GROUND-WATER RESOURCES

of

RAMSEY COUNTY, NORTH DAKOTA

by

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U.S. Geological Survey

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CONTENTS

ILLUSTRATIONS

TABLES

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)	.001233	cubic hectometer (hm^3)
Foot	.3048	meter (m)
Foot per day (ft/d)	.3048	meter per day (m/d)
Foot per mile (ft/mi)	.18943	meter per kilometer (m/km)
Foot squared per day (ft^2/d)	.0929	meter squared per day (m^2/d)
Gallon	.003785	cubic meter (m^3)
Gallon per day (gal/d)	.003785	cubic meter per day (m^3/d)
Gallon per minute (gal/min)	.06309	liter per second (L/s)
Gallon per minute per foot [(gal/min)/ft]	.207	liter per second per meter [(L/s)/m]
Inch	25.4	millimeter (mm)
Mile	1.609	kilometer (km)
Million gallons (Mgal)	3,785	cubic meter (m^3)
Square mile (mi^2)	2.590	square kilometer (km^2)

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ABSTRACT

The quantity, quality, and movement of ground water in Ramsey County was determined by an evaluation of existing hydrologic data and data acquired through a program of test drilling and observation-well development. Ground water is obtainable from sand and gravel deposits in the glacial drift, from fractured shale in the upper 50 to 200 feet (15 to 61 meters) of the Pierre Formation, and from sand and(or) sandstone beds in the Dakota Group.

The major glacial-drift aquifers are the Spiritwood aquifer system and the Starkweather aquifer.

The Spiritwood aquifer system underlies an area of about 152 square miles (394 square kilometers) in southern and western Ramsey County. Properly constructed wells developed in the thicker parts of the aquifer system yield from 500 to 1,000 gallons per minute (32 to 63 liters per second). Dissolved-solids concentrations in water from the aquifer system ranged from 432 to 2,430 milligrams per liter.

The Starkweather aquifer underlies an area of about 13 square miles (34 square kilometers) in central Ramsey County. Well yields from this aquifer generally range from 50 to 250 gallons per minute (3 to 16 liters per second); however, in places yields of as much as 500 gallons per minute (32 liters per second) may be possible. Dissolved-solids concentrations in water from this aquifer ranged from 623 to 2,490 milligrams per liter.

The Spiritwood aquifer system and the Starkweather aquifer contain about 1.2 million acre-feet (1,500 cubic hectometers) of ground water available from storage.

The Pierre aquifer yields as much as 10 gallons per minute (0.63 liters per second) to wells. Dissolved-solids concentrations in water from the Pierre aquifer ranged from 330 to 9,800 milligrams per liter.

The maximum reported well yield from the Dakota aquifer is 280 gallons per minute (18 liters per second). Dissolved-solids concentrations in the water were 3,770 and 3,870 milligrams per liter. Depths to the top of the Dakota aquifer range from 1,150 to 1,450 feet (351 to 451 meters).

INTRODUCTION

The study of the geology and ground-water resources of Ramsey County (fig. 1) was requested and supported by the Ramsey County Board of Commissioners and was made under the statewide cooperative program of the U.S.

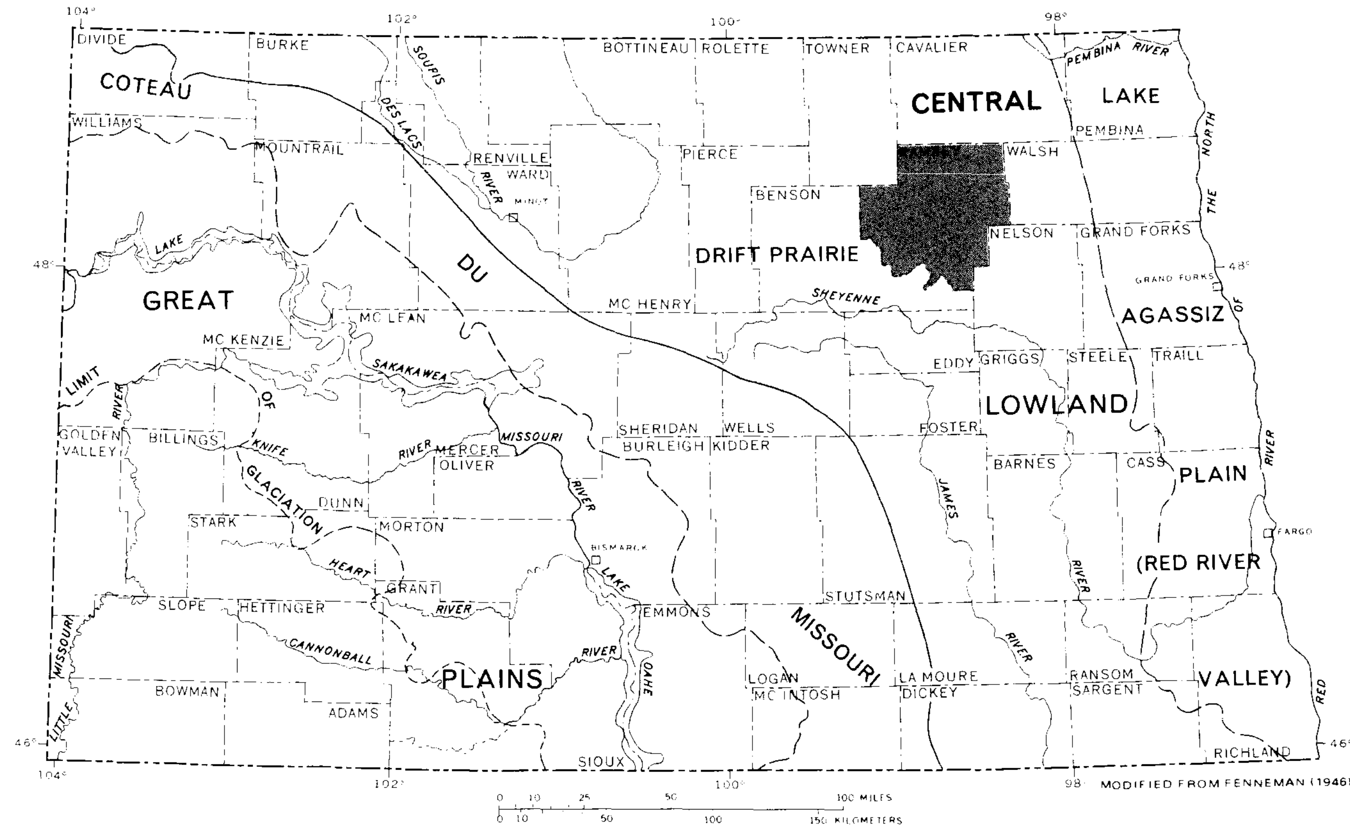


FIGURE 1.—Physiographic divisions in North Dakota and location of study area.

Geological Survey, the North Dakota State Water Commission, and the North Dakota Geological Survey.

The North Dakota Geological Survey mapped the geology of the county and will publish the results as part I of this series. The data used in this report, unless otherwise referenced, are in part II of this series (Hutchinson, 1977a).

Purpose and Scope

The purpose of the investigation was to determine the quantity and quality of ground water available for municipal, domestic, livestock, industrial, and irrigation uses. Specifically, the objectives were: (1) to describe the location, extent, and nature of the major aquifers in Ramsey County; (2) to evaluate the occurrence and movement of ground water, including the sources of recharge and discharge; (3) to estimate the quantities of ground water in storage; (4) to estimate the potential yields to wells; and (5) to determine the chemical quality of the ground water.

Many sources of data have been utilized in the preparation of this report. A well inventory provided data on depth, construction, and productivity of 902 private and public wells in the county. Drilling of 243 test holes supplied information on the thickness, lithology, and extent of the major aquifers. Observation wells constructed in 79 test holes supplied water-level data. One aquifer test was made to determine the transmissivity and storage coefficient of a major glacial-drift aquifer and to help establish a basis for estimating potential yields of other glacial-drift aquifers. Chemical analyses of water samples from 209 selected wells provided data on the quality of the ground water.

Location and Geography

Ramsey County has an area of 1,309 mi^2 (3,390 km^2) in northeastern North Dakota. It is located in the Drift Prairie section of the Central Lowland province (fig. 1).

The land surface is a rolling glacial plain that is interrupted in places by glacial moraines. Numerous prairie potholes, or sloughs, are present on the gently sloping terrain between the morainal ridges. Land-surface altitudes range from about 1,400 feet (430 m) above NGVD of 1929 along the shore of East Devils Lake to about 1,640 feet (500 m) at the crest of Devils Lake Mountain in sec. 35, T. 152 N., R. 62 W.

Most of the county lies within the Devils Lake basin, a large closed drainage basin that extends from the southeastern edge of the Turtle Mountains in Rolette County to a series of prominent hills south of Devils Lake. The principal drainages in the county are Mauvais Coulee (called Big Coulee below Lake Irvine), Starkweather Coulee, and Edmore Coulee. During periods of high runoff Big Coulee is the discharge stream for the lake chain including Sweetwater Lake, Dry Lake, Lake Alice, and Lake Irvine. Edmore and Starkweather

Coulees drain the central and eastern parts of the county. Discharge records from 1958 to 1974 show that surface-water flow in Edmore Coulee occurs less than 30 percent of the time. No data are available for Starkweather Coulee.

Climate

Ramsey County is in a region of temperate continental climate and has long rigorous winters and warm summers. According to the U.S. Environmental Data Service (1975), the mean annual temperature at Devils Lake is 38.7°F (3.7°C). January, with a mean temperature of 4.2°F (−15.4°C), is the coldest month and July, with a mean temperature of 68.9°F (20.5°C), is the warmest month.

The long-term normal precipitation at the city of Devils Lake (1941-70), is 17.15 inches (436 mm). However, for the period 1972-74, during which most of the hydrologic data for this investigation were collected, the mean annual precipitation was 15.05 inches (382 mm), or 2.10 inches (53 mm) less than the long-term normal. About three-fourths of the precipitation falls during the growing season April through September.

Population and Economy

The population of Ramsey County was 12,915 in 1970 (U.S. Bureau of the Census, 1971). Devils Lake was the most populous community in Ramsey County with 7,078 inhabitants and Edmore was second largest with 398. Churchs Ferry, Crary, Hampden, Lawton, and Starkweather had between 100 and 200 inhabitants. Bartlett and Brocket had fewer than 100 inhabitants.

Agriculture is the basis of the economy and the major source of income in Ramsey County. The principal crops are barley, wheat, oats, and hay. Livestock farming is practiced throughout the county and accounts for about 10 percent of farm income.

Previous Investigations

The earliest known report of ground-water data is by Underhill (1890), who described a deep artesian well at Devils Lake. Upham (1895) briefly reported on artesian ground water in Ramsey County as a part of a study of glacial Lake Agassiz. Simpson (1929) described the general geologic and ground-water conditions in Ramsey County (p. 189-196) as part of a statewide survey. Reports describing the occurrence of ground water near the cities of Devils Lake (Babcock, 1902; Paulson and Akin, 1964) and Lawton (Naplin, 1974) also are available.

Chemical-quality data of water from wells in Ramsey County are included in reports by Riffenburg (1929), Abbott and Voedisch (1938), Robinove and others (1958), Scott and Barker (1962), and North Dakota State Department of Health (1962 and 1964).

Location-Numbering System

The location-numbering system used in this report is based on a system of land survey 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 153-063-15ADC is in the SW¼SE¼NE¼ sec. 15, T. 153 N., R. 63 W. Consecutive terminal numerals are added if more than one well is recorded within a 10-acre (4-ha) tract.

Acknowledgments

The collection of data for this report was made possible by the cooperation of the Ramsey County Board of Commissioners and the residents of the county who contributed time and effort. Particular recognition is due Messrs. M. O. Lindvig, C. E. Naplin, R. W. Schmid, and L. D. Smith, Jr., of the North Dakota State Water Commission, who were largely responsible for the test drilling and aquifer-test data. G. O. Muri, chemist for the North Dakota State Water Commission, analyzed most of the water samples collected during the investigation. S. R. Moran, geologist with the North Dakota Geological Survey, provided valuable comments on the glacial geology of the area.

GENERAL CONCEPTS OF GROUND-WATER OCCURRENCE AND QUALITY

All of the ground water in Ramsey County 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 soil is held by capillarity and replaces water previously evaporated or transpired by plants. The excess water, if any, infiltrates downward to the zone of saturation where it becomes available to wells.

Ground water moves under the influence of gravity from areas of recharge to areas of discharge. Ground-water movement may be only a few feet per year. The rate of movement is governed by the hydraulic conductivity of the material through which the water moves and by the hydraulic gradient. Sand and gravel generally are highly conductive, and deposits of these materials commonly form aquifers. Fine-grained materials such as silt, clay, and shale usually have low conductivity.

The water level in an aquifer fluctuates in response to recharge to and discharge from the aquifer. Aquifers exposed at land surface are recharged each

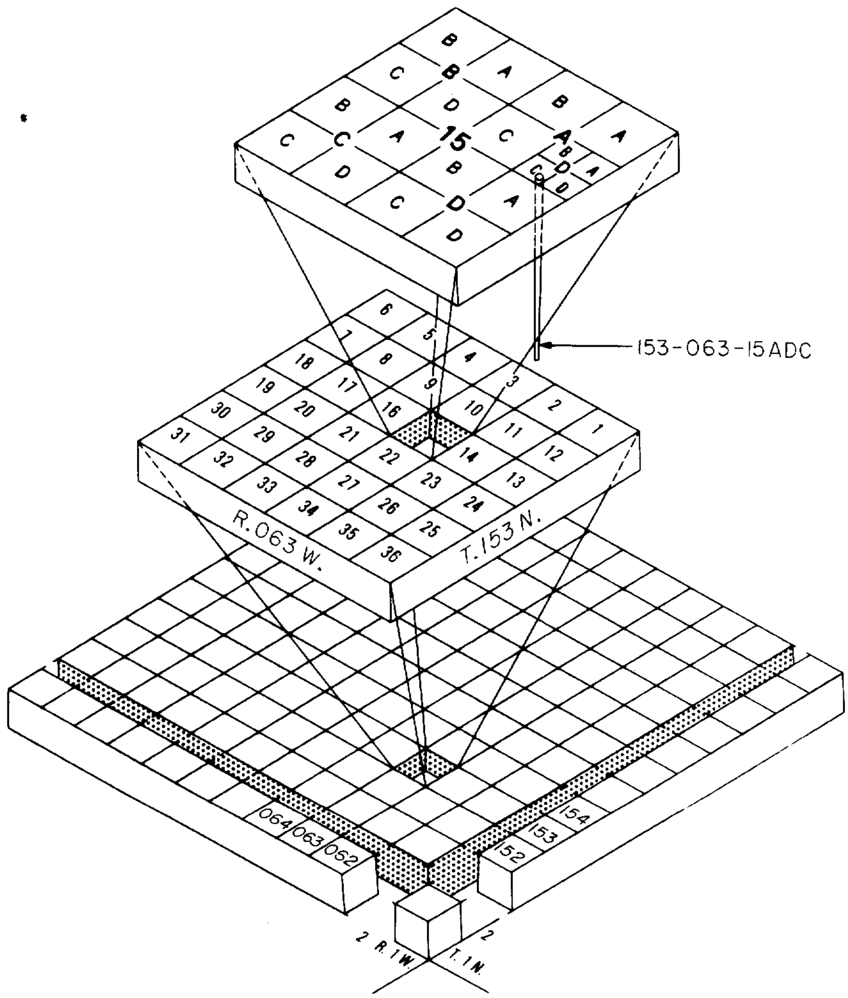


FIGURE 2.—Location-numbering system.

spring and early summer by direct infiltration of precipitation. Recharge to aquifers normally is sufficient to replace losses caused by natural processes and by pumping of wells, although long-term trends of several years may develop during which there are net gains or losses in storage. Aquifers that are confined by deposits of finer grained materials, such as clay or silt, are recharged by leakage from the finer grained materials. The rate of recharge may increase as heads in the confined aquifers are reduced by pumping. Head declines may continue, however, for several years before sufficient recharge is induced to balance the rate of withdrawal. In some cases this balance may never be achieved without a curtailment of withdrawals.

Ground water contains dissolved mineral matter in varying amounts. Rain begins to dissolve mineral matter as it falls, and continues to dissolve mineral matter as the water infiltrates through the soil. The amount and kind of dissolved mineral matter in water depends upon the solubility, the pressure, temperature, and types of matter encountered, the length of time the water is in contact with the matter, the amount of carbon dioxide and soil acids in the water, and other factors. Water that has been underground a long time, or has traveled a long distance from the recharge area, generally is more highly mineralized than water that has been in transit for only a short time.

The suitability of water is determined largely by the kind and amount of dissolved matter. The source, the effects on usability, and the drinking-water limits recommended by the National Academy of Sciences-National Academy of Engineering (1972) for the major chemical constituents in water are given in table 1.

In this report numerous references are made to ground-water types, such as sodium bicarbonate type, calcium bicarbonate type, etc. These types represent the predominant cation (sodium, calcium, or magnesium) and anion (bicarbonate, sulfate, or chloride) in the water, expressed in milliequivalents per liter (meq/L).

The hardness of water determines its usefulness for some industries. Hardness does not seriously affect the use of water for most purposes, but it does increase the consumption of soap. Hardness removal by a softening process increases suitability for domestic, laundry, and industrial purposes. The classifications of hardness used in this report are listed below:

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

Two indices of the suitability of water for irrigation are 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

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. Man-made sources: well casings, pumps, and storage tanks.	If more than 100 ug/L[1] iron is present, it will precipitate when exposed to air; causes turbidity, stains plumbing fixtures, laundry, and cooking utensils, and imparts tastes and colors to food and drinks. More than 200 ug/L is objectionable for most industrial uses.	300 ug/L
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
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[2] 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 200 ug/L may damage some plants.	
Bicarbonate (HCO_3)	Limestone and 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. Maximum limit for Ramsey County is 2.4 mg/L.	Recommended maximum limits depend on average of maximum daily air temperatures. Maximum limits range from 1.4 mg/L at 32°C to 2.4 mg/L at 10°C.
Nitrate (NO_3)	Organic matter, fertilizers, and sewage.	More than 100 mg/L may cause a bitter taste and may cause physiological distress. Concentrations in excess of 45 mg/L have been reported to cause methemoglobinemia 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]Micrograms per liter.
[2]Milligrams per liter.

the indices increase. For further information the reader is referred to "Diagnosis and Improvement of Saline and Alkali Soils" (U.S. Salinity Laboratory Staff, 1954).

GEOLOGIC UNITS AND THEIR HYDROLOGIC PROPERTIES

Geologic units that contain aquifers of economic importance in Ramsey County are: (1) the Dakota Group[1] of Early Cretaceous age, (2) the Pierre Formation of Late Cretaceous age, and (3) the glacial drift of Quaternary age (table 2).

Aquifers in the Bedrock

The only bedrock formations underlying Ramsey County that contain aquifers of importance are the undifferentiated sand and(or) sandstone beds in the Dakota Group and the Pierre Formation.

Dakota Aquifer

The term Dakota aquifer as used in this report includes all the undifferentiated sand and(or) sandstone beds in the Dakota Group. The Dakota aquifer underlies the entire county. Data from oil-test logs and from a few water-well logs indicate that the aquifer dips to the southwest. Depth to the top of the aquifer ranges from about 1,150 feet (351 m) in the northeastern part of the county to about 1,480 feet (451 m) in the southwestern part (fig. 3).

The aquifer is composed of fine to coarse shaly sandstone and quartzose sandstone that ranges in thickness from about 10 to 110 feet (3 to 34 m). Generally the basal part of the aquifer is coarser grained, better sorted, and potentially more productive than the upper part.

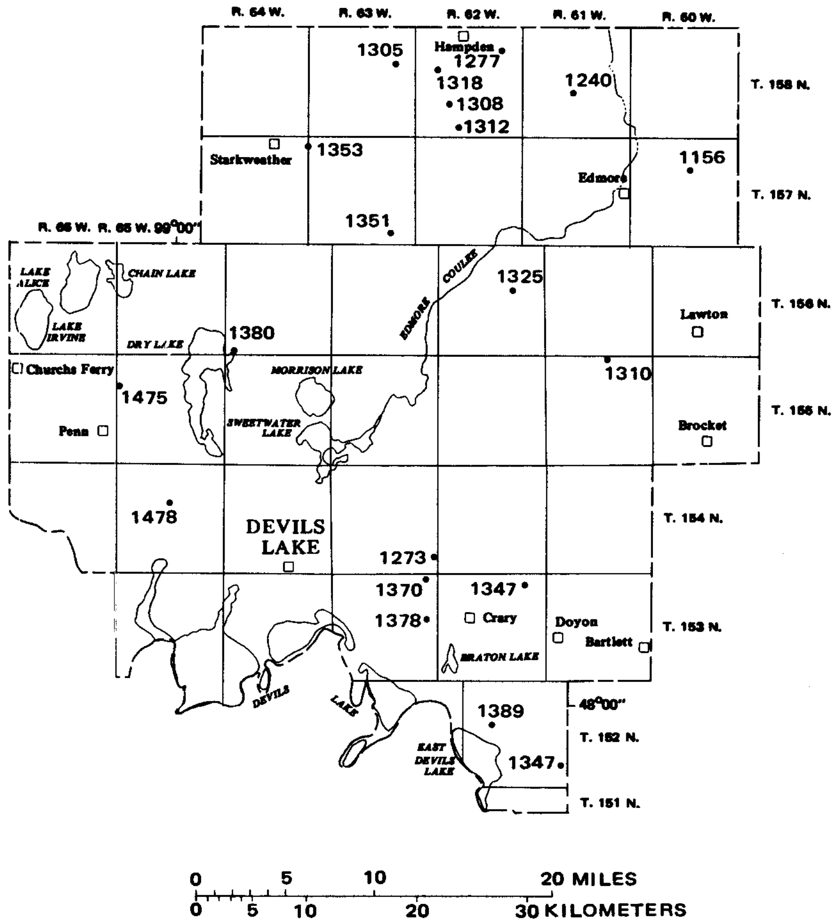
Devils Lake city wells 1, 2, 3, and 4 are the only wells known to tap the Dakota aquifer in Ramsey County. These wells are located in the SE¼ sec. 34, T. 154 N., R. 64 W. and range in depth from 1,496 to 1,530 feet (456 to 466 m). Paulson and Akin (1964) reported that city wells 1 and 2 had respective free flows of about 100 and 150 gal/min (6.3 and 9.5 L/s) in 1952. Because larger yields were required, all four city wells were equipped with pumps and wells 1 and 2 were reported to have respective pumping rates of 280 and 226 gal/min (18 and 14 L/s). After completion of four municipal wells drilled into the Warwick aquifer in northeastern Benson County (Randich, 1977), use of the Dakota wells was discontinued by the city.

Data from Paulson and Akin (1964, p. 207a and 207b) indicate that the water from the Dakota aquifer is soft and may be either a sodium sulfate-bicarbonate

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

TABLE 2. — Generalized lithology of the geologic units and their water-yielding characteristics

Period	Geologic unit	Lithology	Thickness (feet)	Water-yielding characteristics
Quaternary	Undifferentiated Holocene and Pleistocene deposits (glacial drift)	Unsorted mixture of clay, silt, sand, gravel, and boulders; stratified sand and gravel; lake silt and clay.	0-628	As much as 1,000 gal/min can be obtained from major sand and gravel aquifers provided (1) a sufficient thickness of water-bearing materials is present or (2) the deposits are pervious and are in hydrologic continuity with present streams or lakes to facilitate infiltration of surface water.
Cretaceous	Fox Hills Formation	Sandstone, very fine to fine, dark-yellowish-brown to medium-bluish-gray; siltstone, sandy, medium bluish-gray.	0-34	Small areal extent. Not known to be a source of water in the county.
	Pierre Formation	Shale, light-gray to black, partly fractured, siliceous.	0-600	Generally yields less than 10 gal/min from fractures in the upper 50 to 200 feet.
	Niobrara Formation	Shale and marlstone, light-gray to yellowish-brown.	200	Very low hydraulic conductivity. Not known to yield water.
	Carlile, Greenhorn, and Belle Fourche Formations, undifferentiated	Shale, siltstone, and marlstone; medium-gray to black, noncalcareous to calcareous.	500	Very low hydraulic conductivity. Not known to yield water.
	Dakota Group	Sandstone, fine-to coarse-grained, white to buff; gray to black shale.	20-200	Yields as much as 280 gal/min to individual wells.



EXPLANATION

1353 • OIL-AND GAS TEST HOLE—Number is depth to top of Dakota aquifer, in feet below land surface

FIGURE 3.—Depth to top of Dakota aquifer.

type or a sodium sulfate-chloride type. The following table (modified from Paulson and Akin, 1964, p. 207a and 207b) lists selected constituents and physical properties of water from the Dakota aquifer in three of the Devils Lake city wells. Scott and Barker (1962, p. 85) reported that the specific conductance of the water from Devils Lake well 4 was 6,100 umho/cm. The very high sodium and salinity hazards of the water preclude classification for irrigation.

Constituent or physical property	Location		
	154-064-34DCB1	154-064-34DCB2	154-064-34DCC
Iron (Fe) (ug/L)	60	—	—
Calcium (Ca) (mg/L)	12	12	8
Magnesium (Mg) (mg/L)	4.8	5	7.3
Sodium (Na) (mg/L)	1,400	1,370	1,407
Bicarbonate (HCO_3) (mg/L)	843	868	749
Sulfate (SO_4) (mg/L)	1,090	1,050	1,130
Chloride (Cl) (mg/L)	828	880	878
Fluoride (F) (mg/L)	4.5	6.0	5.0
Nitrate (NO_3) (mg/L)	4.0	1.4	1.4
Dissolved solids (mg/L)	3,770	3,770	3,870
Hardness (mg/L)	50	51	50
Sodium-adsorption ratio	86	84	87

Table modified from Paulson and Akin, 1964.

Pierre Aquifer

The Pierre Foundation underlies the glacial drift in the entire county except in the vicinity of test holes 154-063-12BBB, 12CCC, 156-063-11CDD, and 157-063-34ABA1 where the formation has been eroded and the Niobrara Formation subcrops.

The Pierre Formation consists, for the most part, of dark-gray to grayish-black siliceous shale. The formation has a maximum thickness of about 600 feet; however, only the upper 50 to 200 feet (15 to 61 m) is sufficiently fractured to act as an aquifer.

No aquifer tests were made on the Pierre aquifer in Ramsey County. However, its lithology and water-yielding properties are similar to those in adjacent counties where tests have been made.

Hutchinson (1977b) reported on two Pierre aquifer tests in adjacent Cavalier County. Analysis of the data from test well 159-059-35BAC, about 14 miles (23 km) northeast of Edmore (Ramsey County), indicated that the aquifer had a mean transmissivity of about 30 ft^2/d (2.8 m^2/d). Analysis of the data from test well 162-060-17DDD, about 20 miles (32 km) north of Edmore, indicated that the transmissivity of the aquifer was 11.8 ft^2/d (1.1 m^2/d). Aronow, Dennis, and Akin (1953) tested the aquifer at Michigan City, in adjacent Nelson County, and calculated that the transmissivity ranged from 66 to 121 ft^2/d (6.1 to 11.2 m^2/d). The storage coefficient computed from their test data was 0.00042.

The Pierre aquifer has low transmissivities, therefore most wells will yield a maximum of about 10 gal/min (0.63 L/s). However, a system of wells, properly spaced so there is a minimum of interference with each other, could be developed to provide larger quantities of water.

In order to assist in determining the best arrangement for wells in the aquifer, the following table has been prepared.

Theoretical drawdowns at various distances from a well pumping continuously at 10 gal/min (0.63 L/s) from the Pierre aquifer
(Transmissivity 20 ft^2/d (1.9 m^2/d); storage coefficient 0.0004)

Time since pumping started	Drawdown, in feet						
	Distance from pumping well, in feet						
	10	100	300	500	700	1,000	5,000
1 day	54	18	5	1	0.0	0.0	0.0
10 days	71	36	20	12	.0	.0	.0
100 days	89	54	37	29	.4	.0	.0
1 year	99	64	47	39	4	2	.1

Drawdown values in the table were computed by means of the Theis nonequilibrium formula (Theis, 1935). Where there are several wells pumping whose cones of influence overlap, the effect in any one well is the sum of the influences produced by all the wells. Also, the drawdown effects are directly proportional to the pumping rate, so the effect of pumping 5 gal/min (0.3 L/s) would be half that of pumping 10 gal/min (0.63 L/s), as listed in the table.

Drawdown tables for the Pierre aquifer must be used with caution. Accurate prediction of drawdown using the Theis (1935) nonequilibrium formula requires that the aquifer have a uniform distribution of hydraulic properties that would cause water to move symmetrically towards the discharging well. The uneven distribution of the water-yielding fractures in the Pierre can greatly distort the flow pattern and can cause greater drawdowns in some directions than in others.

Long-term drawdowns would not be as large as those shown in the table because there is seasonal recharge to the aquifer by precipitation. Also, water temporarily stored in the overlying glacial drift can move into the Pierre aquifer to some extent; this movement could be increased by lowering the water levels in the aquifer by pumping.

Water-level fluctuations in well 156-062-20BBB (fig. 4) indicate changes in storage resulting from recharge to and discharge from the aquifer. The hydrograph shows a gradual water-level rise during late summer and autumn 1973

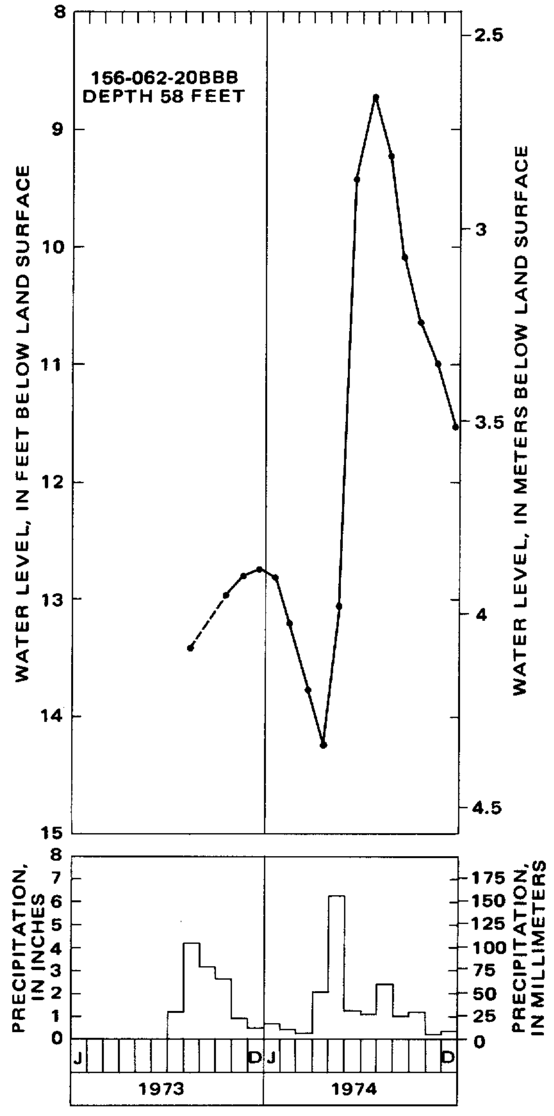


FIGURE 4.—Water-level fluctuations in the Pierre aquifer and precipitation at Edmore.

due to recharge from precipitation through the overlying glacial drift. The water-level decline during the winter months is mainly due to discharge exceeding recharge. Spring snowmelt and above normal rainfall caused recharge to greatly exceed discharge between April and July 1974. The decline in water level after July again shows the result of discharge from the aquifer during a period of decreased recharge.

Chemical analyses of 74 water samples indicate that the quality of the ground water in the Pierre aquifer varies greatly. The water is a sodium type with varying concentrations of bicarbonate, chloride, and sulfate. The water generally is hard to very hard.

Minimum, maximum, and mean values of selected constituents and physical properties of water from the Pierre aquifer are listed in the following table.

Constituent or physical property	Minimum	Maximum	Mean
Iron (Fe) (ug/L)	0	4,700	a/ 610
Manganese (Mn) (ug/L)	10	2,600	330
Calcium (Ca) (mg/L)	7.5	710	73
Magnesium (Mg) (mg/L)	3.3	760	33
Sodium (Na) (mg/L)	6	1,800	810
Bicarbonate (HCO_3) (mg/L)	330	990	680
Sulfate (SO_4) (mg/L)	1.2	6,400	490
Chloride (Cl) (mg/L)	0	3,000	770
Fluoride (F) (mg/L)	.1	.8	.4
Nitrate (NO_3) (mg/L)	0	170	b/ 8.1
Dissolved solids (mg/L)	330	9,800	2,570
Hardness (mg/L)	0	4,700	75
Sodium-adsorption ratio	.1	122	30
Specific conductance (umho/cm)	607	c/	—

a/ Mean value calculated using 67 samples.
b/ Mean value calculated using 71 samples.
c/ Maximum is unknown.

Twenty-four of the 67 samples analyzed for iron had concentrations greater than the 300 ug/L recommended limit. Five of the 74 samples had manganese concentrations greater than the 50 ug/L limit, and more than half of the samples had sulfate and chloride concentrations greater than the 250 mg/L limit. Two of the samples had nitrate greater than the 45 mg/L limit. Fluoride concentrations were less than the recommended limit in all samples. The irrigation classifications ranged from C2-S1 (low sodium hazard and medium salinity hazard) to greater than C4-S4 (very high sodium and salinity hazards).

Aquifers in the Glacial Drift

Aquifers in the glacial drift, particularly those of glaciofluvial origin, have the greatest potential for ground-water development in Ramsey County. The aquifers occur as (1) buried-valley deposits and (2) undifferentiated sand and gravel deposits associated with glacial till. For convenience of discussion and identification in this report and for future reference, aquifer names are continued from adjacent areas — Spiritwood and McVille (pl. 1, in pocket). Newly recognized aquifers are named after local geographic features — Starkweather. The order of discussion is based on economic importance, generally from most productive aquifer to least productive.

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

The potential well yields of the aquifers are shown on the ground-water availability map (pl. 1). The aquifers generally are lenticular in cross section and the largest yields usually are obtainable from the thickest parts. Wells penetrating long, narrow aquifers, such as those in buried valleys, often have lower yields than well tapping aquifers of comparable thickness but having larger areal extent.

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

Spiritwood Aquifer System

The Spiritwood aquifer system in Ramsey County is part of a large complex buried-valley aquifer system. The aquifer system was named by Huxel (1961, p. D179-D181) for its occurrence near the city of Spiritwood in Stutsman County. Subsequent studies (Kelly, 1966; Trapp, 1968; Downey, 1973; Downey and Armstrong, 1977; and Randich, 1977) indicated that the aquifer system underlies parts of Barnes, Eddy, Nelson, Griggs, and Benson Counties.

The Spiritwood aquifer system underlies an area of about 152 mi^2 (394 km^2) in southern and western Ramsey County. It ranges in width from about 2 to 9 miles (3 to 14 km) and extends northwestward from the south edge of T. 151 N., R. 62 W. to the northern edge of T. 156 N., R. 66 W., where it enters Towner

County (P. G. Randich, oral commun., 1978). Along the southern edge of Ramsey County the aquifer system underlies the Devils Lake chain, and in places along the western edge of the county it is contiguous with another segment of the Spiritwood present in adjacent Benson County.

The Spiritwood aquifer system in Ramsey County consists of sand and gravel deposited in one or more buried valleys, and beds or lenses of sand and gravel in the overlying till (figs. 5, 6, and 7). In the southeastern corner of Ramsey County the major part of the aquifer is confined to a single buried valley (fig. 5); however, in the west-central part of the county the aquifer occurs in two adjacent buried valley (figs. 6 and 7). Isolated lenses and beds of sand and gravel generally occur in the till overlying the buried-valley aquifers in the western and northern parts of the study area.

The aquifer consists of very coarse quartz sand that it intermixed and interbedded with gravel. Samples of the aquifer material generally contain abundant lignite fragments and locally are composed largely of shale pebbles.

The aquifer has a maximum aggregate thickness of 336 feet (102 m) and a mean aggregate thickness of 68 feet (21 m).

An aquifer test was conducted by the U.S. Geological Survey on the Spiritwood aquifer system at Camp Grafton in June 1943. The test site was located in sec. 19, T. 153 N., R. 64 W. The production well, 153-064-19AAB2, penetrated 112 feet (34.1 m) of sand and gravel, but the five observation wells used in the tests only penetrated the upper 5 to 45 feet (2 to 14 m) of the material.

The production well was pumped at a constant rate of 83 gal/min (5.2 L/s) for 40 hours. A recovery test was made for 60 hours after the pump was turned off. A transmissivity of about 7,400 ft^2/d (690 m^2/d) and a storage coefficient of 0.0002 was computed from the data by A. L. Greenlee (written commun., July 1943).

An aquifer test was made in the Spiritwood aquifer system during October 1974 as part of this investigation. The test site was on the east shore of Sixmile Bay, 7 miles (11 km) west of the city of Devils Lake. A 12-inch (305-mm) diameter production well (153-065-09BBA3), with 8-inch (203-mm) diameter telescoping 25-slot screen set from 74 to 113 feet (23 to 34.4 m), was pumped at a rate of about 407 gal/min (26 L/s) for a period of 75 hours. Drawdown in the pumped well was about 32 feet (10 m) and the specific capacity of the well was 12.7 (gal/min)/ft [2.63 (L/s)/m] of drawdown. Water-level measurements were made in 24 observation wells during the test. The observation wells were located at distances ranging from 151 to 36,000 feet (46 to 11,000 m) from the production well.

Based on data from the test, the Spiritwood aquifer system at this site had a transmissivity of 5,000 ft^2/d (465 m^2/d) and a storage coefficient of 0.0004 (R. W. Schmid, written commun., March 11, 1975).

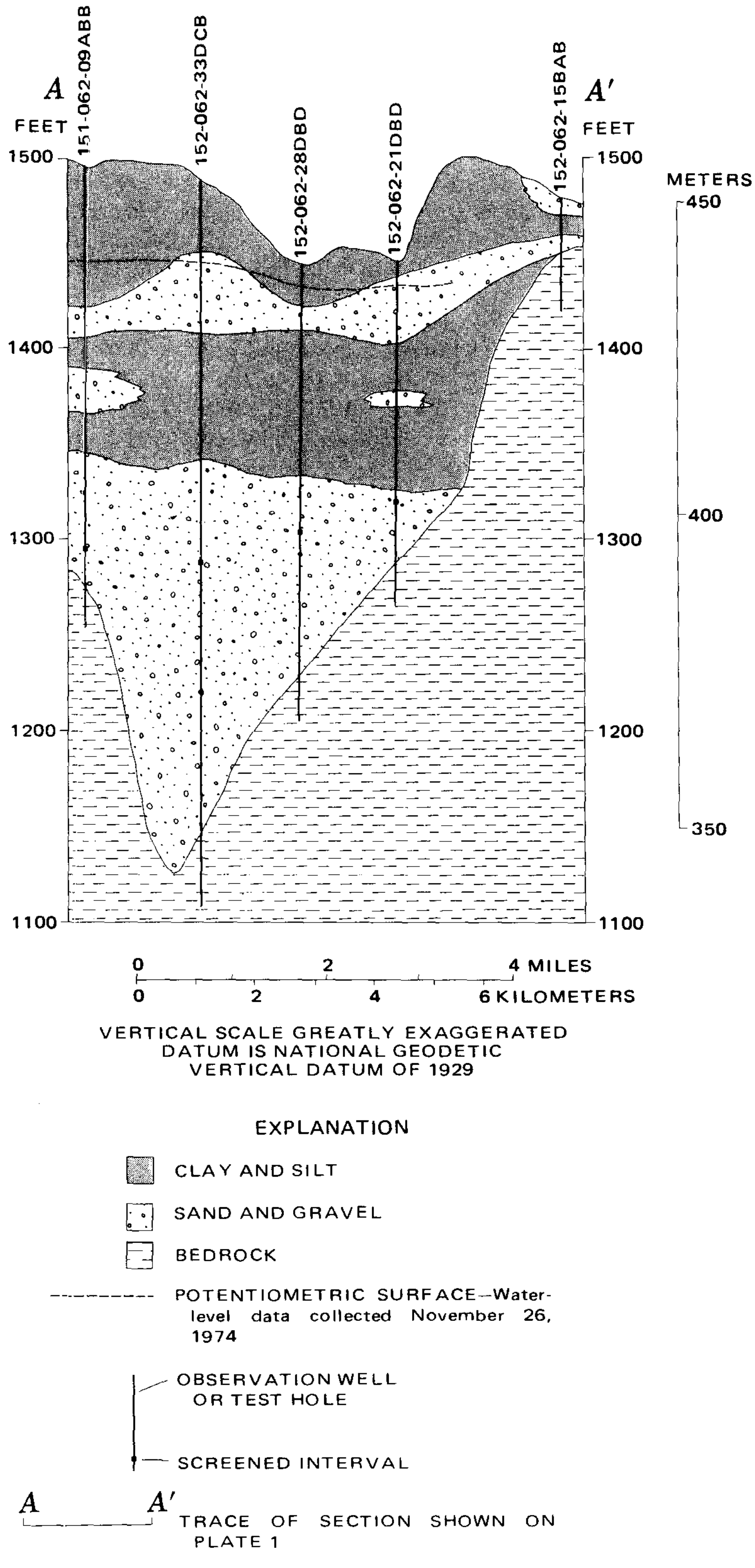


FIGURE 5.—Geohydrologic section in Spiritwood aquifer system.

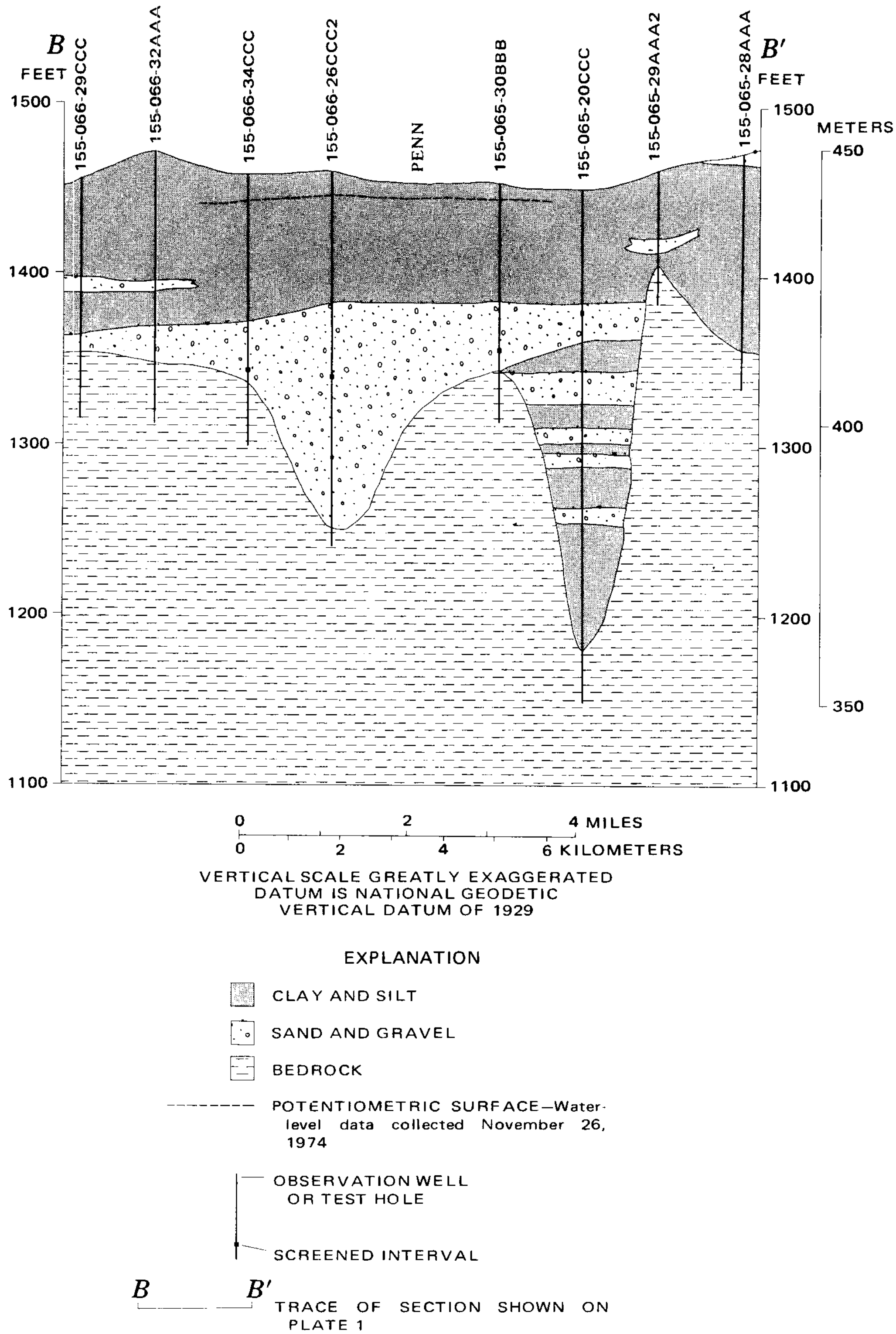


FIGURE 6.—Geohydrologic section in Spiritwood aquifer system.

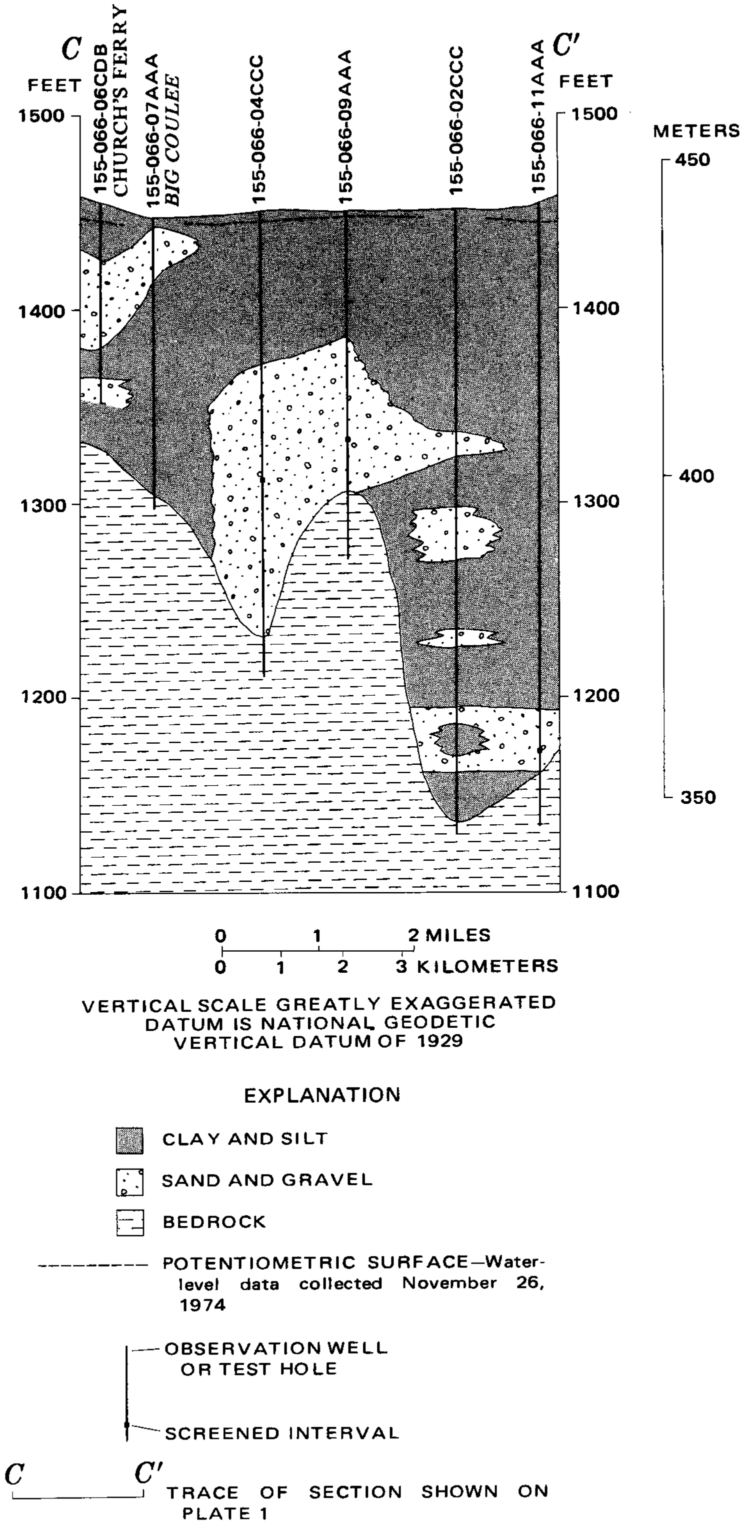


FIGURE 7.—Geohydrologic section in Spiritwood aquifer system.

In order to assist in determining the best arrangement for wells in the aquifer, the following table has been prepared.

Theoretical drawdowns at various distances from a well pumping continuously at 100 gal/min (6.3 L/s) from the Spiritwood aquifer system near Devils Lake (Transmissivity 5,000 ft^2/d (465 m^2/d); storage coefficient 0.0004)

Time since pumping started	Drawdown, in feet — Distance from pumping well, in feet					
	10	100	300	500	700	1,000
1 day	4	2	2	1	1	1
10 days	4	3	2	2	2	2
100 days	5	4	3	3	3	2
1 year	6	4	4	3	3	3

Drawdown values are computed by means of the Theis nonequilibrium formula (Theis, 1935). Where there are several wells pumping whose cones of influence overlap, the effect in any one well is the sum of the influences produced by all the wells. Also, the drawdown effects are directly proportional to the pumping rate, so that the effect of pumping 500 gal/min (32 L/s) would be five times that of pumping 100 gal/min (6.3 L/s), as used to compute the table.

Drawdown tables for the Spiritwood aquifer system must be used with caution. Accurate prediction of drawdown using the Theis nonequilibrium formula requires that the aquifer have a uniform distribution of hydraulic properties that would cause water to move symmetrically towards the discharging well. Few, if any aquifers are so uniform that hydraulic data can be extrapolated without detailed analysis.

Long-term drawdowns would not be as large as those shown in the table because of seasonal recharge to the aquifer system by precipitation. Also, recharge from the overlying glacial till would be increased as the water level in the aquifer system is lowered by pumping.

Well yields from the Spiritwood aquifer system depend mainly upon the thickness of the sand and gravel found at a specific site. Wells located along the central parts of the aquifer system have the greatest possibility of penetrating large thicknesses of sand and gravel. Individual wells located in these areas may yield as much as 1,000 gal/min (63 L/s). Yields decrease toward the aquifer system boundaries because of thinning of the sand and gravel deposits and the low hydraulic conductivity of the confining silt and clay deposits.

Recharge to the Spiritwood aquifer system is from infiltration of precipitation through the overlying and adjacent glacial till. Annual water-level fluctuations in the aquifer system generally are less than 4 feet (1 m). The highest water levels occur after a period of prolonged precipitation (figs. 8 and 9) or after a short intense precipitation event.

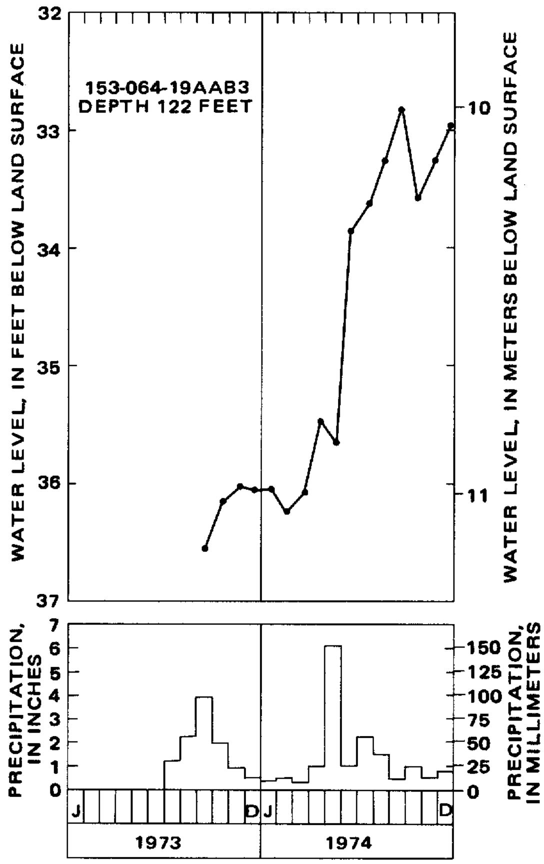


FIGURE 8.—Water-level fluctuations in the Spiritwood aquifer system and precipitation at Devils Lake.

The available data indicate that a ground-water divide probably occurs in the aquifer system in the southeastern quarter of T. 155 N., R. 66 W. Ground water moves northward and southeastward from the divide.

Discharge from the aquifer system southeast of the divide is by pumping, evapotranspiration, and movement into the lakes that form the Devils Lake chain. However, large extended ground-water withdrawals from the aquifer system could reverse the hydraulic gradient and the lakes would become a source of recharge to the aquifer system. Discharge from the northern part of the aquifer system is by pumping, evapotranspiration, and as leakage into the less permeable glacial till.

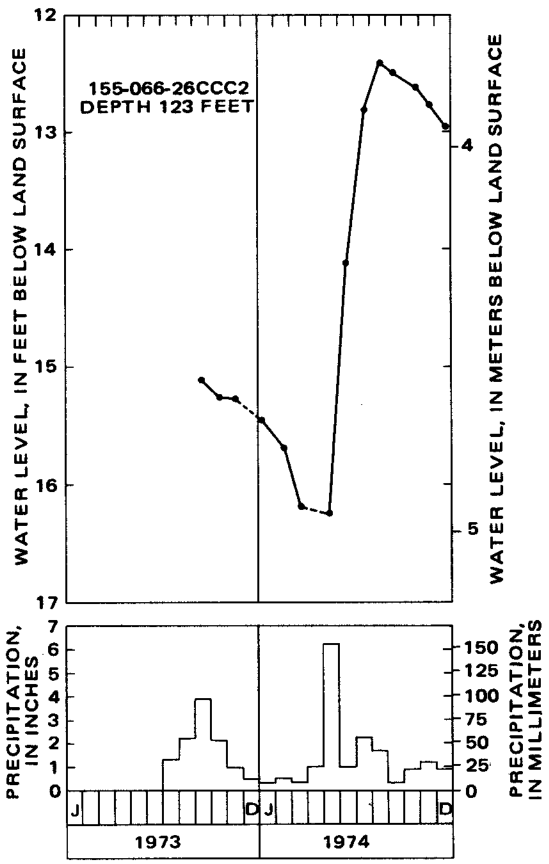


FIGURE 9.—Water-level fluctuations in the Spiritwood aquifer system and precipitation at Devils Lake.

Analyses of 53 water samples from wells in the buried-valley part of the aquifer system indicate that the quality of the water is not consistent throughout the extent of the aquifer. Sodium and calcium are the predominant cations and bicarbonate and sulfate are the predominant anions. The following table shows the minimum, maximum, and mean concentrations of selected constituents and physical properties of water from the system.

Constituent or physical property	Minimum	Maximum	Mean
Iron (Fe) (ug/L)	40	7,900	2,500
Manganese (Mn) (ug/L)	20	1,900	320
Calcium (Ca) (mg/L)	39	260	97
Magnesium (Mg) (mg/L)	18	100	50
Sodium (Na) (mg/L)	29	860	250
Bicarbonate (HCO_3) (mg/L)	360	740	580
Sulfate (SO_4) (mg/L)	49	1,100	460
Chloride (Cl) (mg/L)	5.2	1,000	82
Fluoride (F) (mg/L)	0	.7	.4
Nitrate (NO_3) (mg/L)	0	14	1.6
Dissolved solids (mg/L)	432	2,430	1,280
Hardness (mg/L)	170	1,820	640
Sodium-adsorption ratio	.6	25	8
Specific conductance (umho/cm)	696	4,400	1,890

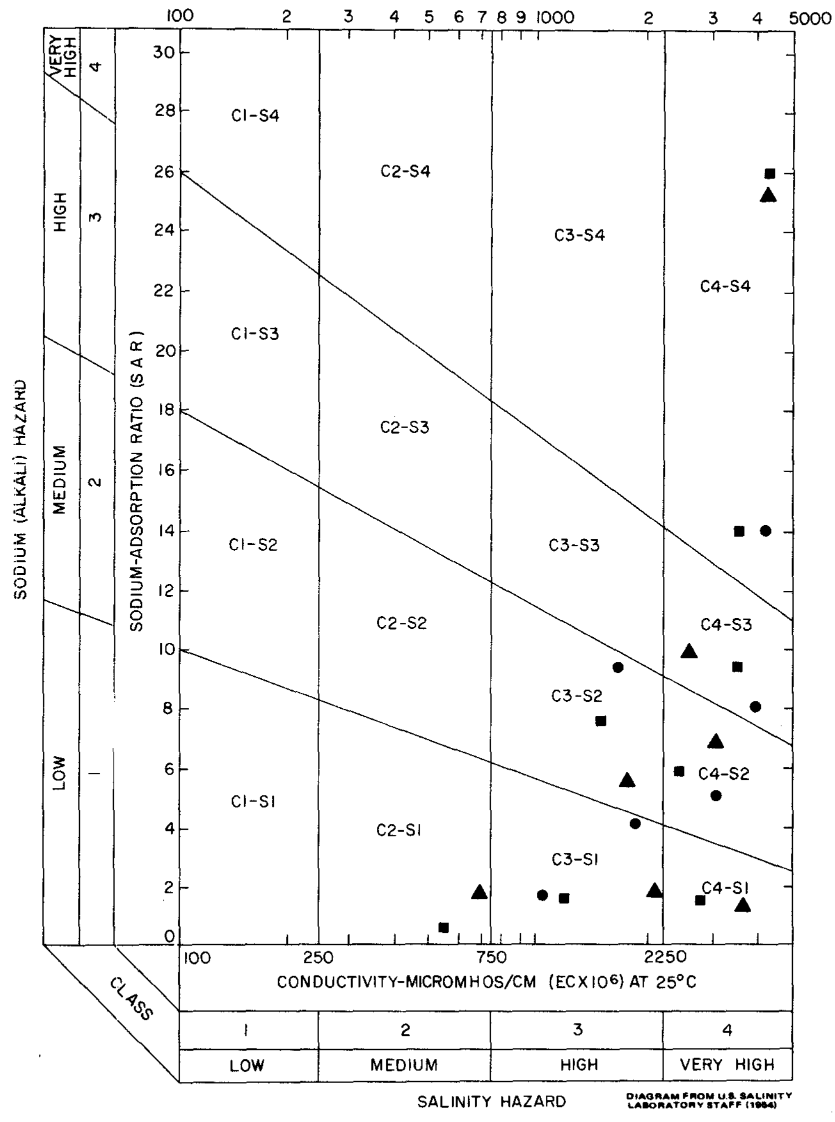
Iron concentrations exceeded the recommended limit of 300 ug/L in all but four samples, and manganese exceeded the 50 ug/L limit in all but two samples. All but six samples had sulfate concentrations exceeding the recommended limit of 250 mg/L. Only one sample had a chloride concentration greater than 250 mg/L, and fluoride and nitrate concentrations in all samples were less than the recommended limits. Irrigation indices for water in the buried-valley part of the Spiritwood aquifer system ranged from C2-S1 to C4-S4 (fig. 10).

Five water samples were collected from wells tapping the sand and gravel deposits in the till. The water was very hard. Two of the samples were calcium bicarbonate type water and three were calcium sulfate type. Dissolved solids ranged from 383 to 2,710 mg/L and sulfate ranged from 53 to 1,500 mg/L. Concentrations of iron generally were less than 300 ug/L and manganese generally was greater than 50 ug/L.

Based on an areal extent of about 152 mi^2 (394 km^2), a mean thickness of 68 feet (21 m), and an estimated specific yield of 15 percent, approximately 990,000 acre-feet (1,220 hm^3) of water is available from storage from the Spiritwood aquifer system.

Starkweather Aquifer

The Starkweather aquifer, named after the city of Starkweather in northwestern Ramsey County, occurs in a buried valley eroded into the Pierre and Niobrara Formations. The valley extends southeastward from the Ramsey-Towner county line in sec. 19, T. 158 N., R. 64 W., to the southwestern corner of sec. 13, T. 154 N., R. 63 W. The valley ranges in width from 0.5 to 1 mile (0.8 to 1.6 km) and has a maximum known depth of 628 feet (191 m). Test holes indicate that the northwestern part of the valley from the west edge of sec. 7, T.



EXPLANATION

▲ SPIRITWOOD AQUIFER SYSTEM

● STARKWEATHER AQUIFER

■ UNDIFFERENTIATED SAND AND GRAVEL AQUIFERS

FIGURE 10.—Classifications of selected water samples from glacial-drift aquifers for irrigation use.

157 N., R. 63 W. to the western county line is filled with glacial till containing isolated lenses or beds of sand and gravel. Test holes drilled south of section 7, however, penetrated significant thicknesses of sand and gravel. As presently defined, the aquifer has an areal extent of about 13 mi^2 (34 km^2). The configuration of the buried valley and its associated aquifer material is shown in figure 11.

The aquifer consists of sand and gravel that is composed largely of shale fragments derived from the Pierre Formation. The sand and gravel lenses generally are interbedded with silt and clay. Individual sand and gravel lenses and beds range from 3 to as much as 319 feet (0.9 to 97.2 m) in thickness. A maximum aggregate aquifer thickness of 432 feet (132 m) was penetrated in test hole 157-063-34ABA1. The mean aggregate thickness is 184 feet (56 m).

Estimated potential yields from the Starkweather aquifer range from 50 to 250 gal/min (3.2 to 16 L/s). Locally short-term yields of as much as 500 gal/min (32 L/s) may be possible.

The Starkweather aquifer is recharged by infiltration of precipitation through the overlying till. Water levels in the aquifer range from about 3 to 14 feet (0.9 to 4.3 m) below land surface. Annual water-level fluctuations in the aquifer generally are less than 3 feet (0.9 m). The highest water level occurs after periods of prolonged precipitation or after short, intense precipitation events. Ground-water movement in the aquifer is to the south at an average hydraulic gradient of about 1.3 ft/mi (0.25 m/km). Water is discharged from the aquifer by pumping and be seepage into less permeable glacial drift.

Analyses of seven water samples collected from the aquifer show that the quality of the water varies from well to well. Sodium was the predominant cation in the water and chloride and bicarbonate were the predominant anions. The minimum, maximum, and mean values of selected constituents and physical properties of the water from the Starkweather aquifer are shown in the following table.

Constituent or physical property	Minimum	Maximum	Mean
Iron (Fe) (ug/L)	80	1,100	460
Manganese (Mn) (ug/L)	240	2,700	1,030
Calcium (Ca) (mg/L)	66	240	150
Magnesium (Mg) (mg/L)	18	73	45
Sodium (Na) (mg/L)	64	660	350
Bicarbonate (HCO_3) (mg/L)	380	620	450
Sulfate (SO_4) (mg/L)	140	450	290
Chloride (Cl) (mg/L)	30	1,000	460
Fluoride (F) (mg/L)	.1	.2	.2
Nitrate (NO_3) (mg/L)	1	12	4.3
Dissolved solids (mg/L)	623	2,490	1,590
Hardness (mg/L)	240	900	550
Sodium-adsorption ratio	1	12	7
Specific conductance (umho/cm)	1,010	4,130	2,200

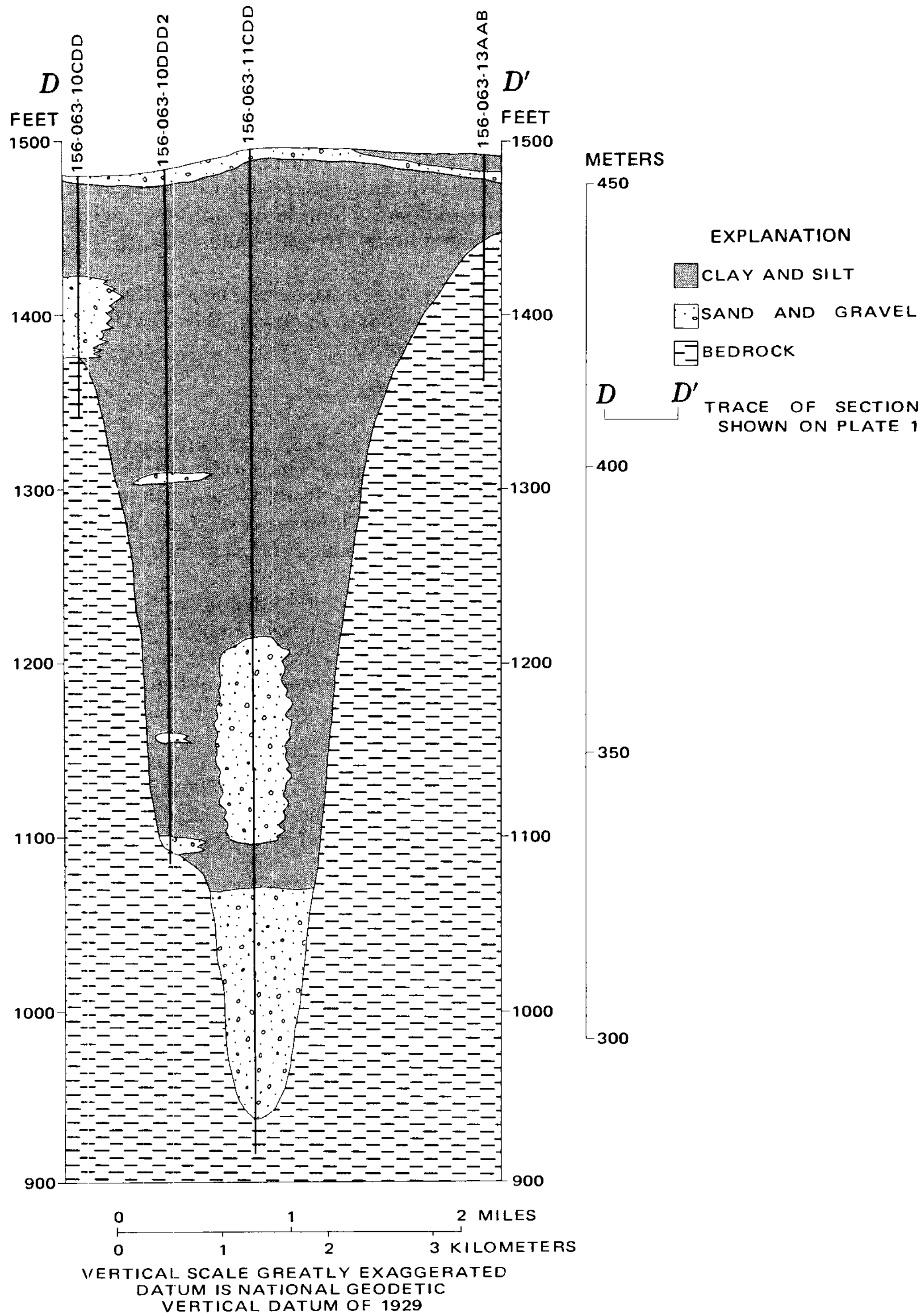


FIGURE 11.—Geohydrologic section in Starkweather aquifer.

All but two of the samples had iron concentrations that exceeded the recommended limit of 300 ug/L and manganese exceeded the 50 ug/L limit in all samples. Sodium exceeded the 250 mg/L limit in all but one sample, sulfate exceeded the 250 mg/L limit in all but two samples, and chloride exceeded the recommended limit in all but three samples. Fluoride and nitrate concentrations were lower than the recommended limits. Irrigation indices ranged from C3-S1 to C4-S4 (fig. 10).

Based on an areal extent of 13 mi^2 (34 km^2), a mean thickness of 184 feet (56 m), and an estimated specific yield of 15 percent, approximately 230,000 acre-feet (284 hm^3) of water is available from storage.

McVille Aquifer

The McVille aquifer was named by Downey (1973, p. 31) for its occurrence near the city of McVille in adjacent Nelson County. The aquifer enters Ramsey County in the southeastern quarter of T. 152 N., R. 62 W. and extends westward to intersect with the Spiritwood aquifer system in secs. 22 and 27, T. 152 N., R. 62 W. The aquifer occupies an area of about 1 mi^2 (2.6 km^2) in Ramsey County.

No data are available to indicate the thickness and lithology of the McVille aquifer in Ramsey County; however, a log of test hole 152-061-30BBB just across the county line in Nelson County (Downey, 1971, p. 244) shows that the aquifer consists of an upper sand bed and a lower sandy gravel bed. The beds have thicknesses of 26 and 63 feet (7.9 and 19 m), respectively, and are separated by about 50 feet (15 m) of sandy silty clay.

Based on data from Nelson County (Downey, 1971, 1973), it is estimated that the McVille aquifer in Ramsey County will yield from 50 to 500 gal/min (3.2 to 32 L/s) of sodium bicarbonate type water. The water probably will have dissolved-solids concentrations ranging from 600 to 700 mg/L.

Undifferentiated Sand and Gravel Aquifers

Undifferentiated sand and gravel deposits that were laid down in a glaciofluvial environment are scattered throughout the glacial till in Ramsey County. Test holes and wells drilled in the study area frequently penetrated one or more beds of sand and(or) gravel at depths from 1 to 190 feet (0.3 to 58 m) below land surface. Most of the sand and gravel deposits appear to be isolated lenses or pockets completely surrounded by till.

Saturated thicknesses of the undifferentiated sand and gravel deposits range from 6 to as much as 62 feet (2 to 19 m; pl. 1).

Wells tapping the undifferentiated sand and gravel deposits probably will yield from 1 to 50 gal/min (0.06 to 3.2 L/s). The thickness and lithology of some of the deposits suggest that greater yields may be obtainable; however, additional test drilling would be needed to determine the areal extent of the deposits.

Chemical analyses of 22 water samples obtained from wells developed in the undifferentiated sand and gravel deposits show that the quality of the water varies considerably from one deposit to another. The water generally is hard to very hard and is a sodium bicarbonate or sodium sulfate type. Dissolved solids in the samples ranged from 224 to 5,420 mg/L. Iron ranged from 0 to 6,500 ug/L and about half the samples had concentrations of less than 300 ug/L. Concentrations of manganese and sulfate generally exceeded the respective limits of 50 ug/L and 250 mg/L. Nitrate concentrations were less than the 45 mg/L limit in all but one sample. SAR values ranged from 0.2 to 25 and values of specific conductance ranged from 337 to 7,030 umho/cm. Irrigation indices ranged from C2-S1 to C4-S4 (fig. 10).

GROUND-WATER USE

Residents of Ramsey County are almost entirely dependent on ground water for their water supplies. About 58 percent of the residents obtain water through public-supply systems and 42 percent have self-supplied systems.

Domestic and Livestock Supplies

Most farm units have at least one well for self-supplied domestic and livestock uses, but no records are available to accurately determine the quantity of water used. The following table is an estimate of ground-water use in 1973.

Use	Individual requirements (gal/d)[a/]	Population	Estimated use (gal/d) (rounded)
Domestic	50	b/ 5,837	292,000
Cattle and calves	15	c/15,000	225,000
Milk cows	35	c/ 1,300	45,500
Hogs	2	c/ 2,100	4,200
Sheep	1.5	c/ 5,200	7,800
Poultry	.04	c/30,000	1,200
Total			575,700

a/Murray, 1965.
b/U.S. Bureau of the Census, 1971.
c/U.S. Department of Agriculture, 1971.

The quantities in the table may be somewhat higher than the amount of ground water actually used because some farms are vacant during the winter and some livestock are watered from ponds and sloughs.

Public Water Supplies

Crary

The city of Crary obtains its water supply from well 153-062-29CCC, about 2 miles (3 km) southwest of the city. The well, which was put into operation in August 1975, taps undifferentiated sand and gravel deposits between 32 and 64 feet (10 and 20 m) below land surface.

No data are available to indicate the amount of water being withdrawn by the city, but the well is reported to yield about 30 gal/min (1.9 L/s); thus it can be assumed that the maximum pumpage would be about 43,000 gal/d (163 m^3/d).

Devils Lake

The city of Devils Lake obtains its water supply from a group of wells in the Warwick aquifer in Benson County (Randich, 1977). The water is piped 17 miles (27 km) to the city. From July 1973 to June 1974 the city used about 356 Mgal (1,347,000 m^3). Daily pumpage ranged from 621,000 gallons (2,350 m^3) to 1.9 Mgal (7,200 m^3).

The Warwick aquifer probably is an adequate source of supply for the foreseeable future. Additional supplies could be obtained from the Spiritwood aquifer only a few miles south and southwest of the city, but the quality of water from the Spiritwood aquifer system is inferior to that in the Warwick aquifer. Dissolved-solids concentrations in water from the Spiritwood aquifer system range from 432 to 2,430 mg/L; whereas, concentrations of dissolved solids in water from the Warwick aquifer range from 222 to 1,010 mg/L (Randich, 1977, p. 45). Also, water from the Spiritwood aquifer system generally has a higher sulfate concentration than that from the Warwick aquifer.

Edmore

The city of Edmore in northeastern Ramsey County obtains its water supply from three wells located on the north side of the city. The wells reportedly are 21 to 24 feet (6.4 to 7.3 m) deep and produce water from the Pierre aquifer and from overlying undifferentiated silty sand and gravel deposits. The deposits are artificially recharged by surface water diverted from a small reservoir on Edmore Coulee. The water is diverted through an open trench to a point about 300 feet (91 m) from the city wells.

In 1973 the city officials estimated that the mean daily usage was about 20,000 gallons (76 m^3), or 7.3 Mgal/yr (27,600 m^3/yr).

In September 1973, 10 test holes were drilled near the Edmore city wells, but no aquifer significantly better than those presently being used by the city was located. The Starkweather aquifer, which is about 13 miles (21 km) east of Edmore could be considered as an alternate source of water. Another potential source of water is the Dakota aquifer, which occurs at a depth of about 1,200 feet (370 m) below land surface.

SUMMARY

Ground water in Ramsey County is obtainable from aquifers in rocks of Cretaceous age and from the glacial drift of Quaternary age. Aquifers of Cretaceous age occur in the Dakota Group and the Pierre Formation.

The Dakota aquifer, which underlies the entire area, is composed of sandstone and occurs at depths ranging from about 1,150 feet (351 m) to 1,480 feet (451 m) below land surface. Wells tapping the aquifer in the city of Devils Lake were reported to flow at rates of as much as 150 gal/min (9.5 L/s). Installation of pumps increased the yield to as much as 280 gal/min (18 L/s). Water from the aquifer is soft and is either a sodium sulfate-bicarbonate type or a sodium sulfate-chloride type; dissolved-solids concentrations were 3,770 and 3,870 mg/L.

The Pierre aquifer consists of hard fractured siliceous shale in the upper 50 to 200 feet (15 to 61 m) of the Pierre Formation. Maximum well yields from the Pierre aquifer are about 10 gal/min (0.63 L/s). The water generally is hard to very hard and is a sodium type with varying concentrations of bicarbonate, chloride, and sulfate. Dissolved-solids concentrations in water from the Pierre aquifer ranged from 330 to 9,800 mg/L.

The glacial-drift aquifers with the greatest potential for development in Ramsey County are the Spiritwood aquifer system and the Starkweather aquifer. The Spiritwood aquifer system is the largest potential source of water from the glacial drift. The system consists of sand and gravel deposited in one or more buried valleys, and beds or lenses of sand and gravel in the overlying till. Wells developed in the aquifer system should yield from 50 to 1,000 gal/min (3.2 to 63 L/s). The water may be either a sodium or calcium type with varying concentrations of bicarbonate and sulfate; the dissolved-solids concentrations ranged from 432 to 2,430 mg/L.

The Starkweather aquifer occurs in a buried valley eroded into the Pierre and Niobrara Formations. The aquifer consists of sand and gravel that is composed largely of shale fragments derived from the Pierre Formation. Wells developed in the aquifer should yield 50 to 500 gal/min (3.2 to 32 L/s). The water may be either a sodium chloride or sodium bicarbonate type. Dissolved-solids concentrations in water from the Starkweather aquifer ranged from 623 to 2,490 mg/L.

Hydrologic data for the glacial-drift aquifers are summarized in table 3.

Small quantities of water [1 to 50 gal/min (0.06 to 3.2 L/s)] are obtainable from the undifferentiated sand and gravel deposits associated with glacial till. Water from the undifferentiated sand and gravel deposits is hard to very hard and is either a sodium bicarbonate type or sodium sulfate type. Dissolved-solids concentrations ranged from 224 to 5,420 mg/L.

Practically all water used in Ramsey County is from ground-water sources.

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

	Spiritwood aquifer system	Starkweather aquifer	McVille aquifer
Areal extent (square miles)	152	13	1
Mean saturated thickness (feet)	68	184	—
Estimated water available from storage (acre-feet)	990,000	230,000	—
Predominant water types	Sodium bicarbonate, sodium sulfate, calcium bicarbonate, and calcium sulfate.	Sodium chloride, sodium bicarbonate.	Sodium bicarbonate.
General irrigation classification	C2-S1 to C4-S4.	C3-S1 to C4-S4.	—
Potential yield to individual wells (gal/min)	50 to 1,000	50 to 500	50 to 500

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DEFINITIONS OF SELECTED TERMS

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

Confining bed — a body of impermeable or distinctly less permeable material adjacent to one or more aquifers. In nature, the hydraulic conductivity of a confining bed may range from near zero to some value distinctly lower than that of the adjacent aquifer. This term replaces aquiclude, aquitard, and aquifuge.

Hydraulic conductivity — a term replacing field coefficient of permeability and expressed as feet per day or meters per day. The ease with which a fluid will pass through a porous material. This is determined by the size and shape of the pore spaces in the rock and their degree of interconnection. Hydraulic conductivity may also be expressed as cubic feet per day per square foot, gallons per day per square foot, or cubic meters per day per square meter. Hydraulic conductivity is measured at the prevailing water temperature.

National Geodetic Vertical Datum of 1929 (NGVD) — NGVD 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.

Potentiometric surface — the surface that represents the static head. It may be defined as the level to which water will rise in tightly cased wells. A water table is a potentiometric surface.

Sodium-adsorption ratio (SAR) — the sodium-adsorption ratio of water is defined as:

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

where ion concentrations are expressed in milliequivalents per liter. Experiments cited by the U.S. Department of Agriculture Salinity Laboratory (1954) show that SAR predicts reasonably well the degree to which irrigation water tends to enter into cation-exchange reactions in soil. High values for SAR imply a hazard of a sodium replacing adsorbed calcium and magnesium. This replacement is damaging to soil structure.

Specific capacity — the rate of discharge of water from a well divided by the drawdown of the water level, normally expressed as gallons per minute per foot of drawdown.

Specific yield — the ratio of the volume of water which a rock or soil, after being saturated, will yield by gravity to the volume of the rock or soil. Generally expressed as a percentage or decimal fraction.

Storage coefficient — the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an artesian aquifer the water derived from storage with decline in head comes mainly from compression of the aquifer and to a lesser extent from expansion of the water. In an unconfined, or water-table aquifer, the amount of water derived from the aquifer is from gravity drainage of the voids.

Subcrop — a subsurface outcrop that describes the areal limits of a truncated rock unit at a buried surface unconformity.

Transmissivity — the rate at which water, at the prevailing temperature, is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity is normally expressed in units of square feet per day but can be expressed as the number of gallons of water that will move in 1 day under a hydraulic gradient of 1 foot per foot through a vertical strip of aquifer 1 foot wide extending the full saturated height of the aquifer.

Zone of saturation — a subsurface zone in which all the interstices are filled with water under pressure greater than that of the atmosphere. Although the zone may contain gas-filled interstices or interstices filled with fluids other than water, it is still considered saturated. This zone is separated from the zone of aeration (above) by the water table.