GROUND-WATER RESOURCES

OF

BOTTINEAU AND ROLETTE COUNTIES,

NORTH DAKOTA

By

P. G. Randich and R. L. Kuzniar

U.S. Geological Survey

COUNTY GROUND-WATER STUDIES 35 — PART III
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

BULLETIN 78 — PART III
North Dakota Geological Survey
Don L. Halvorson, *State Geologist*

Prepared by the U.S. Geological Survey in cooperation
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Bismarck, North Dakota

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

A dual system of measurements — inch-pound units and the International System of Units (SI) — is given in this report. The 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 mile (ft/mi)	0.1894	meter per kilometer (m/km)
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)
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 (L/s)
Inch (in.)	25.4	millimeter (mm)
Micromho per centimeter at 25 °C (umho/cm at 25 °C)	1	microsiemen per centimeter at 25 °C (uS/cm at 25 °C)
Mile (mi)	1.609	kilometer (km)
Square mile (mi^2)	2.590	square kilometer (km^2)

GROUND-WATER RESOURCES OF BOTTINEAU AND ROLETTE COUNTIES, NORTH DAKOTA

By P. G. Randich and R. L. Kuzniar

ABSTRACT

An investigation of the ground-water resources of Bottineau and Rolette Counties, North Dakota, indicates that large quantities of water can be obtained from glacial-drift aquifers. Bedrock aquifers also are a source of water in most of the area, but yields are much less and the water contains more sodium and dissolved solids than water from the glacial-drift aquifers.

Glacial-drift aquifers, exclusive of the Lake Souris surficial sands, underlie about 317 square miles (821 square kilometers) and contain approximately 762,000 acre-feet (940 cubic hectometers) of available ground water. Potential well yields range from less than 50 to 1,000 gallons per minute (3 to 63 liters per second) from the major glacial-drift aquifers. The water from the glacial-drift aquifers is a mixed type. The dominant cations are calcium and sodium and the dominant anions are bicarbonate and sulfate. Dissolved solids in samples collected from these aquifers ranged from 238 to 10,400 milligrams per liter.

The Hell Creek and Fox Hills aquifer systems, which consist of very fine to medium-grained sandstone beds, are the major bedrock aquifers. Wells developed in these aquifer systems yield less than 50 gallons per minute (3 liters per second). The water generally ranges from soft to very hard and is a sodium chloride or sodium sulfate type. Dissolved-solids concentrations in samples collected from these aquifer systems ranged from 680 to 7,200 milligrams per liter.

The rural population and communities in Bottineau and Rolette Counties depend on ground water as a source of supply. Several rural water-distribution systems have been developed to serve rural and municipal users in areas where insufficient quantities of ground water exist or where the quality of the available ground water is unsuitable.

INTRODUCTION

The investigation of the ground-water resources of Bottineau and Rolette Counties (fig. 1) was made cooperatively by the U.S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and the Water Management Districts of Bottineau and Rolette Counties. The results of the investigation are published in three parts. Part I is an interpretive report describing the geology of the study area. Part II (Kuzniar and Randich, 1982) is a compilation of the geologic and hydrologic data collected during the investigation, and is a

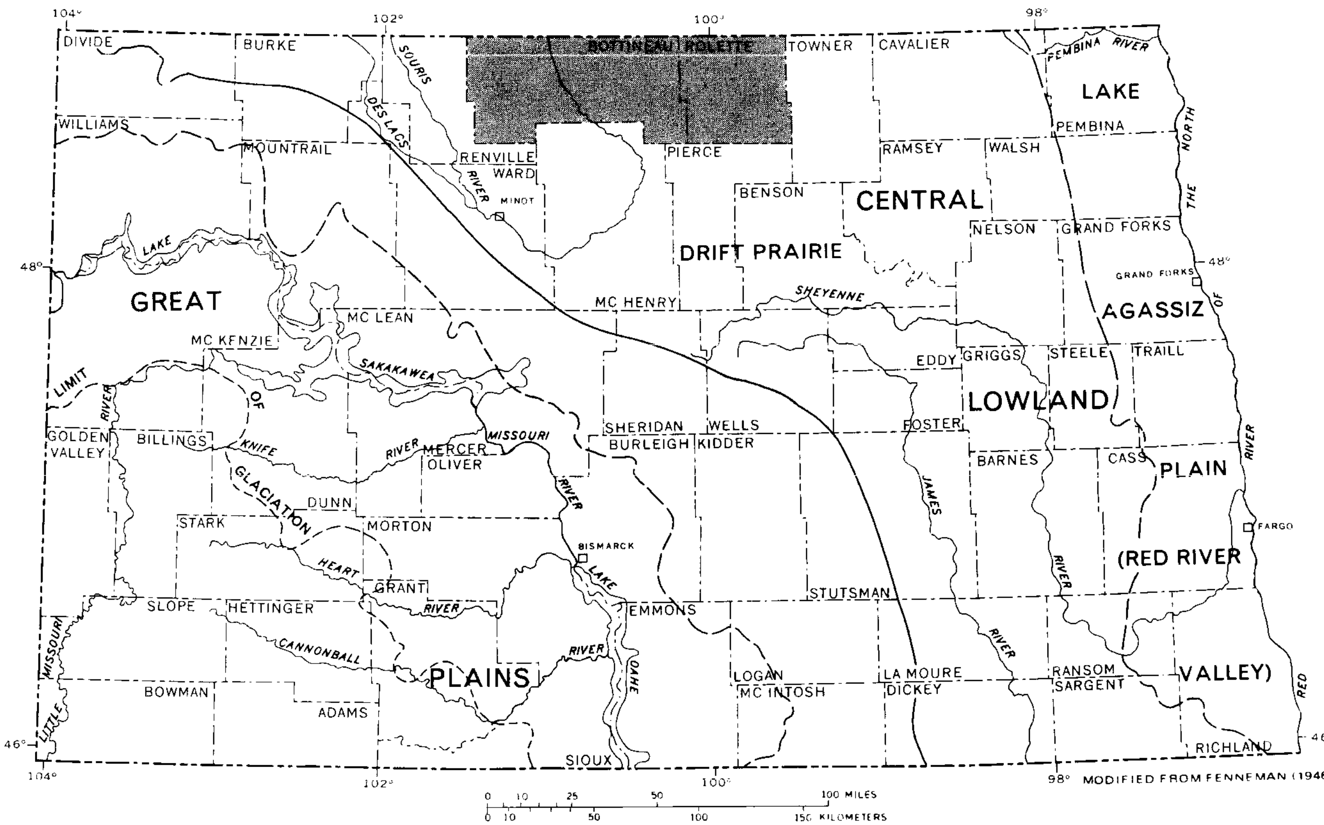


FIGURE 1.—Physiographic divisions in North Dakota and location of study area.

reference for the other two parts. Part III is an interpretive report describing ground-water resources. The reports are prepared and written to assist State and county water managers, consultants to water users, and water users in the development of ground-water supplies for municipal, domestic, livestock, irrigation, industrial, and other uses.

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.

Objectives and Scope

The purpose of this investigation was to provide detailed geologic and hydrologic information needed for the orderly development of water supplies for municipal, domestic, livestock, irrigation, industrial, and similar uses.

The objectives of the investigation 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 the glacial and alluvial aquifers; (4) estimate the potential yields to wells penetrating major aquifers; (5) describe the chemical quality of the ground water; and (6) estimate the water use.

Interpretations contained in this report are based on data from 1,268 wells and test holes. These data include lithologic and geophysical logs of 1,158 test holes and wells; water-level measurements in 120 observation wells; and 201 chemical analyses of ground water. Also used were chemical analyses of water samples from streams where and when ground water constituted most of the stream discharge.

Previous Investigations

The earliest geologic report that included Bottineau and Rolette Counties was by Upham (1895, p. 267-272), who briefly described the area covered by glacial Lake Souris. Simpson (1929) included a brief description of the geology and ground-water resources of Bottineau and Rolette Counties in his report on the geology and ground-water resources of North Dakota. A geologic report (Lemke, 1960) describes the Souris River area, including Bottineau County and part of Rolette County. Many ground-water data for Bottineau County are given in a report by LaRocque and others (1963a). The data were utilized in a subsequent interpretive report (LaRocque and others, 1963b). Deal (1971) reported on the geology of Rolette County, with emphasis on glacial geology and landforms.

Local ground-water studies have been made in several parts of Bottineau and Rolette Counties. Akin (1951) described the geology and ground-water conditions in the Mohall area, which includes parts of Renville and Bottineau Counties. Powell (1959) discussed the geology and occurrence of ground water in the vicinity of Westhope in Bottineau County. Brookhart and Powell (1961) provided a reconnaissance of the geology and ground water in the vicinity of Rolla, St. John, and Mylo areas in Rolette County. Schmid (1964) and Froelich (1967) added subsequent ground-water interpretations based on additional data in the vicinity of Rolla and St. John. Froelich (1963) investigated the ground-water conditions near Bottineau in Bottineau County. Froelich (1966) conducted a water-supply survey for the city of Lansford in Bottineau County. Naplin (1968) reported on a ground-water survey of the Willow City area in Bottineau County. Randich (1975) described the ground-water availability in the Belcourt area in Rolette County. Results of aquifer tests in the Belcourt area were reported by Randich and Ghering (1975).

Acknowledgements

Collection of the data on which this report is based was made possible by the cooperation of residents and officials of Bottineau and Rolette Counties, the U.S. Public Health Service, and council members of the Turtle Mountain Indian Reservation.

Particular recognition is due M. O. Lindvig, R. L. Cline, A. E. Comeskey, P. A. Burke, and G. J. Calheim of the North Dakota State Water Commission for contributing to the interpretation of the geohydrology of the area. Appreciation is expressed to all well drillers and contractors who furnished lithologic logs and records of wells.

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 159-070-15ADC is in the SW¼SE¼NE¼ sec. 15, T. 159 N., R. 070 W. Consecutive terminal numerals are added if more than one well or test hole is recorded within a 10-acre (4-ha) tract.

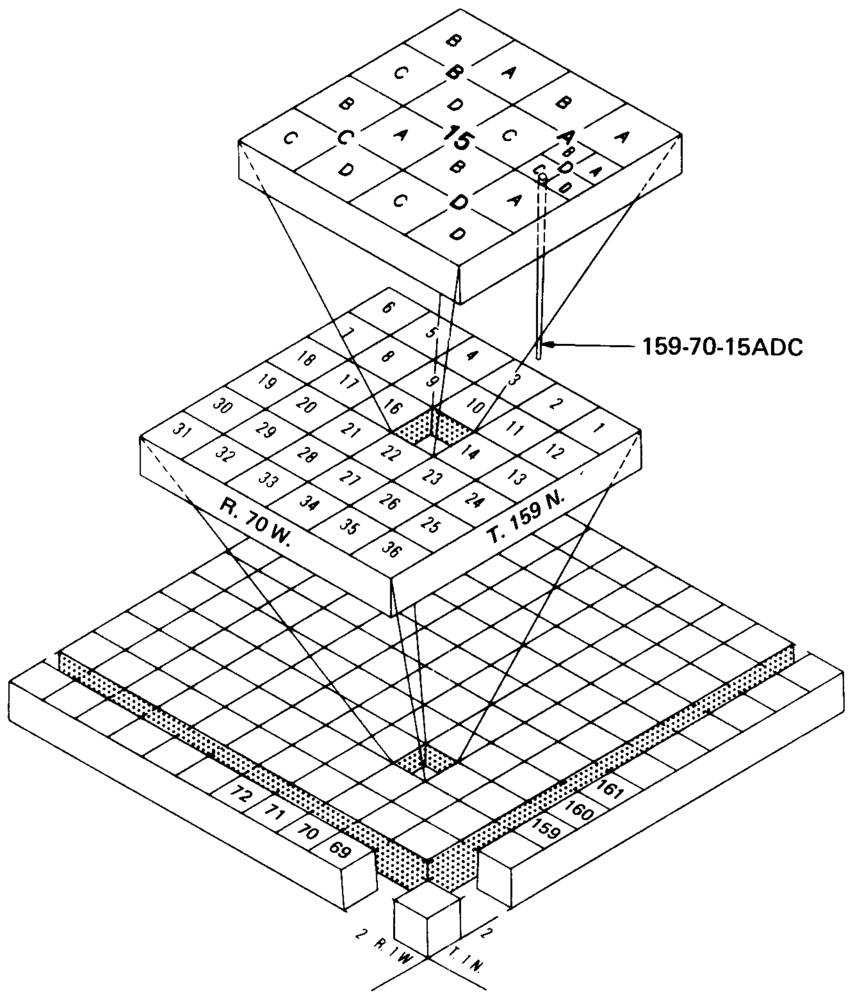


FIGURE 2.—Location-numbering system.

Geography

Bottineau and Rolette Counties are in the Drift Prairie of the Central Lowland physiographic province (fig. 1). The counties have an area of about 2,645 mi^2 (6,851 km^2) in north-central North Dakota — Bottineau County has an area of 1,707 mi^2 (4,421 km^2) and Rolette County has an area of 938 mi^2 (2,430 km^2).

Topography ranges from the generally flat lake plain of the Souris valley to the relatively rugged high relief of the Turtle Mountains. The maximum relief is about 1,135 ft (346 m) in Bottineau County, ranging from an altitude of 1,410 ft (430 m) at the Souris River on the boundary between Manitoba and North Dakota to 2,545 ft (776 m) at Boundary Butte west of Lake Metigoshe. The most prominent land feature in the area is the Turtle Mountains, which stand about 500 ft (150 m) higher than the surrounding area.

The major drainage in most of Bottineau and Rolette Counties is the Souris River. Drainage in the eastern part of Rolette County is to Devils Lake and drainage in the northern part of the Turtle Mountains generally is to the Pembina River, a tributary to the Red River.

The climate is semiarid — mean annual precipitation ranges from 15.48 in. (393 mm) at Willow City to 18.61 in. (473 mm) at Rolla. Most precipitation is received during the growing season, which is the period April through September. The mean annual temperature ranges from 37.0 °F (2.8 °C) at Bottineau to 37.7 °F (3.2 °C) at Westhope (U.S. Environmental Data Service, 1973). The mean annual evaporation from lake surfaces in the area is about 33 in. (840 mm; National Weather Service, 1982).

Bottineau County had a population of 9,239 and Rolette County had a population of 12,177 in 1980 (U.S. Bureau of the Census, 1981).

Dryland farming and livestock raising are the two most important agricultural industries. The principal crops are wheat, barley, sunflowers, hay, oats, and corn. Livestock production includes cattle, hogs, chickens, and sheep. In Bottineau County the economy is enhanced by the development of oil and gas wells. In Rolette County the economy is broadened by tourist attraction to the International Peace Gardens north of Dunseith.

Geohydrologic Setting

The generalized surficial geology of Bottineau and Rolette Counties is shown in figure 3. Deposits of Quaternary age cover all of the area except for small isolated outcroppings of deposits of Tertiary and Cretaceous age on the west side of the Turtle Mountains.

The bedrock units above the Pierre Shale of Late Cretaceous age were evaluated for their water-bearing characteristics. For practical purposes, the unfractured part of the Pierre Shale forms the base of the

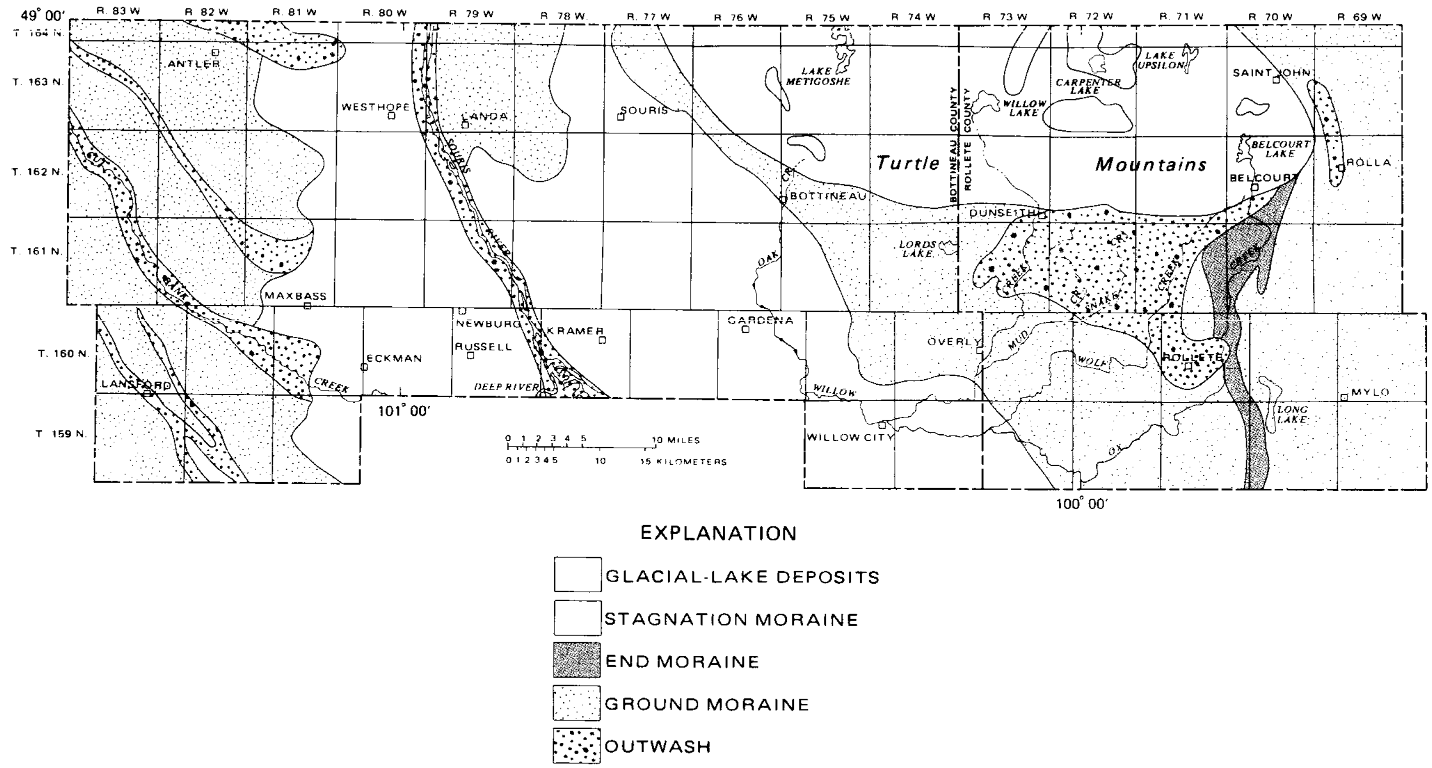


FIGURE 3.—Generalized surficial geology.

fresh-water-bearing units in the study area. The Fort Union Formation of Paleocene age occurs in a part of the Turtle Mountains, but is not a significant aquifer in the study area.

Glacial-drift deposits of Quaternary age were studied in greater detail than the bedrock units because greater quantities of better quality water are found in these deposits. The glacial-drift deposits include water-yielding glacioaqueous materials such as sand and gravel as well as relatively impermeable silt, glacial till, and lacustrine clay. The thickest drift deposits are located in buried bedrock valleys and in the Turtle Mountains.

The generalized bedrock topography of Bottineau and Rolette Counties is shown on plates 1 and 2 (in pocket). Major glacial-drift aquifers are buried within some of the bedrock valleys.

AVAILABILITY AND QUALITY OF GROUND WATER

General Concepts

All ground water is derived 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 that enters the ground is held by capillarity and may evaporate or be transpired. The water in excess of the moisture-holding capacity of the soil infiltrates downward to the water table and ultimately becomes available to wells.

Ground water moves under the effect of gravity and pressure from areas of recharge to areas of discharge. Ground-water movement generally is slow and may be only a few feet per year. The rate of ground-water movement is governed by the hydraulic conductivity of the material through which the water moves and by the hydraulic gradient. Gravel, well-sorted sand, and fractured rocks have a large hydraulic conductivity, and when saturated can be termed aquifers. Cemented deposits and fine-grained materials such as silt, clay, and shale usually have a small hydraulic conductivity and restrict ground-water movement.

The water level in an aquifer generally fluctuates in response to changes in the rate of recharge to and discharge from the aquifer. These fluctuations usually indicate a change in the amount of water stored in the aquifer. However, in confined aquifers, changes in atmospheric pressure or surface load also cause water-level fluctuations. In the study area, 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 these materials or by lateral movement downgradient from a recharge area exposed at the 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 Bottineau and Rolette Counties, surface-water sources, such as the Souris River, numerous creeks, lakes, and potholes are hydraulically connected to the aquifers. The aquifer may either receive recharge from the surface-water source or discharge water into it, depending on the elevation of water levels in streams, lakes, and potholes in relation to the water level in the aquifer.

The ground water in Bottineau and Rolette Counties contains varying concentrations of dissolved solids. Rain begins to dissolve minerals as it falls and continues to dissolve minerals as the water infiltrates the soil. The amount and kind of dissolved minerals 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 also affect the amount of dissolved material. Ground water that has been in transient storage a long time or 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 U.S. Geological Survey has assigned terms for waters of high dissolved solids as follows (Robinove and others, 1958):

	Dissolved solids (milligrams per liter)
Slightly saline	1,000-3,000
Moderately saline	3,000-10,000
Very saline	10,000-35,000
Briny	More than 35,000

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. Sources of the major chemical constituents, their effects on usability, and the recommended and mandatory limits for drinking water are given in table 1. Additional information regarding drinking-water standards may be found in reports by the U.S. Environmental Protection Agency (1976, 1977).

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

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

[Modified from Durfor and Becker, 1964, table 2. Concentrations are in milligrams per liter, mg/L, or micrograms per liter, ug/L]

Constituents	Major Source	Effects upon usability	U.S. Environmental Protection Agency (1976, 1977) recommended and mandatory limits for drinking water
Silica (SiO_2)	Feldspars, quartz, and ferromagnesian and clay minerals.	In presence of calcium and magnesium, silica forms a scale in boilers and on steam turbines that retards heat transfer.	None.
Iron (Fe)	Natural sources: amphiboles, ferromagnesian minerals, ferrous and ferric sulfides, oxides, carbonates, and clay minerals. Man-made sources: well casings, pumps and storage tanks.	If more than 100 ug/L is present, it will precipitate when exposed to air; causes turbidity, stains plumbing fixtures, laundry, and cooking utensils, and imparts tastes and colors to food and drinks. More than 200 ug/L is objectionable for most industrial uses.	300 ug/L (recommended).
Manganese (Mn)	Soils, micas, amphiboles, and hornblende.	More than 200 ug/L precipitates upon oxidation. Causes undesirable taste and dark-brown or black stains on fabrics and procelain 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, proxenes, magnesite, dolomite, and clay minerals.		
Sodium (Na)	Feldspars, clay minerals, and evaporites.	More than 50 mg/L sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers.	None.
Potassium (K)	Feldspars, feldspathoids, micas, and clay minerals.		
Boron (B)	Tourmaline, biotite, and amphiboles.	Essential to plant nutrition. More than 2 mg/L may damage some plants.	None.
Bicarbonate (HCO_3)	Limestone and dolomite.	Heating water dissociates bicarbonate to carbonate, carbon dioxide, or both. The carbonate can combine with alkaline earths (principally calcium and magnesium) to form a scale.	None.
Carbonate (CO_3)			
Sulfate SO_4)	Gypsum, anhydrite, and oxidation of sulfide minerals.	Combines with calcium to form scale. More than 500 mg/L tastes bitter and may be a laxative.	250 mg/L (recommended).
Chloride (Cl)	Halite and sylvite.	In excess of 250 mg/L may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 mg/L.	250 mg/L (recommended).
Fluoride (F)	Amphiboles, apatite, fluorite, and mica.	Optimum concentration in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. Concentrations in excess of optimum may cause mottling of children's teeth.	Mandatory maximum limits depend on average of maximum daily air temperatures. Maximum limits range from 1.4 mg/L at 32°C to 2.4 mg/L at 10°C.
Nitrate (NO_3) as Nitrogen (N)	Organic matter, fertilizers, and sewage.	More than 20 mg/L may cause a bitter taste and may cause physiological distress. Concentrations in excess of 10 mg/L have been reported to cause methemoglobinemia (*blue-baby disease*) in infants.	10 mg/L (mandatory).
Dissolved solids	Anything that is soluble.	Less than 300 mg/L is desirable for some manufacturing process. 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 (Dufor and Becker, 1964).

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 it reaches a level of about 100 mg/L.

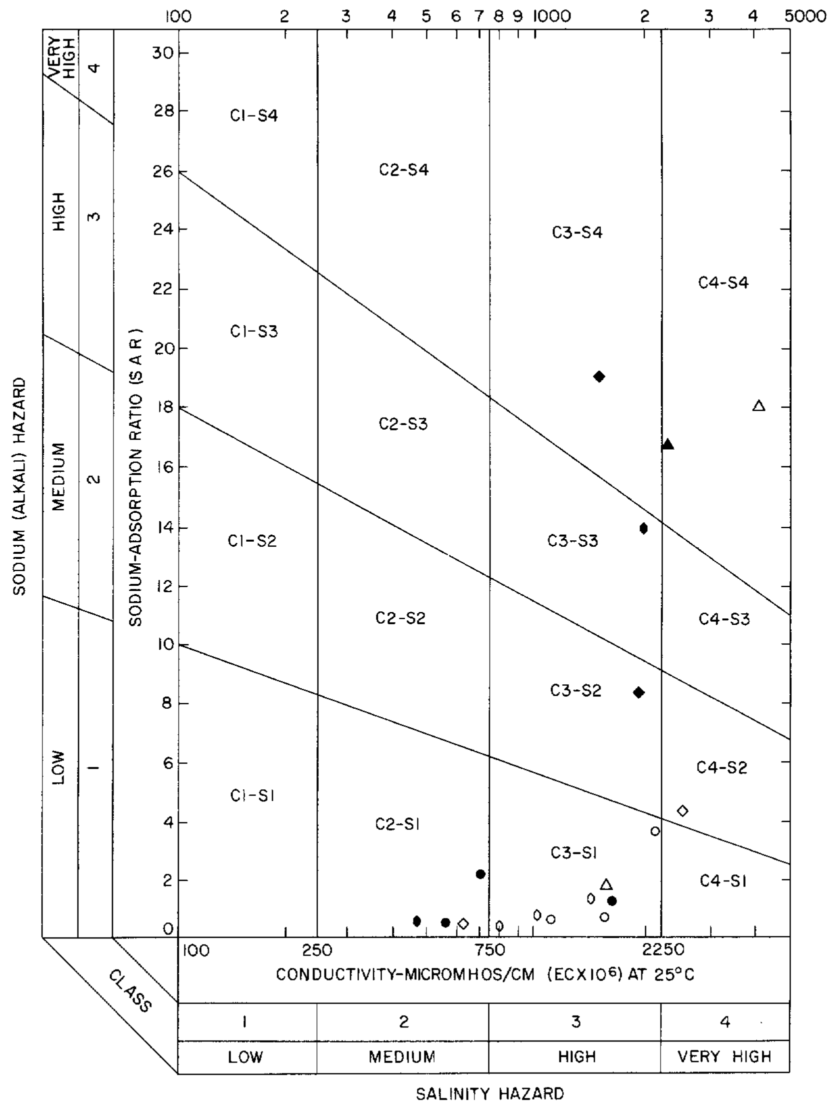
The quality of water used for irrigation is an important factor in productivity and in quality of the irrigated crops. The U.S. Salinity Laboratory Staff (1954) developed an irrigation classification system based on SAR and specific conductance. SAR is related to the sodium hazard and specific conductance is related to the salinity hazard. The hazards increase as the numerical values of the indices increase. Irrigation classifications for selected water samples from aquifers in Bottineau and Rolette Counties were determined using the Salinity Laboratory Staff's classification system. (fig. 4).

Ground Water in the Bedrock Units

Test drilling in Bottineau and Rolette Counties penetrated units as old as the Pierre Shale of Late Cretaceous age and as young as the Cannonball Member of the Fort Union Formation of Paleocene age. No significant amount of water-bearing material was encountered in either the Pierre Shale or the Fort Union Formation in the study area. Locations of the bedrock formations underlying the glacial drift and structure contours of the top of the Pierre Shale are shown in figure 5.

The Fox Hill Sandstone contains the most extensive bedrock aquifer system in Bottineau and Rolette Counties. The thickest sandstone beds occur in the upper part of the Fox Hills beneath the Turtle Mountains and in western Bottineau County. Other sandstone beds are lenticular and appear to be discontinuous.

The Hell Creek Formation underlies most of the Turtle Mountains and extreme western Bottineau County. It contains fine-grained discontinuous sandstone beds that vary in stratigraphic position and thickness.



EXPLANATION

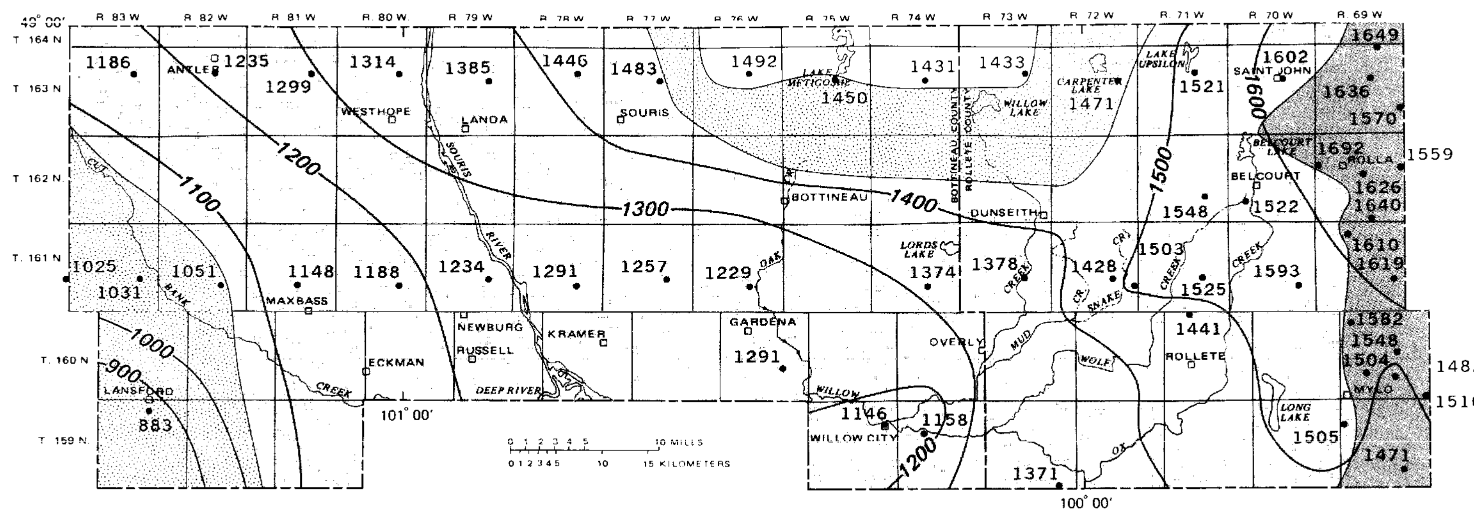
GLACIAL-DRIFT AQUIFER OR AQUIFER SYSTEM

- ● SHELL VALLEY
- ○ ROLLA
- ◆ GLENBURN
- ◇ LAKE SOURIS
- ⬮ BURIED GLACIOFLUVIAL
- ⬯ OUTWASH

BEDROCK AQUIFER SYSTEM (MOST ARE C4-S4)

- ▲ FOX HILLS
- △ HELL CREEK

FIGURE 4.—Classification of selected water samples for irrigation use. [From U.S. Salinity Laboratory Staff, 1954.]



EXPLANATION

CANNONBALL MEMBER OF FORT UNION FORMATION } TERTIARY

HELL CREEK FORMATION
FOX HILLS SANDSTONE } CRETACEOUS
PIERRE SHALE

GEOLOGIC CONTACT

—*1300*— STRUCTURE CONTOUR—Shows altitude of top of Pierre Shale. Contour interval, 100 feet (30.5 meters). National Geodetic Vertical Datum of 1929

•1371 TEST HOLE—Number is altitude of top of Pierre Shale, in feet. National Geodetic Vertical Datum of 1929

FIGURE 5.—Bedrock formations underlying the glacial drift and structure contours of the top of the Pierre Shale.

Fox Hills Aquifer System

The Fox Hills aquifer system underlies all of Bottineau County and all except the eastern townships of Rolette County (fig. 5). In places it is the only aquifer system capable of producing sufficient quantities of water for domestic and stock purposes. The system consists of massive to interbedded sandstone, siltstone, claystone, and shale. The top of the Pierre Shale (fig. 5) is the lower boundary of the system. The upper boundary and thickness of the aquifer system varies due to erosion and structural relief (pl. 3, secs. A-A' and B-B', in pocket). The thickness of the aquifer system ranges from 0 to 292 ft (0 to 89 m).

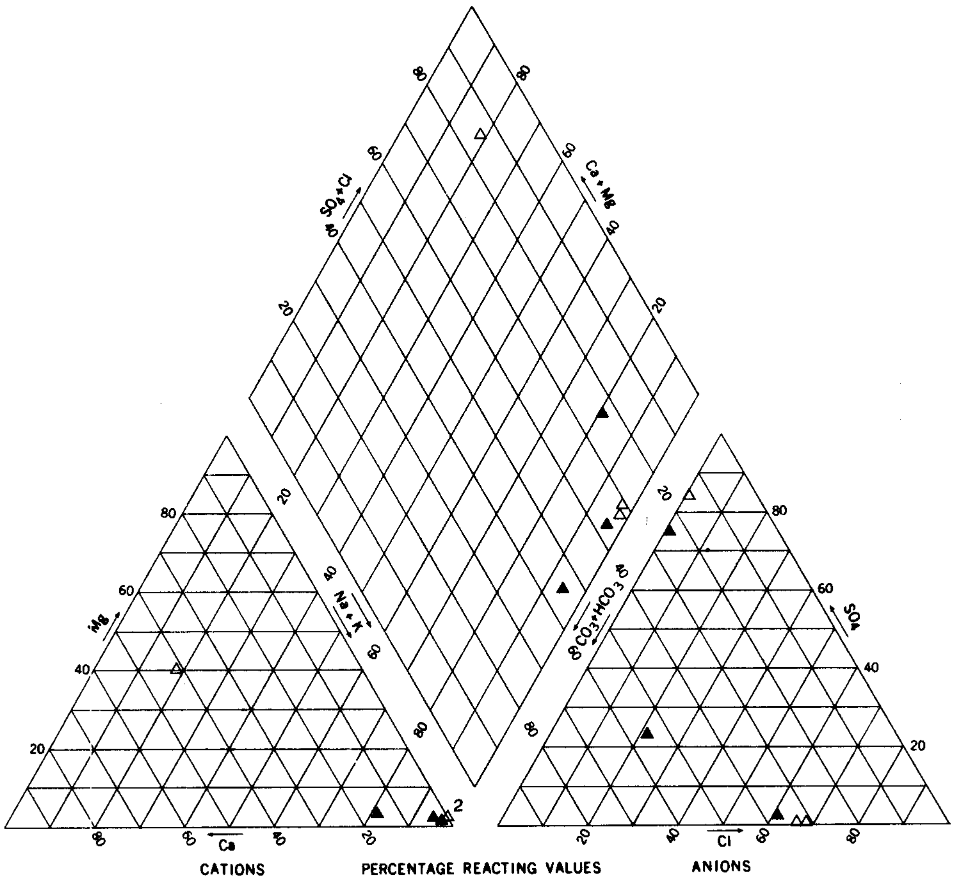
The sandstones, which are the water-bearing beds in the aquifer system, range from 2 to 83 ft (0.6 to 25 m) in thickness. In 38 test holes penetrating the Fox Hills aquifer system, 23 contained from one to five sandstone beds that averaged 25 ft (7.6 m) in thickness. In these 23 test holes the total sandstone thickness averaged 18 percent of the formation. The thickest sections occur where the upper part of the Fox Hills aquifer system has not been extensively eroded. The dominant mineral is quartz, although glauconite, a green iron-rich clay mineral, commonly is prevalent.

Yields to wells completed in the Fox Hills aquifer system range from 2 to 50 gal/min (0.1 to 3 L/s). Maximum potential yields can be obtained from the thickest sandstone beds provided that the well is screened throughout the entire saturated thickness. Flowing wells are common near the base of the Turtle Mountains.

The Fox Hills aquifer system is recharged by infiltration from precipitation through overlying deposits and lateral movement of water from adjacent deposits. Water is discharged from the aquifer system by pumping or flowing wells, seepage into intermittent streams, and lateral movement into glacial-drift deposits in buried valleys. Ground-water movement generally is from the topographic high areas toward the Souris River valley. The hydraulic gradient from west to east in the western part of the area is about 7 ft/mi (1.3 m/km) toward the Souris River valley, and from east to west in the eastern part of the area about 14 ft/mi (2.6 m/km) toward the Souris River valley.

Water samples were collected from 26 wells completed in the Fox Hills aquifer system. Analyses indicate the water ranges from soft to very hard. The dominant cation is sodium, and the dominant anions may be chloride, bicarbonate, or sulfate (fig. 6). The water predominantly is a sodium chloride type.

Dissolved-solids concentrations in the samples ranged from 680 to 7,200 mg/L and averaged 2,340 mg/L. Sodium concentrations ranged from 200 to 2,900 mg/L and averaged 860 mg/L. Chloride concentrations ranged from 10 to 4,700 mg/L and averaged 900 mg/L. Sulfate concentrations ranged from less than 1 to 2,000 mg/L and averaged 290 mg/L. Bicarbonate concentrations ranged from 248 to 1,200 mg/L and averaged



EXPLANATION

▲FOX HILLS AQUIFER SYSTEM

△HELL CREEK AQUIFER SYSTEM

FIGURE 6.—Major constituents in water from bedrock aquifer systems.

580 mg/L. Dissolved-solids, sodium, and chloride concentrations are largest west of the Souris River valley, which is a regional discharge area of the Fox Hills aquifer system in Bottineau County. The Souris valley is the approximate location of an interface between fresh to slightly saline water moving west from the Turtle Mountains and slightly to moderately saline water moving east. Most of the analyses indicate very high salinity and sodium hazards for irrigation purposes.

Hell Creek Aquifer System

The Hell Creek aquifer system underlies the Turtle Mountains area and about five townships in southwestern Bottineau County. The system consists of interbedded to massive sandstone, siltstone, claystone, and shale. The lower boundary of the aquifer system is the top of the glauconitic sandstone at the top of the Fox Hills aquifer system, and the upper boundary is the base of the Fort Union Formation or the glacial drift. The aquifer system is absent over most of the area due to erosion. Where present, the thickness of the aquifer system ranges from 8 to 257 ft (2 to 78 m).

The sandstones, which are the water-bearing beds in the Hell Creek aquifer system, are less than 50 ft (15 m) thick. In 12 test holes penetrating the aquifer system, 10 contain from one to four discontinuous sandstone beds that average about 15 ft (4.6 m) in thickness. The dominant mineral in the sandstones is quartz with a bentonitic clay matrix.

Wells completed in the Hell Creek aquifer system generally yield less than 20 gal/min (1 L/s).

Water samples were collected for chemical analyses from 10 wells completed in the Hell Creek aquifer system. The analyses indicate the water is either soft or very hard. The dominant cation is sodium and the dominant anions are chloride or sulfate (fig. 6). The water predominantly is a sodium chloride type in southwestern Bottineau County and a sodium sulfate type in the Turtle Mountains area.

Dissolved-solids concentrations in the samples ranged from 1,050 to 2,720 mg/L and averaged 1,910 mg/L. Sodium concentrations ranged from 80 to 1,030 mg/L and averaged 550 mg/L. Chloride concentrations ranged from 8.1 to 1,100 mg/L and averaged 380 mg/L. Sulfate concentrations ranged from 0.8 to 1,200 mg/L and averaged 510 mg/L. Most of the analyses indicate a low to very high sodium hazard and a high to very high salinity hazard for irrigation purposes. The city of Dunseith uses water from the Hell Creek aquifer system for its municipal supply.

Ground Water in the Glacial Drift

Aquifers with the greatest potential for ground-water development occur in the glacial deposits. Names of aquifers used in previous reports and in this report are the Shell Valley and Rolla aquifer systems and the Glenburn, Lake Souris, and Souris Valley aquifers. Aquifers recognized and described during this investigation and classified according to glacial origin are called buried glaciofluvial and outwash aquifers.

Water Available from Storage

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

$$V = \overline{m}A\overline{S}y \qquad (1)$$

where:

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

$\overline{m}$ = saturated thickness, in feet;
A = areal extent, in acres; and
$\overline{S}y$ = specified yield of the aquifer.

The specific yield for glacial-drift aquifer materials may range from 0.001 to 0.35. The commonly used range for these materials in North Dakota is 0.10 to 0.20. In confined aquifers, the quantity of water gained due to expansion and compression is insignificant compared to the storage estimates based on long-term specific yield of 15 percent.

Potential Yield of Glacial-Drift Aquifers

Estimated potential yields of glacial-drift aquifers in Bottineau and Rolette Counties are shown on plates 4 and 5 (in pocket). The basic factor used in determining these estimates was transmissivity. Aquifer tests were used to determine transmissivity at selected sites. However, the results are valid only for a local area surrounding the test site, and aquifer tests are very expensive to conduct. Therefore, transmissivities generally were determined by estimating the hydraulic conductivity from lithologic logs at test-hole sites and multiplying the estimated hydraulic conductivity by the thickness of the aquifer. Although the estimates derived are only valid for the site of the logged hole, the large number of logged holes provides a more extensive data base than could be provided by aquifer tests.

The hydraulic conductivity was estimated from lithology by using the empirical values shown in table 2. The range of values represents various degrees of sorting. Estimates were based on the smaller value unless the lithologic log indicated that the material was well sorted. Generally very fine sand and silt were omitted from estimates if they did not contribute more than 5 percent of the total transmissivity. The total transmissivity of the aquifer is the sum of the transmissivities of the separate units.

TABLE 2. — Hydraulic conductivity of common glacial-drift aquifer materials
[Modified from Keech, 1964]

Material	Hydraulic conductivity (feet per day)	(meters per day)
Gravel	267-688	81-204
Gravel and sand	134-267	41-81
Sand, very coarse	120-134	37-41
Sand, coarse	107-120	33-37
Sand, medium to coarse	80-107	24-33
Sand, medium	53-80	16-24
Sand, fine to medium	40-53	12-16
Sand, very fine, silty	13-40	4-12
Silt and clay	1-13	0.3-4

Meyer (1963, p. 338-340, fig. 100) published a chart relating well diameter, specific capacity, and coefficients of transmissivity and storage. The relation shows that for coefficients of storage of less than 0.005 (generally confined aquifers) and for transmissivities within the range of 270 to 13,000 ft^2/d (25 to 1,200 m^2/d) the ratio of transmissivity to specific capacity is about 270:1, when the specific capacity is in units of gallons per minute per foot of drawdown after 24 hours of pumping. The ratio is larger for transmissivities greater than 13,000 ft^2/d (1,200 m^2/d). In most confined aquifers the storage coefficent is within the range of 0.00005 to 0.005, and the chart indicates that within this range large changes in the storage coefficient correspond to relatively small changes in specific capacity. Therefore, in confined aquifers having transmissivities of as much as 13,000 ft^2/d (1,200 m^2/d) the specific capacity of an efficient fully penetrating well may be approximated by dividing the transmissivity by 270. The potential yield of a fully penetrating well at a specific site was estimated by multiplying the specific capacity by an arbitrarily selected drawdown value of 30 ft (9 m).

Where 30 ft (9 m) of drawdown was not available, one-half of the saturated thickness was used to estimate yield.

Meyer's chart shows that for aquifers having a coefficient of storage larger than 0.005 (unconfined aquifers) the specific capacity will be larger, and the ratio of transmissivity to specific capacity approaches 134:1 for small values of transmissivity and large values of storage coefficient.

The principles described above were applied in preparing plates 4 and 5. The estimated potential well yields shown are total yields available from both the unconfined and confined parts of an aquifer system where these two conditions exist. The yield maps (pls. 4 and 5) are intended as a guide in the location of ground-water resources, and not as maps to locate well sites with a given specific yield. Few, if any, aquifers in the glacial drift are so uniform in areal extent and physical properties that production wells could be constructed in them without additional test drilling.

Shell Valley Aquifer System

The Shell Valley aquifer system consists of an unconfined aquifer in surficial outwash and a confined aquifer in a narrow melt-water channel and in other scattered areas. The aquifer system underlies an area of about 56 mi^2 (145 km^2) in south-central Rolette County (pl. 4).

The aquifer system consists of sand and gravel beds interbedded with lenses of silt, clay, and till (fig. 7, sec. C-C'). Data from 85 test holes show that it ranges in thickness from 6 to 117 ft (2 to 34 m) and has an average saturated thickness of about 35 ft (11 m). The aquifer system is underlain by glacial till or the Fox Hills Sandstone.

Water levels in observation wells range from less than 1 ft (0.3 m) below land surface in the Wolf Creek and Snake Creek valleys to about 35 ft (11 m) below land surface in the buried valley. The average ground-water gradient is about 15 ft/mi (2.8 m/km) generally toward the southwest (pl. 6, in pocket), with some local deviations. Water levels normally fluctuate about 3 ft (1 m) annually in response to recharge from precipitation and infiltration or discharge to streams and potholes. Municipal pumping by Belcourt has caused water levels in an observation well 161-071-03CCD4, in the vicinity of the well field, to decline at the rate of about 1 ft/yr (0.3 m/yr), after initial pumping stresses are accounted for. Water levels in observation well 161-071-16AAB1 fluctuate about 3.5 ft/yr (1.1 m/yr) due to nearby pumping for irrigation. Recovery to near static conditions occurs during nonpumping periods.

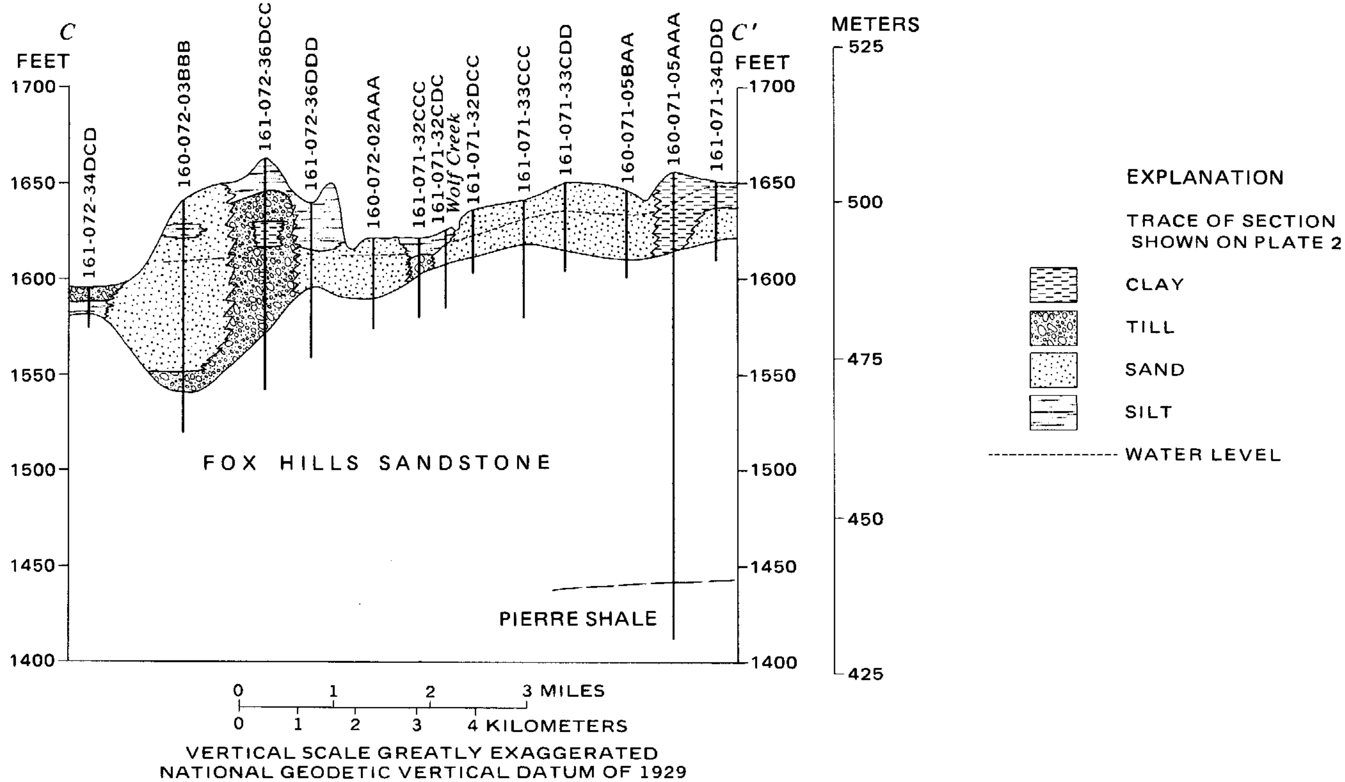


FIGURE 7.—Geohydrologic section C–C′ through the Shell Valley aquifer system.

Low-flow measurements made in April 1974 (Randich, 1975) and 1980 on Wolf Creek show a decrease in discharge of about 50 percent where the creek traverses the northeastern part of the Shell Valley aquifer system. The decrease in flow indicates the creek is a major source of recharge to the aquifer system during periods of runoff. Summer and fall observations show no flow in Wolf Creek except during severe rainstorms, but seeps and springs indicate discharge from the aquifer system into the stream valley.

The hydraulic properties of the Shell Valley aquifer system were determined using transmissivities calculated from lithologic logs (table 2) and data obtained from analyses of two aquifer tests (table 3). The aquifer tests and lithologic logs show the aquifer system is confined at 161-071-07DDD3 and unconfined at 161-071-03CDD4. Analyses of the data show confining beds of varying degree exist throughout the aquifer system. These confining beds generally restrict recharge, resulting in increased drawdown.

TABLE 3. — Summary of data obtained from aquifer tests in the Shell Valley aquifer system

	Test wells	
	161-071-03CDD41/	**161-071-07DDD3**2/
Date of test	11/22/74-11/27/74	6/10/81-6/14/81
Well depth (feet)	38	129
Well screen diameter (inches)	6	5
Screened interval (feet)	28-38	99-129
Discharge (gallons per minute)	120	86
Duration of test (days)	3	4
Static water level (feet below land surface)	10.37	36.42
Drawdown (feet)	8.35	29.78
Specific capacity (gallons per minute per foot)	14.1	2.9
Number of observation wells	9	3
Transmissivity (feet squared per day)	7,760	6,300
Storage coefficient	0.14	0.00035

1/ From Randich and Ghering, 1975.
2/ North Dakota State Water Commission aquifer test results.

Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the Shell Valley aquifer system in Rolette County could yield from 50 to 500 gal/min (3 to 32 L/s; pl. 4). Based on an areal extent of 56 mi^2 (145 km^2), an average saturated thickness of 35 ft (11 m), and an estimated specific yield of 15 percent, about 190,000 acre-ft (234 hm^3) of water is available from storage in the Shell Valley aquifer system.

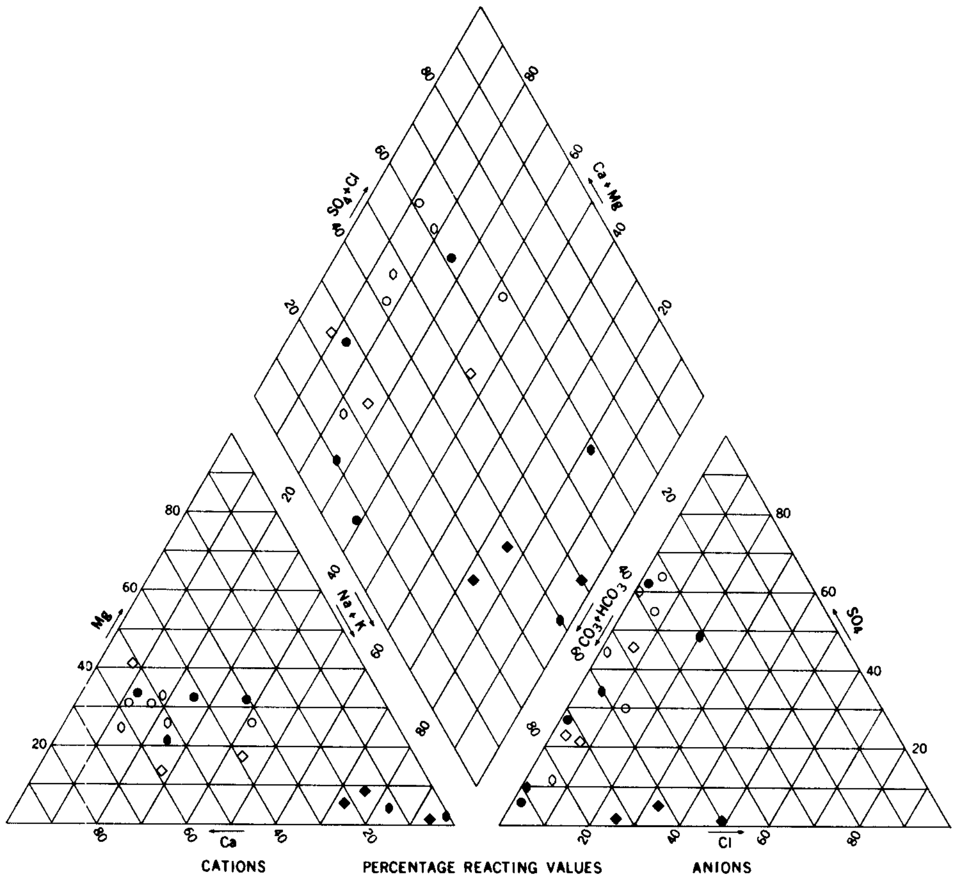
Chemical analyses of water samples from 55 wells completed in the Shell Valley aquifer system indicate the water predominantly is very hard and generally is a mixed type (fig. 8). Dissolved-solids concentrations in the samples ranged from 301 to 1,530 mg/L and averaged 700 mg/L. The dominant cations were calcium (32 samples), sodium (16 samples), and magnesium (7 samples). Calcium concentrations ranged from 15 to 200 mg/L and averaged 89 mg/L; sodium concentrations ranged from 7.5 to 380 mg/L and averaged 90 mg/L; and magnesium concentrations ranged from 3.7 to 380 mg/L and averaged 62 mg/L. The dominant anions were bicarbonate (53 samples) and sulfate (2 samples). Bicarbonate concentrations ranged from 248 to 995 mg/L and averaged 445 mg/L, and sulfate concentrations ranged from 30 to 710 mg/L and averaged 220 mg/L. The buried valley in the southern part of the aquifer system contains a sodium type water that is attributed to recharge from adjacent and underlying bedrock formations. The sodium-adsorption ration (SAR) ranged from 0.2 to 12 and averaged 2.2. Fifty samples indicated a low sodium hazard, 4 samples indicated a medium sodium hazard, and one sample indicated a high sodium hazard for irrigation use; 45 samples indicated a high salinity hazard and 10 samples indicated a medium salinity hazard. Irrigation classifications for selected samples are shown in figure 4.

Chemical analyses of ground water for minor elements collected from the test well at 161-071-03CDD4 are shown in table 4. No significant changes occurred in the samples taken on November 11, 1974, after pumping 150 gal/min (9.5 L/s) for 26 hours and November 27, 1974, after pumping 120 gal/min (7.6 L/s) for 71 hours, and the analyses indicate no excessive amounts of the constituents.

At present (1981) there are many domestic and stock wells completed in the Shell Valley aquifer system that generally yield from 5 to 30 gal/min (0.3 to 2 L/s). Six municipal wells and three irrigation wells completed in the aquifer generally yield from 100 to 500 gal/min (6.3 to 32 L/s).

Rolla Aquifer System

The Rolla aquifer system consists of a group of unconfined and confined glacial aquifers. The aquifer system underlies an area of approximately 48 mi^2 (124 km^2) in northeastern Rolette County.



EXPLANATION

- ● SHELL VALLEY AQUIFER SYSTEM
- ○ ROLLA AQUIFER
- ◆ GLENBURN AQUIFER SYSTEM
- ◇ LAKE SOURIS AQUIFERS
- ⧫ BURIED-GLACIOFLUVIAL AQUIFERS
- 0 OUTWASH AQUIFERS

FIGURE 8.—Major constituents in water from glacial-drift aquifers.

TABLE 4. — Chemical analyses of water for minor elements from test well 161-071-03CDD4[1/]
[Dissolved mineral constituents are in micrograms per liter (ug/L); <is less than]

Constituent	November 11, 1974, after pumping 26 hours at 150 gallons per minute	November 27, 1974, after pumping 71 hours at 120 gallons per minute
Aluminum (Al)	10	10
Arsenic (As)	1	2
Barium (Ba)	<100	<100
Beryllium (Be)	<10	<10
Cadmium (Cd)	0	0
Chromium (Cr)	<10	<10
Cobalt (Co)	0	0
Copper (Cu)	2	2
Cyanide (Cn)	.00	.00
Lead (Pb)	3	1
Lithium (Li)	30	30
Mercury (Hg)	<.1	<.1
Molybdenum (Mo)	3	2
Nickel (Ni)	0	2
Selenium (Se)	0	1
Silver (Ag)	<1	<1
Strontium (Sr)	260	260
Vanadium (V)	2.2	1.8
Zinc (Zn)	30	30

[1/] From Randich and Ghering, 1975.

The aquifer system consists of sand and gravel beds that generally are interbedded with thin lenses of silt, clay, or till. Data from 44 test holes show that the aquifer ranges in thickness from 5 to 86 ft (2 to 26 m) and has an average saturated thickness of about 30 ft (9 m). The aquifer is underlain by glacial till, Fox Hills Sandstone, or Pierre Shale.

Water levels in observation wells range from 2 ft (0.6 m) above land surface south of Rolla (162-069-20DDD2) to about 35 ft (11 m) below land surface in the northern part of the aquifer. The ground-water gradient ranges from about 5 to 15 ft/mi (1 to 2.8 m/km) generally toward the east (pl. 6). Water levels normally fluctuate about 3 ft (0.9 m) annually in response to recharge from precipitation or infiltration from or discharge to streams and potholes. Major recharge to the aquifer system is through surficial sand and gravel deposits and lateral movement from adjacent and underlying deposits in the topographically high western part of the aquifer system. No appreciable drawdown has occurred in the aquifer system as a result of pumping of Rolla municipal wells. Discharge from the aquifer is by pumping and by evapotranspiration where water levels are at or near ground level.

The hydraulic properties of the Rolla aquifer system are based on transmissivities calculated from lithologic logs (table 2), and the results of aquifer tests in the vicinity of Rolla (Schmid, 1964). Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the Rolla aquifer system in Rolette County could yield from 5 to 250 gal/min (0.3 to 16 L/s; pl. 4). Based on an areal extent of 48 mi^2 (124 km^2), an average saturated thickness of 30 ft (9 m), and an estimated specific yield of 15 percent, about 138,000 acre-ft (170 hm^3) of water is available from storage in the Rolla aquifer system.

Chemical analyses of water samples from 10 wells completed in the Rolla aquifer system indicate the water is very hard and generally is a mixed type (fig. 8). Dissolved-solids concentrations in the samples ranged from 639 to 2,100 mg/L and averaged 1,460 mg/L. The dominant cation was calcium in eight samples and the dominant anion was sulfate in eight samples. Calcium ranged from 110 to 360 mg/L and averaged 210 mg/L; sulfate ranged from 170 to 1,100 mg/L and averaged 690 mg/L. Bicarbonate ranged from 329 to 566 mg/L and averaged 460 mg/L. In the western part of the aquifer system and in local recharge areas the water generally is a mixed type; in the northern and deeper parts of the aquifer system the water generally is a calcium sulfate type. The SAR ranged from 0.8 to 3.8 and averaged 1.8. The water had a low sodium hazard and a high salinity hazard for irrigation use (fig 4).

At present (1981), there are numerous domestic and stock wells and six municipal wells completed in the Rolla aquifer system. These wells generally yield from 5 to 100 gal/min (0.3 to 6.3 L/s).

Glenburn Aquifer

The Glenburn aquifer consists of a confined aquifer in a buried valley and underlies an area of about 28 mi^2 (73 km^2) in southwestern Bottineau County (pl. 5). The aquifer consists of sand, gravel, and silt deposits.

Data from 50 test holes show that the aquifer ranges in thickness from 5 to 155 ft (1.8 to 47 m) and has an average saturated thickness of about 40 ft (14 m). The aquifer is bounded by glacial till or bedrock formations of Late Cretaceous age.

Water levels in observation wells range from 6.7 ft (2 m) above land surface at 159-081-08DDA to 33.4 ft (10.2 m) below land surface at 159-083-35BBB1 and 159-085-35BBB2. The ground-water gradient is about 5 ft/mi (1 m/km) toward the southeast. Water levels normally fluctuate from 1 to 5 ft (0.3 to 1.5 m) annually in response to recharge from precipitation or discharge by pumping wells.

The hydraulic properties of the Glenburn aquifer are based on transmissivities calculated from lithologic logs (table 2). Depending upon local aquifer thickness and hydraulic conductivity of material penetrated, properly constructed wells completed in the Glenburn aquifer in Bottineau County could yield from 10 to 1,000 gal/min (0.63 to 63 L/s; pl. 5).

Based on an areal extent of 28 mi^2 (73 km^2), an average saturated thickness of 40 ft (12 m), and an estimated specific yield of 15 percent, about 108,000 acre-ft (133 hm^3) of water is available from storage in the Glenburn aquifer.

Chemical analyses of water samples from 17 wells completed in the Glenburn aquifer indicate the water predominantly is very hard and generally is a sodium bicarbonate type (fig. 8). Three samples from the southeastern part of the aquifer were a sodium chloride type. Dissolved-solids concentrations in the samples ranged from 773 to 2,050 mg/L and averaged 1,370 mg/L; sodium ranged from 190 to 590 mg/L and averaged 405 mg/L; bicarbonate ranged from 486 to 993 mg/L and averaged 785 mg/L; chloride ranged from 36 to 680 mg/L and averaged 292 mg/L; sulfate ranged from 0.4 to 1,100 mg/L and averaged 140 mg/L; iron ranged from 20 to 5,700 ug/L and averaged 1,376 ug/L. Dissolved iron concentration exceeded the recommended limit of 300 ug/L in 14 of 17 samples. The SAR ranged from 5.1 to 33 and averaged 11.3. The irrigation classification of the water ranged from a low to very high sodium hazard and a high to very high salinity hazard (fig. 4).

At present (1981) there are numerous domestic and stock wells and two wells for the Upper Souris Water Users Association completed in the Glenburn aquifer. These wells generally yield from 5 to 120 gal/min (0.3 to 7.6 L/s).

Lake Souris Aquifers

The Lake Souris aquifers, named for glacial Lake Souris, consist of unconfined isolated deposits of surficial sand that are glacioaqueous in origin. Data from 15 test holes show that aquifers range in thickness from 2 to 26 ft (0.6 to 8 m) and have an average thickness of 14 ft (4.3 m). The most extensive aquifer is located near Willow City in southeastern Bottineau County.

Water levels in these unconfined aquifers range from 5 to 18 ft (2 to 5.5 m). Discharge is to streams, potholes, and pumping wells. Recharge to the aquifer is derived predominantly from precipitation infiltrating through surface sediments.

Based on transmissivity estimates from lithologic logs, the estimated potential yields from wells completed in the Lake Souris aquifers may range from less than 5 to 100 gal/min (0.3 to 6.3 L/s). Lack of areal definition precludes developing an estimate of water available from storage in these aquifers.

Chemical analyses of 15 water samples from wells developed in the Lake Souris aquifers indicate the water is very hard and a mixed type (fig. 8). Calcium was the dominant cation in nine samples and magnesium and sodium were each dominant in three samples. Bicarbonate was the dominant anion in 12 samples and sulfate was dominant in 3 samples. Dissolved-solids concentrations in the samples ranged from 290 to 1,940 mg/L and averaged 944 mg/L; calcium ranged from 64 to 310 mg/L and averaged 131 mg/L; magnesium ranged from 18 to 130 mg/L and averaged 56 mg/L; sodium ranged from 3.7 mg/L to 301 mg/L and averaged 89 mg/L; bicarbonate ranged from 221 to 899 mg/L and averaged 506 mg/L; sulfate ranged from 19 to 890 mg/L and averaged 273 mg/L. The SAR ranged from 0.1 to 5.4 and the irrigation classification of the water ranged from a low to medium sodium hazard and a medium to very high salinity hazard (fig. 4).

At present (1981) there are many domestic and stock and four municipal wells completed in the Lake Souris aquifers. These wells generally yield from 5 to 30 gal/min (0.3 to 2 L/s).

Souris Valley Aquifer

The Souris Valley aquifer occupies alluvium and terraces along the Souris River. The aquifer extends from McHenry County northwest through Bottineau County to the Canada-United States border (pl. 5). The aquifer has an areal extent of about 25 mi^2 (65 km^2) in Bottineau County.

Data from eight test holes in a small area show that the aquifer generally consists of sand and gravel. The aquifer materials range in thickness from 3 to 39 ft (0.3 to 12 m) and have an average saturated thickness of 22 ft (6.7 m).

No water levels were obtained in the Souris Valley aquifer in Bottineau County, but levels ranged from 2 to 22 ft (0.6 to 6.7 m) below land surface in McHenry County.

Transmissivities calculated from lithologic logs were used to estimate potential yields from wells completed in the Souris Valley aquifer (pl. 5). Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the aquifer could yield from 5 to 250 gal/min (0.3 to 16 L/s). Based on an areal extent of 25 mi^2 (65 km^2), an average saturated thickness of 22 ft (6.7 m), and an estimated specific yield of 15 percent, an estimated 50,000 acre-ft (62 hm^3) of water is available from storage in the Souris Valley aquifer.

No water samples were collected from the aquifer in Bottineau County. However, analyses of samples collected from the aquifer in McHenry County show the water is very hard and predominatly is a calcium or sodium bicarbonate type. Irrigation classifications in McHenry County ranged from low to very high sodium hazard and medium to very high salinity hazard.

At present (1981) there are no known wells completed in the Souris Valley aquifer in Bottineau County.

Undifferentiated Aquifers in Buried Glaciofluvial Deposits

Undifferentiated sand and gravel deposits occur throughout the glacial drift. These deposits are referred to as buried glaciofluvial aquifers because their origin was in a fluvial environement. Test holes and wells commonly penetrated one or more of these confined aquifers at random depths within the glacial drift. The most extensive and productive aquifers in buried glaciofluvial deposits in Bottineau County are located north of Bottineau, south of Eckman, and in the vicinity of Gardena. In Rolette County they are located near St. John, in the Turtle Mountains, east of Nanson, and in the southwestern corner of the county. The aquifers have a combined areal extent of about 60 mi^2 (155 km^2) in Bottineau County and 40 m^2 (104 km^2) in Rolette County.

The saturated thickness, lithology, and areal extent of each aquifer control the amount of water in storage and potential yield. Transmissivities calculated from lithologic logs (table 2) indicate that potential yields to wells developed in these aquifers range from less than 5 to about 500 gal/min (0.3 to 32 L/s). Based on an areal extent of about 60 mi^2 (155 km^2) in Bottineau County and 40 mi^2 (104 km^2) in Rolette County, an average saturated thickness of 20 ft (6 m), and an estimated specific yield of 15 percent, a combined total of about 190,000 acre-ft (234 hm^3) of water is available from storage in the undifferentiated aquifers in buried glaciofluvial deposits.

Chemical analyses of 53 water samples from wells completed in the undifferentiated aquifers in buried glaciofluvial deposits indicate the water is very hard. Calcium was the dominant cation in 24 samples and sodium was dominant in 25 samples. Sulfate was the dominant anion in 26 samples and bicarbonate was dominant in 24 samples. Dissolved-solids concentrations in the samples ranged from 294 to 10,400 mg/L and averaged 1,790 mg/L; sodium ranged from 8.8 to 1,200 mg/L and averaged 290 mg/L; calcium ranged from 4.6 to 550 mg/L and averaged 170 mg/L; sulfate ranged from 0 to 6,270 mg/L and averaged 750 mg/L; and bicarbonate ranged from 293 to 984 mg/L and averaged 529 mg/L. The

SAR ranged from 0.2 to 41 and the irrigation classification of the water ranged from a low to very high sodium hazard and a medium to very high salinity hazard (fig. 4).

At present (1981), most of the domestic and stock wells in Bottineau and Rolette Counties and the municipal wells for Bottineau and St. John are completed in the undifferentiated aquifers in buried glaciofluvial deposits. These wells generally yield from 5 to 100 gal/min (0.3 to 6.3 L/s).

Undifferentiated Aquifers in Outwash Desposits

Undifferentiated aquifers in outwash deposits large enough to be considered hydrologically significant are present in and adjacent to the stream valleys of Little Deep, Cut Bank, Boundary, and Stone Creeks, Spring and Hulse Coulees, and an unnamed tributary of the Souris River in northwest Bottineau County. The deposits are composed of mixed sand and gravel and range in thickness from 3 to 61 ft (0.9 to 19 m) and have an average saturated thickness of about 15 ft (4.6 m).

Water levels in these confined and unconfined aquifers range from about 1 to 15 ft (0.3 to 4.6 m) below land surface. Recharge to the aquifers is derived predominantly from precipitation infiltrating through surface sediments. Discharge is by seepage towards streams, evapotranspiration, and by pumping wells.

The saturated thickness, lithology, and areal extent control the amount of water in storage and potential yield of each aquifer. Transmissivities calculated from lithologic logs (table 2) indicate that potential yields to wells developed in these aquifers will range from less than 5 to 100 gal/min (0.3 to 6.3 L/s). Based on an estimated areal extent of about 60 mi^2 (155 km^2), an average saturated thickness of 15 ft (4.5 m), and an estimated specific yield of 15 percent, a combined total of about 86,000 acre-ft (105 hm^3) of water is available from storage in undifferentiated aquifers in outwash deposits located in Bottineau and Rolette Counties.

Chemical analyses of 12 water samples from wells completed in undifferentiated aquifers in outwash deposits indicate the water generally is very hard and is a mixed type (fig. 8). Calcium was the dominant cation and bicarbonate was the dominant anion. Dissolved-solids concentrations in the samples ranged from 238 to 2,230 mg/L and averaged 820 mg/L; bicarbonate ranged from 187 to 629 mg/L and averaged 356 mg/L; sulfate ranged from 26 to 820 mg/L and averaged 240 mg/L. The SAR ranged from 0.2 to 1.2. The water had a low sodium hazard and a medium to very high salinity hazard for irrigation use (fig. 4).

At present (1981) there are many domestic and stock, three municipal, and six rural water distribution wells completed in the undifferentiated aquifers in outwash deposits. These wells generally will yield from 5 to 50 gal/min (0.3 to 3 L/s).

GROUND-WATER USE

The principal uses of ground water in Bottineau and Rolette Counties are for domestic, livestock, public, and limited irrigation supplies. The mean annual ground-water use in Bottineau County is approximately 1,660 acre-ft (2.05 hm^3). The mean annual ground-water use in Rolette County is approximately 2,200 acre-ft (2.71 hm^3).

Rural Domestic and Livestock Supplies

The following tables show the approximate quantities of water used during 1980 for each county.

Rural domestic and livestock use, Bottineau County

Use	Individual requirements1/ (gallons per day)	Population	Estimated total consumption (gallons per day)
Domestic	100	2/4,266	426,600
Cattle	20	3/22,000	440,000
Hogs	3	3/1,400	4,200
Sheep	2	3/3,500	7,000
Estimated total consumption			877,800

1/ Murray, 1965.
2/ U.S. Bureau of the Census, 1981.
3/ U.S. Department of Agriculture, Economic Statistics Service, North Dakota Crop and Livestock Reporting Service, 1981.

Rural domestic and livestock use, Rolette County

Use	Individual requirements[1] (gallons per day)	Population	Estimated total consumption (gallons per day)
Domestic	100	[2]7,112	711,200
Cattle	20	[3]23,000	460,000
Hogs	3	[3]1,800	5,400
Sheep	2	[3]3,100	6,200
Estimated total consumption			1,182,800

1/ Murray, 1965.
2/ U.S. Bureau of the Census, 1981.
3/ U.S. Department of Agriculture, Economics Statistics Service, North Dakota Crop and Livestock Reporting Service, 1981.

The quantities in the tables 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.

Areas of western Bottineau County do not have adequate ground-water supplies. When water quality or availability does not meet required standards, residents generally meet their needs by purchasing their water through water cooperatives that service large areas in western Bottineau County.

Public Supplies

The majority of cities in Bottineau and Rolette Counties have public supply distribution systems. Citizens in other communities and rural areas depend on private wells or rural water delivery systems. The following tables show the mean annual pumpage during 1978-80.

Public Supplies — Bottineau County

City/user	Well location[1]	Aquifer	Mean annual pumpage 1978-80 (acre-feet)[2]
Bottineau	162-075-07AA1	Buried glaciofluvial	Mean average for all wells, 383.1
	-07AA2	Buried glaciofluvial	
	-07AA3	Buried glaciofluvial	
	-07AA4	Buried glaciofluvial	
	162-075-07AB	Buried glaciofluvial	
	162-075-07DD	Buried glaciofluvial	
Souris	163-077-33AA	Lake Souris	11.9
Willow City	159-075-12C1	Lake Souris	Mean average for both wells, 61.8
	-12C2	Lake Souris	
Maxbass	161-081-35CB	Lake Souris	10.1
All Season Water Users Association	163-077-33A1	Outwash	1980 average for outwash wells, 98.4
	-33A2	Outwash	
	164-082-27CDD	Outwash	
	-28DAC	Outwash	
	[3]-28DCD	Outwash	
	-28DDD	Outwash	
Upper Souris Water Users Association	159-082-35BB1	Glenburn	Average for both wells, 110
	-35BB2	Glenburn	

1/ Well location given by city/user.
2/ Data from North Dakota State Water Commission.
3/ Well not yet in production.

Public Supplies — Rolette County

City/user	Well location[1]	Aquifer	Mean annual pumpage 1978-80 (acre-feet)[2]
Dunseith	162-073-25AD1	Hell Creek	Mean average for all wells, 45.1
	-25AD2	Hell Creek	
	-25AD3	Hell Creek	
Rolette	160-071-21CC1	Shell Valley	Mean average for all wells, 138.7
	-21CC2	Shell Valley	
	-21CC3	Shell Valley	
Rolla	162-069-16BC	Rolla	Mean average for all wells, 197
	-17AB	Rolla	
	-17DC	Rolla	
	-20A1	Rolla	
	-20A2	Rolla	
	-29A	Rolla	
Belcourt Utilities Comm.	161-071-10BB1	Shell Valley	Mean average for all wells, 290.9
	-10BB2	Shell Valley	
	-10BB3	Shell Valley	

1/ Well location given by city/user.
2/ Data from North Dakota State Water Commission.

Irrigation Supplies

As of the winter of 1981, there were three irrigation wells developed in the Shell Valley aquifer system in Rolette County. Two of the wells in 161-071-16A are pumped at a mean annual rate of 130.6 acre-ft (0.161 hm^3). The third well at 161-071-09D pumped 51 acre-ft (0.063 hm^3) in 1980. The wells are capable of pumping approximately 900 gal/min (57 L/s). They operate two traveling sprinkler systems.

SUMMARY

The objectives of this study 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; (5) describe the chemical quality of the ground water; and (6) estimate the water use.

The Fox Hills aquifer system is the major bedrock aquifer system in Bottineau and Rolette Counties. It underlies all of Bottineau County and all except the eastern townships of Rolette County. The water-bearing beds consist of very fine to medium-grained sandstone and range in thickness from 2 to 83 ft (0.6 to 25 m). Recharge to the aquifer system is from infiltration of precipitation through overlying deposits and lateral movement from adjacent aquifers. Discharge is by pumping or flowing wells, seepage into streams, and lateral movement into glacial-drift deposits in buried valleys. Potential yields to wells developed in the aquifer system are not expected to exceed 50 gal/min (3 L/s). The water generally is a sodium chloride type. Dissolved-solids concentrations in samples collected from the aquifer system ranged from 680 to 7,200 mg/L. Dissolved-solids, sodium, and chloride concentrations are largest in western Bottineau County.

The Hell Creek aquifer system underlies the Turtle Mountains area, and about five townships in southwestern Bottineau County. The aquifer system consists of one to four discontinuous sandstone beds that average about 15 ft (4.6 m) in thickness. Yields to wells developed in the aquifer system are expected to be much less than 20 gal/min (1 L/s). Water from the Hell Creek aquifer system is soft or very hard and is a sodium chloride type in southwestern Bottineau County and a sodium sulfate type in the Turtle Mountains area. Dissolved-solids concentrations in the water samples ranged from 1,050 to 2,720 mg/L.

Aquifers in the glacial drift have the greatest potential for ground-water development. The aquifers are composed of sand and gravel deposits that are confined or unconfined in buried valleys and other glacioaqueous deposits in Bottineau and Rolette Counties. 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, by evapotranspiration, and by pumping of wells. The areal extent, estimated amount of water available from storage, average saturated thickness, and estimated potential yields to wells completed in these aquifers and aquifer systems are summarized in table 5. The water from the glacial-drift aquifers is a mixed type. The dominant cations are calcium and sodium and the dominant anions are bicarbonate and sulfate.

TABLE 5. — Summary of data for glacial-drift and alluvial aquifers
[<, less than]

Aquifer or aquifer system	Approximate areal extent (square miles)	Average saturated thickness (feet)	Estimated amount of water available from storage (acre-feet)	Estimated potential yields to wells (gallons per minute)
Shell Valley	56	35	190,000	50-500
Rolla	48	30	138,000	5-250
Glenburn	28	40	108,000	10-1,000
Lake Souris	—	—	—	<5-100
Souris Valley	25	22	50,000	5-250
Undifferentiated aquifers in buried glaciofluvial deposits	100	20	190,000	<5-500
Undifferentiated aquifers in outwash deposits	60	15	86,000	<5-100
Total	317	162	762,000	

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DEFINITIONS OF SELECTED TERMS

Aquifer — a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to 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, glacial drift, 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 installed 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 may be 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 that atmospheric pressure.