GROUND-WATER RESOURCES

OF

SHERIDAN COUNTY, NORTH DAKOTA

by

M. R. Burkart

U.S. Geological Survey

COUNTY GROUND-WATER STUDIES 32 — PART III
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

BULLETIN 75 — PART III
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Lee Gerhard, *State Geologist*

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

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

A dual system of measurements — inch-pound units and the International System (SI) of metric units — is given in this report. SI is an organized system of units adopted by the 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)
	1,233	cubic meter (m^3)
Foot	0.3048	meter (m)
Foot per day (ft/d)	0.3048	meter per day (m/d)
Foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
Gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
Gallon per minute (gal/min)	0.06309	liter per second (L/s)
Gallon per minute per foot [(gal/min)/ft]	0.207	liter per second per meter [(L/s)/m]
Inch	25.4	millimeter (mm)
Mile	1.609	kilometer (km)
Square mile (mi^2)	2.590	square kilometer (km^2)

GROUND-WATER RESOURCES OF SHERIDAN COUNTY, NORTH DAKOTA

By M. R. Burkart

ABSTRACT

An investigation of the ground-water resources of Sheridan County, North Dakota, indicates that large quantities of water can be obtained from glacial-drift aquifers. Bedrock aquifers also are a source of water throughout most of the county, however, yields are much less than from glacial-drift aquifers.

Glacial-drift aquifers consist of sand and gravel deposits that occupy buried valleys, melt-water channels, and outwash plains. Many of these deposits are part of a network of hydraulically related aquifers constituting the Lake Nettie system. Other glacial-drift aquifers include the Martin system, Butte, Painted Woods Creek, and North Burleigh aquifers. Potential well yields of as much as 500 gallons per minute (32 liters per second) are possible from many of these aquifers. The ground water available to wells from storage in these aquifers is estimated to be 1.9 million acre-feet (2,300 cubic hectometers). The water generally is a sodium bicarbonate or calcium bicarbonate type.

The Hell Creek Formation and Fox Hills Sandstone are the dominant water-bearing bedrock units underlying Sheridan County. Wells developed in aquifers in these bedrock units are not expected to yield more than 50 gallons per minute (3 liters per second). The water generally is soft and is a sodium bicarbonate type.

INTRODUCTION

The investigation of the ground-water resources of Sheridan County (fig. 1) was conducted by the U.S. Geological Survey in cooperation with the North Dakota State Water Commission, North Dakota Geological Survey, and Sheridan County Water Management District. The results of the investigation are published in three parts. Part I is a report describing the geology of the county. Part II (Burkart, 1980) is a compilation of the geologic and hydrologic data collected during the investigation. Part III, this report, is an interpretive report describing ground-water resources. All data used in this report are from part II unless otherwise referenced. The reports are prepared and written to assist public and private water managers and water users in the development of ground-water supplies.

Objectives and Scope

The objectives of the investigation in Sheridan County were to: (1) Determine the location, extent, and nature of major aquifers; (2) evaluate the occurrence and movement of ground water, including recharge and discharge; (3)

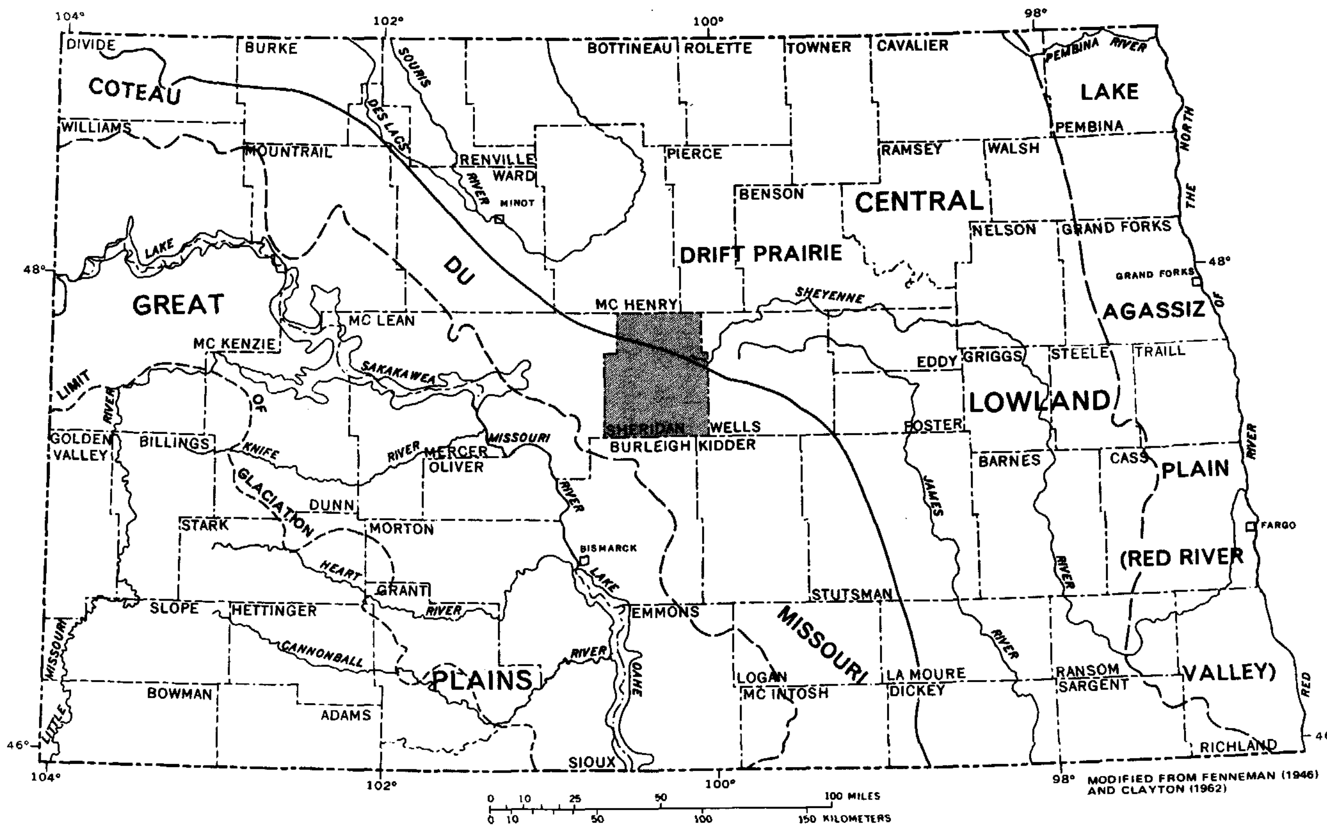


FIGURE 1.—Physiographic divisions in North Dakota and location of study area.

estimate the quantities of water stored in the major aquifers; (4) estimate potential yields to wells penetrating major aquifers; and (5) describe the chemical quality of the ground water.

Interpretations contained in this report are based on data from 320 test holes and wells. These data include lithologic and geophysical logs of 308 test holes and wells, water-level measurements in 61 observation wells, and chemical analyses of 93 samples of ground water.

Previous Investigations

The first geologic and hydrologic study to include Sheridan County was conducted by Simpson (1929). The report resulting from this study includes a brief discussion of the geology of Sheridan County, and the occurrence of water in both bedrock and glacial-drift aquifers.

Benson (1952) reconstructed preglacial drainage patterns in the Knife River area, and Lemke (1960) included parts of Sheridan County in his interpretations of the geology of the Souris River area.

Location-Numbering System

The location-numbering system (fig. 2) used in this report is based on the system of land survey used by the U.S. Bureau of Land Management. 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 148-076-15ADC is in the SW¼SE¼NE¼ sec. 15, T. 148 N., R. 076 W. Consecutive final numerals are added if more than one well is recorded within a 10-acre (4-ha) tract.

Geography

Sheridan County has an area of 1,005 mi^2 (2,611 km^2), and a population of 3,232 (U.S. Bureau of the Census, 1971). The county is located in two major physiographic provinces (fig. 1). About two-thirds of the county is in the Coteau du Missouri district of the Great Plains province (Fenneman, 1946). The northern one-third of the county is in the Drift Prairie of the Central Lowland province.

The part of the county located in the Coteau du Missouri (fig. 1) has a very irregular topographic surface. It is an undrained area of potholes and lakes. The Prophets Mountains and the Lincoln Valley sag (fig. 3) lie within this part of the county. The Lincoln Valley sag is a broad valley near the community of Lincoln Valley; the Prophets Mountains are a series of hills about 200 feet (60 m) higher than the surrounding area located north and west of Pickardville.

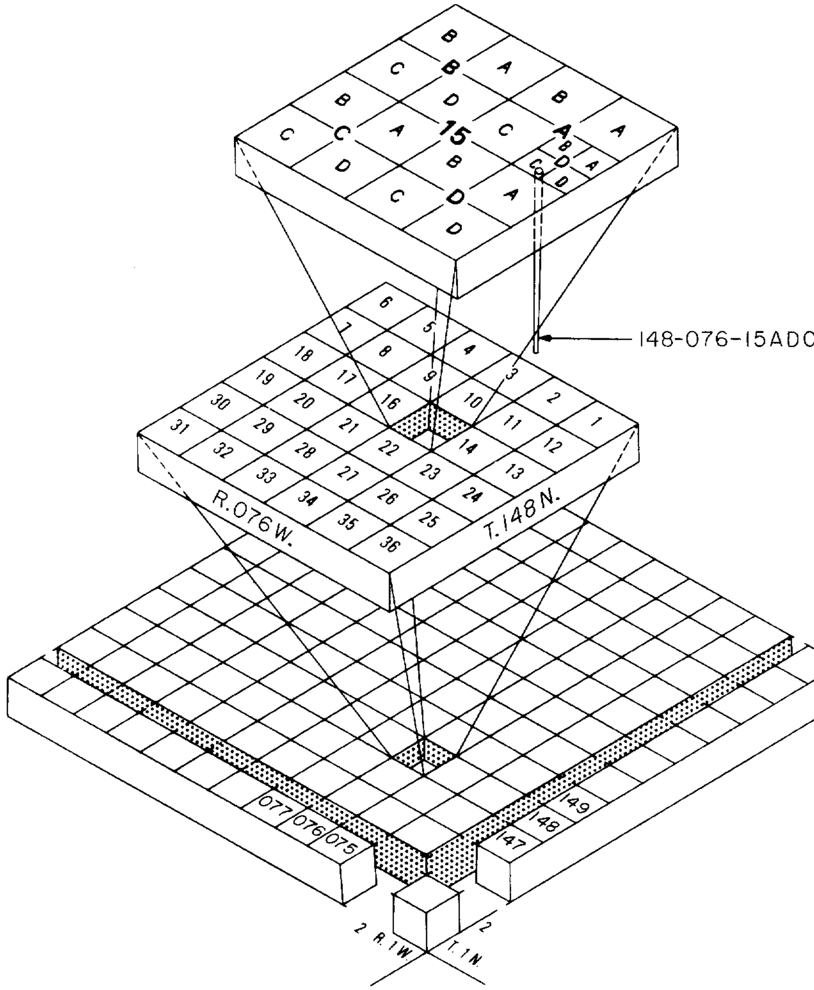


FIGURE 2.—Location-numbering system.

The part of the county located in the Drift Prairie generally has flat to rolling topography with no perennial drainage. Most of this part of the county is in the Sheyenne River drainage basin. A small area in the north-central part of the county is included in the Wintering River drainage basin.

The climate of Sheridan County is semiarid. Mean annual precipitation at McClusky is 17.68 inches (449 mm; U.S. Environmental Data Service, 1973). Most precipitation occurs during the growing season, April through September.

The mean annual temperature at McClusky is 40.2°F (4.6°C). Other climatological stations in surrounding counties have mean annual temperatures ranging from 40.2°F (4.6°C) at Fessenden in Wells County to 40.6°F (4.8°C) at Velva in McHenry County (U.S. Environmental Data Service, 1973).

Dry-land farming and stock raising are the two primary industries in Sheridan County. The principal crops are wheat, hay, oats, flax, and barley. Livestock includes mostly beef and dairy cattle (U.S. Department of Agriculture Economics, Statistics, and Cooperative Service, North Dakota State Statistical Office, 1978).

Geohydrologic Setting

The generalized surficial geology of Sheridan County is shown in figure 3. Deposits of Quaternary age cover all of the county except for small isolated outcroppings of rocks of Late Cretaceous age in the general area of the Sheyenne River.

The bedrock units above the Pierre Shale of Late Cretaceous age were evaluated for their water-bearing characteristics. For practical purposes the Pierre Shale forms the base of the fresh-water-bearing units in the study area, and test drilling stopped when the Pierre was reached in eight of the deepest test holes.

The Fox Hills Sandstone and Hell Creek Formation of Late Cretaceous age are undifferentiated because the facies differences in Sheridan County were not considered sufficient to delineate a definite stratigraphic boundary between the two units. However, for hydrologic purposes, the two units are divided into upper and lower aquifer systems. The lower system, the Fox Hills aquifer system, consists of rocks from the top of the Pierre Shale up to and including a relatively thick and continuous sandstone bed in the Fox Hills that is commonly encountered between 200 and 370 feet (61 and 113 m) above the Pierre Shale. The upper system, the Hell Creek-Fox Hills aquifer system, includes the rocks above the marker sandstone in the lower Fox Hills aquifer system up to the base of the Fort Union Formation of Paleocene age or the glacial drift.

The Fort Union Formation occurs in a small part of southern Sheridan County. However, it 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 were expected to be available. The glacial-drift deposits include relatively impermeable glacial till and water-yielding glaciofluvial materials such as sand, gravel, and silt. The thickest drift deposits are in buried valleys, which can be seen in the bedrock topography (pl. 1, in pocket). Major glacial-drift aquifers occur within some of these valleys.

Acknowledgments

Collection of the data used in this report was made possible by the cooperation of residents and officials of Sheridan County. G. L. Sunderland of the North

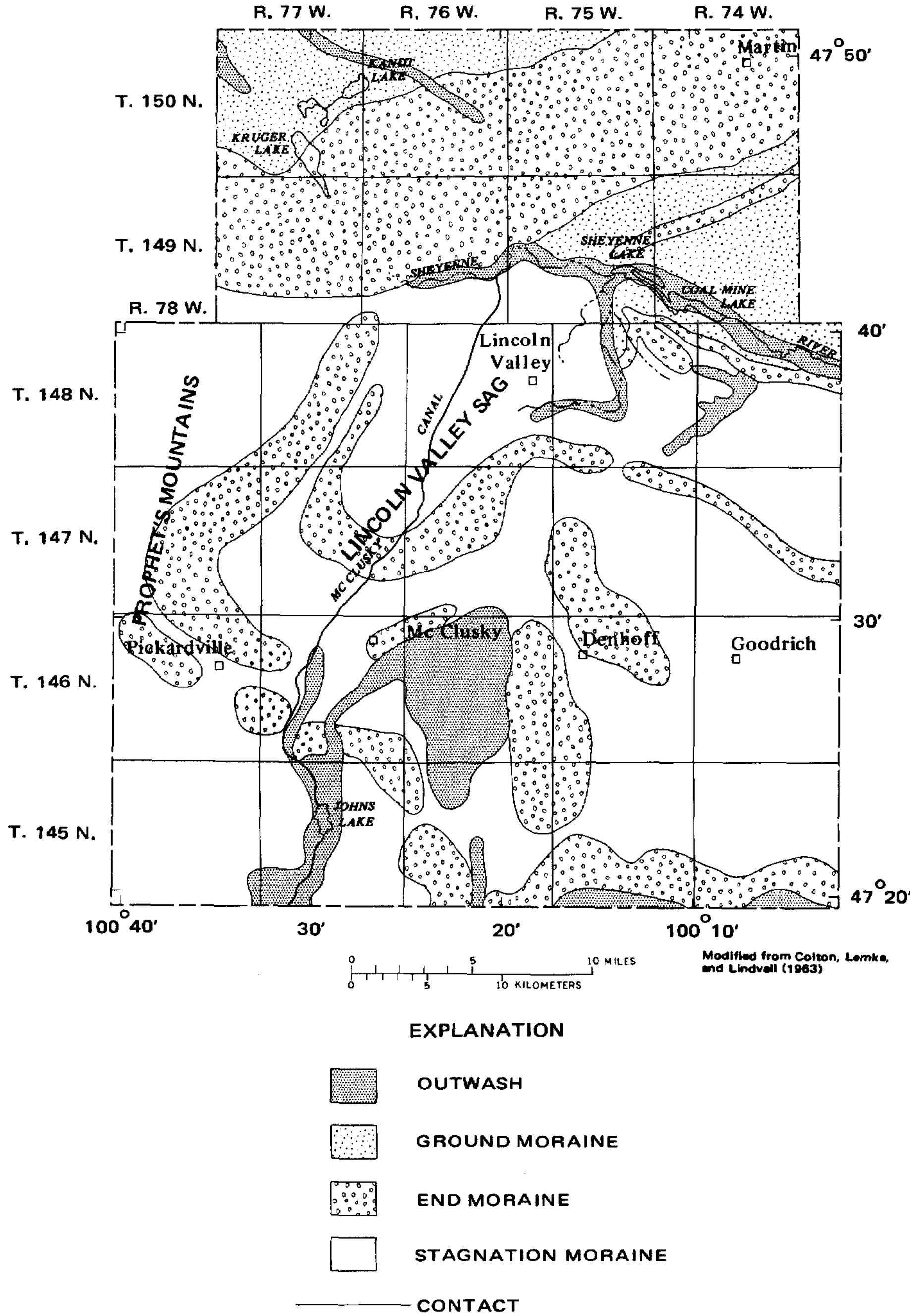


FIGURE 3.—Generalized surficial geology.

Dakota State Water Commission provided lithologic and geophysical logs for most of the test holes drilled for this project. Appreciation is expressed to the U.S. Water and Power Resources Services (formerly the U.S. Bureau of Reclamation) and to well drillers who provided well logs and to the farmers and ranchers in Sheridan County for allowing access to their land.

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 evaporates or is 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 the 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 generally have a relatively 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 relatively 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 and in surface load also cause fluctuations in water level. In the report 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 the 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.

Ground water contains varying concentrations of dissolved mineral matter. Rain begins to dissolve mineral matter as it falls and continues to dissolve mineral matter as the water infiltrates the soil. The amount and kind of dissolved mineral matter in water depends upon the kinds and proportions of minerals that make up the soil and rocks. The pressure and temperature of the water and rock formations, and the concentration of carbon dioxide and soil acids in the water also affect 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 suitability of water for various uses usually is determined by the kind and amount of dissolved mineral matter. The chemical constituents, physical properties, and indices most likely to be of concern are: Iron, sulfate, nitrate, fluoride, boron, chloride, dissolved solids, hardness, temperature, odor, taste, specific conductance, sodium-adsorption ratio (SAR), and percent sodium. The sources of the major chemical constituents, their effects on usability, and the recommended limits are given in table 1. Additional information regarding drinking-water standards may be found in a report by the U.S. Environmental Protection Agency (National Academy of Sciences-National Academy of Engineering, 1972).

In this report numerous 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.

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

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 glacial-drift aquifers in Sheridan County were determined using the Salinity Laboratory Staff's classification system.

Ground Water in the Bedrock Units

Test drilling in Sheridan County penetrated bedrock units as old as the Pierre Shale of Late Cretaceous age and as young as 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.

The Fox Hills Sandstone and the Hell Creek Formation of Late Cretaceous age are not differentiated in this report. However, the stratigraphic interval represented by the two formations is divided into two aquifer systems; the lower system is the Fox Hills aquifer system, and the upper system is the Hell Creek-Fox Hills aquifer system.

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

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

Constituents	Major source	Effects upon usability	National Academy of Sciences — National Academy of Engineering (1972) recommended limits for drinking water
Silica (SiO_2)	Feldspars, quartz, ferromagnesian, and clay minerals.	In presence of calcium and magnesium, silica forms a scale in boilers and on steam turbines that retards heat transfer.	
Iron (Fe)	Natural sources: amphiboles, ferromagnesian minerals, ferrous and ferric sulfides, oxides, carbonates, and clay minerals. Manmade sources: well casings, pumps, and storage tanks.	If more than 0.1 mg/L[1] 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 0.2 mg/L is objectionable for most industrial uses.	0.3 mg/L
Manganese (Mn)	Soils, micas, amphiboles, and hornblende.	More than 0.2 mg/L precipitates upon oxidation. Causes undersirable taste and dark-brown or black stains on fabrics and porcelain fixtures. Most industrial uses require water containing less than 0.2 mg/L.	0.05 mg/L
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. High concentrations of magnesium have a laxative effect.	
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.	
Potassium (K)	Feldspars, feldspathoids, some micas, and clay minerals.		
Boron (B)	Tourmaline, biotite, and amphiboles.	Essential to plant nutrition. More than 2 mg/L may damage some plants.	
Bicarbonate (HCO_3)	Limestone, dolomite.	Heating water dissociates bicarbonate to carbonate and(or) carbon dioxide. The carbonate can combine with alkaline earths (principally calcium and magnesium) to form scale.	
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
Chloride (Cl)	Halite and sylvite.	In excess of 250 mg/L may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 mg/L.	250 mg/L
Fluoride (F)	Amphiboles, apatite, fluorite, and mica.	Optimum concentration in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. Concentrations in excess of optimum may cause mottling of children's teeth.	Recommended maximum limits depend on average of maximum daily air temperatures. Maximum limits its range from 1.4 mg/L at 32°C to 2.4 mg/L at 10°C.
Nitrate (NO_3)	Organic matter, fertilizers, and sewage.	More than 100 mg/L may cause a bitter taste and may cause physiological distress. Concentrations in excess of 45 mg/L have been reported to cause methemoglobinemia in infants.	45 mg/L
Dissolved solids	Anything that is soluble.	Less than 300 mg/L is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	Because of the wide range of mineralization, it is not possible to establish a limiting value.

[1]Milligrams per liter.

Fox Hills Aquifer System

The Fox Hills aquifer system underlies all of Sheridan County, and in many areas is the only aquifer system capable of producing sufficient quantities of water for domestic and stock purposes. The system consists of interbedded sandstone, shale, siltstone, and claystone. The top of the Pierre Shale (fig. 4) is the lower boundary of the system. The upper boundary is the top of a relatively massive sandstone in the Fox Hills. The thickness of the aquifer system varies due to changes in the bedrock altitude, stratigraphic changes, and erosion (pl. 2, sec. A-A′). Thicknesses of the aquifer system range from less than 200 feet (61 m) where the bedrock surface has been eroded below the upper boundary of the aquifer system to as much as 367 feet (112 m) where the system has not been eroded.

The sandstones, which are the water-bearing beds in the aquifer system, range from 1 to about 100 feet (0.3 to 30 m) in thickness. These sandstones are very fine to medium grained and light gray to dark green. The dominant mineral is quartz although glauconite, a green iron-rich clay mineral, commonly is more prevalent. The glauconite content generally is much greater in the sandstones near the base of the system than near the top. The percentage of total sandstone thickness in the Fox Hills aquifer system penetrated by individual wells ranged from 23 to 93 percent; the average was 44 percent.

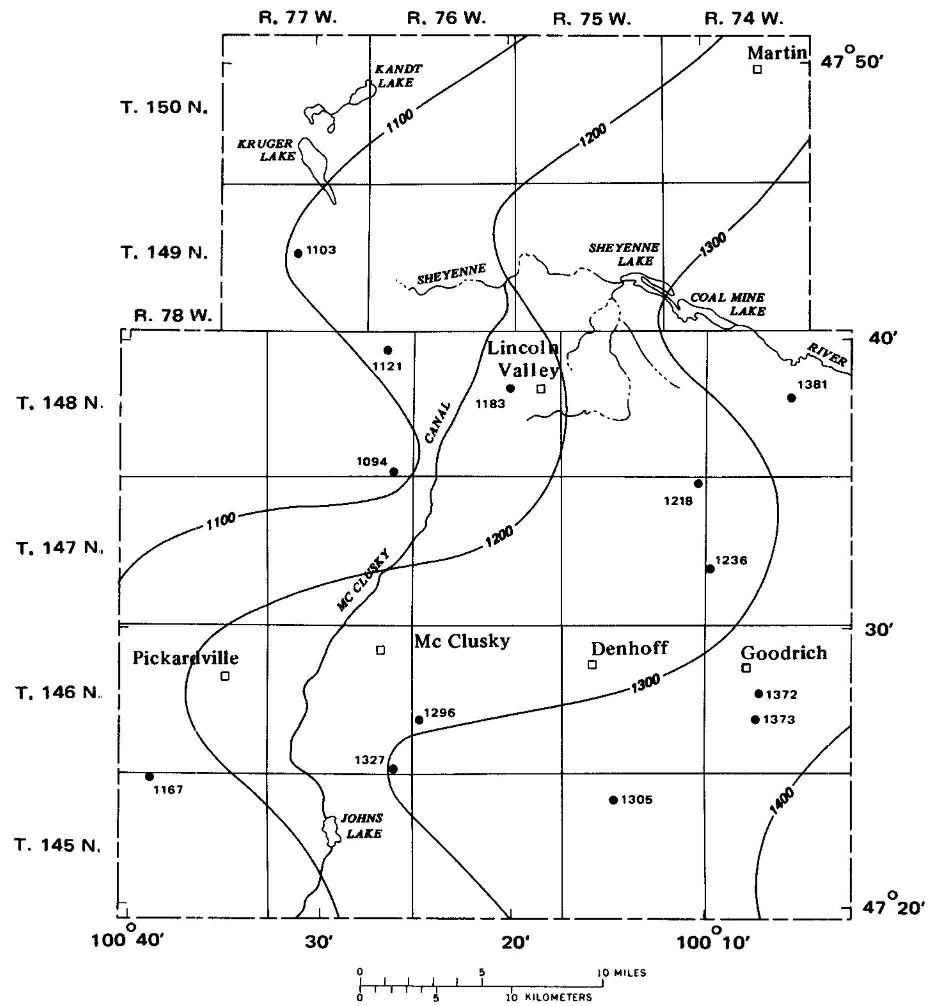
Recharge to the aquifer system in Sheridan County is from adjacent or overlying aquifers and from infiltration through the till where it overlies the aquifer system. Because there are no outcrops of the sandstone beds comprising the aquifer system in the county, there is no direct recharge from precipitation.

General areas of recharge and discharge associated with the aquifer system can be interpreted from the potentiometric surface shown on figure 5. The areas of potential recharge include the west-central and southeastern parts of the county, where the potentiometric surface is highest. Water moves through the system, down gradient, toward the northeast.

Discharge from the aquifer system is vertically to overlying glacial-drift aquifers and laterally to the northeast. The relative position of some of these drift aquifers and the Fox Hills aquifer system is show on plate 2, sections C-C′ and D-D′. Water levels measured in October 1978 indicate that the potentiometric surface of the Fox Hills aquifer system is higher than the potentiometric surface of some of the drift aquifers in the buried valleys. This means the potential is for movement of water from the Fox Hills aquifer system to these drift aquifers. If development lowers the potentiometric surface of the drift aquifers, the potential for discharge from the Fox Hills aquifer system will increase proportionately.

Yields to wells completed in the Fox Hills aquifer system are not expected to exceed 50 gal/min (3 L/s). Where sandstone beds are thin, yields can be expected to be substantially less.

Fifteen water samples were collected for chemical analysis from wells completed in this aquifer system. The analyses indicate the water generally is soft (water from one sample was hard and water from three samples was very hard) and is a sodium bicarbonate type. Dissolved-solids concentrations in the samples

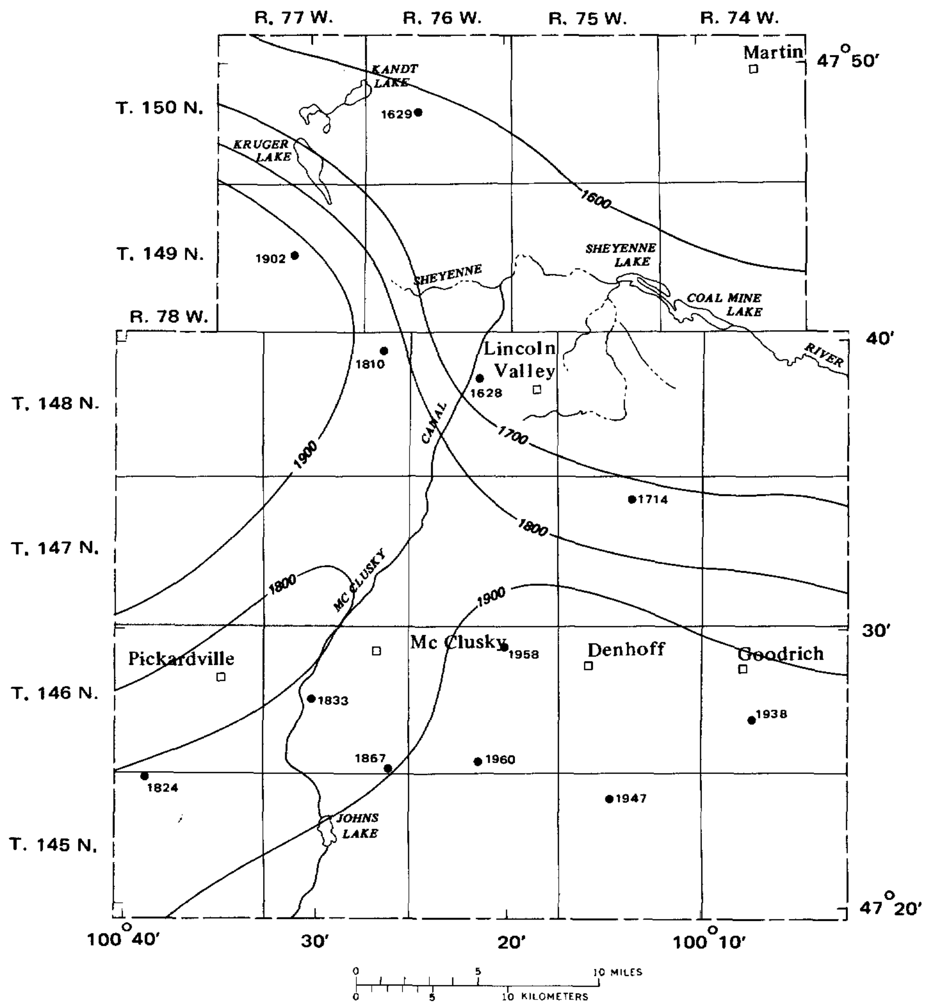


EXPLANATION

1200 — STRUCTURE CONTOUR—Shows altitude of top of Pierre Shale. Contour interval 100 feet (30 meters). Datum is National Geodetic Vertical Datum of 1929

1218 • CONTROL POINT—Number is altitude of top of Pierre Shale. Datum is National Geodetic Vertical Datum of 1929

FIGURE 4.—Structure-contour map of the top of the Pierre Shale.



EXPLANATION

—1800— POTENTIOMETRIC CONTOUR—Shows altitude of potentiometric surface. Contour interval 100 feet (30 meters). Datum is National Geodetic Vertical Datum of 1929

•1824 WELL—Number is altitude of potentiometric surface in feet above National Geodetic Vertical Datum of 1929

FIGURE 5.—Potentiometric surface of the Fox Hills aquifer system, October 1978.

ranged from 828 to 2,470 mg/L and averaged 1,330 mg/L. Sodium concentrations ranged from 250 to 960 mg/L and averaged 500 mg/L; chloride concentrations ranged from 15 to 1,200 mg/L and averaged 230 mg/L; and bicarbonate concentrations ranged from 576 to 1,160 mg/L and averaged 840 mg/L.

The water-quality distribution pattern reflects an increase in dissolved-solids concentrations away from the potential recharge areas. No pattern of water-quality differences can be interpreted in the context of depth below land surface or relative position in the stratigraphic section.

Hell Creek-Fox Hills Aquifer System

The Hell Creek-Fox Hills aquifer system underlies the glacial drift or the Fort Union Formation in Sheridan County. The Hell Creek-Fox Hills aquifer system consists of materials very similar to those in the Fox Hills aquifer system except the sandstone beds are fewer and thinner. The lower boundary of the aquifer system is the top of the marker 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 generally about 300 feet (90 m) thick, except where part of the system has been removed by erosion (pl. 2).

The sandstones in the Hell Creek-Fox Hills aquifer system generally are less than 100 feet (30 m) thick, and are very fine to fine grained. The dominant mineral in the sandstones is quartz; however, some glauconite and bentonite, which is a clay mineral that swells when wet, are present. Clay is present in greater quantities in sandstones of the Hell Creek-Fox Hills aquifer system than in sandstones in the Fox Hills aquifer system. The percentage of total sandstone thickness in the Hell Creek-Fox Hills aquifer system penetrated by individual wells ranged from 0 to about 40 percent; the average was 28 percent.

Only three observation wells were completed in this aquifer system; however, hydrogeologic data from an inventory of domestic and livestock wells are sufficient to conclude that recharge is from adjacent and overlying glacial drift.

Yields to wells completed in the Hell Creek-Fox Hills aquifer system are expected to be much less than 50 gal/min (3 L/s).

Seventeen water samples were collected for chemical analysis from wells completed in the Hell Creek-Fox Hills aquifer system. Analyses indicate the water generally is soft to moderately hard. The water generally is a sodium bicarbonate type, although three samples had large concentrations of sulfate.

Dissolved-solids concentrations in the samples ranged from 531 to 2,650 mg/L and averaged 1,430 mg/L. Sodium concentrations ranged from 180 to 880 mg/L and averaged 490 mg/L; chloride concentrations ranged from 4.1 to 470 mg/L and averaged 70 mg/L; bicarbonate concentrations ranged from 466 yo 996 mg/L and averaged 807 mg/L; and sulfate concentrations ranged from 7.4 to 950 mg/L and averaged 400 mg/L.

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 Lake Nettie aquifer system, Painted Woods Creek aquifer, and North Burleigh aquifer (pl. 3, in pocket). Aquifers initially recognized and described during this investigation are named after local geographic features — Martin aquifer system and Butte aquifer (pl. 3).

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). The volume of water available from an unconfined aquifer is defined by the following formula using average values:

$$V = \overline{m}A\overline{S}y \tag{1}$$

where:

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

The specific yield for glacial-drift aquifer materials may range from 0.01 to 0.35. The commonly used range for these materials in North Dakota is 0.10 to 0.20.

Determination of the amount of water available from storage in a confined aquifer involves a calculation in addition to that shown above owing to (1) expansion of the water and (2) compressibility of the aquifer. The quantity of water gained due to expansion and compression is insignificant and therefore the storage estimates derived for this investigation are based on a long-term specific yield of 15 percent.

Potential Yield of Glacial-Drift Aquifers

Estimated potential yields of glacial-drift aquifers in Sheridan County are shown on plate 3. The basic factor used in determining these estimates was transmissivity. The transmissivity of an aquifer is a measure of its ability to transmit water through connected openings. Often aquifer tests are used to determine transmissivity. However, these test results are valid only for the relatively small area surrounding the test site, and aquifer tests are very expensive to conduct. For this study, transmissivities were determined by estimating the hydraulic conductivity from lithologic logs and multiplying this by the thickness of the aquifer. Although the estimates derived are valid only for the site of the logged hole, the number of logged holes provides a larger 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

TABLE 2. — Hydraulic conductivity of common glacial-drift aquifer materials

Material	Hydraulic conductivity (feet per day)
Gravel	160-600
Sand and gravel	130-200
Coarse sand	80-130
Medium sand	65-95
Fine sand	25-55
Very fine sand	10-25
Silt	5-10

of sorting. Estimates were based on the smaller value unless the lithologic log indicated that the material was well sorted.

Meyer (1963, p. 338-340, fig. 100) published a chart relating well diameter, specific capacity, and coefficients of transmissivity and storage. This chart shows that for coefficients of storage of more than 0.005, and transmissivities ranging from 270 to 13,500 ft^2/d (25 to 125 m^2/d), the ratio of transmissivity to specific capacity is about 267:1, when the specific capacity used is given in gallons per minute per foot of drawdown after 24 hours pumping. The ratio is larger for transmissivities of more than 13,500 ft^2/d (125 m^2/d).

Meyer's chart shows that large changes in the storage coefficient in the range 0.005 to 0.00005 correspond to relatively small changes in specific capacity. In most confined aquifers the storage coefficient is less than 0.005. In those confined aquifers having transmissivities of as much as 13,500 ft^2/d (125 m^2/d), the yield, in gallons per minute, for a fully penetrating well with 10 feet (3 m) of drawdown after 24 hours pumping may be approximated by dividing the transmissivity by 27. The diameter of the well also will affect the yield, but this effect is small compared to the inaccuracies encountered in estimating transmissivity from lithology.

The principles described above were applied in preparing plate 3. Aquifer-boundary conditions will affect the yields to wells, therefore, the estimated yields were arbitrarily reduced. The estimated potential well yields shown on plate 3 are total yields available from both the unconfined and confined parts of an aquifer system where the two conditions exist.

The yield map (pl. 3) is intended as a guide in the location of ground-water resources, and not as a map to locate wells with a specific yield. Few, if any, aquifers are so uniform in areal extent and physical properties that production wells could be constructed in them without additional test drilling.

Lake Nettie Aquifer System

The Lake Nettie aquifer system occupies parts of buried bedrock valleys in central and southern Sheridan County (pls. 2 and 3). The aquifer system underlies an area of about 200 mi^2 (520 km^2) in Sheridan County. The Lake Nettie aquifer system was first described by Klausing (1974) in McLean County. The Lost Lake aquifer, which also was first described by Klausing (1974), occurs in Sheridan County in sec. 30, T. 146 N., R. 78 W, and is included as part of the Lake Nettie aquifer system in this report. The Lake Nettie aquifer system consists of two hydrologic units; the lower Lake Nettie aquifer and the upper Lake Nettie aquifer system (pl. 2).

Lower Lake Nettie aquifer

The lower Lake Nettie aquifer is a confined aquifer that occupies deep buried bedrock valleys beneath the upper Lake Nettie aquifer system in west-central Sheridan County. The aquifer is generally about 0.5-mile (0.8-km) wide and has an areal extent of about 26 m^2 (67 km^2) in Sheridan County (fig. 6).

Data from 13 test holes indicate the aquifer consists of sand and gravel beds. The aquifer ranges in thickness from 19 to 308 feet (6 to 94 m) and has an average thickness of 116 feet (35 m). Depths at which the aquifer occurs range from 238 to 729 feet (73 to 222 m) below land surface. The aquifer generally occurs between altitudes of 1,190 and 1,600 feet (363 and 488 m).

Recharge to the aquifer is by infiltration from overlying aquifers through the confining till and from adjacent and underlying bedrock aquifers. By comparing figure 5 to figure 6, it can be seen that in the southeastern part of the lower Lake Nettie aquifer there is a potential for leakage from the Fox Hills aquifer system, which has a higher potentiometric surface.

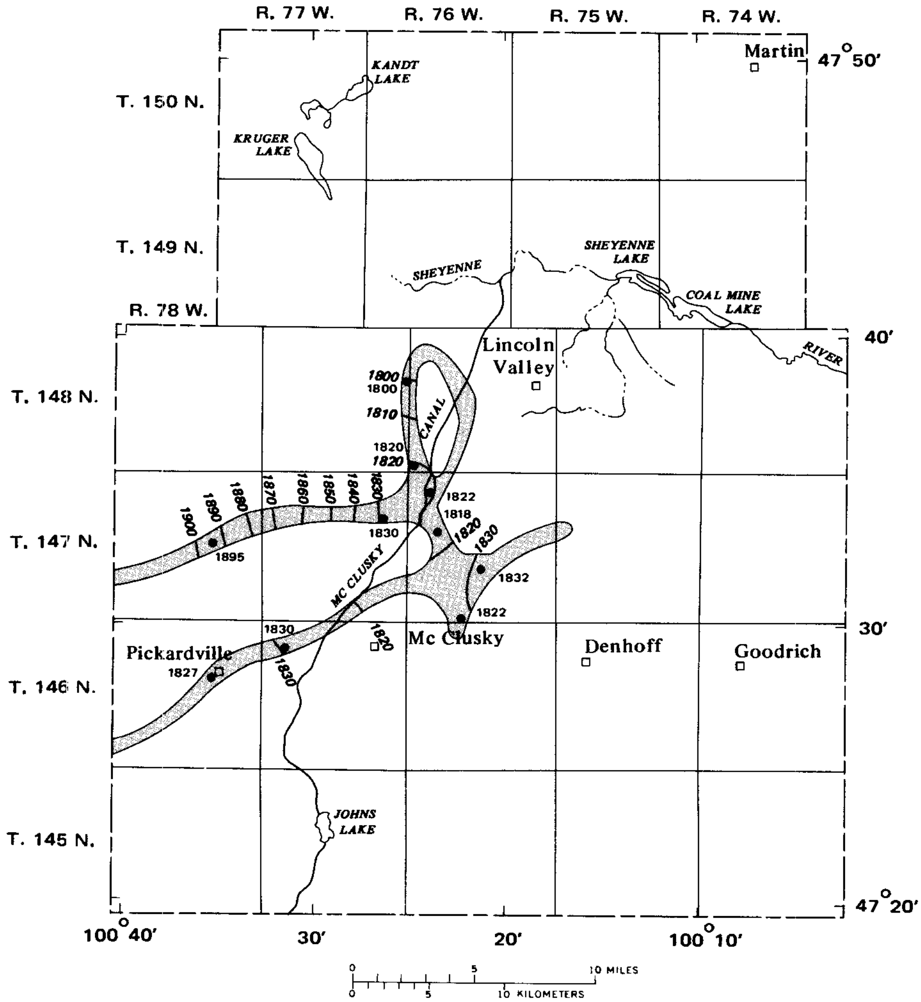
Water movement in the lower Lake Nettie aquifer is generally northeast toward Lincoln Valley (fig. 6). Based on transmissivity estimates from lithologic logs, the estimated potential yields from wells completed in the lower Lake Nettie aquifer may range from 50 to more than 500 gal/min (3.2 to 33 L/s). An estimated 290,000 acre-feet (358 hm^3) of water is available from storage in the part of the lower Lake Nettie aquifer in Sheridan County. This estimate is based on the following factors: Average thickness, 116 feet (35 m); areal extent, 26 mi^2 (67 km^2); and specific yield, 0.15. Currently (1979) only four domestic wells are known to be completed in the aquifer.

Chemical analyses of 14 water samples from the lower Lake Nettie aquifer indicate that the water generally is a sodium bicarbonate type, and is moderately to very hard. Dissolved-solids concentrations in the samples ranged from 887 to 1,810 mg/L and averaged 1,190 mg/L. The irrigation classifications of the water samples (fig. 7) ranged from C3-S1 to C4-S4.

Upper Lake Nettie aquifer system

The upper Lake Nettie aquifer system is, in places, confined, and, in others, unconfined. It occupies bedrock valleys in central, southern, southeastern, and western Sheridan County. The system underlies an area of approximately 200 mi^2 (520 km^2) in Sheridan County (fig. 8).

Data from 33 test holes indicate that the aquifer system includes many individual sand and gravel beds. The beds are not all in direct hydraulic connection with each other and therefore do not comprise a single aquifer (pl. 2).



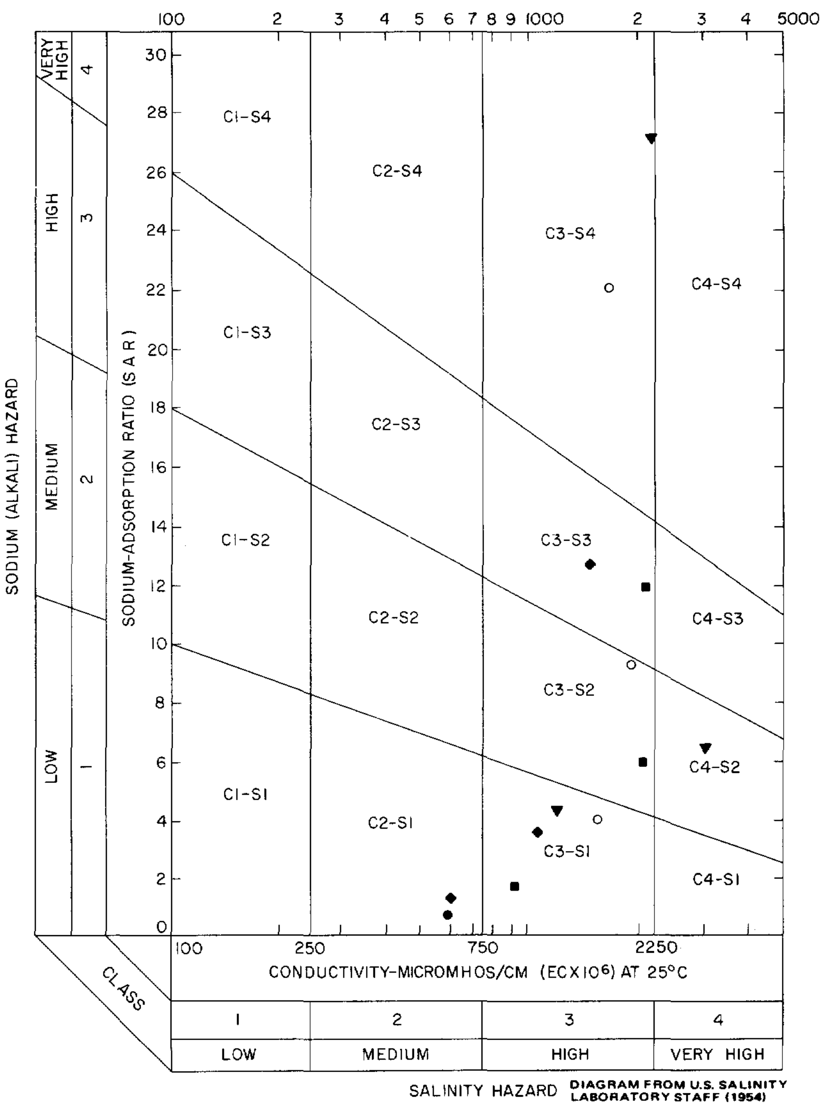
EXPLANATION

LOWER LAKE NETTIE AQUIFER

1830 POTENTIOMETRIC CONTOUR—Shows altitude of potentiometric surface. Contour interval 10 feet (3 meters). National Geodetic Vertical Datum of 1929

•1830 WELL—Number is altitude of potentiometric surface, in feet. National Geodetic Vertical Datum of 1929

FIGURE 6.—Potentiometric surface of the lower Lake Nettie aquifer, October 1978.



EXPLANATION

○ LOWER LAKE NETTIE AQUIFER

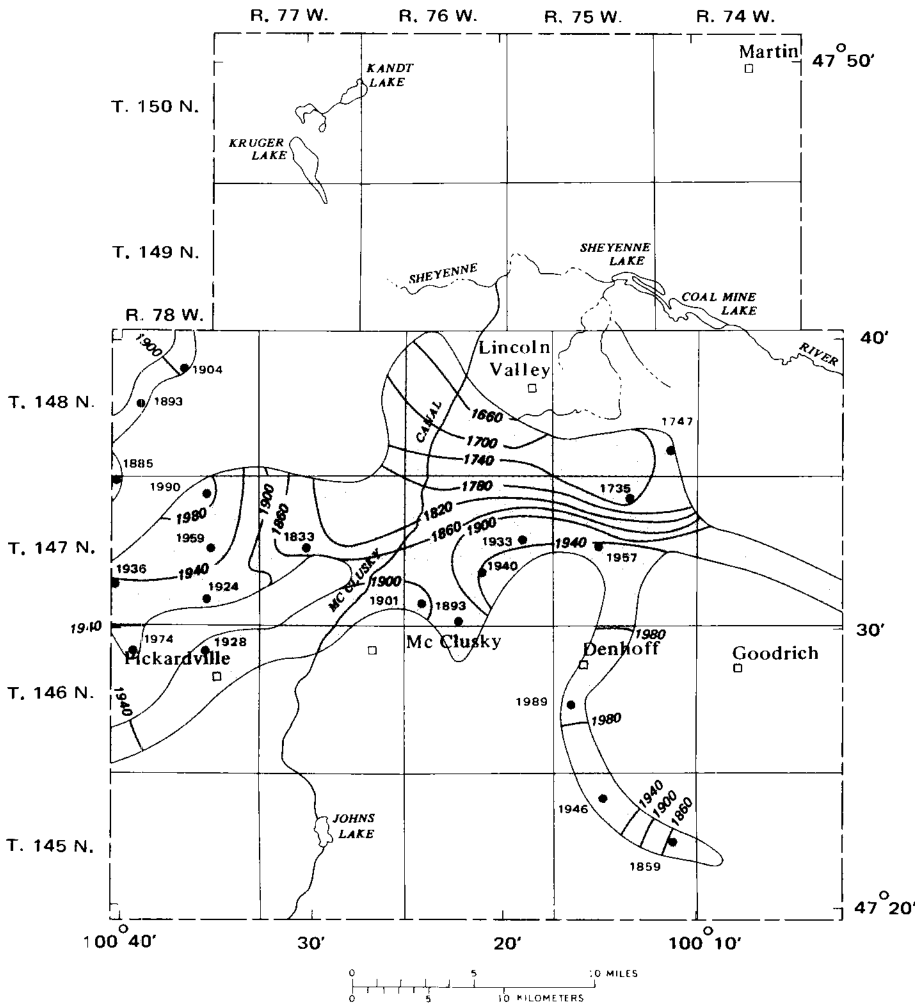
◆ UPPER LAKE NETTIE AQUIFER SYSTEM

■ MARTIN AQUIFER SYSTEM

▼ BUTTE AQUIFER

● NORTH BURLEIGH AQUIFER

FIGURE 7.—Irrigation classifications of selected water samples.



EXPLANATION

UPPER LAKE NETTIE AQUIFER

1900 POTENTIOMETRIC CONTOUR—Shows altitude of potentiometric surface. Contour interval 40 feet (12 meters). National Geodetic Vertical Datum of 1929

1928 WELL—Number is altitude of potentiometric surface, in feet. National Geodetic Vertical Datum of 1929

FIGURE 8.—Potentiometric surface of the upper Lake Nettie aquifer system, October 1978.

The thickness of individual sand and gravel beds ranges from a few feet to more than 140 feet (43 m). Aggregate thickness of the sand and gravel beds in the system ranges from 10 to 185 feet (3 to 56 m); average thickness is 62 feet (19 m). Depths at which the aquifer system occurs range from land surface to 443 feet (135 m) below land surface. The aquifer system generally occurs between altitudes of 1,600 and 2,000 feet (488 to 610 m).

Water levels in wells completed in the upper Lake Nettie aquifer system are highest in the recharge areas northwest of McClusky and near Denhoff. These areas are topographically high and contain numerous lakes, potholes, and marshes. The surface ponding of precipitation and snowmelt provides a source for infiltration either directly into surficial aquifers or by percolation through confining material to buried aquifers within the upper Lake Nettie aquifer system.

The potentiometric surface shown on figure 8 is a schematic diagram for most of the flow system. The contours show that ground-water movement is generally toward the northeastern part of the system.

Discharge from the upper Lake Nettie aquifer system is to surface features as well as to other aquifers. Potential discharge to the lower Lake Nettie aquifer is evident because of the higher potentiometric surface in the upper Lake Nettie aquifer system. In addition, potential discharge to bedrock aquifers exists.

Based on transmissivity estimates from lithologic logs, the estimated potential yields from wells completed in the upper Lake Nettie aquifer system may range from 50 to more than 500 gal/min (3.2 to 32 L/s).

An estimated 1.2 million acre-feet (1,480 hm^3) of water is available from storage in the Sheridan County part of the upper Lake Nettie aquifer system. This estimate is based on the following factors: Average thickness, 62 feet (19 m); areal extent, 200 mi^2 (520 km^2); and specific yield, 0.15.

Current (1979) use of the aquifer system in Sheridan County is limited to domestic and stock wells. Several irrigation systems in adjacent McLean County withdraw water from part of this aquifer system.

Chemical analyses of 21 water samples from the upper Lake Nettie aquifer system indicate that the water is very hard and is a sodium bicarbonate or calcium-magnesium bicarbonate type. Sodium concentrations were as much as 400 mg/L and sulfate concentrations were as much as 550 mg/L. Dissolved-solids concentrations in the samples ranged from 202 to 1,460 mg/L and averaged 880 mg/L. The irrigation classifications of the water samples ranged from C2-S1 to C3-S3 (fig. 7).

Martin Aquifer System

The Martin aquifer system consists of a group of unconfined and confined aquifers that overlie and occupy a shallow bedrock valley in the northeastern part of Sheridan County (pl. 3). The aquifer system underlies an area of approximately 46 mi^2 (119 km^2) in Sheridan County.

Data from test holes indicate the aquifer system consists of many sand and gravel beds. The system can be divided into two unconnected zones; a shallow zone and a deeper zone. Thickness of individual sand and gravel beds in the shallow zone ranges from a few feet to 110 feet (34 m); average aggregate thickness is approximately 50 feet (15 m). The shallow zone occurs at or very near land surface to as much as 110 feet (34 m) below land surface.

Only one test hole drilled during this study penetrated the deeper zone; however, several test holes drilled by the U.S. Water and Power Resources Service penetrated at least part of this deeper zone. Thickness of sand and gravel beds in the deeper zone ranges from 20 to 85 feet (6 to 26 m); average aggregate thickness is about 46 feet (14 m). Depths at which the deeper zone occurs range from about 110 to 300 feet (30 to 91 m) below land surface. The areal distribution of the deeper zone is not known, but it is estimated to be no more than one-half that of the shallow zone.

Recharge to the Martin aquifer system is largely from direct infiltration of precipitation and snowmelt. Additional recharge may be from underlying bedrock aquifers that have higher potentiometric surfaces than the Martin system.

Discharge from the aquifer system apparently is to lakes, potholes, and marshes that intersect the water table. Locally, the water levels in the system may be higher than those of the underlying bedrock aquifers and downward discharge through underlying till may occur.

Transmissivities calculated from lithologic logs were used to estimate potential yields from wells completed in the Martin aquifer system (pl. 3). Properly constructed wells may yield from 50 to 500 gal/min (3.2 to 32 L/s), if the complete sequence of sand and gravel is screened.

An estimated 320,000 acre-feet (395 hm^3) of water is available from storage in the part of the Martin aquifer system in Sheridan County. This estimate is based on the following factors: (1) Shallow zone — average thickness, 50 feet (15 m); areal extent, 46 mi^2 (119 km^2); and specific yield, 0.15; and (2) deeper zone — average thickness, 46 feet (14 m); areal extent, 23 mi^2 (60 km^2); and specific yield, 0.15.

Chemical analyses of six water samples from the Martin aquifer system indicate that the water is very hard. Calcium and magnesium are the dominant cations in water from the shallow zone (wells less than 100 feet or 30 m deep); sodium is the dominant cation in water from the deeper zone. Bicarbonate was the dominant anion in four samples and sulfate was the dominant anion in two; however, there was no correlation in the zones. Bicarbonate concentrations ranged from 374 to 650 mg/L and sulfate from 160 to 650 mg/L. One sample, from well 150-075-30AAA, had a chloride concentration of 250 mg/L, which is almost 10 times greater than in any of the other samples. Samples of water from wells in the shallow zone had an irrigation classification of C3-S1, and samples from the deeper zone had irrigation classifications of C3-S2 and C3-S3 (fig. 7).

Butte Aquifer

The Butte aquifer is a generally confined aquifer that occupies a narrow melt-water channel in the northwest corner of Sheridan County. The aquifer may be part of the network comprising the Lake Nettie system, but the hydraulic connection is not apparent. The total areal extent of the aquifer in Sheridan County is about 9 mi^2 (23 km^2).

Data from five test holes indicate the aquifer consists of sand and gravel deposits. Thickness of the aquifer ranges from 18 to 87 feet (5 to 27 m); average thickness is 54 feet (16 m). Depths at which the aquifer occurs range from 3 to 197 feet (0.9 to 60 m) below land surface. The aquifer generally occurs between altitudes of 1,470 and 1,710 feet (448 and 521 m).

Recharge to the Butte aquifer is by leakage from underlying and adjacent bedrock aquifers as well as by infiltration of water through overlying materials. The potentiometric surface shown on figure 9 indicates movement is from the northwest and southeast toward Krueger Lake. Discharge is dominantly to Krueger Lake.

Transmissivities calculated from lithologic logs were used to estimate potential yields from wells completed in the Butte aquifer (pl. 3). Yields of 50 to 250 gal/min (3.2 to 16 L/s) may be expected from properly constructed wells that screen all intervals of sand and gravel.

An estimated 47,000 acre-feet (58 hm^3) of water is available from storage in the Butte aquifer in Sheridan County. This estimate is based on the following factors: Average thickness, 54 feet (16 m); areal extent, 9 mi^2 (23 km^2); and specific yield, 0.15.

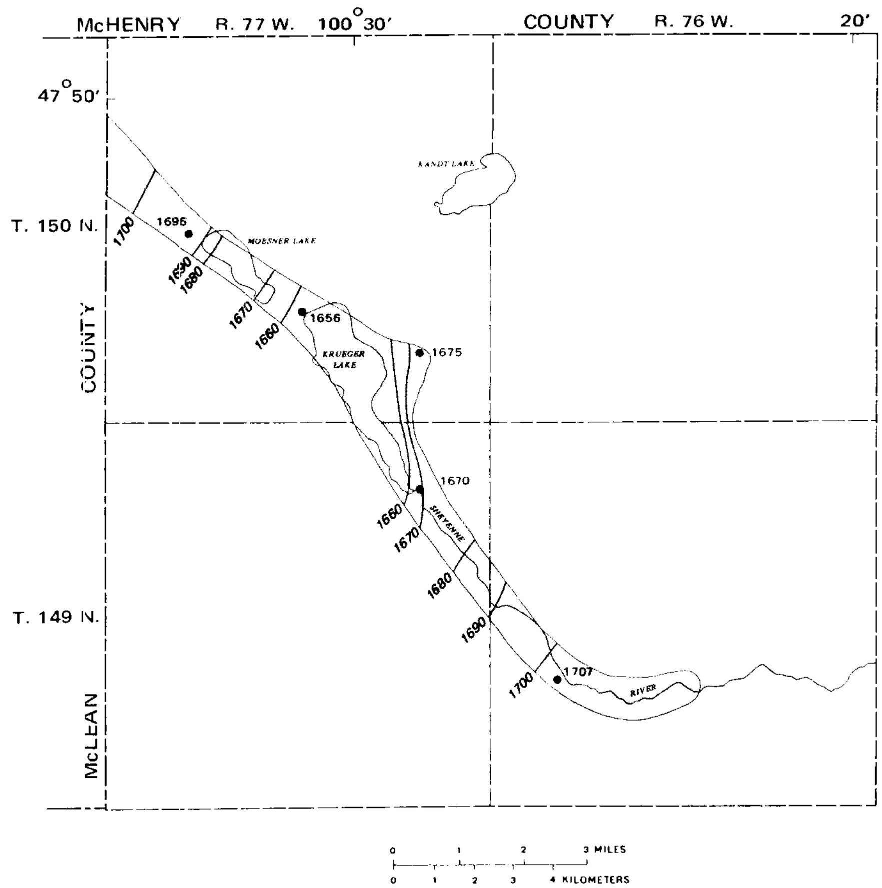
Chemical analyses of five water samples from the Butte aquifer indicate that the water is soft to very hard and is a sodium bicarbonate type. Two samples had chloride concentrations of 210 and 430 mg/L. Sodium concentrations ranged from 170 to 840 mg/L, bicarbonate concentrations ranged from 510 to 1,100 mg/L, and sulfate concentrations ranged from 21 to 1,100 mg/L. Dissolved-solids concentrations ranged from 783 to 2,260 mg/L. The irrigation classifications of the water samples were C3-S1, C3-S4, C4-S2, and two of the samples were C4-S4.

Painted Woods Creek Aquifer

The Painted Woods Creek aquifer is a generally unconfined aquifer that underlies approximately 12 mi^2 (31 km^2) in the southwest part of Sheridan County. The aquifer was first described by Randich and Hatchett (1966) in Burleigh County.

Twenty-three test holes, including 18 drilled by the U.S. Water and Power Resources Service, penetrated at least part of the aquifer in Sheridan County. The aquifer consists of sand and gravel beds that have an aggregate thickness of 9 to 53 feet (3 to 16 m); average thickness is about 30 feet (9 m). The aquifer occurs at or near land surface to as much as 81 feet below land surface, and occurs between altitudes of 1,780 and 1,920 feet (543 and 585 m).

Recharge to the aquifer is controlled by precipitation and runoff. The potentiometric surface shown in figure 10 indicates movement is toward Johns Lake and the general area of the McClusky Canal. Discharge is to the McClusky Canal and through evaporation and transpiration.



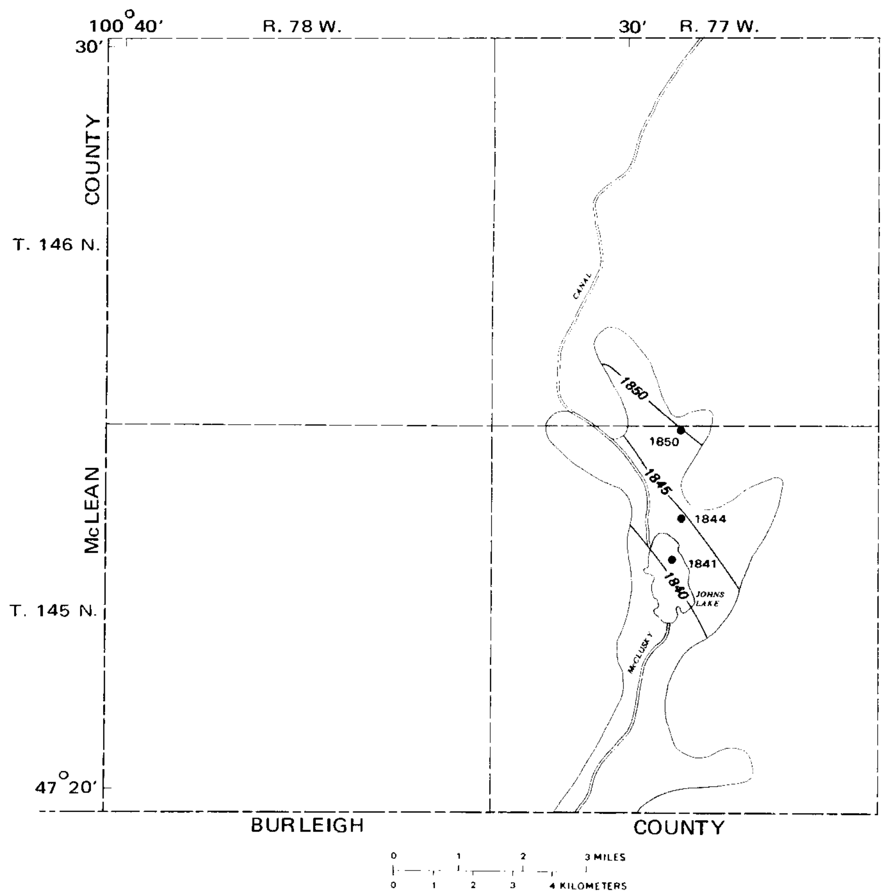
EXPLANATION

BUTTE AQUIFER

—*1690*— POTENTIOMETRIC CONTOUR—Shows altitude of potentiometric surface. Contour interval 10 feet (3 meters). National Geodetic Vertical Datum of 1929

•1696 WELL—Number is altitude of potentiometric surface, in feet. National Geodetic Vertical Datum of 1929

FIGURE 9.—Potentiometric surface of the Butte aquifer, October 1978.



EXPLANATION

PAINTED WOODS CREEK AQUIFER

1840 — POTENTIOMETRIC CONTOUR—Shows altitude of potentiometric surface. Contour interval 5 feet (1.5 meters). National Geodetic Vertical Datum of 1929

•1844 WELL—Number is altitude of potentiometric surface, in feet. National Geodetic Vertical Datum of 1929

FIGURE 10.—Potentiometric surface of the Painted Woods Creek aquifer, October 1978.

Transmissivities calculated from lithologic logs were used to estimate the potential yields from wells completed in the Painted Woods Creek aquifer. Estimated yields (pl. 3) range from 50 to 500 gal/min (3.2 to 32 L/s).

An estimated 35,000 acre-feet (43 hm^3) of water is available from storage in the part of the Painted Woods Creek aquifer in Sheridan County. This estimate is based on the following factors: Average thickness, 30 feet (9 m); areal extent, 12 mi^2 (31 km^2); and specific yield, 0.15.

Chemical analyses of two water samples from the Painted Woods Creek aquifer are available. One sample from a well completed in the dry bed of Johns Lake contained an abnormally large dissolved-solids concentration (27,200 mg/L) and is not considered representative of water from the aquifer. The other sample was a calcium bicarbonate type water that was very hard. The irrigation classification of the sample was C2-S2.

North Burleigh Aquifer

The North Burleigh aquifer is a surficial outwash deposit that underlies about 6 mi^2 (16 km^2) in southeastern Sheridan County. The aquifer was first described by Randich and Hatchett (1966) in Burleigh County.

Two test holes drilled during this study, and one private test hole drilled for irrigation use have penetrated the aquifer in Sheridan County. The aquifer consists of very fine sand to medium gravel that ranges in thickness from 14 to 38 feet (4 to 12 m). Thin lenses of till are interspersed through the aquifer. The aquifer occurs at land surface to as much as 98 feet (30 m) below land surface.

Recharge to the aquifer is from direct infiltration of precipitation and from potholes in topographically high areas. The potholes act as recharge points to the aquifer during and following periods of precipitation and snowmelt. Discharge from the aquifer occurs by withdrawal for irrigation and by evapotranspiration in low-lying areas, which are characterized by saline lakes; Salt Lake is a typical example.

Transmissivities calculated from lithologic logs were used to estimate potential yields from wells completed in the North Burleigh aquifer (pl. 3). Yields of from 50 to 500 gal/min (3.2 to 32 L/s) may be expected from properly constructed wells that screen the complete sequence of sand and gravel.

An estimated 14,000 acre-feet (17 hm^3) of water is available from storage in the North Burleigh aquifer in Sheridan County. This estimate is based on the following factors: Average thickness, 25 feet (8 m); areal extent, 6 mi^2 (16 km^2); and specific yield, 0.15.

One chemical analysis of a water sample indicates the water is very hard and is a calcium bicarbonate type. Dissolved-solids concentration in the sample was 401 mg/L, and the irrigation classification was C2-S1.

Undifferentiated Sand and Gravel Aquifers

Undifferentiated sand and gravel deposits occur throughout the glacial deposits. These deposits are referred to as buried glaciofluvial aquifers because of the assumed origin in a fluvial environment. Test holes and wells commonly penetrated one or more of these aquifers at random depths within the glacial deposits. These aquifers are known to be as much as 98 feet (30 m) thick.

The thickness, lithology, and areal extent of each aquifer will control the amount of water in storage. The potential yields of wells developed in one of these aquifers may be as much as 250 gal/min (16 L/s); however, most of the aquifers are too small to support sustained yields of this magnitude.

Chemical analyses of 12 water samples from these aquifers indicate the water generally is very hard and is a sodium bicarbonate type; however, calcium was the dominant cation in three of the samples.

GROUND-WATER USE

The principal uses of ground water in Sheridan County are domestic, livestock, and municipal. Water-level measurements in selected observation wells will be continued as part of a statewide program to monitor ground-water resources. This program will provide data to governmental agencies responsible for managing the water resources of the State.

Rural Domestic and Livestock Use

Rural domestic and stock wells were found to be from 90 to 615 feet (27 to 187 m) deep and were cased with 2 to 4 inch (50 to 100 mm) pipe. Estimated consumption of water is summarized in the following table. With the exception of domestic consumption, it is difficult to estimate the proportion of the consumption derived from ground water.

Use	Individual requirements[1] (gallons per day)	Population	Estimated total consumption (gallons per day)
Domestic	100	[2] 2,268	226,800
Cattle	20	[3] 28,000	560,000
Hogs	3	[3] 1,500	4,500
Sheep	2	[3] 700	1,400
	Estimated total consumption		792,700

[1] *Murray, 1965.*
[2] *U.S. Bureau of the Census, 1971.*
[3] *U.S. Department of Agriculture Economics, Statistics, and Cooperative Service, North Dakota State Statistical Office, 1978.*

Public Supplies

All the communities in Sheridan County rely on ground-water sources for their water supplies. The cities of Goodrich and McClusky have distribution systems. Citizens in other communities depend on private wells for their supplies.

Goodrich

The city of Goodrich obtains its water supply from two wells completed in the Fox Hills aquifer. At the present time (1979), only the well at 146-074-08DCB2 is being used. The well reportedly is capable of producing about 60 gal/min (4 L/s). The mean annual use during 1977-79 was 48 acre-feet (59,000 m^3). A water sample from the municipal supply was a sodium bicarbonate type, soft, and contained 995 mg/L dissolved solids.

McClusky

The city of McClusky obtains its water supply from two wells at 146-077-11ADB completed in the Fox Hills aquifer. The wells reportedly are capable of producing about 120 gal/min (8 L/s). The total mean annual use during 1977-79 was 79 acre-feet (97,000 m^3). A water sample taken from the municipal supply was a sodium bicarbonate type, hard, and contained 1,200 mg/L of dissolved solids and 220 mg/L of chloride.

Irrigation Supplies

As of 1979, only two wells at 145-075-34D in the North Burleigh aquifer produced water for irrigation in Sheridan County. Each well is reportedly capable of producing about 750 gal/min (47 L/s) through a sprinkler system. The reported mean annual pumpage during 1977-79 was 83.5 acre-feet (103,000 m^3).

SUMMARY AND CONCLUSIONS

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

The Fox Hills aquifer system is the major bedrock aquifer system in Sheridan County. It underlies most of the county and in many areas is the only aquifer capable of producing sufficient quantities of water for domestic and stock use. The water-bearing beds in the aquifer system consist of very fine to medium-grained sandstone, which ranges in thickness from 1 to about 100 feet (0.03 to 30 m). Recharge to the aquifer system is from adjacent or overlying aquifers and from infiltration through the till. Discharge is dominantly to glacial-drift aquifers in the McClusky Canal area and north of the Sheyenne River valley. Potential yields to wells developed in the aquifer system are not expected to exceed 50 gal/min (3 L/s).

Chemical analyses of water samples from the Fox Hills aquifer system indicate the water is soft and generally a sodium bicarbonate type. Dissolved-solids concentrations in the samples ranged from 828 to 2,470 mg/L; the concentrations increased away from the potential recharge areas.

The Hell Creek-Fox Hills aquifer system underlies the glacial drift in approximately 60 percent of Sheridan County. The aquifer materials are very similar to those in the Fox Hills aquifer system, except the sandstone beds are fewer and thinner, and the sandstones are very fine to fine grained. Yields to wells developed in the aquifer system are expected to be much less than 50 gal/min (3 L/s).

Water from the Hell Creek-Fox Hills aquifer system generally is soft to moderately hard and is a sodium bicarbonate type. Dissolved-solids concentrations in 17 samples ranged from 531 to 2,650 mg/L.

Aquifers in the glacial drift have the greatest potential for ground-water development. Most aquifers are at least partly buried and occur in bedrock valleys. The aquifers are composed of sand and gravel and include the Lake Nettie aquifer system (lower and upper), Martin aquifer system, and the Butte, Painted Woods Creek, and North Burleigh aquifers. The areal extent, thickness, estimated amount of water in storage, and estimated potential yields to wells in these aquifers and aquifer systems are summarized in table 3.

TABLE 3. — Summary of data from glacial-drift aquifers

Aquifer or aquifer system	Approximate areal extent (square miles)	Average thickness (feet)	Estimated amount of water available from storage (acre-feet)	Estimated potential yield to wells (gallons per minute)
Lake Nettie				
Lower	26	116	290,000	50 to more than 500.
Upper	200	62	1,200,000	50 to more than 500.
Martin				
Deeper zone	23	46	(combined)	
Shallow zone	46	50	320,000	50 to 500.
Butte	9	54	47,000	50 to 250.
Painted Woods Creek	12	30	35,000	50 to 500.
North Burleigh	6	25	14,000	50 to 500.
Total			1,906,000	

SELECTED REFERENCES

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

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

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

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

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

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

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, 1972 [1973], Water-quality criteria, 1972: U.S. Environmental Protection Agency, Ecological Research Series, Report EPA R3-73-033, 594 p.

Randich, P. G., and Hatchett, J. L., 1966, Geology and ground-water resources of Burleigh County, North Dakota: North Dakota State Water Commission County Ground-Water Studies 3, part III and North Dakota Geological Survey Bulletin 42, part III, 91 p.

Simpson, H. E., 1929, Geology and ground-water resources of North Dakota: U.S. Geological Survey Water-Supply Paper 598, 312 p.

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

U.S. Department of Agriculture Economics, Statistics, and Cooperative Service, North Dakota State Statistical Office, 1978, North Dakota crop and livestock statistics, annual summary for 1977 and revisions for 1976: U.S. Department of Agriculture Statistics no. 42.

U.S. Environmental Data Service, 1973, Monthly normals of temperature, precipitation, and heating and cooling degree days 1941-70: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Climatography of the United States, no. 81 (by State) North Dakota.
U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Department of Agriculture Handbook 60, 160 p.

DEFINITIONS OF SELECTED TERMS

Aquifer – a body of rock that contains sufficient saturated permeable material to conduct ground water and to yield economically significant quantities of ground 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.

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 log and radioactivity log.

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.

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

Hydraulic conductivity – the rate of flow of water in gallons per day through a cross section of 1 square foot under unit hydraulic gradient.

Hydraulic gradient – the rate of change of pressure head per unit of distance of flow.

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

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

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

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 ground water will rise in a 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 –

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

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 water 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.

Surface load – a temporary load at land surface that tends to compress the aquifer.

Unconfined – used in this report as an adjective for an aquifer having a free water table, that is, water not confined under pressure beneath impermeable materials.