GROUND-WATER RESOURCES

of

GRIGGS and STEELE COUNTIES, NORTH DAKOTA

by

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U.S. Geological Survey

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SELECTED FACTORS FOR CONVERTING ENGLISH UNITS TO THE INTERNATIONAL SYSTEM (SI) OF METRIC UNITS

A dual system of measurements — English units and the International System (SI) of metric units — is given in this report. SI is an organized system of units adopted by the Eleventh General Conference of Weights and Measures in 1960. Selected factors for converting English units to SI are given below.

Multiply English units	By	To obtain SI units
Acres	0.4047	hectares (ha)
	.004047	square kilometers (km^2)
Acre-feet	.001233	cubic hectometers (hm^3)
	1.233×10^{-6}	cubic kilometers (km^3)
Feet	.3048	meters (m)
Feet per day (ft/d)	.3048	meters per day (m/d)
Feet per mile (ft/mi)	.18943	meters per kilometer (m/km)
Feet squared per day (ft^2/d)	.0929	meters squared per day (m^2/d)
Gallons	.003785	cubic meters (m^3)
Gallons per day (gal/d)	.003785	cubic meters per day (m^3/d)
Gallons per minute (gal/min)	.06309	litres per second (l/s)
Gallons per minute per foot [(gal/min)/ft]	.207	liters per second per meter [(l/s)/m]
Inches	25.4	millimeters (mm)
Miles	1.609	kilometers (km)
	1,609	meters (m)
Million gallons per day (Mgal/d)	3,785	cubic meters per day (m^3/d)
Square miles (mi^2)	2.590	square kilometers (km^2)

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ABSTRACT

Griggs and Steele Counties, in east-central North Dakota, are underlain by bedrock of Ordovician, Jurassic, and Cretaceous ages. The Fall River and Lakota Formations of Cretaceous age form the Dakota aquifer. The fractured upper part of the Pierre Formation (shale), also of Cretaceous age, forms another bedrock aquifer. The Dakota aquifer, which consists mainly of interbedded shale and sandstone units, may yield as much as 500 gallons per minute (32 liters per second) of sodium sulfate water to wells at selected locations. The Pierre aquifer yields from 1 to 10 gallons per minute (0.06 to 0.63 liters per second) of sodium bicarbonate or sodium sulfate water to wells.

Four major glacial-drift aquifers are present in the study area. The Spiritwood aquifer system may supply as much as 1,500 gallons per minute (95 liters per second) of water to wells. Water samples contained dissolved-solids concentrations ranging from 244 to 9,800 milligrams per liter. The Galesburg aquifer will yield as much as 1,000 gallons per minute (63 liters per second) of water to wells. Water samples contained dissolved-solids concentrations ranging from 317 to 2,170 milligrams per liter. The McVille aquifer will yield as much as 500 gallons per minute (32 liters per second) to wells. Water samples contained dissolved-solids concentrations ranging from 449 to 2,200 milligrams per liter. The Elk Valley aquifer could yield 30 gallons per minute (2 liters per second) to wells. Water samples contained dissolved-solids concentrations ranging from 397 to 2,890 milligrams per liter.

Six communities in the project area use ground-water supplies. Rural water districts are being developed in the two-county area that will provide dependable ground-water supplies for many farms and small municipalities. The Spiritwood aquifer system and the McVille and Galesburg aquifers are capable of supplying the water needs of these districts and could also provide water for irrigation.

INTRODUCTION

The study of the ground-water resources of Griggs and Steele Counties (fig. 1) was made cooperatively by the U.S. Geological Survey, the North Dakota State Water Commission, the North Dakota Geological Survey, and the Griggs and Steele Counties Water Management Districts.

This investigation is one of a series of studies to obtain information on the ground-water resources of North Dakota. The purpose of the study was to evaluate the quantity and the quality of ground water for municipal, domestic, livestock, and irrigation uses. Accordingly, the report contains descriptions of

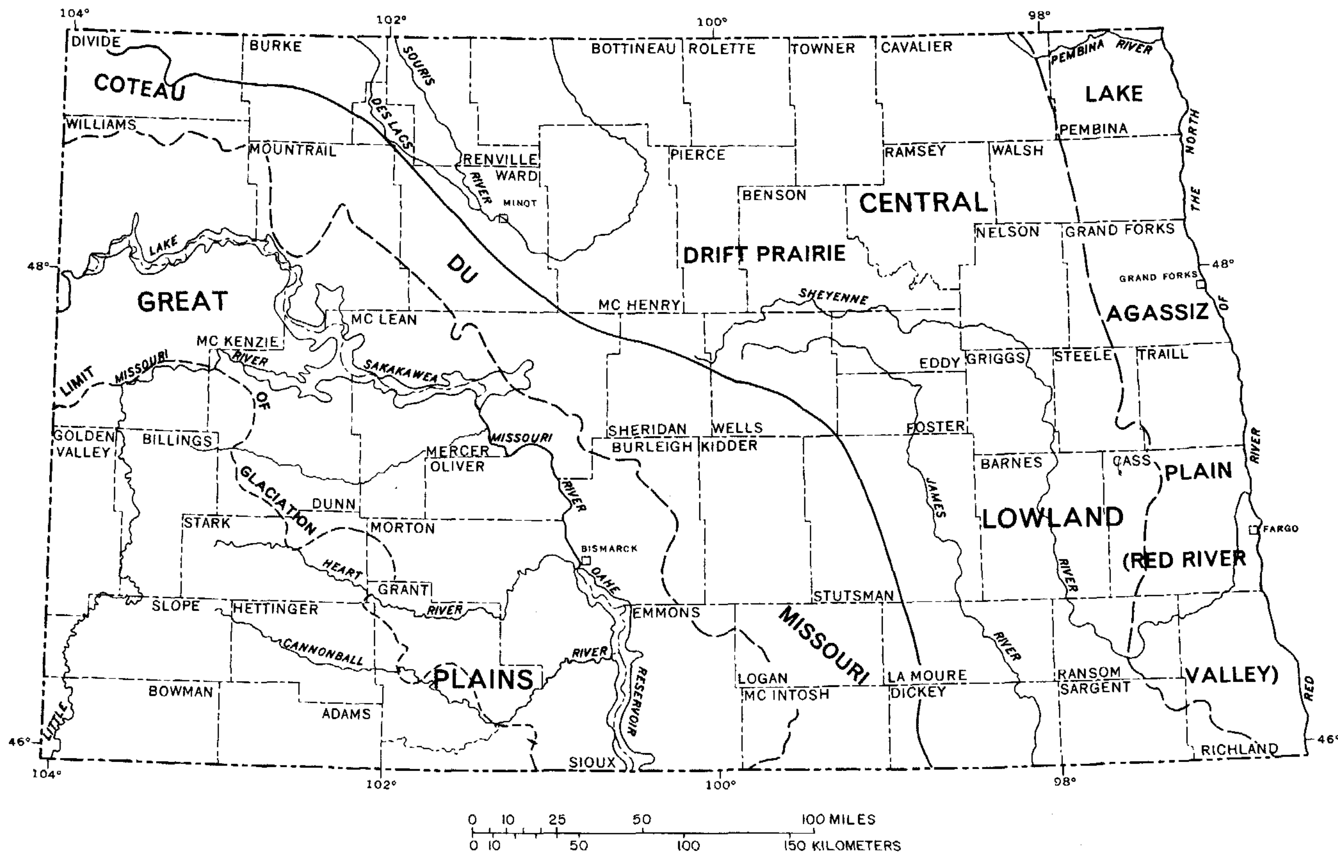


FIGURE 1.— Physiographic divisions in North Dakota and location of study area.

the location, areal extent, thickness, and nature of the major aquifers; estimates of the quantities of water stored in these aquifers; estimates of the potential yields of wells tapping the aquifers; and descriptions of the chemical quality of the ground water.

Many sources of data were utilized in the preparation of this report. A well inventory provided data on depth, construction, and productivity of the private and public wells in the counties. Test drilling supplied information on the thickness, extent, and hydrologic parameters of the major aquifers. Chemical analyses of water samples from selected wells were made to determine the quality of the ground water. The basic data collected during this study have been published as part II of the Griggs and Steele Counties ground-water study (Downey and others, 1973). The geology of both counties was studied by John P. Bluemle of the North Dakota Geological Survey and is published as part I of the series (Bluemle, 1975). This report, part III, is based largely on interpretation of the basic data contained in part II.

The stratigraphic nomenclature used in this report is that of the North Dakota Geological Survey and does not necessarily follow the usage of the U.S. Geological Survey.

Previous Investigations

The earliest report of geohydrologic interest was by Upham (1895), who reported on selected geological features in Griggs and Steele Counties as a part of a study of glacial Lake Agassiz. Simpson (1929) briefly described the ground-water conditions in Griggs County (p. 142-144) and Steele County (p. 228-230) as part of a statewide survey. Abbott and Voedisch (1938) listed chemical data from selected wells in both counties, and Dennis (1947 and 1948) reported on the geology and occurrence of ground water in the Sharon and Hope areas of Steele County. Adolphson (1962) reported on the occurrence of ground water in the Hatton area of Traill and Steele Counties, and Beeks (1967) reported on the occurrence of ground water in the Hatton area of Grand Forks, Traill, and Steele Counties. Selected data from these older reports have been utilized in the preparation of this report.

Acknowledgments

The authors express their appreciation to members of the Griggs and Steele Counties Water Management Districts and the County Boards of Commissioners, city officials of Cooperstown, Finley, and Hope, and to the many residents of both counties who contributed time and effort towards the completion of this study. Particular recognition is due M. O. Lindvig, R. W. Schmid, and C. E. Naplin of the North Dakota State Water Commission who were largely responsible for the test drilling and aquifer-test data. Appreciation also is expressed for the well logs furnished by C. C. Smith Drilling Co., the city of Luverne, Empire Drilling Co., Frederickson's, Inc., Burlington Northern, Inc., I. J.

Wilhite Co., Lako Drilling Co., Lehigh Portland Cement Co., Northern Resources, Inc., Russell Drilling Co., Simcox Oil Co., U.S. Bureau of Reclamation, and the U.S. Air Force.

Well-Numbering System

The numbering of wells, test holes, and other data points in this report is based upon a public lands survey system of the U.S. Bureau of Land Management. The first numeral of the numbering system 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 (fig. 2). 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 148-057-15ADD is in the SE¼SE¼NE¼ sec. 15, T. 148 N., R. 57 W. Consecutive terminal numerals are added if more than one well is recorded within a 10-acre (4-ha) tract. This numbering system is also used for the location of small areas.

Geography

Griggs and Steele Counties (fig. 1) have an area of about 1,430 mi^2 (3,704 km^2) and a 1970 population of 7,933 (U.S. Bureau of the Census, 1971). The economy of both counties is based upon agriculture — small grains are the main crops.

Both counties are located within the drainage system of the Red River of the North, which is a part of the larger Hudson Bay system. The major tributaries of the Red River that cross the area are the Sheyenne River in Griggs County and the Maple and Goose Rivers in Steele County.

The topography is varied. A broad, nearly flat plain formed by glacial Lake Agassiz characterizes the eastern part of Steele County; whereas, rolling prairie (Drift Prairie; fig. 1) dotted with numerous sloughs or prairie potholes characterizes the western part of Steele County and all of Griggs County.

Maximum topographic relief in the report area is about 755 feet (230 m). The highest altitude is about 1,730 feet (527 m) above msl (mean sea level) at 148-061-15BBD in northwestern Griggs County, and the lowest is about 975 feet (297 m) above msl where the Goose River leaves Steele County. Local relief rarely exceeds 100 ft/mi (19 m/km), and in parts of the Lake Agassiz plain it is less than 5 ft/mi (0.9 m/km).

Griggs and Steele Counties have a continental climate characterized by cold and snowy winters and warm summer days with cool nights. Major weather systems crossing the area bring a variety of weather in all seasons. According to the National Weather Service (1964-70), the mean annual temperature at Cooperstown is 39.3°F (4°C). Maximum temperatures during June, July, and August average about 81°F (27°C) and temperatures during the winter months

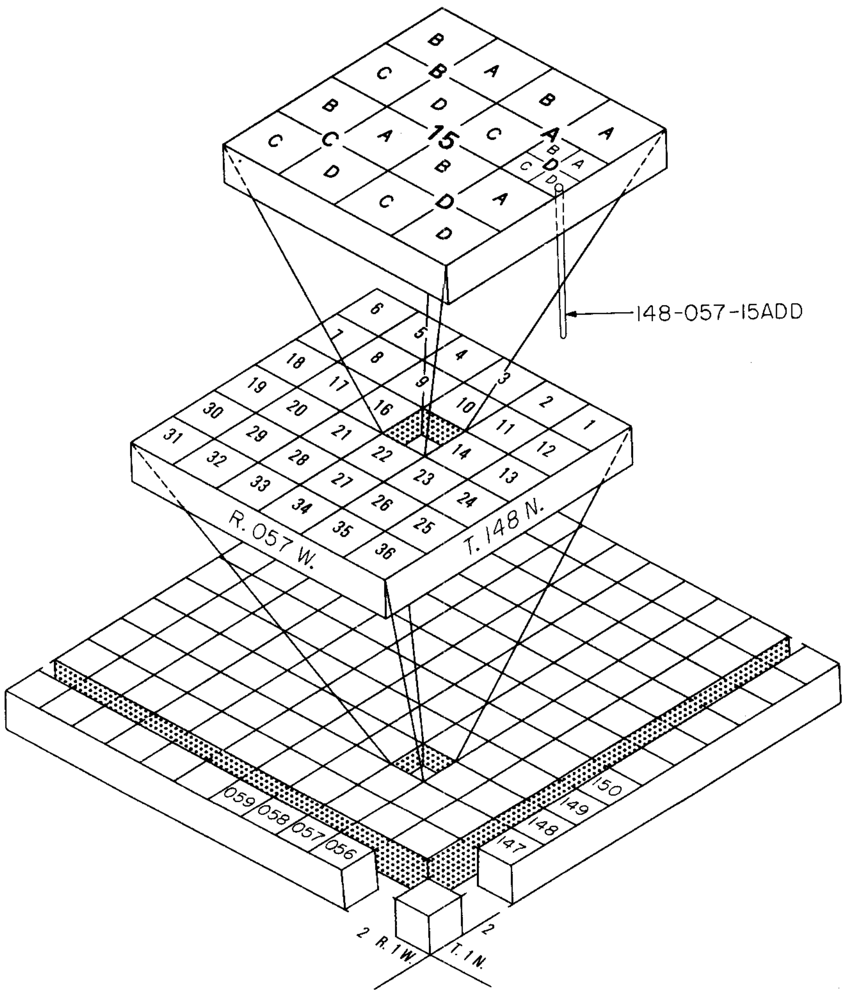


FIGURE 2.— System of numbering wells, test holes, and other data points.

average about 8°F (-13°C). The mean annual precipitation at Cooperstown is 18.23 inches (463 mm), of which about three-fourths falls as rain during the growing season.

AVAILABILITY AND QUALITY OF GROUND WATER

General Concepts

All ground water of economic importance in Griggs and Steele Counties is derived from precipitation, either directly or by percolation from nearby areas. 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 the ground. A large quantity of the water that enters the ground is held temporarily in the soil and is then returned to the atmosphere by evaporation or transpiration of plants. After the soil and plant requirements have been satisfied, the excess water, if any, percolates downward and enters the aquifer as recharge.

Ground water moves by gravity from areas of recharge to areas of discharge. Ground-water movement is generally very slow; it 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. Gravel and well-sorted sand generally are highly conductive, and deposits of these materials commonly form aquifers. Fine-grained materials such as silt and clay usually have low conductivity.

The water level in an aquifer fluctuates in response to recharge to and discharge from the aquifer. Under natural conditions, over a long period of time, the rate of discharge from an aquifer approximately equals the rate of recharge. When equilibrium exits for a long period of time, the amount of water in storage remains constant.

Withdrawal of water from an aquifer causes two or more of the following: (1) a decrease in the rate of natural discharge, (2) an increase in the rate of recharge, or (3) a reduction in the volume of water in storage. If ground-water withdrawal and natural discharge do not exceed recharge to an aquifer, the water level in the aquifer will approach equilibrium. If the discharge exceeds recharge, the excess will be withdrawn from storage. When water is taken from storage, the water level continues to decline as long as water is discharged from the aquifer.

The maximum rate of ground-water withdrawal that can be maintained indefinitely is related directly to the rate of recharge. However, recharge is regulated largely by climatic, hydrologic, and geologic controls and generally is difficult to quantify without large amounts of data.

In Griggs and Steele Counties the major rivers and streams along with the many small lakes and potholes are in hydraulic connection with aquifers. The aquifers either may receive recharge from these sources or may discharge into them, depending on the prevailing head relationships.

All ground water contains dissolved mineral matter in varying amounts. Rainfall begins to dissolve mineral matter from the atmosphere as it falls, and continues to dissolve mineral matter as the water percolates through the soil. The amount and kind of dissolved mineral matter in water depends upon many factors including the solubility and types of rocks encountered, temperature, pressure, the length of time the water is in contact with the rocks, and the amount of carbon dioxide in the water. 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 because of the more varied conditions encountered.

The suitability of water for various uses is determined largely by the kind and amount of dissolved matter. The chemical constituents, physical properties, and indices most likely to be of concern are iron, sulfate, nitrate, fluoride, total dissolved solids, hardness, temperature, odor, taste, specific conductance, sodium-adsorption ratio (SAR), trace elements, and percent sodium. The classifications of water hardness used in this report are shown in the following table:

Hardness range (in milligrams per liter of calcium carbonate)	Hardness description
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

The sources of the major chemical constituents, their effects on usability, and the limits recommended by the U.S. Public Health Service are given in table 1. Additional information regarding drinking water standards may be found in "Drinking Water Standards" published by the U.S. Public Health Service (1962).

The dissolved-solids concentration and conductivity of water can be described in terms of salinity. For this report, the following classifications of the relative freshness and salinity have been adopted from Robinove and others (1958).

Class	Dissolved solids (milligrams per liter)	Specific conductance (micromhos per centimeter at 25°C)
Fresh	Less than 1,000	Less than 1,400
Slightly saline	1,000 to 3,000	1,400 to 4,000
Moderately saline	3,000 to 10,000	4,000 to 14,000
Very saline	10,000 to 35,000	14,000 to 50,000
Brine	More than 35,000	More than 50,000

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

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

Constituents	Major source	Effects upon usability	U.S. Public Health Service recommended limits for drinking water[1]
Silica (SiO_2)	Feldspars, 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, pump parts, and storage tanks.	If more than 100 ug/l[2] iron is present, it will precipitate when exposed to air; causes turbidity, stains plumbing fixtures, laundry and cooking utensils, amd imparts tastes and colors to food and drinks. More than 200 ug/l is objectionable for most industrial uses.	300 ug/l
Manganese (Mn)	Similar to iron in its occurrence and chemical behavior in natural water, but is generally less abundant than iron.	More than 200 ug/l precipitates upon oxidation. Causes undesirable tastes and dark-brown or black stains on fabrics and porcelain fixtures. Most industrial users object to water containing more than 200 ug/l.	50 ug/l
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, calcite, aragonite, 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, dolomite, magnesite, and clay minerals.		
Sodium (Na)	Feldspars, clay minerals, and evaporites.	More than 50 mg/l[3] 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.	Many plants are damaged by concentrations of more than 2,000 ug/l.	
Bicarbonate (HCO_3) Carbonate (CO_3)	Limestone and dolomite.	Upon heating of water to the boiling point, bicarbonate is changed to steam, carbonate, and carbon dioxide. Carbonate combines with alkaline earths (principally calcium and magnesium) to form scale.	
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 limits depend on annual average of maximum daily air temperatures. Limits range from 0.6 mg/l at 32°C to 1.7 mg/l at 10°C.
Nitrate (NO_3)	Nitrogenous fertilizers, animal excrement, legumes, and plant debris.	More than 100 mg/l may cause a bitter taste and may cause physiological distress. Concentrations greatly in excess of 45 mg/l have been reported to cause methemoglobinemia in infants.	45 mg/l
Dissolved solids	Anything that is soluble.	More than 500 mg/l is not desirable if better water is available. Less than 300 mg/l is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	500 mg/l

[1]U.S. Public Health Service, 1962.
[2]Micrograms per liter.
[3]Milligrams per liter.

Two indices used to show the suitability of water for irrigation in this report are SAR and specific conductance. SAR is related to the sodium hazard; the specific conductance is related to the salinity hazard. The hazards increase as the numerical values of the indices increase. The reader is referred to the report "Diagnosis and Improvement of Saline and Alkali Soils," (U.S. Salinity Laboratory Staff, 1954) for further use of these indices. The irrigation classifications of water from several glacial-drift aquifers in Griggs and Steele Counties are shown in figure 3.

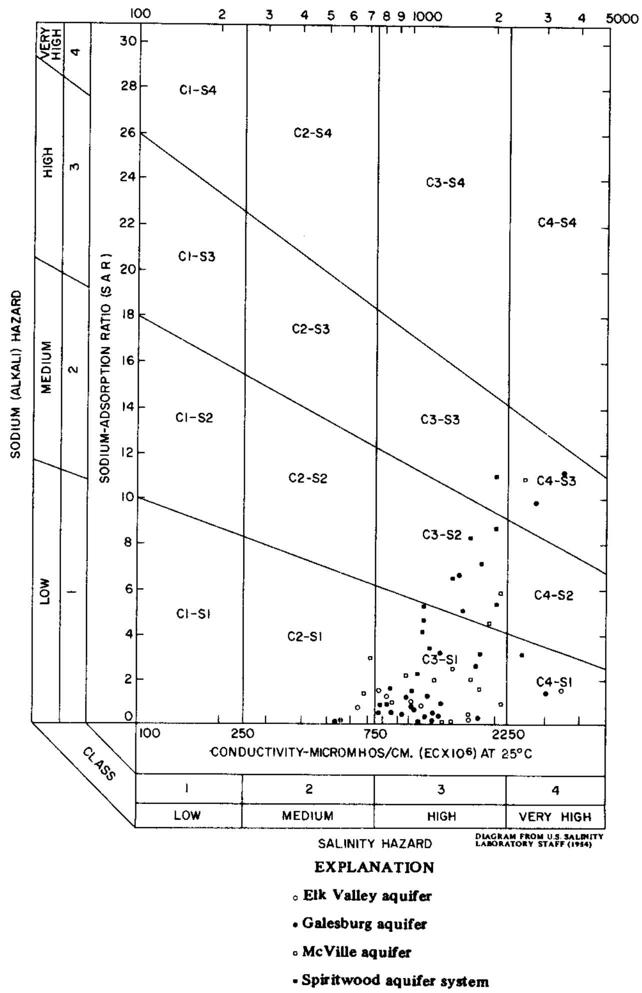


FIGURE 3.— Classifications of water from glacial-drift aquifers for irrigation use.

Ground Water in Bedrock

Rocks of Precambrian Age

Crystalline rocks of Precambrian age (table 2) occur at depths that range from about 1,000 feet (300 m) in southeastern Steele County to about 2,900 feet (880 m) in northwestern Griggs County. These rocks appear to contain only small amounts of very saline water in joints and fractures and it is doubtful that substantial quantities of water could be obtained from them.

Rocks of Ordovician Age

Rocks of Ordovician age (table 2) have been subdivided into the Winnipeg, Red River, and Stony Mountain Formations. The Winnipeg Formation generally consists of 20 to about 65 feet (6 to 20 m) of shale, sandstone, and shaly limestone overlying rocks of Precambrian age. Although the Winnipeg Formation was not identified in test holes drilled in Griggs and Steele Counties as part of the present study, test hole 151-061-32BC north of the study area in Nelson County penetrated 47 feet (14 m) of clayey shale at a depth of 2,864 to 2,911 feet (873 to 887 m) that may represent the formation in the project area (Downey, 1973). Test-hole data from adjacent Grand Forks County indicate that the Winnipeg Formation contains an aquifer of potential importance. Although its areal extent is poorly defined (Kelly and Paulson, 1970), the aquifer probably underlies a large area of Griggs and Steele Counties, also.

The Red River Formation overlies the Winnipeg Formation in the study area. This formation was described by Ballard (1963), who divided it into two units: a lower unit of fragmental microgranular dolomite and an upper unit of fragmental limestone, argillaceous dolomite, and minor amounts of anhydrite. The formation thickness is about 570 feet (174 m).

Few data are available concerning the water-yielding characteristics of the Red River Formation in Griggs and Steele Counties. The productivity of carbonate rocks, such as limestone and dolomite, is dependent upon the number and the continuity of fractures and solution cavities that are open to the well. Well yields will be high where a large number of extensive fractures and solution cavities are present, whereas solid limestone will yield little or no water.

The Stony Mountain Formation, which overlies the Red River Formation, consists of interbedded shale, dolomite, and limestone. Few data are available as to the thickness of the formation in Griggs and Steele Counties; however, in Nelson County to the north the formation ranges in thickness from 142 feet (43 m) in oil test 151-060-06AA to 92 feet (28 m) in oil test 149-059-15BD (Downey, 1973).

If water were obtained from Ordovician rocks in Griggs and Steele Counties, it probably would be very saline, with dissolved-solids concentrations exceeding 20,000 mg/l (Downey, 1973). The principal constituents are sodium and chloride.

TABLE 2.—Generalized geologic section and water-yielding characteristics of geologic units in Griggs and Steele Counties

System	Formation	Dominant lithology	Maximum thickness (feet)	Water-yielding characteristics
Quaternary	Glacial drift	Clay, silt, sand, and gravel.	550+	Yields as much as 1,500 gal/min to individual wells from thicker and more permeable sand and gravel deposits.
Cretaceous	Pierre Formation	Shale	200	Yields from 1 to 10 gal/min to individual wells from fractures. Low hydraulic conductivity except where fractured.
	Niobrara Formation Carlile Formation Greenhorn Formation Belle Fourche Formation Mowry Formation	Calcareous shale. Shale. Calcareous shale. Shale. Shale.	160 240 80 250 100	Very low hydraulic conductivity except for thin sandstone units which may yield small quantities of water.
	Newcastle Formation Skull Creek Formation Fall River Formation (Dakota Lakota Formation aquifer)	Sandstone and shale. Sandy shale. Sandstone, shale, and siltstone.	80 90 285	Yields from 250 to 500 gal/min to individual wells from thicker and more permeable sandstone units.
Jurassic	Unnamed	Red shale and siltstone.	100	Very low hydraulic conductivity except for thin interbedded sandstone units which may yield 1 to 10 gal/min to individual wells at selected locations.
Ordovician	Stony Mountain Formation Red River Formation Winnipeg Formation	Limestone and dolomite. Limestone and dolomite. Calcareous shale and sandstone.	140 570 65	Yields from limestone and dolomite units dependent upon number of joints, solution cavities, and fractures open to well. Locally, high yields are possible. Shale units are not water yielding. Yields from sandstone units unknown.
Precambrian	Unnamed	Granodiorite, granite, schist, and gneiss.	Unknown	Relatively impermeable.

Rocks of Jurassic Age

Rocks of Jurassic age (table 2) have not been identified in Griggs and Steele Counties, although geologic data from adjacent areas (Downey, 1973) suggest that they may be present. These rocks are composed predominantly of shale, and siltstone, but locally may contain thin lenses of sandstone that are capable of yielding 1 to 10 gal/min (0.06 to 0.63 l/s) of moderately saline water to individual wells.

Rocks of Cretaceous Age

Rocks of Cretaceous age contain two important aquifers in Griggs and Steele Counties; the Dakota and Pierre. The other formations of Cretaceous age do not yield significant amounts of water to wells.

Dakota aquifer.–The Dakota aquifer (table 2), consisting of the Lakota and Fall River Formations (or their equivalents), underlies much of the Great Plains in the United States and Canada. It is potentially the most productive bedrock aquifer in Griggs and Steele Counties. However, most wells presently (1974) tapping the aquifer in the study area are unused but are maintained on a standby basis. The water-bearing materials consist mainly of fine- to coarse-grained quartz sandstone interbedded with gray shale from about 580 to 865 feet (180 to 264 m) below land surface. The sandstone occurs in thin lenses, as shown by the log of well 145-054-27CDC (Downey and others, 1973).

Because of the variable nature of the sandstone lenses in the Dakota aquifer, extension of aquifer parameters from one area to another within the aquifer is of questionable value. Estimates based on sample examination and data available from adjacent counties (Downey, 1973; Kelly and Paulson, 1970) indicate a transmissivity of about 6,000 ft^2/d (557 m^2/d) and a storage coefficient of 0.0002 for the Dakota aquifer in Griggs and Steele Counties. Yields ranging from 250 to 500 gal/min (16 to 32 l/s) may be possible from individual wells tapping the thicker sandstone lenses.

Analyses of nine water samples from six wells tapping the Dakota aquifer in Griggs and Steele Counties are available (Downey and others, 1973). The samples had a dissolved-solids concentration of 2,960 to 5,190 mg/l with a median value of 3,800 mg/l. Chloride concentrations ranged from 581 to 1,510 mg/l with a median of 1,350 mg/l. The chloride concentration of water from the aquifer apparently increases from south to north with a large increase occurring about midway across the counties.

Little use is made of the water from the Dakota aquifer in Griggs and Steele Counties because it is saline and also because there generally is better quality water available at shallower depths.

Pierre aquifer.–The Pierre Formation (table 2) directly underlies the glacial drift or crops out in much of the project area. It generally consists of light-gray to black shale, marlstone, and claystone with yellowish to white bentonite layers in the lower part of the formation. The upper part of the Pierre Formation in Griggs and Steele Counties consists of a black fissile shale that contains fractures caused by glacial action. The fractured shale ranges in depth from 25 to 140 feet (8 to 43 m) below land surface and forms an aquifer that is a source of water for many farms in northeastern Griggs and northwestern Steele Counties.

A study of the hydraulic characteristics of the aquifer at Michigan in Nelson County was made by Aronow, Dennis, and Akin (1953). They reported transmissivities for the aquifer that ranged from about 66 to 121 ft^2/d (6.1 to 11.2 m^2/d) and averaged 95 ft^2/d (8.8 m^2/d). The storage coefficients computed from their test data averaged 0.00042. Similar values were obtained from short-term pumping tests on the Pierre aquifer near Fairdale in Walsh County (Downey, 1973).

Individual well yields from the Pierre aquifer range from less than 1 to 10 gal/min (0.06 to 0.63 l/s). However, yields greater than 5 gal/min (0.32 l/s) should not be expected in most areas of Griggs and Steele Counties.

Recharge to the Pierre aquifer is derived mainly from percolation through the overlying glacial drift or direct infiltration in outcrop areas. In areas where the fracture zones are in hydraulic connection with the glacial drift, water is able to move rather quickly into the shale and along the fractures toward areas of discharge. In such areas, water-level rises in the shale are closely related to periods of precipitation. Where the fracture zones are poorly developed, water moves very slowly through the shale from areas of recharge to areas of discharge. The amount of water in storage in the Pierre aquifer is related directly to the extent and thickness of the fracture zones.

Water from the Pierre aquifer is moderately hard to very hard and of a sodium bicarbonate or sodium sulfate type. Five samples had dissolved-solids concentrations ranging from 308 to 2,550 mg/l with a median value of 1,230 mg/l. The principal ions were sodium, calcium, bicarbonate, sulfate, and chloride. The sodium-adsorption ratio ranged from 0.8 to 36 with a median value of 6.5.

Ground Water in Glacial Drift

Griggs and Steele Counties are mantled by glacial drift, except along streams where it has been removed by postglacial erosion. The drift commonly is less than 100 feet (30 m) thick in much of the two-county area; the maximum thickness is more than 550 feet (167 m).

Glacial drift occurs in many types. Till, the first and most prevalent type, is a nonsorted mixture of clay, silt, sand, gravel, and boulders. Till was deposited directly from glaciers and ice sheets with little sorting by water action; its composition depends to a large extent upon the type of bedrock over which the glacier or ice sheet had moved.

The second type of glacial drift is glacial outwash, which includes delta deposits, ice-contact deposits, and many buried sand and gravel deposits. Outwash deposits normally are stratified and sorted according to grain size and are very permeable. Outwash deposits comprise all the major glacial-drift aquifers in Griggs and Steele Counties.

The third type of glacial drift — lake deposits — consists of clay, silt, and sand deposited in the proglacial lakes that existed at or near the edge of a glacier. The deposits of silt and clay in eastern Steele County are included in this type. Also included are beach deposits formed along the shores of the lakes.

Spiritwood Aquifer System

The largest glacial-drift aquifer in the two-county area, the Spiritwood aquifer system, is located in the western part of Griggs County and extends from T. 144 N., R. 58 W. northwestward through T. 148 N., R. 61 W. (pl. 1, in pocket). The system, is composed of the Spiritwood aquifer of Huxel (1961), the New Rockford aquifer of Trapp (1968), and several small unnamed tributary aquifers. The system, which underlies about 350 mi^2 (900 km^2) in Griggs County, extends into Barnes County on the south and Eddy, Foster, and Nelson Counties on the west and north.

The Spiritwood aquifer system consists of lenticular deposits of sand and gravel interbedded with clay and silt. It ranges in thickness from less than 1 foot (0.3 m) at the edge to more than 550 feet (170 m). However, the thickness of the saturated sand and gravel averages about 100 feet (30 m). The deeper aquifer materials were deposited in preexisting bedrock channels (pl. 2, in pocket, and fig. 4[1]) by flowing water. After the channels were filled, deposition continued until the valleys were filled. Locally, low divides between the valleys also were buried.

A 100-hour aquifer test was made on the Spiritwood aquifer system near Binford, N. Dak. The pumping rate for the test was 1,515 gal/min (95.6 l/s). Analysis of the data (R. W. Schmid, North Dakota State Water Commission, written commun., 1972), using methods developed by Theis (1935), indicates a transmissivity of about 4,500 ft^2/d (418 m^2/d) and a storage coefficient of about 0.02.

The yields from wells located in the Spiritwood aquifer system depend mainly upon the thickness of sand and gravel found at the well location. Wells located along the central parts of the aquifer offer the greatest possibility of penetrating large thicknesses of sand and gravel, and individual wells located in these areas may yield more than 1,000 gal/min (63 l/s). The aquifer-test data suggest that individual well yields of about 1,500 gal/min (95 l/s) may be obtained at selected locations in the aquifer. Yields decrease toward the aquifer boundaries due to the thinning of the sand and gravel and the low hydraulic conductivity of the confining clay, silt, and till deposits.

Because of the facies changes within the Spiritwood aquifer system, extension of yield data from one area to another within the aquifer is somewhat tenuous, but correlations made where conditions are similar usually are valid.

[1] Locations of sections are shown on plate 1.

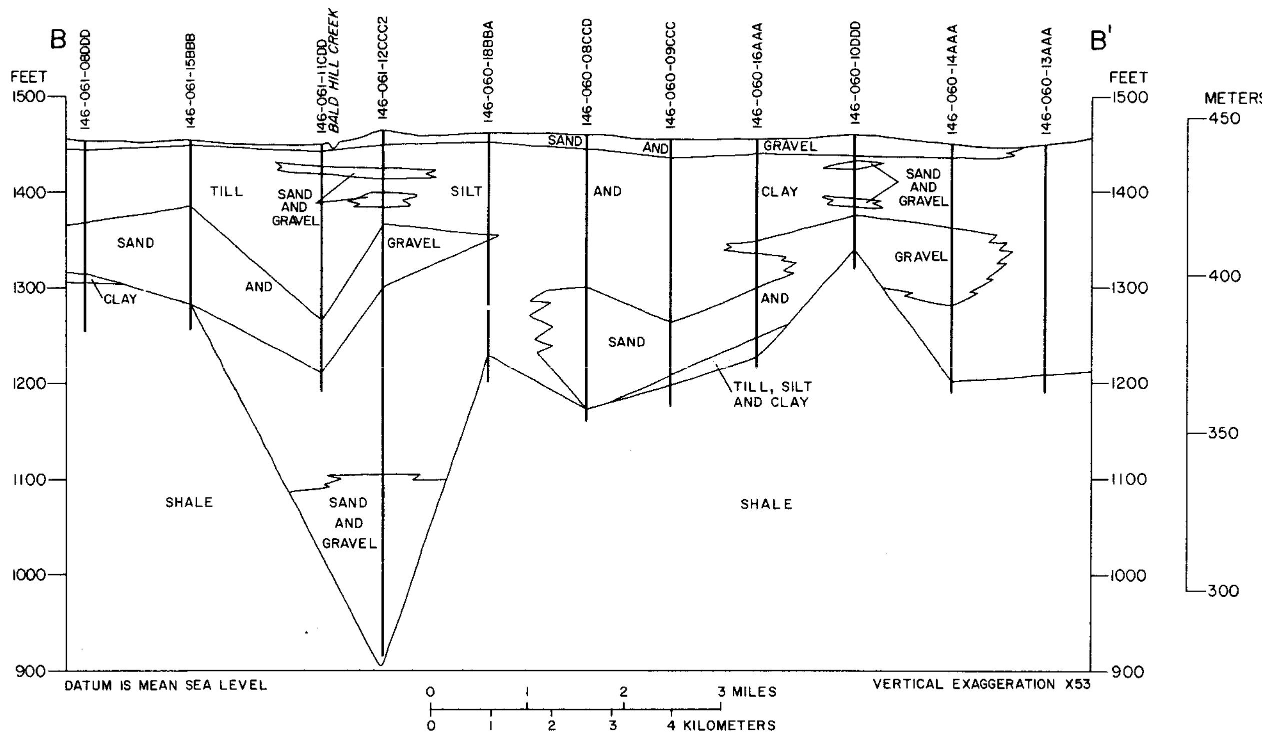


FIGURE 4.— Section through the Spiritwood aquifer system.

Recharge to the Spiritwood aquifer system is from direct precipitation and snowmelt on the aquifer surface. Water-level fluctuations in the aquifer are generally small with the highest water levels following spring snowmelt. Yearly fluctuations generally are less than 3 feet (1 m), although somewhat greater fluctuations do occur at a few locations. The potentiometric surface (fig. 5) generally slopes towards, and water is discharged into, Bald Hill Creek.

In general water from the Spiritwood aquifer system is very hard and is a sodium bicarbonate type. Locally, however, the water is a sodium sulfate or calcium sulfate type. Water samples were collected from 101 wells penetrating the Spiritwood aquifer system. Dissolved-solids concentrations ranged from 244 to 9,800 mg/l; the median was 800 mg/l. Hardness ranged from 63 to 5,030 mg/l and sulfate ranged from 19 to 5,660 mg/l. Chloride concentrations ranged from 0.7 to 649 mg/l, but only eight of the samples contained more than the U.S. Public Health Service (1962) recommended chloride limit of 250 mg/l. All of the samples with concentrations greater than 700 mg/l sulfate or more than 250 mg/l chloride were collected from wells located near the edge of the aquifer, suggesting recharge from the Pierre Formation.

The sodium-adsorption ratio ranged from 0.1 to 13 and exceeded 6 in 29 samples. The aquifer system has water that generally is classified as C3-S1 to C3-S2 for irrigation (fig. 3).

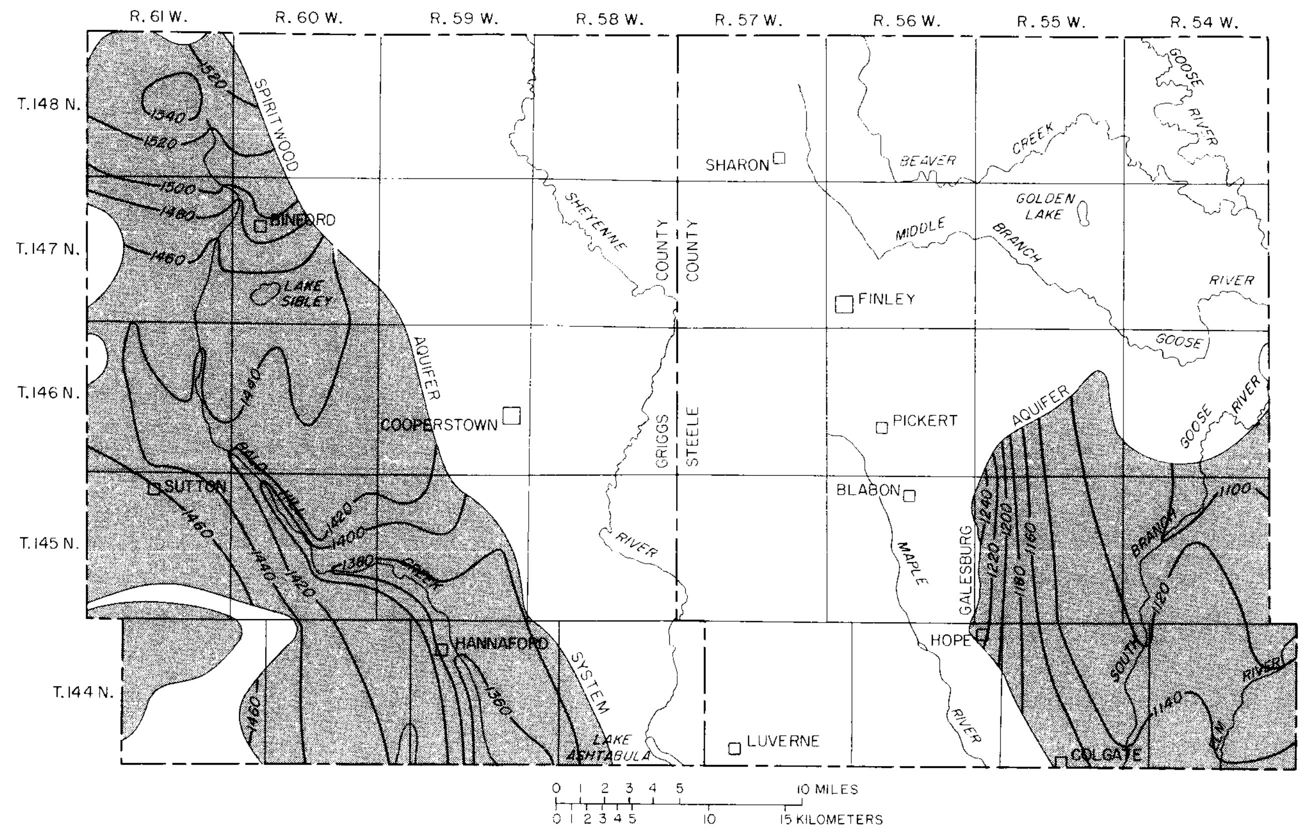
Based on an average saturated thickness of 100 feet (30 m), an estimated average specific yield of 0.15, and an areal extent of 350 mi^2 (900 km^2), about 3,400,000 acre-feet (4.2 km^3) of water may be available from storage from the Spiritwood aquifer system in Griggs County. Silts and clays also contain considerable water in storage, but the rate of drainage from these deposits is too slow to add significantly to the available storage within a period of a few years.

McVille Aquifer

The McVille aquifer (Downey, 1973) extends from T. 144 N., R. 57 W. in Steele County to T. 148 N., R. 59 W. in Griggs County (pl. 1). It underlies about 13 mi^2 (34 km^2) in the two-county area and extends from Barnes County on the south to Nelson County on the north. The aquifer is contained in a buried valley (fig. 6) cut into the Pierre Formation and the overlying till. It has a length of about 34 miles (55 km) and ranges in width from about a quarter of a mile (400 m) to about 20 miles (4 km) with an average width of about three-eighths of a mile (600 m).

Test drilling indicates that the McVille aquifer generally is composed of fine sand, sandy gravel, and clayey silty sand interbedded with lenses of silty clay and glacial till. The sand and gravel generally is coarser in the northern part of the aquifer than in the southern part. The aquifer ranges in thickness from less than 1 foot (0.3 m) at the edges to more than 300 feet (90 m) near the southern boundary of Steele County and contains an average of about 80 feet (24 m) of saturated sand and gravel.

A pumping test of the McVille aquifer was not made as a part of this study; however, data from a test made in Nelson County (Downey, 1973) indicate that



EXPLANATION

——1460—— **POTENTIOMETRIC CONTOUR–Shows altitude at which water level would have stood in tightly cased wells, fall-winter 1970. Contour interval 20 feet (6.1 m). Datum is mean sea level**

FIGURE 5.— Generalized map of the potentiometric surface in the Spiritwood aquifer system and Galesburg aquifer.

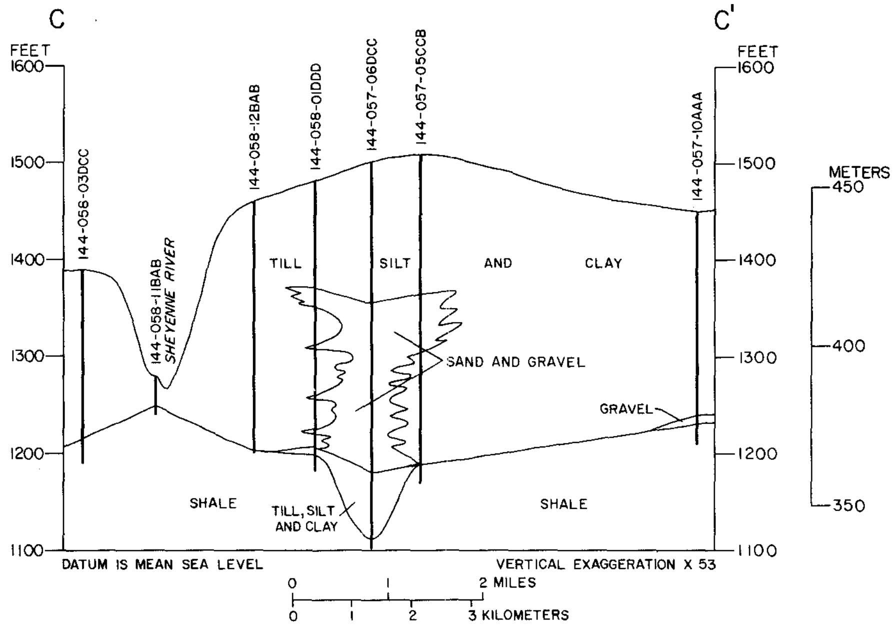


FIGURE 6.— Section through the McVille aquifer.

the transmissivity ranges from about 2,000 to 9,000 ft^2/d (186 to 836 m^2/d). Somewhat smaller transmissivities should be expected in the southern part of the aquifer near the city of Luverne where the aquifer is composed of finer grained materials. Maximum yields of individual wells tapping the McVille aquifer are estimated at about 500 gal/min (32 l/s).

Recharge to the McVille aquifer is from direct precipitation, snowmelt, and inflow from the Sheyenne River. The relationship between the aquifer and the river is shown graphically in figure 7, where periods of high and low water levels in observation well 146-058-26CBC, located about 200 feet (61 m) from the river, coincide with periods of high and low flows in the river.

Water in the McVille aquifer generally is very hard, and the dissolved-solids concentration varies to a great extent with the water's position in the aquifer. Water from the more permeable parts of the aquifer generally has relatively low concentrations of dissolved solids with a high proportion of calcium and bicarbonate ions. Toward the edges of the aquifer and in those areas where the aquifer is isolated from the Sheyenne River, dissolved solids and the proportion of sodium and sulfate ions increase. Water samples collected from the aquifer had dissolved-solids concentrations ranging from 449 mg/l in the northern part of the aquifer to 2,200 mg/l in the southern part near the city of Luverne.

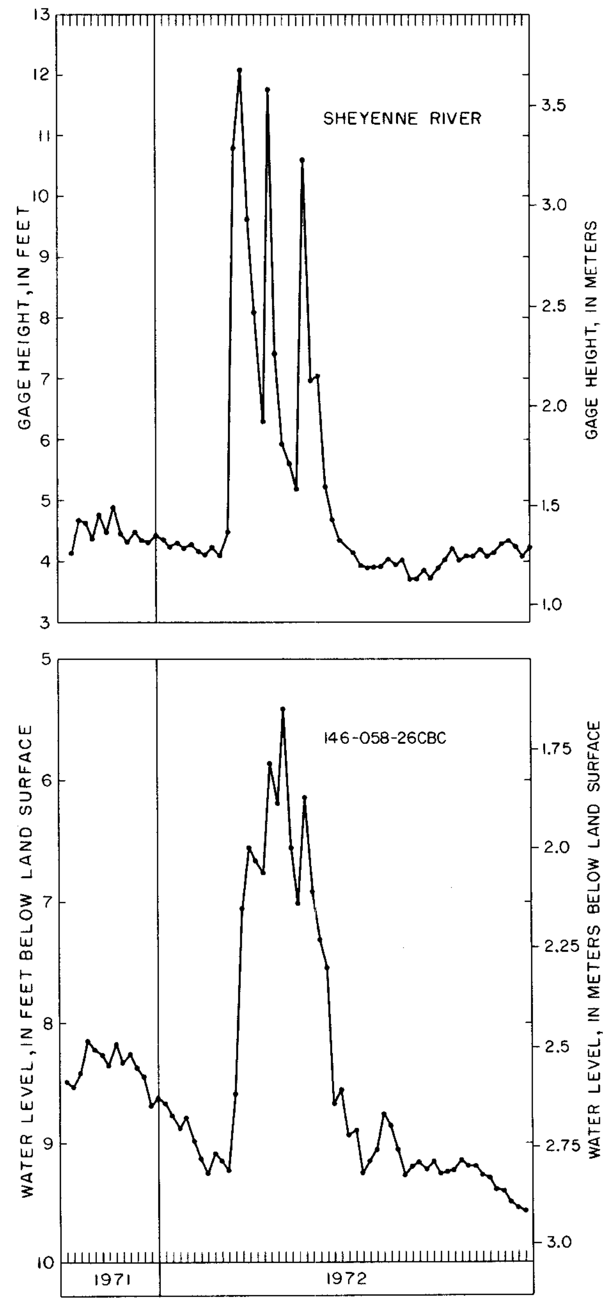


FIGURE 7.— Water-level fluctuations in well 146-058-26CBC and the Sheyenne River near Cooperstown.

The sodium-adsorption ratio ranged from 0.1 to 11 with a median value of 2.1. The aquifer has water that generally is classified C2-S1 to C3-S2 for irrigation (fig. 3).

Based on an areal extent of 13 mi^2 (34 km^2), an average saturated thickness of 80 feet (24 m), and an estimated average specific yield of 0.15, about 100,000 acre-feet (0.1 km^3) of water may be available from storage in the aquifer.

Galesburg Aquifer

The Galesburg aquifer (Bluemle, 1967) underlies an area of about 165 mi^2 (427 km^2) in southeastern Steele County. It extends into Traill and Cass Counties to the east and south and includes the deposits assigned to the Page aquifer by Klausing (1968) in Cass County.

Geologically, the Galesburg aquifer is a part of the Galesburg delta (Bluemle, 1967), which formed along the shore of glacial Lake Agassiz. The aquifer materials were deposited in a near-shore environment of the lake and consist of lenticular deposits of sand and gravel interbedded with clay and silt. Glacial till occurs within several stratigraphic sequences (pl. 2, and fig. 8), indicating that glacial ice moved across the surface of the delta at various times during its formation. Glacial till also occurs as a layer capping the aquifer throughout most of the area. The aquifer ranges in thickness from less than 1 foot (0.3 m) near the western edge to about 400 feet (122 m) in the southeastern corner of Steele County with an average thickness of about 210 feet (64 m). The average thickness of saturated sand and gravel in the aquifer is about 43 feet (13 m).

Because of the nature of origin of the Galesburg aquifer, the lithology is variable from one location to another. The thickness and extent of sand and gravel deposits change rapidly within a short distance. Individual sand and gravel lenses range in thickness from about 2 feet (0.6 m) to 115 feet (35 m) with an average thickness of about 25 feet (7.6 m).

Geologic logs of test holes (Downey and others, 1973) drilled through the Galesburg aquifer indicate that the aquifer in general consists of two units: an upper near-surface unit consisting of lenses of fine sand and a deeper unit composed of interbedded sand and gravel (pl. 2, and fig. 8). The two units are separated by varying thicknesses of glacial till and(or) silt and clay. Klausing (1968) noted the occurrence of these two separate units within the Page aquifer (Galesburg equivalent) in Cass County; however, in Traill County (Jensen and Klausing, 1971) the two units were not identified, most likely because of the lack of test holes that penetrated the deeper unit.

Because of facies changes that occur within short distances in the Galesburg aquifer, extrapolation of aquifer properties from one area to another is somewhat tenuous. Schmid (written commun., 1973), using methods developed by Theis (1935) and data from a pumping test at 144-054-22DCD, where the aquifer is 78 feet (24 m) thick, reported that the Galesburg aquifer had a transmissivity of approximately 5,000 ft^2/d (464 m^2/d) and a storage coefficient of about 0.001 in this area. The specific capacity of the test well was 7.8 (gal/min)/ft [1.6 (l/s)/m]. Based on available data, it is estimated that individual well yields of 500 to 1,000

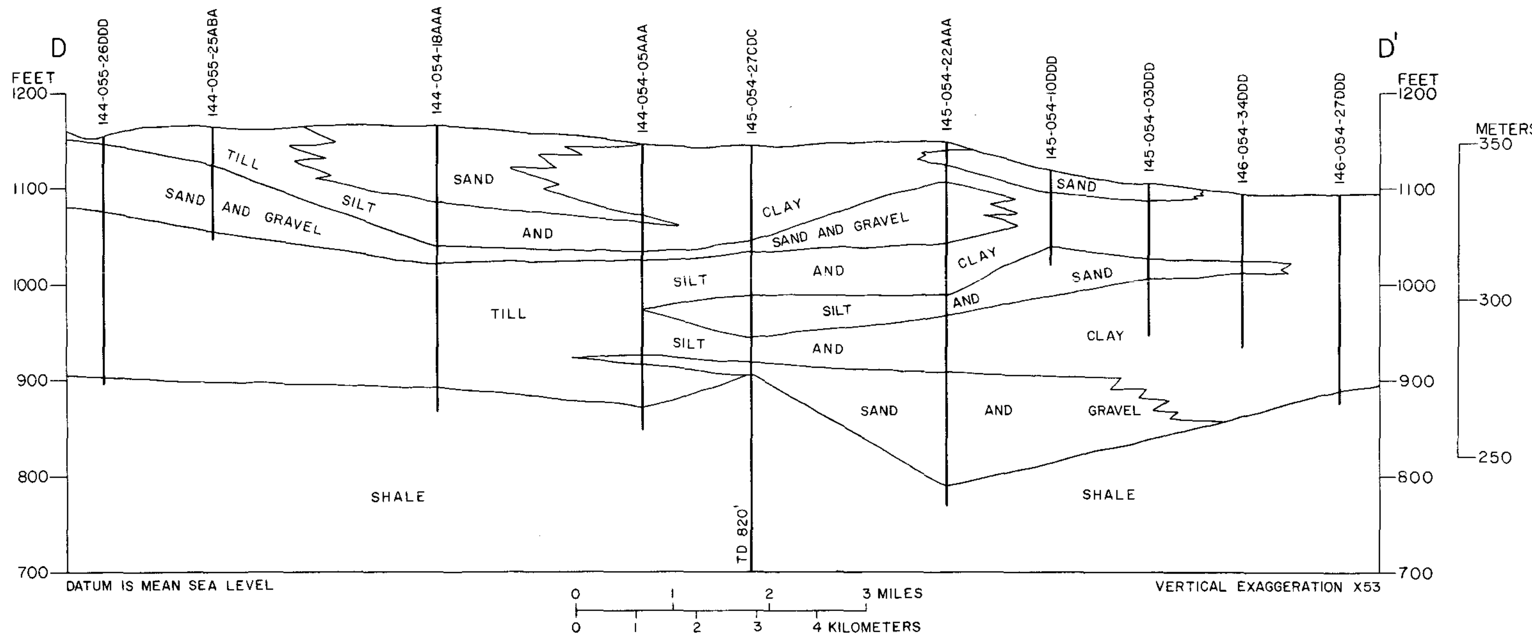


FIGURE 8.— Section through the Galesburg aquifer.

gal/min (32 to 63 l/s) may be expected from about one-fourth of the area of the Galesburg aquifer. Data from the pumping test and the potentiometric-surface map (fig. 5) indicate that the Elm and South Branch Goose Rivers act as drains for the ground-water system.

Recharge to the Galesburg aquifer is from direct precipitation upon the aquifer surface and infiltration from snowmelt in the spring. Discharge is limited to outflow to the Elm and South Branch Goose Rivers, evapotranspiration, and small-capacity wells.

Water from the Galesburg aquifer is very hard and generally is either a calcium sulfate or a calcium bicarbonate type. Dissolved-solids concentrations in 41 samples ranged from 317 to 2,170 mg/l with a median value of 856 mg/l. Iron, manganese, and sulfate commonly exceeded the recommended limits shown in table 1.

The sodium-adsorption ratio of the samples analyzed ranged from 0.2 to 1.6. The water generally is classified C3-S1 for irrigation purposes (fig. 3).

Based on an areal extent of 165 mi^2 (427 km^2), an average saturated thickness of 43 feet (13 m), and an estimated average specific yield of 0.15, about 680,000 acre-feet (0.8 km^3) of water may be available from storage in the Galesburg aquifer.

Elk Valley Aquifer

The Elk Valley aquifer (Kelly and Paulson, 1970) underlies an area of about 48 mi^2 (124 km^2) in northeastern Steele County (pl. 2). Test drilling indicates that the aquifer consists of sand and gravel interbedded with clay and silt (fig. 9). It ranges in thickness from a few feet to about 100 feet (30 m); however, the sand and gravel units have an average thickness of about 23 feet (7 m) and are normally found at less than 100 feet (30 m) below land surface.

Jensen and Klausing (1971) reported an estimated transmissivity for the Elk Valley aquifer at Hatton in Traill County of 134 ft^2/d (12.4 m^2/d). A similiar value is estimated for the aquifer deposits in Steele County. Most wells in the aquifer presently yield only a few gallons per minute but yields as high as 30 gal/min (2 l/s) probably could be obtained from some ideally located wells that fully penetrate the aquifer.

Water from the Elk Valley aquifer in Steele County normally is very hard and generally is a calcium or sodium bicarbonate type. The dissolved-solids concentration in samples collected during this study ranged from 397 to 2,890 mg/l with a median value of 549 mg/l.

The sodium-adsorption ratio of the samples analyzed ranged from 0.2 to 1.6. The water generally is classified C3-S1 for irrigation purposes (fig. 3).

Although the Elk Valley aquifer underlies about 7 percent of the area of Steele County, its low hydraulic conductivity will restrict future development to small capacity wells.

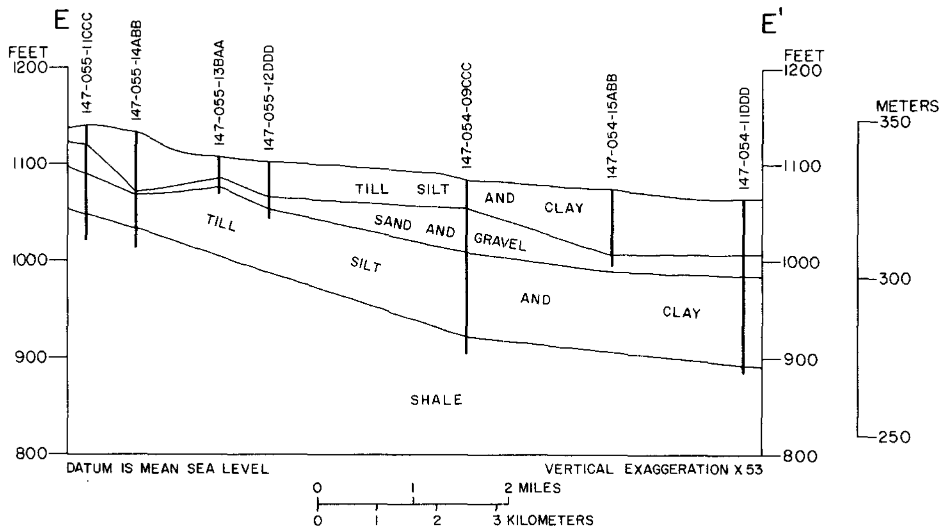


FIGURE 9.— Section through the Elk Valley aquifer.

Based on an areal extent of 48 mi^2 (124 km^2), an average saturated thickness of 23 feet (7 m), and an estimated average specific yield of 0.15, about 110,000 acre-feet (0.14 km^3) of water may be available from the sand and gravel units.

Undifferentiated Drift Aquifers

Small deposits of sand and gravel commonly are interspersed in the glacial till throughout much of eastern Griggs County and much of Steele County. These deposits were formed wherever there was sufficient melt water to cause sorting and stratification. Many of the deposits are contained in small narrow channels, but the full extent of the channels could not be determined because of insufficient data to determine the exact boundaries.

In general the sand and gravel deposits are limited both in thickness and areal extent. They are also limited as to recharge because of the overlying till, which ranges in hydraulic conductivity from about 0.00004 to 0.05 ft/d (0.000012 to 0.02 m/d; Downey, 1973) depending upon the amount of clay, silt, and sand present. Yields from individual wells tapping these sand and gravel deposits may be as high as 50 gal/min (3 l/s), but generally are less than 5 gal/min (0.3 l/s).

Many farm wells in the eastern part of Griggs County and the western part of Steele County tap deposits of glacial till. These wells yield sufficient water to meet the needs of small farm operations even though many of them failed to penetrate any significant thickness of sand or gravel. In some places the water is produced from very thin sand and gravel lenses that are interbedded with the till, in others the water comes from joints or other fractures in the till. Because joints, fractures, and sand and gravel lenses in the till are not apparent at the surface, considerable test drilling is necessary before installation of production wells.

In order to insure the best possible yield from till aquifers, it is necessary to install large-diameter wells that will provide a large area for seepage and also act as reservoirs for storage of water. Proper design of wells tapping till aquifers will minimize the tendency for these wells to be pumped dry after a short pumping period. It will also decrease the length of time required to refill after being pumped dry.

Hydrographs plotted from water-level measurements from till wells commonly show large fluctuations. These large fluctuations generally are attributed to the effects of precipitation. However, Schneider (1961) and Willis and others (1964) have shown that water-level fluctuations in fine-grained materials can occur in the absence of precipitation due to the formation of ice crystals within the sediments, thereby removing water from the system. When these ice crystals melt in the spring, the water is returned to the ground-water system resulting in a rise in water levels. Preliminary data from a series of temperature sensors installed from 5.6 to 78 inches (142 to 1,980 mm) below land surface in Cavalier County (R. D. Hutchinson, written commun., 1974) indicate that with the freezing of the till there is a corresponding decrease in water levels in nearby observation wells, and with spring melting there is a rise in water levels.

Many small ice-contact deposits of sand and gravel are found in Griggs and Steele Counties. In general, these deposits are the result of glacial ice melting in place and leaving a deposit of sand or gravel. Often the bulk of these deposits is above the general water table of the area and only a thin water-saturated zone exists near the base. During periods of the year when precipitation is at a minimum, these deposits may be completely dry.

A few of the larger ice-contact deposits may yield sufficient water for general farm use; however, in most cases the ice-contact deposits are not capable of yielding more than 5 to 10 gal/min (0.3 to 0.6 l/s) to individual wells over a long period of time.

The chemical quality of water from undifferentiated drift aquifers differs widely from one location to another. This variation of water quality mainly is due to the great variety of minerals in the deposits, sources of recharge, and hydraulic connection with other aquifers. In samples collected from undifferentiated drift aquifers the dissolved-solids concentration ranged from 333 to 7,760 mg/l and total hardness ranged from 200 to 3,100 mg/l. Iron, manganese, and sulfate commonly exceeded the recommended limits set by the U.S. Public Health Service (1962).

UTILIZATION OF GROUND WATER

Nearly the entire population of Griggs and Steele Counties is dependent upon ground water for their supply of water for domestic and livestock needs. Based on 1970 population figures, about 61 percent of the two-county population has self-supplied systems and 39 percent depends on a public supply. Six communities — Binford, Cooperstown, Finley, Hannaford, Hope, and Sharon — have municipal water supplies; all use ground-water sources.

Based on a 1970 population of 7,933 people, it is estimated that about 850,000 gal/d (3,000 m^3/d) of water is being used in the two-county area.

Rural Domestic and Livestock Use

In Griggs and Steele Counties, many of the older domestic and livestock wells are of large diameter and of hand-dug or bored construction. Dug wells may be satisfactory where an adequate supply of water can be obtained near the surface, but they have certain disadvantages. Wells cannot be dug by hand very far below the water table; consequently, if the water table is lowered substantially, the wells must be deepened or they will go dry. Because they penetrate only a few feet of the upper part of the aquifer, individual wells commonly have low yields, normally less than 5 gal/min (0.3 l/s). Dug wells tapping shallow aquifers are often subject to surface sources of contamination. Furthermore, it is difficult to seal a dug well properly and still provide access for repairs.

Because of the disadvantages of dug wells, many have been replaced by drilled or bored wells in recent years. Most of the drilled farm wells are from 4 to 6 inches (102 to 152 mm) in diameter and are completed in the most productive aquifer available. In the western part of Griggs County the Spiritwood aquifer system is the principal source of water. In the central part of the two-county area the Pierre, undifferentiated drift, and McVille aquifers supply most of the farms. Farms in northeastern Steele County obtain water from the Elk Valley aquifer, while those in southeastern Steele County utilize the Galesburg aquifer.

Most farm units in the two-county area have at least one well for their domestic and livestock uses, but records are not available to accurately determine the quantity of water used.

Public Supply

Binford

The city of Binford (population 242) in northwestern Griggs County obtains its public supply of water from a well located at 147-060-08CBC. The supply is obtained from a 114-foot (35-m) well finished in the Spiritwood aquifer system. Reported pumpage is about 4,000 gal/d (15 m^3/d). Additional water for the city system may be obtained by further development of the Spiritwood aquifer system.

Cooperstown

The city of Cooperstown, located in east-central Griggs County, is the major population (1,485) center of the county. Cooperstown obtains its water from three wells, 146-058-26BDB1, BDB2, and BDB3 (38, 47, and 139 feet deep; 12, 14, and 42 m), finished in the McVille aquifer east of the city. Only the 47-foot and 139-foot wells are used for the city supply; the 38-foot well is for reserve. Daily pumpage averages about 274,000 gal/d (1,028 m^3/d), and the 47-foot and 139-foot wells, which have capacities of 75 gal/min (4.7 l/s) and 175 gal/min (11 l/s), respectively, are adequate to supply this amount.

Finley

The city of Finley, the major population (809) center of Steele County, obtains its water from several wells tapping a shallow deposit of sand and gravel east of the city. These wells range from 20 to 32 feet (6 to 10 m) in depth and appear to be adequate to supply the city's average daily pumpage of 55,000 gallons (208 m^3). If necessary, additional water could be obtained by development of the Galesburg or McVille aquifers.

Hannaford

The city of Hannaford in south-central Griggs County obtains its water supply from a well 180 feet (55 m) deep developed in the Spiritwood aquifer system.

Pumpage records are not available for the city, but the water supply appears to be more than adequate for the 244 residents (1970 census) of the city. The well probably is being pumped on the average between 14,000 and 15,000 gal/d (53 m^3/d and 57 m^3/d). This is far below the capacity of the well and there is no foreseeable shortage of water. If need did arise, however, further development of the Spiritwood aquifer system would produce an adequate supply.

Hope

The city of Hope (population 364), in south-central Steele County, obtains its water supply from two wells in the Galesburg aquifer. Daily pumpage ranges from 25,000 gal/d (95 m^3/d) in the winter to 60,000 gal/d (227 m^3/d) in the summer. Average daily pumpage is about 42,500 gal/d (161 m^3/d). The Galesburg aquifer is capable of meeting the future water needs of the city.

Sharon

The city of Sharon (population 201), located in northwestern Steele County, obtains its water from a 65-foot (20-m) well that taps an undifferentiated drift aquifer. Reported daily pumpage for 1972 was 9,000 gal/d (34 m^3/d).

Rural Water Districts

Since 1970, several rural water districts were developed in eastern North Dakota, including one planned to provide water from the Galesburg aquifer to a large area of Griggs and Steele Counties. With proper planning, these districts are able to provide large quantities of water to farms and small municipalities. Three aquifers — the Spiritwood, McVille, and Galesburg — in the two-county area could be used as sources of water to supply the needs of any additional water districts.

SUMMARY

Ground water in Griggs and Steele Counties may be obtained from sandstone units in the Dakota aquifer, fracture zones in the shale in the Pierre aquifer, and from sand and gravel aquifers in glacial deposits. Available data suggest that water from the bedrock units of Precambrian, Ordovician, and Jurassic age is moderately saline to very saline. Well yields from the Precambrian, Ordovician, and Jurassic units are low.

The Dakota aquifer, at a depth of about 580 feet (180 m) below land surface, is potentially the most productive bedrock aquifer in the two-county area. This aquifer is capable of yielding as much as 500 gal/min (32 l/s) to properly constructed individual wells. Water samples from the Dakota aquifer had dissolved-solids concentrations of from 2,960 to 5,190 mg/l, and generally would be considered too saline for most uses.

The Pierre aquifer, directly underlying the glacial drift, supplies water for farms in the northeastern part of Griggs County and the northwestern part of Steele County. Individual well yields from the Pierre aquifer are as much as 10 gal/min (0.6 l/s), but generally are less than 5 gal/min (0.3 l/s). Water samples from the Pierre aquifer had dissolved-solids concentrations ranging from 308 to 2,550 mg/l.

The aquifers with the greatest potential for development are those in the glacial deposits associated with buried valleys, such as the Spiritwood and McVille aquifers, and deltas associated with glacial Lake Agassiz. The sediments in both types of deposits are lenticular, thus the thickness of any particular sand or gravel body may vary within a short distance.

Hydrologic data for the Spiritwood aquifer system, McVille, Galesburg, and Elk Valley aquifers are listed in the summary table.

The rural population of Griggs and Steele Counties is dependent upon ground water for domestic and much of their livestock needs. In addition, the communities of Binford, Cooperstown, Finley, Hannaford, Hope, and Sharon obtain their public supplies from wells.

Planned rural water districts will be able to provide large quantities of water to many farms in the two-county area from three glacial-drift aquifers — the Spiritwood system, McVille, and Galesburg.

Summary of data for major aquifers in the glacial drift

Aquifer	Spiritwood system	McVille	Galesburg	Elk Valley
Areal extent (mi^2)	350	13	165	48
Average saturated sand and gravel thickness (feet)	100	80	43	23
Estimated maximum yield to individual wells (gal/min)	1,500	500	1,000	30
Estimated amount of water available from storage (acre-feet)	3,400,000	100,000	680,000	110,000
Dissolved solids range (mg/l)	244 to 9,800	449 to 2,200	317 to 2,170	397 to 2,890
Dominant ions	Sodium, calcium, bicarbonate, and sulfate.	Calcium sodium, bicarbonate, and sulfate.	Calcium sulfate, and bicarbonate.	Calcium, sodium, and bicarbonate.
Hardness	Very hard.[1]	Very hard.	Very hard.	Very hard.
General irrigation classification	C3-S1 to C3-S2.	C2-S1 to C3-S2.	C3-S1.	C3-S1.

[1]More than 180 mg/l of calcium carbonate.

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DEFINITIONS OF SELECTED TERMS

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

Artesian well–A well in which the water level stands above an artesian or confined aquifer. A flowing artesian well is a well in which the water level is above the land surface. See confined ground water.

Cone of depression–The conical low produced in a water table or potentiometric surface by a discharging well.

Confining bed–A body of relatively impermeable 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.

Confined ground water–Water in an aquifer that is contained by a confining bed, and under pressure significantly greater than atmospheric.

Gaining stream–A stream whose flow is being increased by the inflow of ground water from springs and seeps along its course.

Head, static–The height above a standard datum at which the upper surface of a column of water or other liquid can be supported by the static pressure at a given point. The term static head, which is a measure of potential, is sometimes expressed simply as head.

Homogeneous–Having identical properties everywhere in space.

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.

Losing stream–A stream that is losing water to the ground along its course.

Porosity–The ratio of the volume of the voids in a rock to the total volume. The ratio may be expressed as a decimal fraction or as a percentage. The term effective porosity refers to the amount of interconnected pore spaces or voids in a rock or soil and is expressed as a percentage of the total volume occupied by the interconnecting pores.

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–The ratio expressing the relative activity of sodium ions in exchange reaction with soil and is an index of the sodium or alkali hazard to the soil. Sodium-adsorption ratio is expressed by the equation

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

where the concentrations of the ions are expressed in milliequivalents per liter or equivalents per million.

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.

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 less 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.

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 feet squared per day or meters squared 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.

Water table–Is a surface in an unconfined aquifer at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the aquifer just far enough to hold standing water.

Zone of saturation–In the saturated zone of an aquifer all voids are ideally filled with water. The water table is the upper limit of this zone. In nature, the saturated zone may depart from the ideal in some repsects. A rising water table may trap air in parts of the zone and other natural fluids may occupy voids in the lower part of an aquifer.