedrock or glacial-drift deposits and from infiltration of precipitation through surface sediments. Many lakes and potholes represent "windows" into the water table, acting as localized recharge and sometimes discharge sources for the aquifer depending upon altitude and the hydraulic connection to the aquifer. The hydraulic gradient is about 20 ft/mi (4 m/km) northwest toward the Souris River valley from a ground-water divide near Voltaire. The gradient to the southeast is about 2 ft/mi (0.4 m/km) with local seasonal deviations due to recharge from or discharge to lakes and potholes.

The hydraulic properties of the Voltaire aquifer are based on three aquifer tests. The data show transmissivities range from 6,500 to 18,000 ft^2/d (604 to 1,670 m^2/d), hydraulic conductivities range from 160 to 250 ft/d (49 to 76 m/d), and storage coefficients range from 0.10 to 0.15. The test analyses show that flank boundaries restrict recharge, decreasing sustained well yields.

Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the Voltaire aquifer could yield from 50 to 500 gal/min (3 to 32 L/s; pl. 3). Based on an areal extent of 32 mi^2 (83 km^2), a mean thickness of 25 ft (8 m), and an estimated specific yield of 15 percent, about 80,000 acre-ft (100 hm^3) is available to wells from storage in the Voltaire aquifer.

Analyses of eight water samples from the Voltaire aquifer indicate that the water is very hard, and predominantly a mixed sodium-calcium bicarbonate or sulfate type. Dissolved-solids concentrations ranged from 335 to 2,230 mg/L, and had a mean of 917; sodium ranged from 13 to 590 mg/L, and had a mean of 175 mg/L; bicarbonate ranged from 216 to 1,290 mg/L, and had a mean of 459 mg/L; sulfate ranged from 34 to 730 mg/L, and had a mean of 340 mg/L.

The SAR ranged from 2.3 to 11, and had a mean of 4.2. The irrigation classification of the water ranges from low to very high sodium hazard and medium to high salinity hazard with a mean of C3-S1 (fig. 5).

At present (1979), four industrial and four public-supply wells are completed in the western part of the Voltaire aquifer. These wells yield about 500 gal/min (32 L/s) for an estimated pumpage of approximmmely 910 acre-ft (1.8 hm^3) per year. There has been very little, if any, permanent water-level decline in the aquifer.

Denbigh Aquifer System

The Denbigh aquifer system comprises a surficial and, in part, a buried valley in north-central McHenry County (pl. 3). The aquifer system extends from northwest of the city of Denbigh, for which it is named, south and southeast to the Souris River valley. It has an areal extent of about 25 mi^2 (65 km^2).

The aquifer system consists of sand and gravel beds (pl. 2, sec. F-F′). Data from 18 test holes show that the aquifer ranges in thickness from 14 to 81 ft (4 to 25 m) and has a mean thickness of about 40 ft (12 m).

Water levels in the Denbigh aquifer system range from about 3 to 17 ft (0.9 to 5 m) below land surface. Water-level fluctuations in the aquifer system are shown in figure 13. The fluctuations reflect changes in ground-water levels resulting from pumping of two irrigation wells and changes in recharge due to climatic conditions.

Recharge to the aquifer system is derived from infiltration of precipitation through surface sediments and from adjacent or underlying bedrock deposits. The ground-water gradient is about 5 ft/mi (0.9 m/km) south and southeast toward the Souris River valley, with local deviations due to recharge or discharge from lakes and potholes.

Transmissivities calculated from lithologic logs were used to estimate potential yield from wells completed in the Denbigh aquifer system (pl. 3). Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the Denbigh aquifer system could yield from 50 to 1,000 gal/min (3.2 to 63 L/s). Based on an areal extent of 25 mi^2 (65 km^2), a mean thickness of 40 ft (12 m), and an estimated specific yield of 15 percent, about 96,000 acre-ft (118 hm^3) of water is available to wells from storage in the Denbigh aquifer system.

Analyses of 17 water samples from the Denbigh aquifer system indicate that the water predominantly is very hard and is a calcium bicarbonate, sodium chloride, or sodium bicarbonate type. Dissolved-solids concentrations ranged from 263 to 1,520 mg/L. and had a mean of 500 mg/L; calcium ranged from 12 to 93 mg/L, and had a mean of 63 mg/L; sodium ranged from 7.6 to 600 mg/L, and had a mean of 99 mg/L; bicarbonate ranged from 275 to 760 mg/L, and had a mean of 407 mg/L; chloride ranged from 0.6 to 520 mg/l, and had a mean of 73 mg/L. The SAR ranged from 0.2 to 37 and had a mean of 4.8. Water in the aquifer system had a low to high sodium hazard and a medium to very high salinity hazard for irrigation use; the mean classification was C2-S2 (fig. 5).

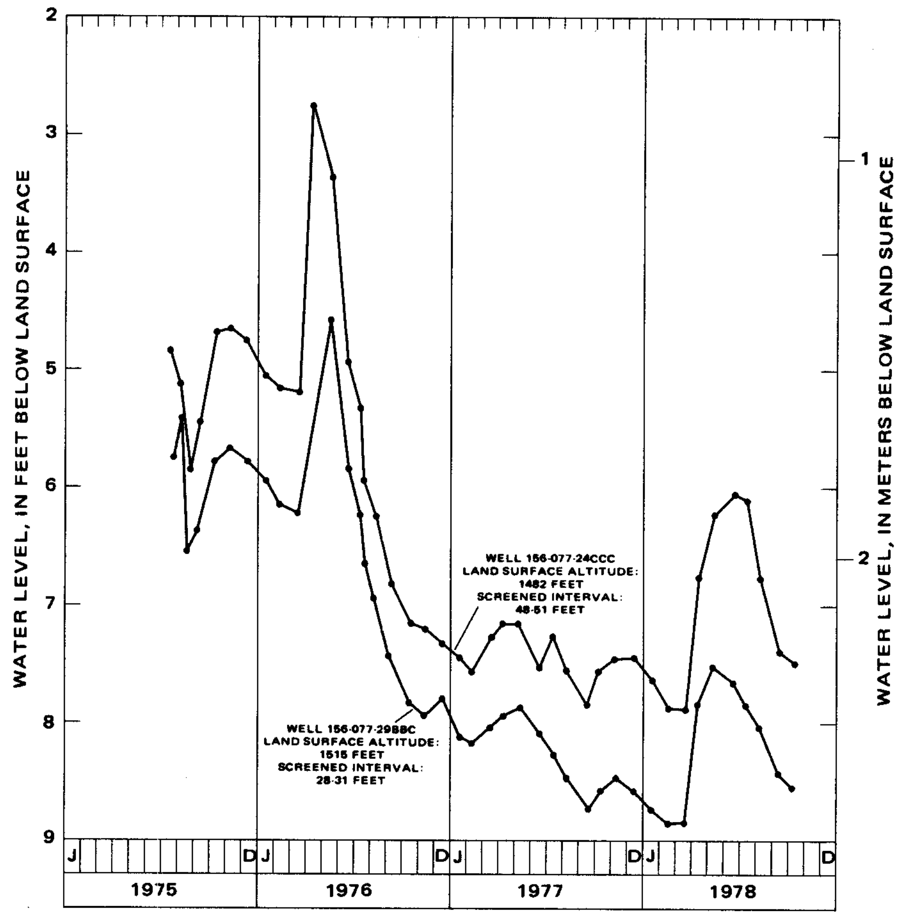


FIGURE 13.—Water-level fluctuations in the Denbigh aquifer system affected by pumping of irrigation wells.

Six irrigation wells are completed in the Denbigh aquifer system. These wells yield from 150 to 750 gal/min (9.5 to 47 L/s), and average about 200 gal/min (13 L/s). Estimated pumpage is approximately 412 acre-ft (0.5 hm^3) per year.

Butte Aquifer

The Butte aquifer is present in a buried valley in southwestern McHenry County (pl. 3). The aquifer extends from the Wintering Lake area southeast into McLean County. The aquifer generally is about 1 mi (1.6 km) wide, and has an areal extent of 20 mi^2 (52 km^2) in McHenry County.

The aquifer consists of sand and gravel beds (pl. 2, sec. E-E′). Data from 11 test holes show that the aquifer ranges in thickness from 11 to 109 ft (3.4 to 33 m) and has a mean thickness of about 35 ft (13 m).

Water levels in the Butte aquifer range from about 1 to 16 ft (0.3 to 4.9 m) below land surface. The aquifer is under confined conditions. Recharge is derived from precipitation infiltrating through surface sediments and ground-water movement from adjacent or underlying bedrock deposits. The ground-water gradient is about 2 ft/mi (0.4 m/km) toward the southeast, with local deviations due to localized recharge or discharge conditions from streams and potholes.

Transmissivities calculated from lithologic logs were used to estimate potential yield from wells completed in the Butte aquifer (pl. 3). Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the aquifer could yield from 50 to 500 gal/min (3 to 32 L/s). Based on an areal extent of 20 mi^2 (52 km^2), a mean thickness of 35 ft (12 m), and an estimated specific yield of 15 percent, about 67,000 acre-ft (83 hm^3) of water is available to wells from storage in the Butte aquifer.

Analyses of five water samples from the Butte aquifer indicated that the water is predominantly moderately hard and is a sodium bicarbonate type. Dissolved-solids concentrations ranged from 655 to 921 mg/L, and had a mean of 820 mg/L; sodium ranged from 210 to 330 mg/L, and had a mean of 260 mg/L; bicarbonate ranged from 461 to 660 mg/L, and had a mean of 564 mg/L; sulfate ranged from 120 to 270 mg/L, and had a mean of 190 mg/L. The SAR ranged from 6.6 to 16, and had a mean of 10.7. Water from the aquifer had a medium to high sodium hazard and a high salinity hazard for irrigation use. Mean irrigation classification was C3-S2 (fig. 5).

At present (1979), several domestic and stock wells are completed in the Butte aquifer. These wells generally yield less than 10 gal/min (0.6 L/s), and have had no noticeable effects on the water levels in the aquifer.

Cut Bank Creek Aquifer

The Cut Bank Creek aquifer occupies a buried-outwash deposit overlying a buried valley in northwestern McHenry County. The aquifer is located about 7 mi (11 km) southwest of Upham, trends northwest (pl. 3), and has an areal extent of about 20 mi^2 (52 km^2). The aquifer is named after Cut Bank Creek.

The aquifer consists of sand and gravel beds (pl. 2, sec. A-A′). Data from 15 test holes show that the aquifer ranges in thickness from about 14 to 82 ft (4 to 25 m) and has a mean thickness of about 40 ft (12 m).

Water levels in the Cut Bank Creek aquifer range from flows to about 28 ft (8 m) below land surface. Some commercial test holes in the south-central part of the aquifer were reported to flow and were cemented off prior to this study. The aquifer is under confined conditions. Recharge to the aquifer is derived from overlying and adjacent drift deposits, the underlying bedrock, and from precipitation infiltrating through surface sediments in the northwestern part of the aquifer. The ground-water gradient slopes to the southeast at about 4 ft/mi (0.8 m/km).

Transmissivities calculated from lithologic logs were used to estimate potential yields from wells completed in the Cut Bank Creek aquifer (pl. 3). Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the aquifer could yield from 50 to 500 gal/min (3 to 32 L/s). Based on an areal extent of 20 mi² (52 km²), a mean thickness of 40 ft (12 m), and an estimated specific yield of 15 percent, about 77,000 acre-ft (95 hm³) of water is available to wells from storage in the Cut Bank Creek aquifer.

Analyses of four water samples from the Cut Bank Creek aquifer indicate that the water ranges from soft to very hard and is a calcium bicarbonate or a sodium bicarbonate type. Dissolved-solids concentrations ranged from 325 to 974 mg/L, and had a mean of 598 mg/L; calcium ranged from 8.6 to 68 mg/L, and had a mean of 38 mg/L; sodium ranged from 21 to 380 mg/L, and had a mean of 179 mg/L; bicarbonate ranged from 316 to 616 mg/L, and had a mean of 458 mg/L; chloride ranged from 1.2 to 250 mg/L, and had a mean of 91 mg/L. The SAR ranged from 0.6 to 26, and had a mean of 11.5. The irrigation classifications of the water ranged from low to very high sodium hazard and medium to high salinity hazard, with a mean of C3-S2 (fig. 5).

At present (1979), several domestic and stock wells pump water from the Cut Bank Creek aquifer. These wells generally yield less than 10 gal/min (0.6 L/s), and have had no noticeable effects on water levels in the aquifer.

Martin Aquifer System

The Martin aquifer system consists of surficial and buried sand and gravel deposits that, in part, occupy a shallow buried valley in southeastern McHenry County (pl. 3). The aquifer system has an areal extent of about 20 mi² (52 km²) in McHenry County.

The aquifer system consists of sand and gravel beds (pl. 2, sec. D-D'). Data from 23 test holes show that the aquifer system ranges in thickness from 4 to 60 ft (1 to 20 m), and has a mean thickness of 25 ft (8 m).

The aquifers within the system are both confined and unconfined. Recharge to the system is derived from precipitation infiltrating through surface sediments, and from adjacent or underlying bedrock deposits. Recharge also is obtained from lakes, potholes, and marshes that intersect the water table; however, during periods of little precipitation, they are sources of discharge from the Martin aquifer system.

Transmissivities calculated from lithologic logs were used to estimate potential yields from wells completed in the Martin aquifer system (pl. 3). Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the aquifer could yield from 5 to 50 gal/min (0.3 to 3 L/s). Based on areal extent of 20 mi² (52 km²), a mean thickness of 25 ft (8 m), and an estimated specific yield of 15 percent, about 48,000 acre-ft (59 hm³) of water is available to wells from storage in the Martin aquifer system.

Analyses of six water samples from the Martin aquifer system indicate that the water is very hard and generally is a calcium or sodium bicarbonate type. Dissolved-solids concentrations ranged from 400 to 1,150 mg/L, and had a mean of 683 mg/L; calcium ranged from 18 to 110 mg/L, and had a mean of 70 mg/L;

sodium ranged from 45 to 390 mg/L, and had a mean of 125 mg/L; bicarbonate ranged from 315 to 769 mg/L, and had a mean of 462 mg/L; sulfate ranged from 34 to 310 mg/L, and had a mean of 162 mg/L. The SAR ranged from 1 to 19, and had a mean of 6.2. The irrigation classifications of the water ranged from low to very high sodium hazard and medium to high salinity hazard, with a mean of C3-S2 (fig. 5).

At the present (1979), there are several domestic and stock wells, and one municipal well (pumping 55.4 acre-ft or 0.07 hm^3 per year) developed in the Martin aquifer system. These wells generally yield from 5 to 35 gal/min (0.3 to 2 L/s).

Karlsruhe Aquifer

The Karlsruhe aquifer, named for the city of Karlsruhe, occupies a surficial outwash plain in south-central McHenry County. The northern flank of the aquifer borders the New Rockford aquifer system (pl. 3). The aquifer has an areal extent of about 20 mi^2 (52 km^2).

The aquifer predominantly consists of sand and lenticular beds of sandy gravel (pl. 2, sec. C-C′). Data from 22 test holes show that the aquifer ranges in thickness from 5 to 40 ft (2 to 12 m). The aquifer has a mean thickness of about 25 ft (8 m).

Water levels in the Karlsruhe aquifer range from 4 to 28 ft (1 to 9 m) below land surface. The aquifer is under unconfined conditions. Recharge to the aquifer is derived predominantly from precipitation infiltrating through surface sediments. The ground-water gradient slopes north and northeast at about 3 ft/mi (0.6 m/km). Local deviations occur where potholes or creeks intercept the water table.

Transmissivities calculated from lithologic logs and existing irrigation wells were used to estimate potential yields from wells completed in the Karlsruhe aquifer (pl. 3). Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the aquifer could yield from about 50 to 500 gal/min (3 to 32 L/s). Based on an areal extent of 20 mi^2 (52 km^2), a mean thickness of 25 ft (8 m), and an estimated specific yield of 15 percent, about 48,000 acre-ft (59 hm^3) of water is available to wells from storage in the Karlsruhe aquifer.

Analyses of four water samples from the Karlsruhe aquifer indicate that the water is very hard and generally is a sodium or calcium bicarbonate type. Dissolved-solids concentrations ranged from 475 to 1,130 mg/L, and had a mean of 655 mg/L; calcium ranged from 53 to 83 mg/L, and had a mean of 70 mg/L; sodium ranged from 29 to 250 mg/L, and had a mean of 108 mg/L; bicarbonate ranged from 346 to 929 mg/L, and had a mean of 515 mg/L; sulfate ranged from 17 to 170 mg/L, and had a mean of 102 mg/L. The SAR ranged from 0.7 to 5.4, and had a mean of 2.7. The irrigation classifications of the water ranged from low to medium sodium hazard and medium to high salinity hazard, with a mean of C3-S1 (fig. 5).

At present (1979), there are many domestic and stock wells, two municipal wells (pumping a total of 17.5 acre-ft or 0.02 hm^3 per year), and two irrigation wells (pumping a total of 154.5 acre-ft or 0.2 hm^3 per year) completed in the Karlsruhe aquifer. These wells generally yield from about 5 to 500 gal/min (0.3 to 30 L/s).

Lake Souris Aquifers

The Lake Souris aquifers, named for glacial Lake Souris, occur as isolated areas of surficial sand (pl. 2, secs. A-A', D-D', and F-F') that is glacioaqueous or eolian in origin. These aquifers have an areal extent of about 45 mi^2 (117 km^2) in McHenry County (pl. 3).

Data from 25 test holes show that the aquifers range in thickness from 5 to 57 ft (1.5 to 17 m). The aquifers have a mean thickness of 22 ft (6.7 m).

Water levels in the Lake Souris aquifers range from less than 1 to 14 ft (0.3 to 4.3 m) below land surface. These aquifers are under unconfined conditions. Recharge to the aquifers is derived predominantly from precipitation infiltrating through surface sediments; discharge is toward streams and lakes.

Transmissivities calculated from lithologic logs were used to estimate potential yields from wells completed in the Lake Souris aquifers (pl. 3). Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the aquifers could yield from 5 to 50 gal/min (0.3 to 3 L/s). Based on an areal extent of 45 mi^2 (117 km^2), a mean thickness of 22 ft (6.7 m), and an estimated specific yield of 12 percent, about 76,000 acre-ft (94 hm^3) of water is available to wells from storage in the Lake Souris aquifers.

Analyses of 23 water samples from the Lake Souris aquifers indicate that the water is very hard and generally is a calcium bicarbonate type. Dissolved-solids concentrations ranged from 232 to 1,620 mg/L, and had a mean of 638 mg/L; calcium ranged from 54 to 210 mg/L, and had a mean of 88 mg/L; sodium ranged from 4.0 to 290 mg/L, and had a mean of 62 mg/L; bicarbonate ranged from 214 to 895 mg/L, and had a mean of 424 mg/L; sulfate ranged from 4.9 to 760 mg/L, and had a mean of 140 mg/L. The SAR ranged from 0.1 to 6, and had a mean of 1.2. The irrigation classification of the water ranged from low to medium sodium hazard and medium to high salinity hazard, with a mean of C3-S1 (fig. 5).

At present (1979), there are many domestic and stock wells completed in the Lake Souris aquifers. These wells predominantly are hand-driven sandpoints that yield from 2 to less than 50 gal/min (0.1 to 3 L/s).

Souris Valley Aquifer

The Souris Valley aquifer occupies alluvium (pl. 2, secs. C-C' and F-F') and terraces along the Souris River. The aquifer extends from Ward County west of Velva to Bottineau County north of Upham (pl. 3). The aquifer has an areal extent of about 70 mi^2 (180 km^2) in McHenry County.

Data from 33 test holes show that the aquifer generally consists of sand and gravel but has localized areas of cobbles and boulders near Verendrye and

Towner. The aquifer materials range in thickness from 4 to 44 ft (1 to 13 m) and have a mean thickness of 23 ft (7 m).

Water levels in the Souris Valley aquifer range from 2 ft (0.6 m) above land surface to 22 ft (7 m) below land surface. The mean water level is about 7 ft (2 m) below land surface. The aquifer generally is unconfined, but locally may be confined by overlying silt and clay beds. Water-level fluctuations in well 156-076-08AAB and maximum monthly stage of the Souris River are shown in figure 14. Water-level response to river stage is very uniform. Recharge to the aquifer is derived from precipitation and flood water infiltrating through surface sediments, and movement from adjacent Lake Souris aquifers or underlying glacial-drift aquifers.

Transmissivities calculated from lithologic logs and aquifer tests were used to estimate potential yields from wells completed in the Souris Valley aquifer (pl. 3). Aquifer test results at site 157-075-31CA (LaRocque and others, 1963b) indicated the transmissivity was 10,000 ft^2/d (929 m^2/d), and the coefficient of storage was 0.16. Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the aquifer could yield from 10 to 500 gal/min (0.6 to 32 L/s). Based on an areal extent of 70 mi^2 (180 km^2), a mean thickness of 23 ft (7 m), and an estimated specific yield of 14 percent, about 144,000 acre-ft (178 hm^3) of water is available to wells from storage in the Souris Valley aquifer.

Analyses of 23 water samples from the Souris Valley aquifer indicate that the water is very hard and predominantly is a calcium or sodium bicarbonate type. Dissolved-solids concentrations ranged from 229 to 2,660 mg/L, and had a mean of 640 mg/L; calcium ranged from 30 to 230 mg/L, and had a mean of 76 mg/L; sodium ranged from 6.6 to 530 mg/L, and had a mean of 102 mg/L; bicarbonate ranged from 258 to 911 mg/L, and had a mean of 427 mg/L; sulfate ranged from 0.4 to 1,200 mg/L, and had a mean of 145 mg/L; chloride ranged from 2.5 to 390 mg/L, and had a mean of 38 mg/L. The SAR ranged from 0.2 to 20, and had a mean of 3.1. Irrigation classifications ranged from low to very high sodium hazard and medium to very high salinity hazard, with a mean of C3-S1 (fig. 5).

At present (1979), there are many domestic and stock wells, two municipal wells (pumping 244.8 acre-ft or 3 hm^3 per year), and six irrigation wells (pumping 35.8 acre-ft or 0.04 hm^3 per year) completed in the Souris Valley aquifer. These wells generally yield from about 5 to 500 gal/min (0.3 to 32 L/s).

Kilgore Aquifer

The Kilgore aquifer occupies a buried valley in east-central McHenry County (pl. 3). The aquifer extends from Pierce County into McHenry County. The aquifer is about 1 mi (1.6 km) wide and has an areal extent of about 6 mi^2 (16 km^2) in McHenry County.

Data from four test holes show that the aquifer consists of poorly sorted silty to clayey sand and gravel beds that range in thickness from 26 to 100 ft (8 to 30 m). The aquifer has a mean thickness of about 50 ft (15 m).

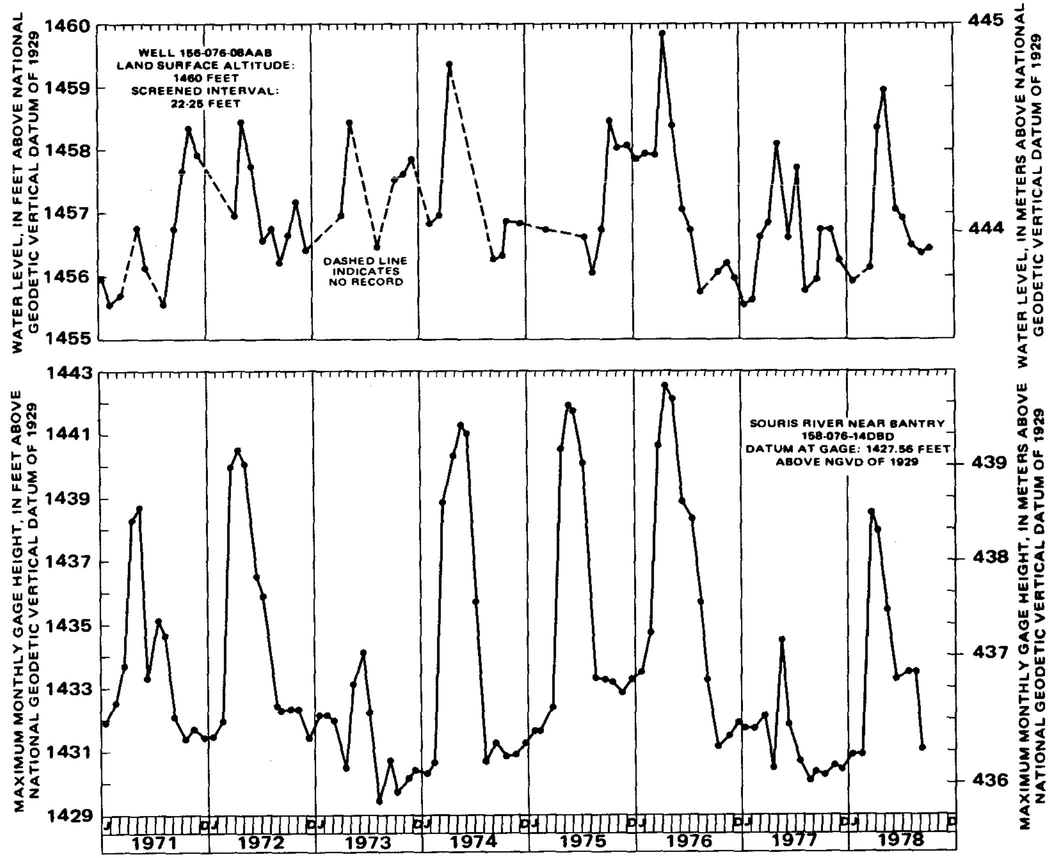


FIGURE 14.—Water-level fluctuations in the Souris Valley aquifer and maximum monthly stage of the Souris River near Bantry.

Water levels in the Kilgore aquifer generally are less than 10 ft (3 m) below land surface and are within overlying confining beds of till, which indicates the aquifer is under confined conditions. Recharge is derived from precipitation infiltrating through surface sediments and from adjacent or underlying bedrock deposits.

Transmissivities calculated from lithologic logs were used to estimate potential yields from wells completed in the Kilgore aquifer (pl. 3). Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the aquifer could yield from 2 to about 50 gal/min (0.1 to 3 L/s). Based on an areal extent of 6 mi^2 (16 km^2), a mean thickness of 50 ft (15 m), and an estimated specific yield of 10 percent, about 20,000 acre-ft (25 hm^3) of water is available to wells from storage in the McHenry County part of the Kilgore aquifer.

No water samples were collected from the aquifer in McHenry County. However, water analyses from the aquifer in Pierce County show the water is very hard and generally is a sodium bicarbonate type with a medium to high salinity hazard and a low to medium sodium hazard.

At present (1979), there are six domestic and stock wells completed in the Kilgore aquifer that yield less than 10 gal/min (0.6 L/s).

Undifferentiated Aquifers in Surficial Outwash Deposits

There are three primary areas in west-central McHenry County where aquifers in surficial outwash deposits are found. These areas are located east of Deering, in the vicinity of Granville, and near Buffalo Lodge and Rock Lakes (pl. 3). They have a combined areal extent of about 18 mi^2 (47 km^2).

Data from nine test holes show that the aquifers consist of mixed sand and gravel deposits that range in thickness from 5 to 59 ft (2 to 18 m), and have a mean thickness of about 20 ft (6 m).

Water levels in these aquifers range from 2 to 16 ft (0.6 to 4.9 m), below land surface. The aquifers are under unconfined conditions. Natural discharge is to potholes and streams. Recharge to the aquifers is derived predominantly from precipitation infiltrating through surface sediments.

Transmissivities calculated from lithologic logs and aquifer tests were used to estimate potential yields from wells completed in the aquifers (pl. 3). Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the aquifers could yield from 5 to 500 gal/min (0.3 to 32L/s). Based on an areal extent of 18 mi^2 (47 km^2), a mean thickness of 30 ft (9 m), and an estimated specific yield of 15 percent, about 52,000 acre-ft (64 hm^3) of water is available to wells from storage in the aquifers.

Analyses of three water samples from undifferentiated aquifers in surficial outwash deposits indicate that the water is very hard and is a calcium bicarbonate type. Dissolved-solids concentrations are 485, 539, and 551 mg/L. Calcium concentrations were 83, 95, and 100 mg/L, and bicarbonate concentrations were 300, 355, and 578 mg/L. The SAR values were 0.4, 0.5, and 0.9. The water had a low sodium hazard and medium to high salinity hazard for irrigation. The mean irrigation classification was C2-S1 (fig. 5).

At present (1979), there are numerous domestic and stock wells, two municipal wells, and one irrigation well completed in the aquifers. These wells generally yield from 5 to 150 gal/min (0.3 to 9.5 L/s).

Undifferentiated Aquifers in Buried Outwash Deposits

Isolated sand and gravel outwash deposits are interspersed with till in many parts of McHenry County. These sand and gravel deposits form undifferentiated aquifers in buried outwash deposits. The aquifers range from less than 1 to about 10 mi^2 (3 to 26 km^2) in areal extent. The total areal extent of these aquifers is estimated to be about 50 mi^2 (130 km^2).

Data from 32 test holes show that these aquifers consist of mixed sand and gravel beds that range in thickness from 4 to 61 ft (1.2 to 19 m). The aquifers have a mean thickness of 30 ft (9 m).

Water levels in these aquifers range from 1 to 62 feet (0.3 to 19 m) below land surface and the aquifers generally are under confined conditions. Recharge is derived from precipitation infiltrating through the overlying and adjacent glacial drift or ground-water movement from underlying bedrock deposits.

Most of the aquifers probably could not sustain well yields of more than 10 gal/min (0.6 L/s) because of their very limited areal extent. However, in some areas where more than one saturated interval exists, well yields of 2 to 50 gal/min (0.1 to 3 L/s) may be possible. Based on an areal extent of 50 mi^2 (130 km^2), a mean thickness of 30 ft (9 m), and an estimated specific yield of 15 percent, about 140,000 acre-ft (173 hm^3) of water is available to wells from storage in the aquifers.

Chemical analyses of 15 water samples from buried outwash deposits indicate that water quality is highly variable. Dissolved-solids concentrations ranged from 295 to 4,580 mg/L, and had a mean of 1,313 mg/L; calcium ranged from 3.5 to 570 mg/L, and had a mean of 115 mg/L; sodium ranged from 24 to 520 mg/L, and had a mean of 252 mg/L; bicarbonate ranged from 264 to 820 mg/L, and had a mean of 516 mg/L; sulfate ranged from 13 to 2,500 mg/L, and had a mean of 440 mg/L, chloride ranged from 2.4 to 400 mg/L, and had a mean of 121 mg/L. The SAR ranged from 0.7 to 33, and had a mean of 7.3. The irrigation classifications of the water were low to very high sodium hazard and medium to very high salinity hazard, with a mean of C3-S2.

At present (1979), there are numerous domestic and stock wells, and three municipal wells (pumping 17.6 acre-ft or 0.02 hm^3 per year) completed in these aquifers. The wells generally yield less than 5 to 40 gal/min (0.3 to 3 L/s).

GROUND-WATER USE

The principal uses of ground water in McHenry County are for domestic, livestock, public, irrigation, and industrial supplies. In McHenry County, the total mean annual ground-water use was 4,523.7 acre-ft (5.6 hm^3) for 1977-79.

Rural Domestic and Livestock Supplies

Rural domestic and stock wells are from 10 to 507 ft (3 to 155 m) deep, and commonly yield less than 10 gal/min (0.6 L/s). The following table shows the approximate quantity of water used during 1978.

The quantities in the table may be larger than the amount of ground water actually used because some farms are vacant during the winter and some livestock are watered from dugouts, sloughs, or streams.

Use	Individual requirements (gallons per day[1])	Population	Estimated pumpage, 1978 (gallons per day)
Domestic (does not include public supply)	100	[2] 5,030	503,000
Cattle	20	[3] 81,000	1,620,000
Hogs	3	[3] 6,500	19,500
Sheep	2	[3] 3,200	6,400
Estimated total pumpage (rounded)			2,150,000 or 7.3 acre-feet

[1] *Murray, 1965.*
[2] *U.S. Bureau of the Census, 1971.*
[3] *U.S. Department of Agriculture, 1979.*

Public Supplies

All cities and villages in McHenry County depend on ground water for their supplies. Municipalities without distribution systems depend on individual private supplies. Also, North Prairie Water Users has installed a rural distribution system in southwestern McHenry County. The following table shows the reported mean annual quantity of ground water pumped through distribution systems during 1977-79.

City/user	Well location	Aquifer	Mean annual pumpage, 1977-79 (acre-feet)[1]
Anamoose	151-075-23BCC	Hell Creek	0.12
Deering	157-080-30ABA	Outwash deposits	7.0
Drake	151-076-23BCC	Martin	55.4
Granville	155-079-08A	Hell Creek	12.0
	-09BB	Outwash deposits	10.0
Karlsruhe	153-077-07BDC1	Karlsruhe	8.2
	-07BDC2	Karlsruhe	9.3
Towner	156-076-11BAB	Souris Valley	122.4
	-11BAC	Souris Valley	122.4
Upham	159-078-21BAB2	Buried outwash	8.3
	-22BCD3	Buried outwash	5.2
	-22DCB	Buried outwash	4.1
Velva	153-080-25BCD	Voltaire	64.0
	-25DC	Voltaire	65.0
North Prairie Rural Water Users	153-080-36AAC2	Voltaire	18.4
	-36AAC3	Voltaire	19.1
Total pumpage			530.92

[1]*Data from the North Dakota State Water Commission.*

Irrigation Supplies

At present (1979) there are 24 wells pumping ground water for irrigation in McHenry County. Also, there are 15 other permits that were either not used or not presently developed. These have a potential for using an additional 6,000 acre-ft (7.4 hm^3) of ground water annually. The following table shows the reported mean annual quantity of ground water pumped for irrigation use during 1977-79.

Aquifer/total mean annual pumpage for irrigation use (1977-79)	Well location	Mean annual pumpage, 1977-79 (acre-feet)[1]
Karlsruhe	153-078-02CAA	131.5
(255.5 acre-feet)	154-078-35BCC2	124.0
New Rockford	154-077-28ABD	181.0
(1,474.8 acre-feet)	-30CDB1	136.9
	-30CDB2	133.6
	-31A	136.5
	-32CDB	146.0
	-35BCA2	130.7
	154-078-25CBB1	192.4
	-26ACD	154.6
	-26CAA	263.1
Denbigh	156-077-22DBA2	86.9
(412.4 acre-feet)	-22DBC	26.8
	-23ADC	16.5
	-23BDD	119.3
	-23CAB	65.0
	-23DBD	97.9
Souris Valley	157-075-31DAD	10.8
(35.8 acre-feet)	-31DBC	4.7
	-31DBD	5.1
	-31DCC	5.1
	-31DDA	5.1
	-31DDB	5.0
Outwash deposits	157-080-35DBC	8.6
(8.6 acre-feet)		
Total pumpage		2,187.1

[1]*Data from North Dakota State Water Commission.*

Industrial Supplies

At present (1979) there are four wells pumping water for industrial use in McHenry County. All these wells are completed in the Voltaire aquifer. The following table shows the reported mean annual quantity of ground water pumped for industrial use during 1978 and 1979.

User	Well location	Mean annual pumpage, 1978-79 (acre-feet)
Basin Electric	153-079-31CAB	371.0
	-31CAC	148.4
	-31CBB	222.6
C. F. Industries	152-080-02AA	3.7
Total pumpage		745.7

SUMMARY

Water in McHenry County is available from aquifers in bedrock formations of Late Cretaceous and Tertiary age and the glacial drift of Quaternary age. Rocks older than Late Cretaceous age generally occur at depths greater than 1,900 ft (580 m) and contain saline water.

The bedrock aquifers predominantly consist of very fine to medium-grained sandstone beds that range in thickness from 5 to about 100 ft (2 to 30 m). The Hell Creek and Fox Hills aquifers are the most extensive bedrock aquifers underlying McHenry County. Recharge to the aquifers is derived from precipitation infiltrating through overlying deposits or through outcrops in topographically high areas. Water movement in the bedrock aquifers generally is northeast and upward through the regional aquifer systems. Wells completed in these aquifers generally yield less than 50 gal/min (3 L/s). The water generally is soft and is a sodium bicarbonate or sodium chloride type. Dissolved-solids concentrations in samples collected from these aquifers ranged from 410 to 3,180 mg/L. The water is used mostly for domestic, livestock, and municipal supplies.

Aquifers with the greatest potential for ground-water development in glacial deposits are those associated with buried-valley and other glacioaqueous deposits in McHenry County. The areal extent, estimated amount of water available from storage, general water type, and estimated potential yields to wells completed in the glacial-drift and alluvial aquifers are summarized in table 4.

Recharge to the glacial-drift aquifers is derived from precipitation infiltrating through surface materials and from adjacent or underlying bedrock aquifers. Discharge occurs where streams intercept the aquifers, and from domestic, livestock, municipal, industrial, and irrigation pumpage. The largest use is from 24 irrigation wells pumping about 2,187 acre-ft (2.7 hm^3) annually. Municipal and irrigation pumping is causing water levels to decline in the New Rockford aquifer system. The rate of decline is gradual, but may become a concern to water managers in the future if the declining trend continues or substantially increases.

TABLE 4. — Summary of data for glacial-drift and alluvial aquifers

Aquifer or aquifer system	Approximate areal extent (square miles)	Estimated amount of water available from storage (acre-feet)	General water type	Estimated potential yields to wells (gallons per minute)
New Rockford	104	900,000	Calcium or sodium bicarbonate	50-2,000
Voltaire	32	80,000	Sodium-calcium bicarbonate or sulfate	50-500
Denbigh	25	96,000	Calcium or sodium bicarbonate or sodium chloride	50-1,000
Butte	20	67,000	Sodium bicarbonate	50-500
Cut Bank Creek	20	77,000	Calcium or sodium bicarbonate	50-500
Martin	20	48,000	Calcium or sodium bicarbonate	5-50
Karlsruhe	20	48,000	Sodium or calcium bicarbonate	50-500
Lake Souris	45	76,000	Calcium bicarbonate	5-50
Souris Valley	70	144,000	Calcium or sodium bicarbonate	10-500
Kilgore	6	20,000	Sodium bicarbonate	2-50
Undifferentiated surficial outwash	18	52,000	Calcium bicarbonate	5-500
Undifferentiated buried outwash	50	140,000	—	2-50
Totals	430	1,748,000		

SELECTED REFERENCES

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

Adolphson, D. G., 1961, Geology and ground-water resources of the Drake area, McHenry County, North Dakota: North Dakota State Water Commission Ground Water Studies no. 31, 44 p.

Andrews, D. A., 1939, Geology and coal resources of the Minot region, North Dakota: U.S. Geological Survey Bulletin 906-B, 81 p.

Bensen, W. E., 1952, Geology of the Knife River area, North Dakota: U.S. Geological Survey Open-File Report, 323 p.

Burkart, M. R., 1980, Ground-water data for Sheridan County, North Dakota: North Dakota Geological Survey Bulletin 75, part II and North Dakota State Water Commission County Ground-Water Studies 32, part II, 302 p.

Burkart, M. R., and Randich, P. G., 1980, Preliminary map showing availability of ground water from glacial-drift aquifers in Sheridan County, central North Dakota: U.S. Geological Survey Open-File Report 80-504W, 1 p.

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

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

Fenneman, N. M., 1946, Physical divisions of the United States: U.S. Geological Survey Map prepared in cooperation with the Physiographic Commission, U.S. Geological Survey, scale 1:700,000 [Reprinted 1964].

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

Jacob, C. E., 1946, Report of the subcommittee on permeability: American Geophysical Union Transactions, v. 27, no. 2, p. 245-256.

Johnson, A. I., 1963, Application of laboratory permeability data: U.S. Geological Survey Open-File Report, 33 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., 6 pls.

Klausing, R. L., 1974, Ground-water resources of McLean County, North Dakota: North Dakota State Water Commission County Ground-Water Studies 19, part III and North Dakota Geological Survey Bulletin 60, part III, 73 p.

LaRocque, G. A., and others, 1963a, Tables of hydrologic data, Crosby-Mohall area, North Dakota, 1945-51: U.S. Geological Survey Open-File Report, 177 p.

——— 1963b, Ground water in the Crosby-Mohall area, North Dakota: North Dakota State Water Commission Ground-Water Studies no. 54, 57 p.

Lemke, R. W., 1960, Geology of the Souris River area, North Dakota: U.S. Geological Survey Professional Paper 325, 138 p.
Meyer, R. R., 1963, A chart relating well diameter, specific capacity, and the coefficients of transmissibility and storage, *in* Bentall, Ray, Methods of determining permeability, transmissibility, and drawdown: U.S. Geological Survey Water-Supply Paper 1536-I, p. 338-340.
Murray, C. R., 1965, Estimated use of water in the United States: U.S. Geological Survey Circular 556, 53 p.
North Dakota State Department of Health, 1962, The low sodium diet in cardiovascular and renal disease: Sodium content of municipal waters in North Dakota: 11 p.
——— 1964, Chemical analysis of municipal waters in North Dakota: 25 p.
——— 1970, Water quality standards for surface waters of North Dakota: 45 p.
Paulson, Q. F., and Powell, J. E., 1957, Geology and ground-water resources of the Upham area, McHenry County, North Dakota: North Dakota State Water Commission Ground-Water Studies no. 26, 66 p.
Pettyjohn, W. A., 1967, Geohydrology of the Souris River valley in the vicinity of Minot, North Dakota: U.S. Geological Survey Water-Supply Paper 1844, 53 p.
——— 1968, Geology and ground-water resources of Renville and Ward Counties, North Dakota; part 2, Ground-water basic data: North Dakota Geological Survey Bulletin 50 and North Dakota State Water Commission County Ground-Water Studies 11, 302 p.
Pettyjohn, W. A., and Hutchinson, R. D., 1971, Ground-water resources of Renville and Ward Counties: North Dakota Geological Survey Bulletin 50, part III and North Dakota State Water Commission County Ground-Water Studies 11, part III, 100 p.
Randich, P. G., 1977, Ground-water resources of Benson and Pierce Counties, North Dakota: North Dakota Geological Survey Bulletin 59, part III and North Dakota State Water Commission County Ground-Water Studies 18, part III, 76 p.
——— 1980, Preliminary map showing availability of ground water from glacial-drift aquifers in McHenry County, north-central North Dakota: U.S. Geological Survey Open-File Report 80-562.
——— 1981, Ground-water data for McHenry County, North Dakota: North Dakota Geological Survey Bulletin 74, part II and North Dakota State Water Commission County Ground-Water Studies 33, part II, 447 p.
Riggs, H. C., 1968, Low-flow investigations: U.S. Geological Survey Preliminary Report, 15 p.
Schroer, F. W., 1970, A study of the effect of water quality and management on the physical and chemical properties of selected soils under irrigation: North Dakota Water Resources Institute Report of Investigations, 48 p.
Simpson, H. E., 1929, Geology and ground-water resources of North Dakota: U.S. Geological Survey Water-Supply Paper 598, 312 p.
Stallman, R. W. 1963, Electric analog of three-dimensional flow to wells and its application to unconfined aquifers: U.S. Geological Survey Water-Supply Paper 1536-H, p. 205-242.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: American Geophysical Union Transactions, v. 16, p. 519-524.
Theis, C. V., Brown, R. H., and Meyer, R. R., 1963, Estimating the transmissibility of aquifers from the specific capacity of wells, *in* Bentall, Ray, Methods of determining permeability, transmissibility, and drawdown: U.S. Geological Survey Water-Supply Paper 1536-I, p. 331-336.
U.S. Bureau of the Census, 1971, 1970 census of population, number of inhabitants, North Dakota: U.S. Bureau of the Census Report PC(1)-A36, 26 p.
U.S. Department of Agriculture, Economic, Statistics and Cooperative Service, North Dakota State Statistical Office, 1979, North Dakota crop and livestock statistics, annual summary for 1978 and revisions for 1977: U.S. Department of Agriculture Statistics no. 44.
U.S. Environmental Data Service, 1972-79, Climatological data, North Dakota; Annual summaries 1971-78: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, v. 80-87, 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 1, p. 17143-17147.
U.S. Public Health Service, 1962, Drinking water standards: U.S. Public Health Service Publication 956, 61 p.
U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Department of Agriculture Handbook 60, 160 p.
Upham, Warren, 1895 [1896], The glacial Lake Agassiz: U.S. Geological Survey Monograph 25, 658 p.
Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments: Journal of Geology, v. 30, p. 377-392.

DEFINITIONS OF SELECTED TERMS

Aquifer — a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to conduct ground water and to yield economically significant quantities of water to wells and springs.
Aquifer system — a body of both permeable and less permeable material that acts as a water-yielding hydraulic unit of regional extent.
Bedrock — a general term for the rock that underlies soil or other unconsolidated surficial material.
Confined — used in this report as an adjective for an aquifer that contains ground water under pressure that is significantly greater than atmospheric pressure.

Discharge — used in this report as the flow of ground water out of an aquifer to the land surface, to bodies of surface water, to the atmosphere, or to other aquifers.

Drawdown — decline in the water level in a well due to withdrawal of ground water.

Facies — any observable characteristic or characteristics of one part of a rock as contrasted with another or several other parts of the same rock, and the changes that may occur in these characteristics over a geographic area.

Fluvial deposits — materials deposited by streams.

Geophysical log — a record obtained by lowering an instrument into a borehole or well and recording continuously on a meter at the surface some physical property of the material surrounding the borehole. Examples used in this investigation include electric logs and radioactivity logs.

Glacial drift — all rock material (clay, sand, gravel, boulders) transported by a glacier and deposited directly by or from the ice or by running water that originated in the ice.

Glacioaqueous — pertaining to or resulting from the combined action of ice and water.

Glaciofluvial — pertaining to streams flowing from glaciers.

Ground water — the part of the subsurface water that is in the zone of saturation.

Hydraulic conductivity — 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 flow.

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

Infiltration — used in this report as movement of water and solutes through interstices in surficial material.

Lacustrine deposits — materials deposited in lakes.

Lithologic log — a record of the description of the distribution of materials and their properties with depth in a borehole or well.

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."

Observation well — a well drilled for the purpose of measuring factors such as water levels and pressure changes.

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

Permeability — the property of a porous rock or unconsolidated material for transmitting fluids.

Porosity — the property of a rock, soil, or other material of containing interstices or voids and may be expressed quantitatively as the ratio of the volume of its interstices to its total volume.

Potential yield — used in this report as the rate of withdrawal of water that can be expected from a properly constructed well to an aquifer.

Potentiometric surface — an imaginary surface representing the level to which water will rise in a tightly cased well.

Pressure head — head pressure expressed as the height of a column of water that the pressure can support.

Recharge — the processes involved in the addition of water to the zone of saturation or the transfer of water to an aquifer from the surrounding material.
Saturated — a condition in which the openings of a material are filled with water.
Sodium-adsorption ratio —

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

where ions are expressed in milliequivalents per liter. This ratio can be used to predict the degree to which water tends to enter a chemical reaction which is damaging to soil structure.
Specific capacity — the rate of discharge of a well per unit of drawdown.
Specific yield — the ratio of the volume of water a given mass of material will yield by gravity to the volume of that mass.
Storage coefficient — the volume of water released from storage per unit area if the water table or potentiometric surface declines a unit distance. In an unconfined aquifer it is approximately equal to specific yield.
Till — nonsorted and nonstratified sediment deposited by a glacier. Generally composed of clay or silt with varying amounts of sand, pebbles, and boulders.
Transmissivity — the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths.
Unconfined — used in this report as an adjective for an aquifer having a free water table, that is, water not confined under pressure significantly greater than atmospheric pressure beneath impermeable materials.