GROUND-WATER RESOURCES

OF

TOWNER COUNTY, NORTH DAKOTA

By

P. G. Randich and R. L. Kuzniar

U.S. Geological Survey

COUNTY GROUND-WATER STUDIES 36 — PART III
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

BULLETIN 79 — PART III
North Dakota Geological Survey
Don L. Halvorson, *State Geologist*

Prepared by the U.S. Geological Survey in cooperation
with the North Dakota State Water Commission,
North Dakota Geological Survey,
and the Towner County Board of Commissioners

1984

GROUND-WATER RESOURCES

OF

TOWNER COUNTY, NORTH DAKOTA

By

P. G. Randich and R. L. Kuzniar

U.S. Geological Survey

COUNTY GROUND-WATER STUDIES 36 — PART III
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

BULLETIN 79 — PART III
North Dakota Geological Survey
Don L. Halvorson, *State Geologist*

Prepared by the U.S. Geological Survey in cooperation
with the North Dakota State Water Commission,
the North Dakota Geological Survey,
and the Towner County Board of Commissioners

1984

Bismarck, North Dakota

CONTENTS

ILLUSTRATIONS

TABLES

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 used 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)
Foot (ft)	0.3048	meter (m)
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)
Inch (in.)	25.4	millimeter (mm)
Micromho per centimeter at 25° Celsius (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)

To convert degrees Fahrenheit (°F) to degrees Celsius (°C) use the following formula: °C = (°F-32)x 5/9.

GROUND-WATER RESOURCES OF TOWNER COUNTY, NORTH DAKOTA

By

P. G. Randich and R. L. Kuzniar

ABSTRACT

An investigation of the ground-water resources of Towner County, North Dakota, indicates that large quantities of water can be obtained from glacial-drift aquifers. The underlying Pierre aquifer is more extensive than aquifers in the glacial drift, but yields are only about 10 gallons per minute and the water contains more sodium and dissolved solids.

Glacial-drift aquifers occur as sand and gravel deposits associated with buried valleys and glaciofluvial deposits in Towner County. The saturated thickness of these deposits ranges from 4 to 287 feet (1 to 87 meters). Glacial-drift aquifers underlie about 550 square miles (1,420 square kilometers) in Towner County and contain approximately 2.8 million acre-feet (3,450 cubic hectometers) of water that is available from storage. The most extensive glacial-drift aquifer is the Spiritwood aquifer system, which has an areal extent of about 370 square miles (960 square kilometers). Potential well yields range from 5 to 1,500 gallons per minute (0.3 to 95 liters per second) from the major glacial-drift aquifers; however, the Spiritwood is the only major glacial-drift aquifer that has potential well yields of more than 500 gallons per minute (32 liters per second). Water from the glacial-drift aquifers generally is very hard. Dissolved-solids concentrations in samples collected from these aquifers ranged from 396 to 4,450 milligrams per liter.

The Pierre aquifer consists of a fractured siliceous shale that ranges from 25 to 400 feet (7.6 to 122 meters) in thickness in the upper part of the formation. Most wells developed in this aquifer yield less than 10 gallons per minute (0.6 liters per second). Dissolved-solids concentrations in water samples collected from the Pierre aquifer ranged from 976 to 6,590 milligrams per liter.

The rural population and most communities in Towner County depend on ground water, largely from the drift aquifers, as a source of supply.

INTRODUCTION

The investigation of the ground-water resources of Towner County (fig. 1) was made cooperatively by the U.S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and the Towner County Board of Commissioners. 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, 1983) is a compilation of the geologic and

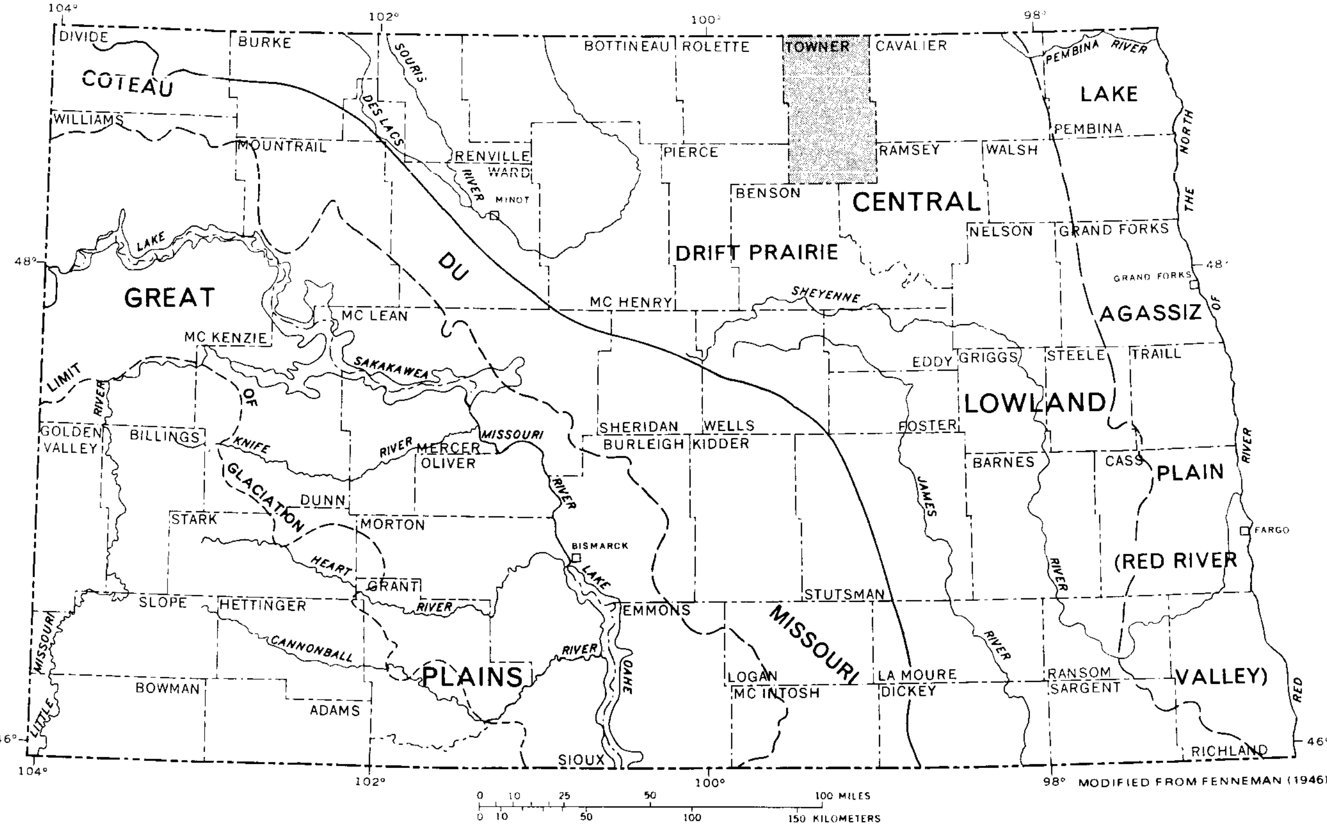


FIGURE 1.—Physiographic divisions in North Dakota and location of study area.

hydrologic data collected during the investigation, and is a reference for the other two parts. Part III is an 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 water users in the development of ground-water supplies.

Objectives and Scope

The purpose of the 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 nature of the major aquifers; (2) evaluate the occurrence and movement of ground water, including sources of recharge and discharge; (3) estimate the quantities of water stored in the glacial aquifers; (4) estimate the potential yields to wells tapping the major aquifers; (5) determine the chemical quality of the ground water; and (6) identify current and potential use of the ground water.

Interpretations contained in this report are based on data obtained from existing wells and from test holes drilled during the investigation. These data include lithologic and geophysical logs of 312 test holes and wells; water-level measurements in 46 observation wells; and 178 chemical analyses of ground-water samples.

Water-level measurements will be continued in selected observation wells 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 earliest geologic report that included Towner County was written by Upham (1895, p. 169-193), who briefly described the glacial moraines and drainage to Devils Lake. Simpson (1929, p. 236-240), included a brief description of the geology and ground-water resources of North Dakota. A local ground-water study was made by Kahil (1965) in the vicinity of Rock Lake. Bluemle (1977) described the glacial geology of Towner County.

Acknowledgments

Collection of the data on which this report is based was made possible by the cooperation of residents and officials of Towner County. Recognition is given to M. O. Lindvig and A. E. Comeskey for contracting and providing most lithologic and geophysical logs. Particular recognition is due C. A. Simpson and Son drilling contractors who furnished many 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 163-065-15ADC is in the SW¼SE¼NE¼ sec. 15, T. 163 N., R. 065 W. Consecutive final numbers are added if more than one well or test hole is recorded within a 10-acre (4-ha) tract.

Geography

Towner County is in the Drift Prairie of the Central Lowland physiographic province (fig. 1). The county has an area of 1,049 mi^2 (2,717 km^2) in north-central North Dakota and a population of 4,052 (U.S. Bureau of the Census, 1981).

Topography ranges from the generally flat lake plain of glacial Lake Cando (Colton and others, 1963) with an altitude of 1,450 ft (440 m) to the rugged rolling morainal area north of Perth with an altitude of 1,750 ft (533 m). South of Rock Lake the major drainage generally is south to Devils Lake in Ramsey County. North of Rock Lake drainage is to the Pembina River in Canada. The Pembina River is a tributary to the Red River of the North drainage system.

The climate is semiarid — mean annual precipitation ranges from 15.8 in. (401 mm) at Hansboro, near the Canadian border, to 18.3 in. (465 mm) at Bisbee, in the southwestern part of the county. Most precipitation is received during the growing season, April through September. The mean annual temperature ranges from 36.9°F (2.7°C) near Hansboro to 37.9°F (3.3°C) at Bisbee (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, 1973). The mean annual evaporation from lake surfaces in the area is about 30 in. (760 mm; U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, 1982).

Dryland farming and stock raising are the two most important agricultural interests. The principal crops are wheat, barley, sunflowers, potatoes, flax, corn, oats, soybeans, and hay. Livestock production includes cattle, sheep, hogs, and chickens.

Geohydrologic Setting

Glacial deposits of Quaternary age, from several glacial advances, cover all of Towner County except for small isolated exposures of Pierre Shale, of Late Cretaceous age, in the Rock Lake area. The glacial-drift deposits include

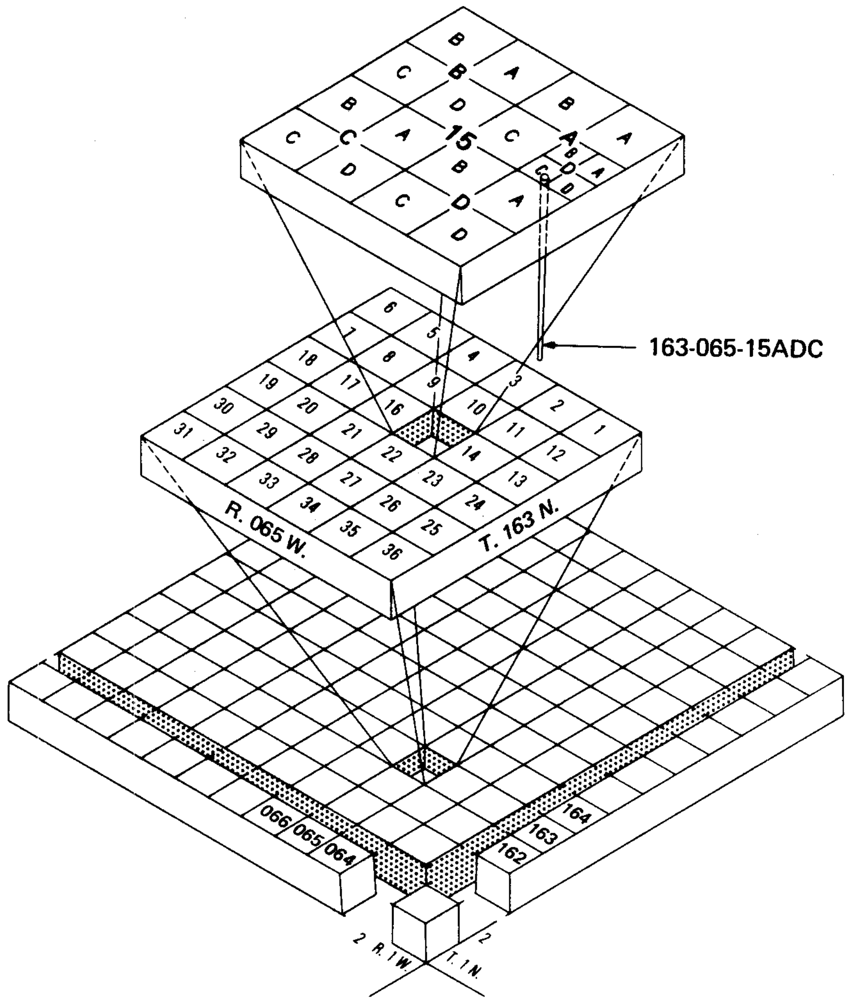


FIGURE 2.—Location-numbering system.

relatively impermeable glacial till and lacustrine clay, and water-yielding glaciofluvial materials such as sand and gravel. The thickest drift deposits (500 ft or 152 m) are in the buried bedrock valleys; consequently, the bedrock valleys contain the major glacial-drift aquifers in Towner County.

The Pierre Shale underlies the glacial drift throughout Towner County. Ground water is obtained from fractures in the upper part of the Pierre Shale and, for practical purposes, the lower, unfractured part of the formation forms the base of the fresh-water-bearing units in the study area. The Pierre Shale and the glacial drift were studied in detail with special reference to their water-bearing properties.

The generalized topography of the Pierre Shale in Towner County is shown on plate 1 (in pocket). Test-hole and surficial geologic data were used in construction of the map. Glacial advances altered the bedrock topography before subsequent deposition of the glacial deposits occurred. The most prominent features are northwest-trending buried valleys incised into the bedrock that once contained streams along the margins of the glaciers.

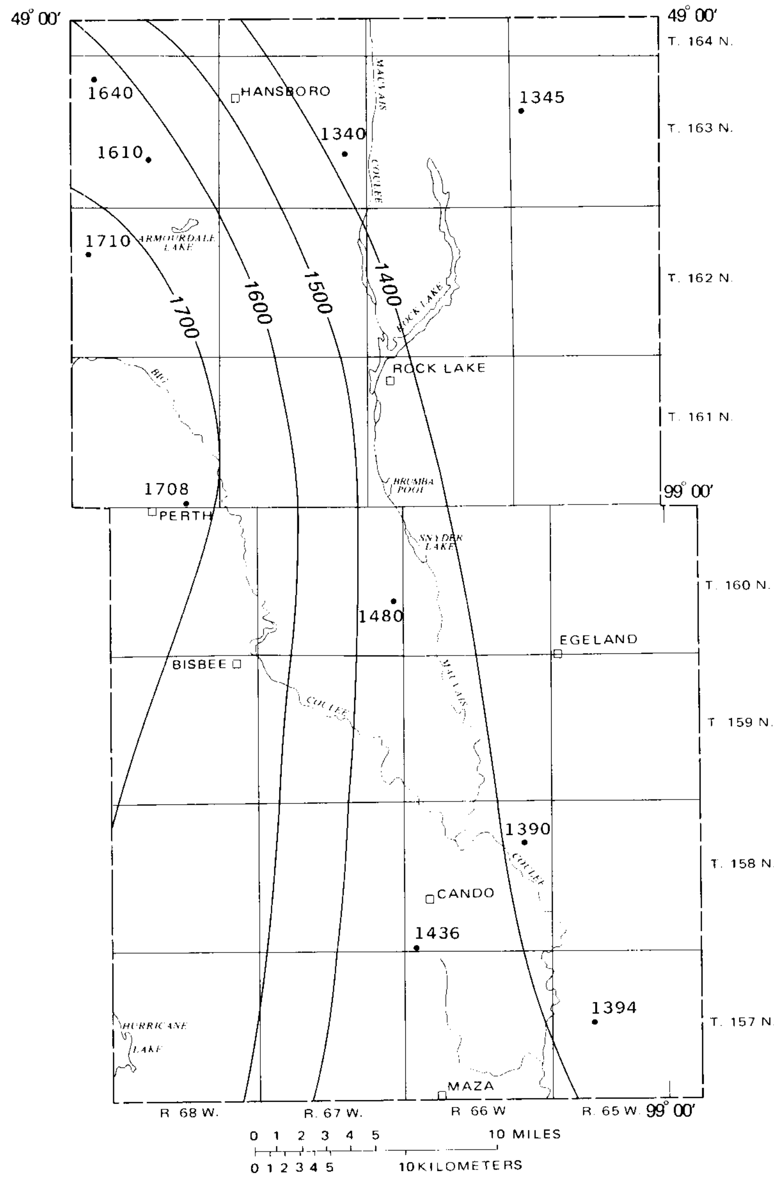
The Dakota Sandstone of Early Cretaceous age underlies the entire area. Depth to the Dakota Sandstone is shown in figure 3. The Dakota contains water that generally is saline and undesirable for domestic or irrigation use. Although the Dakota is not used in Towner County, it is used for livestock watering, domestic, and public supplies in some adjoining counties where no other water is available. If water from the Dakota were to be used for the aforesaid supplies in Towner County an economical desalinization process would be required.

AVAILABILITY AND QUALITY OF GROUND WATER

General Concepts

All ground water is derived from precipitation. After the 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 effects 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 may have large conductivities, and where saturated, may form important aquifers. Cemented deposits and fine-grained materials such as silt, clay, and shale usually have small conductivities and restrict ground-water movement.



EXPLANATION

—1500— LINE OF EQUAL DEPTH TO TOP OF THE DAKOTA SANDSTONE—Interval, 100 feet. Datum is land surface

•1390 DATA POINT—Number is depth to top of Dakota Sandstone, in feet below land surface

FIGURE 3.—Depth to the top of the Dakota Sandstone.

The water level in an aquifer generally fluctuates in response to changes in the rate of recharge to or discharge from an 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. Aquifers exposed at land surface are recharged each spring, summer, and early fall by the direct infiltration of precipitation. Aquifers that are confined by overlying thick deposits of fine-grained materials may be recharged by seepage from these materials. 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 Towner County, surface-water sources, such as Big, Hidden Island, and Mauvais Coulees, lakes, and potholes may be in connection with aquifers. An aquifer may either receive recharge from a surface-water source or discharge water into it, depending on the comparative altitudes of the water levels.

The ground water in Towner County contains varying concentrations of dissolved minerals. 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 transit 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 suitability of water for various uses usually is determined by the kind and amount of dissolved minerals. 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 are given in table 1. Additional information regarding drinking-water standards may be found in a report prepared for the U.S. Envirionmental Protection Agency (National Academy of Sciences, National Academy of Engineering, 1973).

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

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

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

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

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

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 crop productivity and in effects on the soil. 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 glacial-drift aquifers in Towner County were determined using the Salinity Laboratory Staff's classification system.

In this report numerous references are made to ground-water types, such as sodium sulfate type and calcium sulfate type. These types are derived from inspection of water analyses and represent the predominant cation (sodium, calcium, or magnesium) and anion (bicarbonate, sulfate, or chloride), as expressed in milliequivalents per liter. Results of some analyses indicate that the water is a mixed chemical type in which two or more cations or anions are present in nearly equal concentrations.

Water in the Bedrock

Pierre Aquifer

The Pierre Shale consists of light-gray to black siliceous shale, marlstone, and claystone with thin lenses of yellowish to white bentonite. A test hole in western Towner County indicated a thickness of 535 ft. The Pierre directly underlies the glacial drift and crops out in small isolated areas near Rock Lake. The upper part of the Pierre Shale in Towner County consists of extensively fractured black siliceous shale. The fractured shale ranges in thickness from 25 to 400 ft (7.6 to 120 m) and forms an aquifer that is a source of water for many farms in Towner County.

Studies of the hydraulic characteristics of the aquifer in Benson County by Aronow, Dennis, and Akin (1953), in Walsh County by Downey (1973), and in Cavalier County by Hutchinson (1977) indicate the transmissivity of the fracture system in the Pierre ranges from 22 to 121 ft^2/d (2 to 11.2 m^2/d). Because of the low transmissivities of the Pierre, most wells developed in the aquifer are not expected to yield more than 10 gal/min (0.6 L/s) in Towner County.

Recharge to the Pierre aquifer is derived mainly from precipitation percolating through the overlying glacial drift. Ground water in the Pierre aquifer moves toward and discharges into the buried valleys in Towner County. The amount of water in transient storage in the Pierre aquifer is related directly to the extent and thickness of the fracture zones, which vary significantly.

Analyses of water samples from 42 wells completed in the Pierre aquifer indicate that the chemical quality of the water differs widely within the aquifer. The analyses indicate the water ranges from soft to very hard but predominantly is either moderately or very hard. Dissolved-solids concentrations ranged from 976 to 6,590 mg/L and averaged 2,470 mg/L.

The dominant cation was sodium. The dominant anion in 25 of the 42 samples was chloride. Sodium concentrations ranged from 100 to 2,400 mg/L and averaged 870 mg/L. Chloride concentrations ranged from 37 to 4,000 mg/L and averaged 890 mg/L; sulfate concentrations ranged from less than 1 to 1,700 mg/L and averaged 310 mg/L; and bicarbonate concentrations ranged from 422 to 963 mg/L and averaged 682 mg/L. Most of the analyses indicate very high salinity and sodium hazards for irrigation purposes.

Water in the Glacial Drift

Aquifers that have the largest potential for ground-water development occur in the glacial deposits. The Spiritwood (Randich, 1977, and Hutchinson and Klausing, 1980) and Rolla (Randich and Kuzniar, 1983) aquifer systems extend into Towner County from adjacent areas (pl. 2, in pocket) and previously were named in reports describing those areas. Smaller aquifers recognized and described during this investigation were not individually named, but were classified according to origin as buried glaciofluvial and outwash aquifers.

Water Available from Storage

Where sufficient data are available, an estimate of ground water available from storage is calculated 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:

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

where:

V = volume of water available from storage, in acre-feet;
$\overline{m}$ = saturated thickness, in feet;
A = areal extent, in acres; and
$\overline{Sy}$ = long-term specific yield of the aquifer.

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

Potential Yield of Glacial-Drift Aquifers

The estimated yields of the glacial-drift aquifers in Towner County are shown on plate 2. The basic factor used in determining these estimates was transmissivity. Aquifer tests were used to determine the transmissivity of various aquifer materials at selected sites. However, these transmissivities 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 five 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	267-668	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 coefficient 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 chosen drawdown value of 30 feet (9 m). Where 30 feet (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 the storage coefficient. Therefore, fully penetrating wells generally yield about twice as much water from unconfined aquifers as similar wells in confined aquifers having the same transmissivity.

The principles described above were used to prepare plate 2. 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 map (pl. 2) is intended as a guide in the location of ground-water resources, and not as a map to locate well sites within 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.

Spiritwood Aquifer System

The Spiritwood aquifer system underlies an area of about 370 mi^2 (960 km^2) in Towner County. It is part of a large, complex buried-valley aquifer system that extends northward from Benson and Ramsey counties, through central Towner County, and into Canada (pl. 2).

The Spiritwood aquifer system in Towner County consists of sand and gravel beds interbedded with lenses of silt, clay, and till (pl. 3, in pocket). Data from 138 test holes show that the aquifer system ranges in thickness from 4 to 287 ft (1 to 87 m) and has an average aggregate thickness of 67 ft (20 m). The deeper aquifer materials are derived primarily from shale and igneous rocks, whereas the upper materials are derived primarily from carbonate and siliceous rocks.

Water in the Spiritwood aquifer system generally is under confined conditions. Water levels in observation wells range from about 14 ft (4 m) above land surface at 159-066-29DDD to 125 ft (38 m) below land surface at 161-067-07DDD. Based on a relatively short period of record, annual water-level fluctuations range from about 1 to 4 ft (0.3 to 1 m). These fluctuations probably are in response to recharge from precipitation and to discharge to streams, lakes, and the underlying Pierre aquifer.

The potentiometric surface and areas where flowing wells might be developed in the Spiritwood aquifer system are shown on plate 4 (in pocket). The ground-water gradient is about 4 ft/mi (0.8 m/km) toward the southeast from the ground-water divide northwest of Rock Lake, and toward the northeast north of the divide. In the topographically high area in northwestern Towner County, the ground-water gradient is about 20 ft/mi (4 m/km) east toward the center of the buried valley. Water levels in wells developed in the upper part of the Spiritwood aquifer system are at higher altitudes than water levels in wells developed in the lower part of the system (pl. 3) and indicate water movement is downward through the system.

Transmissivities calculated from lithologic logs (table 2) and analyses of aquifer tests in Towner and adjacent counties indicate the transmissivity of the Spiritwood aquifer system ranges from 4,000 to 20,000 ft^2/d (370 to 1,860 m^2/d). Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the Spiritwood aquifer system in Towner County should yield from 50 to 1,500 gal/min (3 to 95 L/s; pl. 2).

Based on an areal extent of 370 mi^2 (960 km^2), an average saturated thickness of 67 ft (20 m), and an estimated specific yield of 15 percent, about 2.4 million acre-ft (2,960 hm^3) of water is available from storage in the Spiritwood aquifer system in Towner County.

Analyses of water samples from 95 wells completed in the Spiritwood aquifer system indicate that the water predominantly is very hard and extremely variable in composition. There is some evidence that dissolved-solids concentrations increase with depth and that hardness decreases with depth. Dissolved-solids concentrations in the samples ranged from 396 to 2,560 mg/L and averaged 1,670 mg/L.

Sodium was the dominant cation in 50 samples, calcium was dominant in 44 samples, and magnesium was dominant in 1 sample. Sulfate was the dominant anion. Sodium concentrations ranged from 6.7 to 650 mg/L and averaged 280 mg/L, and calcium concentrations ranged from 15 to 380 mg/L and averaged 190 mg/L. Sulfate concentrations ranged from 57 to 1,400 mg/L and averaged 690 mg/L, and bicarbonate concentrations ranged from 279 to 775 mg/L and averaged 555 mg/L. The irrigation classifications of the water samples ranged from C2-S1 to C4-S4 and were dominantly C3-S1 or C4-S2 (fig. 4).

Rolla Aquifer System

The Rolla aquifer system consists of a group of confined aquifers underlying an area of about 9 mi^2 (23 km^2) in northwestern Towner County (pl. 2).

The aquifer system consists of sand and gravel beds that generally are interbedded with thin lenses of silt, clay, or till. Data from two test holes in Towner County show aquifer thicknesses of 30 and 46 ft (9 and 14 m). Major recharge to the aquifer system is from percolation of precipitation through overlying drift deposits and by underflow from extensions of the aquifer system west of Towner County. Ground-water movement generally is southeastward (Randich and Kuzniar, 1983, pl. 6) and discharge is into the Spiritwood aquifer system.

Yields from the Rolla aquifer system in Towner County were estimated using transmissivities calculated from lithologic logs (table 2). Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in the Rolla aquifer system should yield from 5 to 200 gal/min (0.3 to 13 L/s; pl. 2). Based on an areal extent of 9

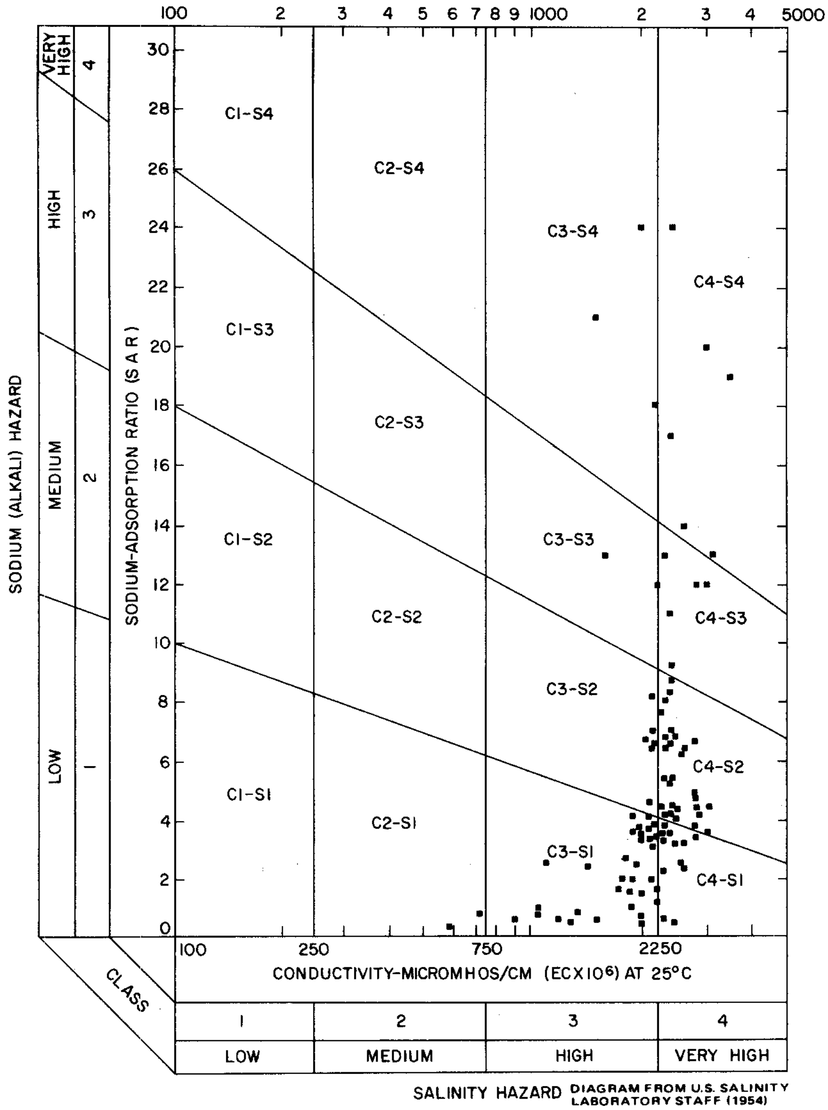


FIGURE 4.—Classification of water from the Spiritwood aquifer system for irrigation use.

mi^2 (23 km^2), an average saturated thickness of 30 ft (9 m), and an estimated specific yield of 15 percent, about 26,000 acre-ft (32 hm^3) of water is available from storage in the Rolla aquifer system in Towner County.

Chemical analyses of water samples from three wells completed in the Rolla aquifer system indicate the water is very hard. Two of the samples were a sodium-calcium sulfate type water and one sample was a calcium sulfate type water. Dissolved-solids concentrations in the three samples were 1,440, 1,460, and 1,560 mg/L; sulfate concentrations were 620, 630, and 660 mg/L; calcium concentrations were 180, 190, and 230 mg/L; and sodium concentrations were 150, 240, and 250 mg/L. Two of the samples were classified C3-S1 for irrigation use and one was classified C3-S2.

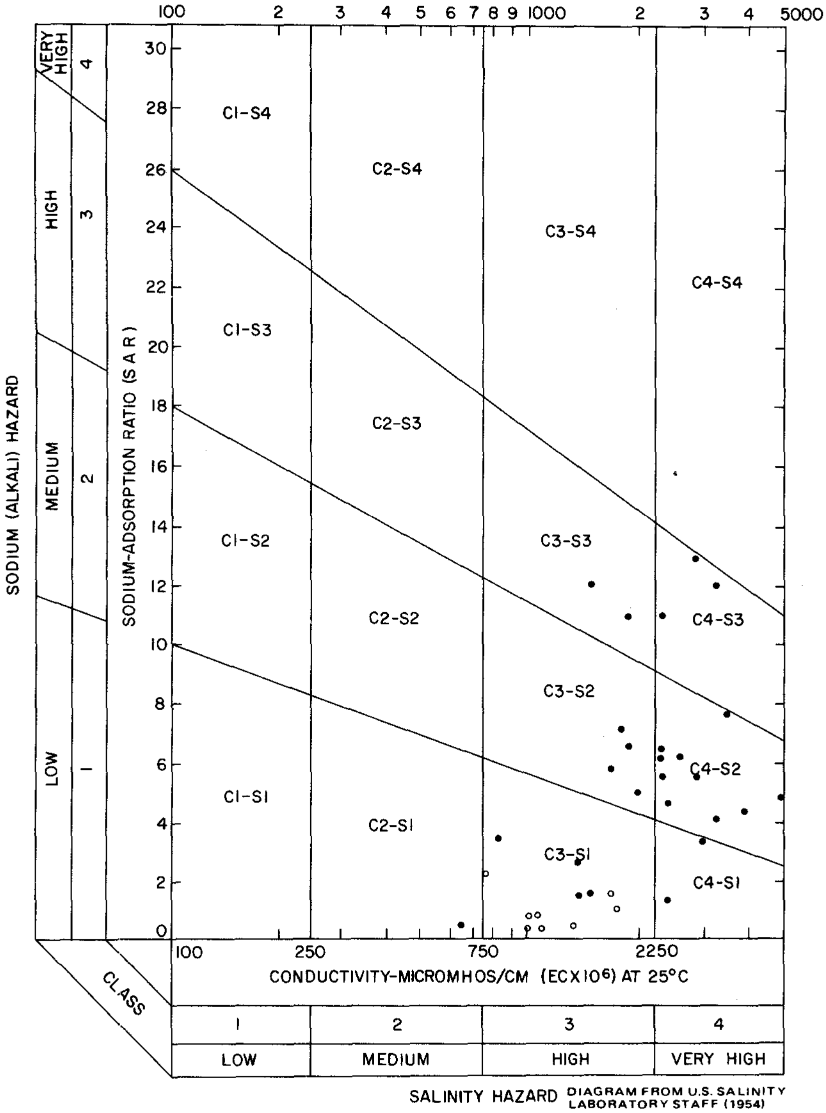
Undifferentiated Aquifers in Buried Glaciofluvial Deposits

Lenticular beds of sand and gravel are interspersed randomly with till in most parts of Towner County and form undifferentiated aquifers in buried glaciofluvial deposits. These aquifers range from less than 1 to about 25 mi^2 (2.6 to 65 km^2) in areal extent. The cumulative total extent of these aquifers is estimated to be about 75 mi^2 (190 km^2).

Data from 49 test holes show that these aquifers consist of interbedded sand and gravel. Generally the aquifers are less than 50 ft (15 m) thick and have an average thickness of about 20 ft (6 m). Water levels in the aquifers range from about 1 to 120 ft (0.3 to 37 m) below land surface, and the aquifers generally are under confined conditions. Recharge is derived from precipitation infiltrating through the overlying glacial drift. Most of the aquifers probably could not sustain well yields of more than 10 gal/min (0.6 L/s) because of their limited areal extent. However, in some areas, such as the eastern parts of Tps. 158 and 162 N., R. 065 W. (pl. 2), where areal extent and saturated thickness are adequate, well yields of 500 gal/min (32 L/s) may be possible.

Based on an areal extent of 75 mi^2 (190 km^2), and average thickness of 20 ft (6 m), and an estimated specific yield of 15 percent, about 144,000 acre-ft (178 hm^3) of water is available to wells from storage in the aquifers.

Chemical analyses of water samples from 25 wells completed in the undifferentiated aquifers in buried glaciofluvial deposits indicate that the water is very hard and is highly variable in chemical character. The dominant cation generally is sodium and the dominant anion generally is sulfate. Dissolved-solids concentrations in the samples ranged from 449 to 4,450 mg/L and averaged 1,760 mg/L. Sodium concentrations ranged from 16 to 550 mg/L and averaged 310 mg/L; calcium concentrations ranged from 37 to 580 mg/L and averaged 180 mg/L; sulfate concentrations ranged from 98 to 2,300 mg/L and averaged 680 mg/L; and bicarbonate concentrations ranged from 311 to 865 mg/L and averaged 496 mg/L. The irrigation classifications of the water samples ranged from C2-S1 to C4-S3 (fig. 5).



EXPLANATION

• BURIED GLACIOFLUVIAL

◦ OUTWASH

FIGURE 5.—Classification of water from the undifferentiated aquifers for irrigation use.

Undifferentiated Aquifers in Outwash Deposits

Most of the stream valleys contain narrow outwash deposits of sand and gravel. The major areas of outwash in Towner County are collapsed river sediment (Clayton, 1980). The saturated interval of these sand and gravel deposits forms the undifferentiated aquifers in outwash deposits. The aquifers have a combined areal extent of about 100 mi² (260 km²).

Data from 18 test holes show that the aquifers range in thickness from 4 to 43 ft (1 to 13 m) and average 30 ft (9 m). Water levels in these aquifers range from 8 to 30 ft (2 to 9 m) below land surface. The undifferentiated aquifers in outwash deposits are under unconfined conditions. Recharge to the aquifers is derived from precipitation infiltrating through surface sediments and seepage from streams, lakes, and potholes. Discharge is by pumping wells and ground-water movement to streams, potholes, and lakes during the relatively dry seasons.

Transmissivities calculated from lithologic logs were used to estimate potential yields from wells completed in these aquifers. Depending upon local aquifer thickness and hydraulic conductivity of the material penetrated, properly constructed wells completed in these aquifers could yield from 5 to 300 gal/min (0.3 to 19 L/s). Based on an areal extent of 100 mi² (260 km²), and average thickness of 30 ft (9 m), and an estimated specific yield of 15 percent, about 288,000 acre-ft (355 hm³) of water is available to wells from storage in the undifferentiated aquifers in outwash deposits.

Chemical analyses of water samples from eight wells completed in the undifferentiated aquifers in outwash deposits indicate that the water is very hard. The dominant cation is calcium and the dominant anion is bicarbonate. Dissolved-solids concentrations in the samples ranged from 490 to 1,460 mg/L and averaged 930 mg/L; calcium concentrations ranged from 68 to 240 mg/L and averaged 150 mg/L; bicarbonate concentrations ranged from 319 to 624 mg/L and averaged 442 mg/L; and sulfate concentrations ranged from 85 to 680 mg/L and averaged 310 mg/L. The irrigation classification of the water samples was C3-S1 (fig. 5).

GROUND-WATER USE

The principal uses of ground-water in Towner County are for domestic, livestock, and public supplies. The estimated total mean annual ground-water use was 623 acre-ft (0.77 hm³) for 1981.

Rural Domestic and Livestock Supplies

Rural domestic and stock wells in Towner County are from 23 to 474 ft (7 to 144 m) deep and commonly yield 5 to 50 gal/min (0.3 to 3 L/s). The following table shows the approximate quantity of ground water used during 1981.

Rural domestic and livestock use, Towner County

Use	Individual requirements[1] (gallons per day)	Population	1981 Estimated pumpage (gallons per day)
Domestic (does not include public supplies)[3]	100	[2]2,269	226,900
Cattle	20	[4]7,000	140,000
Hogs	3	[4]2,000	6,000
Sheep	2	[4]2,900	5,800
Estimated total pumpage			378,700 (1.16 acre-ft)

[1]Murray, 1965.
[2]U.S. Bureau of the Census, 1981.
[3]Includes municipalities that rely on private wells.
[4]U.S. Department of Agriculture, Statistical Reporting Service, North Dakota Crop and Livestock Reporting Service, 1982.

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 out of dugouts, sloughs, or streams.

Public Supplies

Most cities and towns in Towner County depend on ground water for their supplies. The following table shows the estimated mean annual quantity of ground water pumped through distribution systems during 1981.

City	Well location	Aquifer	Mean annual pumpage 1981 (acre-feet)
Cando	158-066-20CAA1	Spiritwood	Mean annual pumpage
	-20CAA2	Spiritwood	for all wells
	-20CAA3	Spiritwood	167.6
Rock Lake	161-066-06CAD	Spiritwood	32.1
Estimated total pumpage			199.7 acre-feet

SUMMARY

The objectives of this study were to: (1) Determine the location, extent, and nature of the major aquifers; (2) evaluate the occurrence and movement of ground water, including sources of recharge and discharge; (3) estimate the quantities of water stored in the glacial aquifers; (4) estimate the potential yields to wells tapping the major aquifers; (5) determine the chemical quality of the ground water; and (6) identify current and potential use of the ground water.

Water in Towner County is available from aquifers in the Pierre Shale of Late Cretaceous age, and in the glacial drift of Quaternary age. The Pierre Shale forms the bedrock surface below the glacial drift and crops out locally in Towner County. The Pierre consists of light-gray to black siliceous shale, marlstone, and claystone with thin lenses of bentonite. The Pierre aquifer consists of fractured black siliceous shale in the upper 25 to 400 ft (7.6 to 120 m) of the formation. This aquifer is a source of water for many farms in Towner County. Most wells developed in the Pierre aquifer yield less than 10 gal/min (0.6 L/s). Recharge to the aquifer is derived from precipitation percolating through the overlying glacial drift. Ground-water movement through the aquifer generally is from topographically high areas toward buried valleys incised into the Pierre aquifer. Dissolved-solids concentrations in water samples collected from the aquifer ranged from 976 to 6,590 mg/L.

Aquifers in the glacial drift have the greatest potential for ground-water development. An estimated 2.8 million acre-feet (3,450 hm^3) of water is available from storage in these aquifers. The aquifers are composed of saturated sand and gravel deposits that range in thickness from 4 to 287 ft (1 to 87 m). The Spiritwood aquifer system is the largest glacial-drift aquifer in Towner County. The areal extent, estimated amount of water available from storage, estimated potential yield to wells, and dissolved-solids ranges for the glacial-drift aquifers are summarized in table 3. Recharge to the glacial-drift aquifers is derived from precipitation infiltrating through surface materials and, in places, from adjacent or underlying bedrock aquifers. Water in the Spiritwood aquifer system moves toward the southeast from the ground-water divide near Rock Lake, and toward the northeast north of the divide. In the topographically high area in northwestern Towner County movement is east toward the center of the buried valley. Water movement in the Rolla aquifer generally is southeastward.

The principal uses of ground water in Towner County are for domestic, livestock, and public supplies. The estimated mean annual ground-water use in 1981 was 623.1 acre-ft (0.77 hm^3).

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

Aquifer or aquifer system	Approximate areal extent (square miles)	Estimated amount of water available from storage (acre-feet)	Estimated potential yields to wells (gallons per minute)	Dissolved-solids range (milligrams per liter)
Spiritwood aquifer system	370	2,400,000	50-1,500	396-2,560
Rolla aquifer system	9	26,000	5-200	1,440-1,560
Undifferentiated aquifers in buried glaciofluvial deposits	75	144,000	<10-500	449-4,450
Undifferentiated aquifers in outwash deposits	100	288,000	5-300	490-1,460

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.

Aronow, Saul, Dennis, P. E., and Akin, P. D., 1953, Geology and ground-water resources of the Minnewaukan area, Benson County, North Dakota: North Dakota State Water Commission and North Dakota Geological Survey, North Dakota Ground-Water Studies 19, 125 p.

Bluemle, J. P. 1977, The face of North Dakota, the geologic story: North Dakota Geological Survey Educational Series 11, pl. 1.

Clayton, Lee, 1980, Geologic map of North Dakota: U.S. Geological Survey Map G77220, 1 sheet.

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.

Comly, H. H., 1945, Cyanosis in infants caused by nitrates in well water: American Medical Association Journal, v. 129.

Downey, J. S., Ground-water resources of Nelson and Walsh Counties, North Dakota: North Dakota Geological Survey Bulletin 57, Part III, and North Dakota State Water Commission County Ground-Water Studies 17, Part III, 67 p.

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.

Federal Water Pollution Control Administration, 1968, Report of the Committee on the water-quality criteria: Washington, United States Government Printing Office, 234 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 (2d ed.): U.S. Geological Survey Water-Supply Paper 1473, 363 p.
Hutchinson, R. D., 1977, Ground-water resources of Cavalier and Pembina Counties, North Dakota: North Dakota Geological Survey Bulletin 62, Part III, and North Dakota State Water Commission County Ground-Water Studies 20, Part III, 68 p.
Hutchinson, R. D., and Klausing, R. L., 1980, Ground-water resources of Ramsey County, North Dakota: North Dakota Geological Survey Bulletin 71, Part III, and North Dakota State Water Commission County Ground-Water Studies 26, Part III, 36 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.
Kahil, A. A., 1965, Ground-water survey of the Rock Lake area, Towner County, North Dakota: North Dakota State Water Commission Ground-Water Studies 63, 32 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.
Keys, W. S., and MacCary, L. M., 1971, Application of borehole geophysics to water-resource investigations: Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 2, Chapter E1, 126 p.
Kuzniar, R. L., and Randich, P.G., 1982, Ground-water data for Bottineau and Rolette Counties, North Dakota: North Dakota Geological Survey Bulletin 78, Part II, and North Dakota State Water Commission County Ground-Water Studies 35, Part II, 742 p.
______ 1983, Ground-water data for Towner County, North Dakota: North Dakota Geological Survey Bulletin 79, Part II, and North Dakota State Water Commission County Ground-Water Studies 36, Part II, 280 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.
National Academy of Sciences, National Academy of Engineering, 1973 [1974], Water quality criteria 1972: U.S. Environmental Protection Agency, Ecological Research Series, Report EPA R3-073-033, March 1973, 594 p.
North Dakota State Department of Health, 1962, The low sodium diet in cardiovascular and renal diseases: Sodium content of municipal waters in North Dakota: 11 p.

______ 1964, Chemical analyses of municipal waters in North Dakota: 25 p.

______ 1970, Water quality standards for surface waters of North Dakota: 45 p.

______ 1977, Regulations for public water supply systems of the State of North Dakota: Regulation 61-28.1-02, 18 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.

Randich, P. G., and Kuzniar, R. L., 1982, Preliminary map showing availabilty of water from glacial-drift aquifers in Towner County, North Dakota: U.S. Geological Survey Open-File Report 82-767, 1 sheet.

______ 1983, Ground-water resources of Bottineau and Rolette Counties, North Dakota: North Dakota Geological Survey Bulletin 78, Part III, and North Dakota State Water Commission County Ground-Water Studies 35, Part III.

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.

Skougstad, M. W., Fishman, M. S., Friedman, L. C., Erdmann, D. E., and Duncan, S. S. (eds.), 1979, Methods of determination of inorganic substances in water and fluvial sediment: Techniques of Water-Resources Investigations, Book 5, Chapter A1, 626 p.

Smith, Carole, 1953, Summary of the National Bulk Carries Inc., Edna L. Hild No. 1, Towner County, North Dakota: North Dakota Geological Survey Circular no. 41, 12 p.

______ 1954a, Summary of the Rhodes-Langenfeld, R. R. Gibbons No. 1, Towner County, North Dakota: North Dakota Geological Survey Circular no. 35, 9 p.

______ 1954b, Summary of the Midwest Exploration Corporation, Union Central Life Insurance, and H. Amann No. 1, Towner County, North Dakota: North Dakota Geological Survey Circular no. 82, 8 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.

Strasburg, Morton, 1954, Summary of the Midwest Exploration Company, P. Juntunen No. 1, Towner County, North Dakota: North Dakota Geological Survey Circular no. 81, 7 p.

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, 1981, 1980 Census of population, Number of inhabitants, North Dakota: U.S. Bureau of the Census Final Report PC 80-1-A36.
U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, 1973, Monthly normals of temperature, precipitation, and heating and cooling degree days 1941-70: Climatography of the United States, no. 81 (by State) North Dakota.
U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, 1982, Evaporation atlas for the contiguous 48 United States: National Oceanic and Atmospheric Administrtation Technical Report NWS33, 27 p., 4 maps.
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 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 of 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 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 containing interstices or voids and may be expressed quantitatively as the ratio of the volume of the 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.