HYDROGEOLOGY AND GROUND-WATER QUALITY OF CONFINED AQUIFERS IN BURIED VALLEYS IN ROCK COUNTY, MINNESOTA AND MINNEHAHA COUNTY, SOUTH DAKOTA

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Contents

Illustrations

Tables

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER QUALITY UNITS

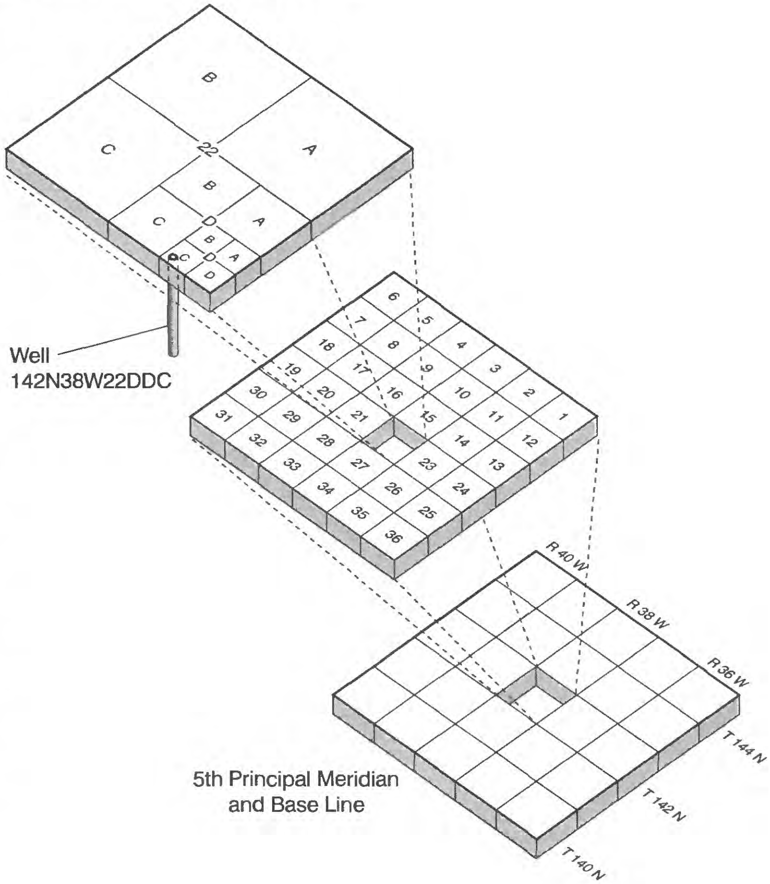
Multiply inch-pound unit	By	To obtain metric unit
acre	0.4047	hectare
inch (in.)	25.4	millimeter
inch per year (in./yr)	25.4	millimeter per year
foot (ft)	.3048	meter
mile (mi)	1.609	kilometer
foot per day (ft/d)	.3048	meter per day
foot per mile (ft/mi)	.1894	meter per kilometer
foot squared per day (ft^2/d)	.09290	meter squared per day
gallon (gal)	.003785	cubic meter
gallon per minute (gal/min)	.06309	liter per second
square mile (mi^2)	2.590	square kilometer

Chemical concentrations are given in metric units. Chemical concentrations of substances in water are given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

Sea level In this report "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929".

Test-hole and Well Numbering System

Two systems of numbering test-holes and wells were used for this study. The second system is based on the U.S. Bureau of Land Management's system of land subdivision (township, range, and section). The diagram to the right illustrates the second numbering sustem. The first number of the site location indicates the township (the N after the township number is an abbreviation for north); the second, the range (the W after the range number is an abbreviation for west); and the third the section. Uppercase letters after the section number indicate location within the section; the first letter denotes the 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. The number of uppercase letters indicates accuracy of the location number. For instance, if a point can be located within a 10-acre tract, three uppercase letters are shown in the location number. The number 142N38W22DDC indicates the site is located in the SW 1/4 of the SE ¼ of the SE ¼, section 22, township 142 north, range 38 west, 5th principal meridian and base line. Within a given tract successive numbers beginning with 1 are added as suffixes, indicating the first test-hole or well located in that tract.



Hydrogeology and Ground-Water Quality of Confined Aquifers in Buried Valleys in Rock County, Minnesota and Minnehaha County, South Dakota

By Richard J. Lindgren

ABSTRACT

Confined glacial and bedrock aquifers are present within Quaternary and Cretaceous deposits that fill buried valleys incised in the Sioux Quartzite surface in Rock County, in southwestern Minnesota and Minnehaha County, South Dakota. This report describes the areal extent, thickness, water-bearing characteristics, water-supply potential, and water-quality characteristics of confined aquifers within buried-valley deposits in Rock County.

Hydrogeologic units present within buried-valley deposits in Rock County include unconfined and confined drift aquifers, undifferentiated Cretaceous aquifers, the Split Rock Creek aquifer, and interbedded confining units. The undifferentiated Cretaceous aquifers consist of sandstone layers within interbedded claystone and siltstone overlying the Split Rock Creek Formation or Sioux Quartzite. The Split Rock Creek Formation consisting of sand units (comprising the Split Rock Creek aquifer) and interbedded layers of siltstone and claystone, is present in buried valleys incised in the Sioux Quartzite surface in southern and possibly northeastern Rock County, Minnesota.

Confined drift aquifers with thicknesses greater than 5 feet were penetrated in 6 of 10 test holes. Thicknesses of the confined drift aquifers in Rock County range from at least 2 to greater than 32 feet. Estimated horizontal hydraulic conductivity for a confined drift aquifer derived from specific-capacity information from one domestic well log was 73 feet per day.

No major (thickness greater than 5 feet) undifferentiated Cretaceous aquifers were penetrated in 10 test holes. Thicknesses of the undifferentiated Cretaceous aquifers compiled from the geologic logs for four domestic wells ranged from at least 7 feet to greater than 46 feet. Estimated horizontal hydraulic conductivity for an undifferentiated Cretaceous aquifer derived from specific-capacity information from one domestic well log was 55 feet per day.

Cumulative sand thicknesses for the Split Rock Creek aquifer in 10 test holes ranged from zero to 128.5 feet in 2 to 6 layers. The largest cumulative sand thicknesses were penetrated near the southern margin of the Sioux Quartzite high in northern Rock County and in an east-west trending buried valley (Brandon Embayment) entering Rock County from Minnehaha County, South Dakota. These comparatively large cumulative sand thicknesses are probably due to a high-energy depositional environment.

Estimated horizontal hydraulic conductivities for the Split Rock Creek aquifer in Rock County derived from analysis of three slug tests were 0.1, 0.2, and 1 foot per day. The corresponding aquifer transmissivities, calculated as the horizontal hydraulic conductivity multiplied by the cumulative sand thickness, were 3, 16, and 130 feet squared per day. The greatest horizontal hydraulic conductivity and transmissivity estimates were for a site near the southern margin of the Sioux Quartzite high. The water-supply potential of the Split Rock Creek aquifer in Rock County is generally limited by the low transmissivity of the aquifer due to the fineness of the aquifer material (generally very fine- to fine-grained sand).

Recharge to the Split Rock Creek aquifer is thought to be derived primarily from hydraulic connection to the Sioux Quartzite aquifer as infiltration of precipitation moves through the fractures and joints of the Sioux Quartzite to the Split Rock Creek aquifer. The regional directions of flow in the aquifer are to the south away from the Sioux Quartzite high and to the west in the Brandon Embayment in Minnehaha County and its east-west trending extension into Rock County.

The predominant ions in water from two wells screened in confined drift aquifers in Rock County were calcium and bicarbonate and in water from a third well were calcium and sulfate. The predominant ions in water from one well screened in an undifferentiated Cretaceous aquifer in Rock County were calcium and bicarbonate and in water from a second well were calcium and sulfate. The predominant ions in water from two wells screened in the Split Rock Creek aquifer in Rock County were calcium and bicarbonate and in water from a third well were calcium and sulfate.

INTRODUCTION

Historically, southwestern Minnesota has depended on ground water for most of its domestic, agricultural, and municipal needs. Within the glacial drift that overlies the bedrock in southwestern Minnesota, there is a complex layering of glacial tills and outwash deposits. The bedrock consists of sedimentary rocks of Cretaceous age and much older igneous and metamorphic rocks of Precambrian age. Much of the ground water used for domestic, agricultural, and municipal supplies is withdrawn from shallow outwash deposits in the drift, hereinafter termed unconfined drift aquifers. Six major unconfined drift aquifers composed of outwash and alluvial material are associated with stream valleys in southwestern Minnesota (Adolphson, 1983). These unconfined drift aquifers contain sufficient saturated material at many places to yield large quantities of water to wells. The estimated potential yields to properly constructed wells in the aquifers are as much as 1,000 gal/min (Adolphson, 1983). The major unconfined drift aquifers in Rock County are the outwash deposits and alluvium underlying the valleys of the Rock River and Beaver Creek. The largest water users in Rock County, including the city of Luverne and the Rock County Rural Water District, withdraw all their water from the unconfined drift aquifer underlying the Rock River in eastern Rock County, Minnesota.

The unconfined drift aquifers are susceptible to contamination resulting from human activity. These aquifers are not well protected from surface infiltration and are vulnerable to contamination from domestic, agricultural, and municipal sources. Also, because of their shallow location and long, narrow, valley-controlled morphology, the unconfined drift aquifers contain water that is predominantly derived directly from local precipitation. Therefore, they are subject to diminished yield during times of drought. These factors have prompted the consideration of alternative water sources in southwestern Minnesota, including imported surface water from the Missouri River.

Schneider and Rodis (1961) reported that confined aquifers are present in linear meltwater deposits parallel to end moraines that were deposited along the southwest flank of the Des Moines glacial lobe in southwestern Minnesota. Southwick and others (1993) suggested that glacial meltwater channels formed repeatedly along the north side of the erosionally resistant topographic high in the Precambrian surface, which has the Sioux Quartzite as its core, in southwestern Minnesota and neighboring areas in South Dakota.

The distribution of confined drift aquifers and the availability of water from these aquifers is not well defined for southwestern Minnesota. Chandler (1994) used the gravity geophysical method to investigate the thickness of the Quaternary and Cretaceous deposits in Rock County and mapped buried valleys in the Sioux Quartzite surface. The Quaternary and Cretaceous deposits in the southwestern, south-central, and eastern parts of Rock County are thick, but largely unexplored, sequences that could contain aquifers. However, the distribution of aquifers within the Quaternary and Cretaceous deposits in southwestern Minnesota, including Rock County, is poorly known due to poor drill-hole control (Setterholm, 1990). Test-drilling results from the same geologic setting (buried valleys in the Sioux Quartzite surface) in neighboring counties in South Dakota indicate that these buried valleys may contain sand and gravel deposits with sufficient yield for domestic, agricultural, and municipal water needs. Two aquifers have been identified in Minnehaha County, South Dakota within the Quaternary and Cretaceous deposits filling the east-west trending buried valley that enters Rock County near Valley Springs, South Dakota (Lindgren and Niehus, 1992).

Periods of below-normal precipitation and increasing demands for ground water in southwestern Minnesota, including Rock County, have increased the need for information on the availability and quality of water supplies. Investigations are needed to evaluate the viability of utilizing ground water from buried aquifers, as an alternative to importing surface water or to the continued use of environmentally vulnerable shallow ground-water systems. The U.S. Geological Survey, in cooperation with the Minnesota Department of Natural Resources (MDNR), conducted a three-year study (October 1993 to September 1996) to evaluate confined aquifers present within Quaternary and Cretaceous deposits filling buried valleys in the Sioux Quartzite surface in Rock County, Minnesota. Results also will contribute to a better understanding of ground-water systems in this type of hydrogeologic setting.

Purpose and Scope

This report describes the availability and quality of ground water in confined glacial and bedrock aquifers present within Quaternary and Cretaceous deposits filling buried valleys incised in the Sioux Quartzite surface in Rock County in southwestern Minnesota. Bedrock aquifers discussed in this report include undifferentiated Cretaceous aquifers and the Split Rock Creek aquifer. The objectives of the report are to: (1) describe the areal extent and thickness of confined glacial and bedrock aquifers present in buried valleys, (2) describe the water-bearing and water-yielding characteristics of the aquifers, and (3) describe the water-quality characteristics of the aquifers.

Confined glacial aquifers, hereinafter termed confined drift aquifers, are present outside the boundaries of the buried valleys incised in the Sioux Quartzite surface, hereinafter termed buried valleys. However, a comprehensive discussion and mapping of confined drift aquifers in Rock County is beyond the scope of the study and this report. Four wells screened in confined drift aquifers that are outside, but near, the mapped boundaries of the buried valleys are included in the data analysis and discussion due to subjectiveness in defining the boundaries. Also, two wells located outside the mapped boundaries of the buried valleys and screened in undifferentiated Cretaceous aquifers are included in the data analysis and discussion due to the very limited amount of data available for these aquifers.

Test-hole drilling and data-collection activities for the study were limited to the south-central and southwestern parts of Rock County. The Sioux Quartzite is near land surface and Cretaceous deposits are absent in the northwest and north-central parts of Rock County. Previously defined aquifers in adjacent Minnehaha County, South Dakota facilitated the analysis and characterization of hydrogeologic units in southwestern and south-central Rock County. The analysis and discussion of confined drift and bedrock aquifers present within Quaternary and Cretaceous deposits filling buried valleys in eastern Rock County soley relies on previously existing information and is limited due to scant hydrogeologic information.

Location and Description of Study Area

The study area covers approximately 575 mi^2 and includes Rock County in the southwestern corner of Minnesota and a portion of neighboring Minnehaha County in South Dakota (fig. 1). The land surface of Rock County is a gently undulating prairie, characterized by a Sioux Quartzite ridge extending from near Luverne northward. The top of the Sioux Quartzite ridge stands from 1,650 to 1,750 ft above sea level and is terminated abruptly on the southeast by a quartzite cliff at Blue Mounds State Park that rises about 175 ft above the Rock River. The drainage is southwestward to the Big Sioux River (located west of the study area), the main tributaries of which are the Rock River and Beaver Creek. The Rock River, the largest stream in the county, flows southward across the eastern portion of the county. The Rock River occupies a 1-to 2-mile-wide valley and receives many tributaries that enter through narrow, gorge like valleys.

Annual precipitation is about 25 in. in the study area (Baker and Kuehnast, 1978). Moisture is adequate for optimum plant growth in spring and early summer during a normal year but a moisture deficiency common during August and September results in less than optimum growth. Annual precipitation varies widely from year to year; however, wet and dry years tend to occur in groups. Rural and municipal water shortages were common during droughts occurring in the 1930's and the 1980's. Potential annual evapotranspiration calculated by the Thornthwaite method is about 24 to 25 in. and annual runoff is about 3 in. (Baker and others, 1979).

Sand and gravel aquifers within the glacial deposits are the primary source of water for domestic, agricultural, and municipal water supplies in the study area. The city of Luverne, Minnesota and the Rock County Rural Water District withdraw water from the unconfined drift aquifer that underlies the Rock River valley. The towns of Valley Springs, Beaver Creek, Hills, and Steen withdraw water from confined drift aquifers. Some domestic wells in the southern and eastern parts of Rock County are screened in Cretaceous bedrock aquifers. The town of Beaver Creek has a backup municipal well screened in the Cretaceous Split Rock Creek aquifer. The Precambrian Sioux Quartzite is utilized as a source of water for domestic purposes in the northern part of Rock County in areas where it is near land surface and glacial and Cretaceous aquifers are absent.

Methods of Investigation

Field work for this study was conducted from July 1994 through November 1995. Hydrogeologic maps were prepared using reported data from 36 test holes and well logs obtained from files of the Minnesota Geological Survey (MGS) and the U.S. Geological Survey, and geologic logs from 10 test holes in Rock County drilled for this study using mud rotary drilling. Nine of the 10 test holes were drilled to the Sioux Quartzite surface. Two-inch-diameter steel-casing monitoring wells with 5-foot-long stainless-steel screens were installed in three of the test holes. Two of the monitoring wells were screened in the Split Rock Creek aquifer and one was screened in a confined drift aquifer. The locations of test holes and wells used to determine aquifer thickness, estimate aquifer hydraulic properties, measure water levels, and collect water samples for chemical analysis are shown in figure 1. Hydrogeologic information for the confined drift and Split Rock Creek aquifers in Minnehaha County, South Dakota was obtained from Lindgren and Niehus (1992), Tomhave (1994), and L.D. Putnam (U.S. Geological Survey, written commun., 1996).

The locations for drilling test holes for this study were based primarily on the delineation of buried valley boundaries by Chandler (1994) using the gravity

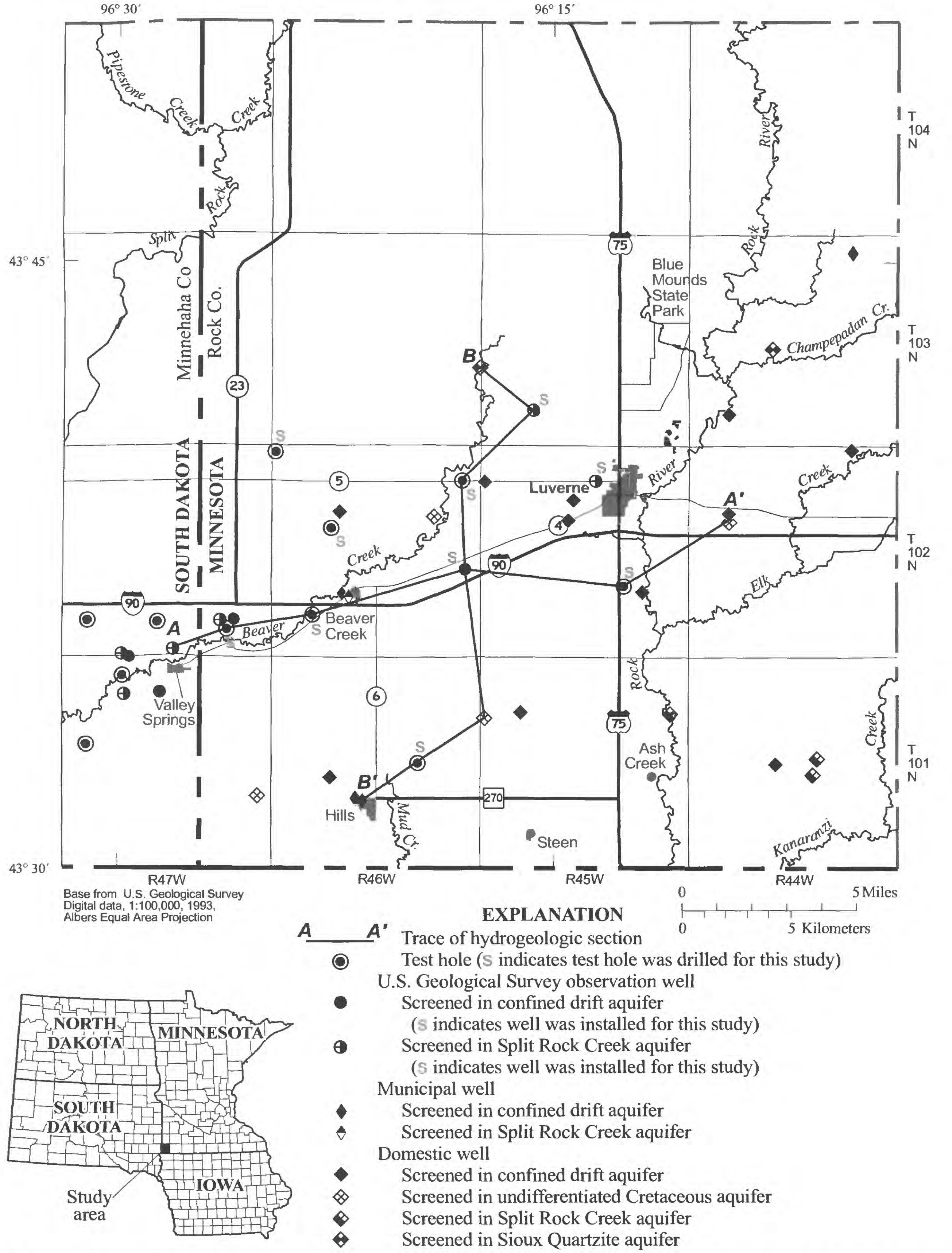


Figure 1. Location of study area, traces of hydrogeologic sections, and locations of test holes and wells.

geophysical method. The Quaternary and Cretaceous deposits in southwestern Minnesota form a mostly unconsolidated, low-density fill that overlies a basement of much denser Precambrian rocks. Because gravity is directly related to mass, changes in thickness of the fill produce subtle anomalies in the earth's gravity field. If these subtle anomalies can be properly interpreted, they can be used to estimate fill thickness and bedrock topography. The gravity method could not be used to differentiate between Quaternary and Cretaceous deposits or between aquifer (sand and gravel) and non-aquifer (till and clay) materials.

Seismic refraction surveys were conducted by the MDNR for two buried valleys in western Rock County to differentiate between the Quaternary and Cretaceous deposits filling these valleys prior to the start of test drilling in August 1994. Four seismic lines were made between Beaver Creek and Valley Springs across the east-west trending buried valley that enters Rock County near Valley Springs, South Dakota. Two seismic lines were made across a north-south trending buried valley extending to the north from Beaver Creek. The seismic refraction surveys provided estimates of depths to the top of and thicknesses of the Quaternary and Cretaceous deposits for the two buried valleys and were used to guide the placement of test holes. No existing test holes or well borings were known to penetrate the entire thickness of the Quaternary and Cretaceous deposits in Rock County in the buried valleys prior to the test drilling done for this study.

Transmissivity and horizontal hydraulic conductivity was estimated from slug tests conducted for this study at three wells screened in the Split Rock Creek aquifer. Slug tests were conducted and the results analyzed using methods described by Bouwer and Rice (1976), Bouwer (1989), and Cooper and others (1967). Butler and others (1996) discuss some potential problems with slug tests and propose a series of guidelines for the design, performance, and analysis of slug tests. Specific-capacity information available from well logs for one well screened in a confined drift aquifer and for one well screened in an undifferentiated Cretaceous aquifer was used to estimate horizontal hydraulic conductivity for the aquifers using a method described by Heath (1983, p. 60-61).

Depth to static water levels were measured in 13 domestic, municipal, and observation wells during November 1995 to determine hydraulic heads and ground-water flow directions in confined drift and bedrock aquifers in buried valleys in the study area. Five of the 13 wells were screened in confined drift aquifers, three were screened in the undifferentiated Cretaceous aquifers, and five were screened in the Split Rock Creek aquifer.

Water samples were collected from eight wells during September through November 1995 and analyzed for common cations and anions to determine the general water-quality characteristics of the confined drift and bedrock aquifers in buried valleys in the study area. Three of the eight wells were screened in confined drift aquifers, two were screened in undifferentiated Cretaceous aquifers, and three were screened in the Split Rock Creek aquifer. Water samples were analyzed at the U.S. Geological Survey Laboratory in Arvada, Colorado.

Acknowledgments

The author is grateful to well owners, well drillers, and State and local agencies for data used in preparing this report. Thanks also to land owners who permitted the drilling of test holes and the installation of observation wells, and to well owners who permitted sampling of their wells and measurement of water levels. Special thanks to Dale Setterholm, Minnesota Geological Survey, for providing geologic information and for providing geophysical logging of the test holes. Special thanks also to Val Chandler, Minnesota Geological Survey, and to Stan Pence, South Dakota Geological Survey, for providing geologic information.

GEOLOGIC SETTING

Most of Rock County is underlain by the Precambrian Sioux Quartzite, an Early Proterozoic quartz arenitic redbed sequence that crops out extensively in southwestern Minnesota and adjoining parts of South Dakota, Nebraska, and Iowa (Chandler, 1994). Besides quartzite, the formation also includes minor conglomerates and thin layers of argillite (Southwick and others, 1986). Gentle dips (generally less than 10 degrees) in the quartzite define a circular subbasin in the quartzite outcrop area of northern Rock County (Chandler, 1994). In the outcrop areas the quartzite is typically well cemented by interstitial quartz, and forms resistant ridges that are glacially scoured and wind-polished. On the basis of stratigraphy and projected dips, Baldwin (1951) estimated a maximum thickness for the Sioux Quartzite in Rock County of 1.0-1.5 mi. Highly deformed gneissic and supracrustal rocks of Archean or Early Proterozoic age are believed to underlie the Sioux Quartzite, and some of these rocks may subcrop in the extreme northeastern corner of Rock County (Chandler, 1994).

The Precambrian rocks are partially overlain by the Upper Cretaceous Split Rock Creek Formation, a near-shore marine facies associated with embayments in the Sioux Quartzite Ridge along the eastern margin of the

Cretaceous Western Interior seaway (Setterholm, 1990; Ludvigson and others, 1981). The Split Rock Creek Formation represents the transgressive sequence of sediment deposited in embayments in the Sioux Quartzite Ridge as Cretaceous seas encroached upon South Dakota, Minnesota, and Iowa (Suzanne Kairo, Purdue University, written commun., 1987). Weathering and deterioration of the exposed irregular surface of the Sioux Quartzite over an extended time prior to the Cretaceous Period resulted in the deposition of a rounded quartzite sand in paleotopographic lows. The Split Rock Creek Formation consists of these sand deposits interbedded with organic rich clays and coals in some places. The Split Rock Creek Formation ranges in thickness from less than 1 to 400 ft (Chandler, 1994). Quartz arenite and gray claystone that form the lower part are overlain by a thinner upper unit consisting chiefly of spiculite (a rock unit composed almost wholly of sponge spicules). The Split Rock Creek Formation laps onto the Sioux Quartzite Ridge.

The Split Rock Creek Formation in Rock County is overlain by undifferentiated Cretaceous deposits consisting of interbedded claystone, siltstone, and sandstone. The undifferentiated Cretaceous deposits may include facies of the Carlile Shale, Graneros Shale, and Greenhorn Formation (Dale Setterholm, Minnesota Geological Survey, oral commun., 1996).

All of the Cretaceous rocks and much of the Sioux Quartzite in Rock County are covered by unconsolidated Quaternary till and outwash, the old gray drift of pre-Illinoian age (Hobbs and Goebel, 1982). The old gray drift, which may actually include several till sequences, has a well-dissected surface that is commonly covered by loess (Patterson, 1993). In Rock County, the Quaternary deposits range in thickness from less than 1 to 400 ft, with the thickest parts present in the southern and eastern parts of the county (Setterholm, 1990).

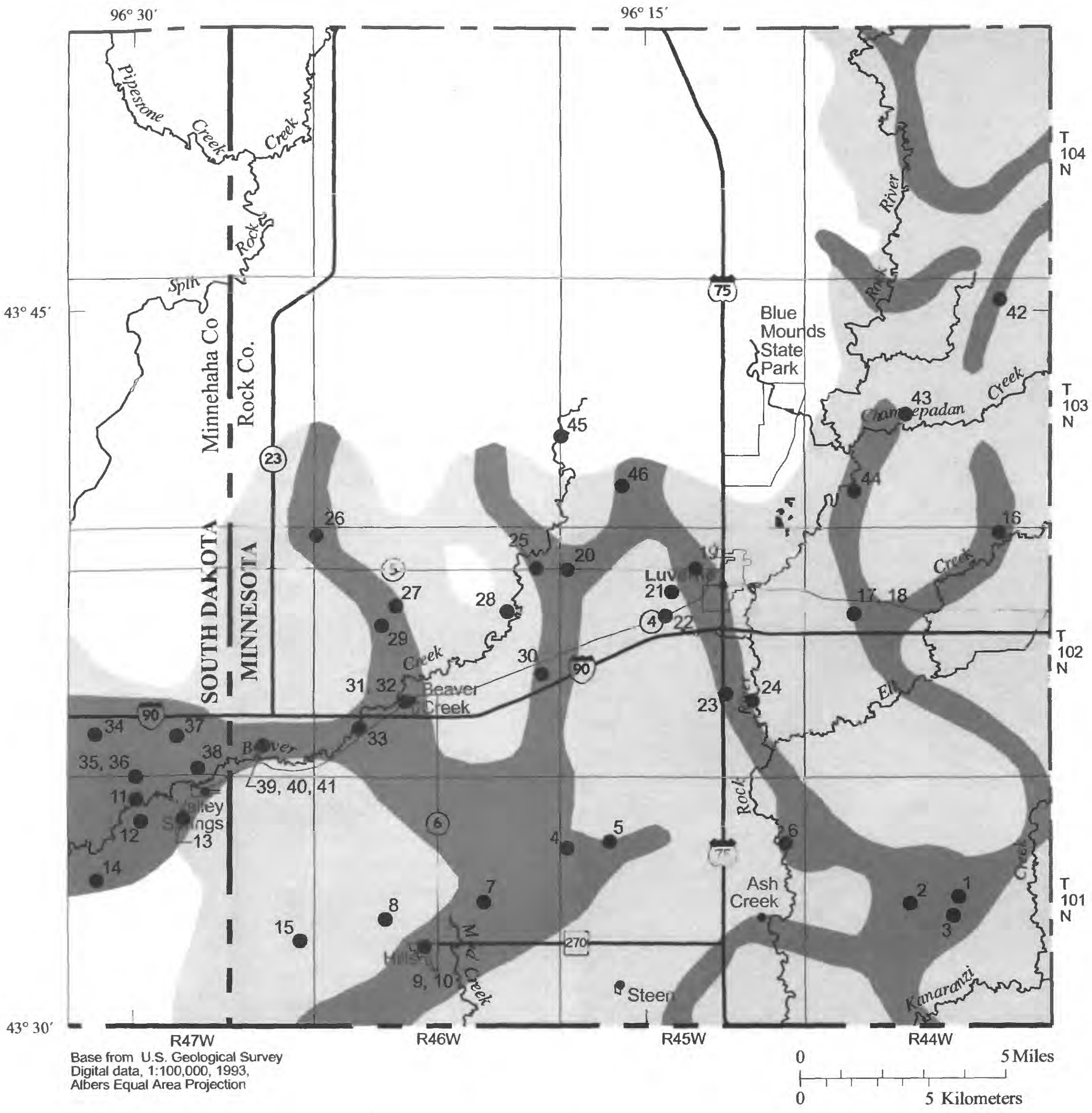
Gravity surveys conducted in Rock County by Chandler (1994) indicate the presence of buried valleys trending to the south and east away from the erosionally resistant topographic high in the Precambrian surface, hereinafter termed the Sioux Quartzite high, in northwestern and north-central Rock County. The Sioux Quartzite high (a portion of the regional Sioux Qaurtzite Ridge) corresponds to the area in northwestern and north-central Rock County shown in figure 2 where the Sioux Quartzite is at or near land surface and Cretaceous deposits are absent. In southwestern, southeastern, and northeastern Rock County, the combined thickness of the Quaternary and Cretaceous deposits filling the buried valleys is interpreted to exceed 600 ft (Chandler, 1994). The thick Quaternary and Cretaceous deposits filling the buried valleys in southwestern Rock County connect with a buried channel in South Dakota that has been referred to as the Brandon Embayment (Suzanne Kairo, Purdue University, written commun., 1987). The Brandon Embayment is a depression in the Precambrian surface, with the deepest part more than 500 ft below the quartzite outcrop areas around the perimeter of the embayment (L.D. Putnam, U.S. Geological Survey, written commun., 1996). The embayment includes the entire trough along the northern part of T. 101 N., R. 47 W. and the southern part of T. 102 N.,R. 47 W. The Brandon Embayment in the southeastern part of Minnehaha County contains thick sand deposits of the Split Rock Creek Formation. The Split Rock Creek Formation in the Brandon Embayment is described by Tomhave (1994) as consisting of up to 240 ft of fine- to medium-grained pink sand.

HYDROGEOLOGY

The 400- to 700-ft thick fill along the irregular and locally abrupt southern margin of the Sioux Quartzite high in northwestern and north-central Rock County provides a favorable environment for aquifers. Channels that incised the quartzite here probably provided drainage for the quartzite highlands to the north, during both Cretaceous and Quaternary Periods. Therefore, parts of these channels may contain significant deposits of sand and gravel. By the same reasoning, the relatively minor channels cut into the eastern and western margins of the Sioux Quartzite high may also contain sand and gravel.

Two aquifers have been identified in South Dakota within the Quaternary and Cretaceous deposits filling the Brandon Embayment in southeastern Minnehaha County (Lindgren and Niehus, 1992). The Valley Springs aquifer is a confined drift aquifer composed of fine to coarse sand and fine to medium pebble gravel with 5- to 10-foot thick layers of interbedded silty clay and till in some areas. The city of Valley Springs derives its water supply from the Valley Springs aquifer. The Split Rock Creek aquifer is a Cretaceous bedrock aquifer composed of fine-to coarse-grained, well-sorted quartzose sand derived from erosion of the underlying Sioux Quartzite. The Split Rock Creek Formation consists of layers of sand and, typically, are interbedded with layers of siltstone and claystone. Test drilling and analysis of existing geologic logs were conducted for this study to determine whether or not these confined drift and Cretaceous bedrock aquifers present in Minnehaha County, South Dakota are also present in similar geologic settings in Rock County, Minnesota.

Hydrogeologic units present within buried-valley deposits in Rock County include unconfined and



EXPLANATION

(white)	Area where Sioux Quartzite is at or near land surface
(light gray)	Maximum probable extent of Cretaceous rocks. Boundary in Rock County from Chandler (1994), in Minnehaha County from Tomhave (1994).
(dark gray)	Buried valley. Modified from Chandler (1994).
●4	Aquifer-thickness data site and identification label.

Figure 2. Areas where Sioux Quartzite is at or near land surface, maximum probable extent of Cretaceous rocks, extent of buried valleys, and aquifer-thickness data sites.

confined drift aquifers, undifferentiated Cretaceous aquifers, the Split Rock Creek aquifer, and interbedded confining units (fig. 3). Within the glacial deposits, there is a complex layering of glacial tills (confining units) and meltwater deposits (aquifers). The meltwater deposits consist primarily of sand and gravel. Some of these meltwater deposits are exposed at land surface (unconfined aquifers). Other meltwater deposits were buried by till deposited at a later time (confined aquifers).

The glacial deposits are underlain by Cretaceous bedrock, including the undifferentiated Cretaceous aquifers and the Split Rock Creek aquifer, except in the northwestern and north-central parts of Rock County where the Sioux Quartzite is at or near land surface and Cretaceous deposits are absent. The undifferentiated Cretaceous aquifers consist of sandstone layers within interbedded claystone and siltstone overlying the Split Rock Creek Formation or Sioux Quartzite. The Split Rock Creek Formation, consisting of sand units (comprising the Split Rock Creek aquifer) and interbedded layers of siltstone and claystone, is present in buried valleys incised in the Sioux Quartzite surface in southern and possibly northeastern Rock County. The Split Rock Creek aquifer is referred to as a single aquifer, but actually consists of multiple disconnected layers of sand, as shown in figure 3. The available hydraulic head information, however, indicates that water levels in wells screened in different sand layers are similar. Also, in many areas the layers of siltstone and claystone separating the sand layers are thin and discontinuous.

Confined Drift Aquifers

Confined drift aquifers with thicknesses greater than 5 ft were penetrated in 6 of the 10 test holes drilled for this study (table 1, fig. 2). Geologic logs from the files of the MGS indicated that 11 domestic wells and 4 municipal wells in Rock County were screened in confined drift aquifers within or near buried-valley deposits. The towns of Beaver Creek and Hills withdraw water from wells screened in confined drift aquifers for municipal supplies. Single-layer thicknesses of the confined drift aquifers in Rock County range from at least 2 to greater than 32 ft. Most of the supply wells screened in the confined drift aquifers do not penetrate the full thicknesses of the aquifers, resulting in uncertainties in aquifer thickness. Multiple glacial sand layers in a vertical sequence, probably comprising multiple aquifers, are present at some locations (table 1, fig. 2). The greatest number of confined drift aquifers are present near the southern and eastern margins of the Sioux Quartzite high (table 1, fig. 2), probably due to a high-energy depositional environment in these areas. The frequency of confined drift aquifers within or near buried-valley deposits is less in southern Rock County (T. 101 N.) farther from the Sioux Quartzite high where the bedrock valleys are less well defined and the depositional environment was of lower energy (Dale Setterholm, Minnesota Geological Survey, oral commun., 1996). About 47 percent of the test holes or well borings in T. 101 N. penetrated a confined drift aquifer, compared to about 68 percent of the test holes or well borings in T. 102 N. and T. 103 N. (table 1). Areally persistent confined drift aquifers at similar altitudes are present in southwestern Rock County from east of the town of Beaver Creek extending southwestward to near the town of Valley Springs (fig. 1, fig. 3 cross-section A-A'). These aquifers may be in hydraulic connection with each other and with the Valley Springs aquifer previously identified in South Dakota by Lindgren and Niehus (1992).

Specific-capacity information was available for one well screened in a confined drift aquifer (fig. 4, table 2). The estimate for horizontal hydraulic conductivity derived from specific-capacity information was 73 ft/d. Transmissivity could not be estimated because the well boring did not penetrate the entire aquifer thickness. Delin (1988) reported that horizontal hydraulic conductivities for confined drift aquifers in the Brooten-Belgrade area in west-central Minnesota ranged from about 10 to 750 ft/d, and transmissivities ranged from 500 to 3,000 ft^2/d.

Lindgren and Niehus (1992) reported that yields from properly-constructed wells screened in the Valley Springs aquifer in Minnehaha County, South Dakota may be as much as 200 gal/min in the northern part of the aquifer, but generally are less than 10 gal/min in the south-central part where the thickness is less than 10 ft. The water yielding potential from the confined drift aquifers present in buried-valley deposits in Rock County appears to be greatest in the southwestern part of the county from east of the town of Beaver Creek extending southwest to near the town of Valley Springs, where areally persistent confined drift aquifers at similar altitudes are present. Existing municipal and domestic wells currently withdraw water from confined drift aquifers in this area.

Recharge to ground water is predominantly by infiltration of precipitation that percolates downward to the saturated zone. Recharge to confined drift aquifers occurs by the vertical movement of water through confining units. Recharge to confined drift aquifers is greatest where (1) the confining unit is thin, or (2) the vertical hydraulic conductivity of the confining unit material is comparatively high (sandy or highly-fractured till). Stark and others (1991) reported long-

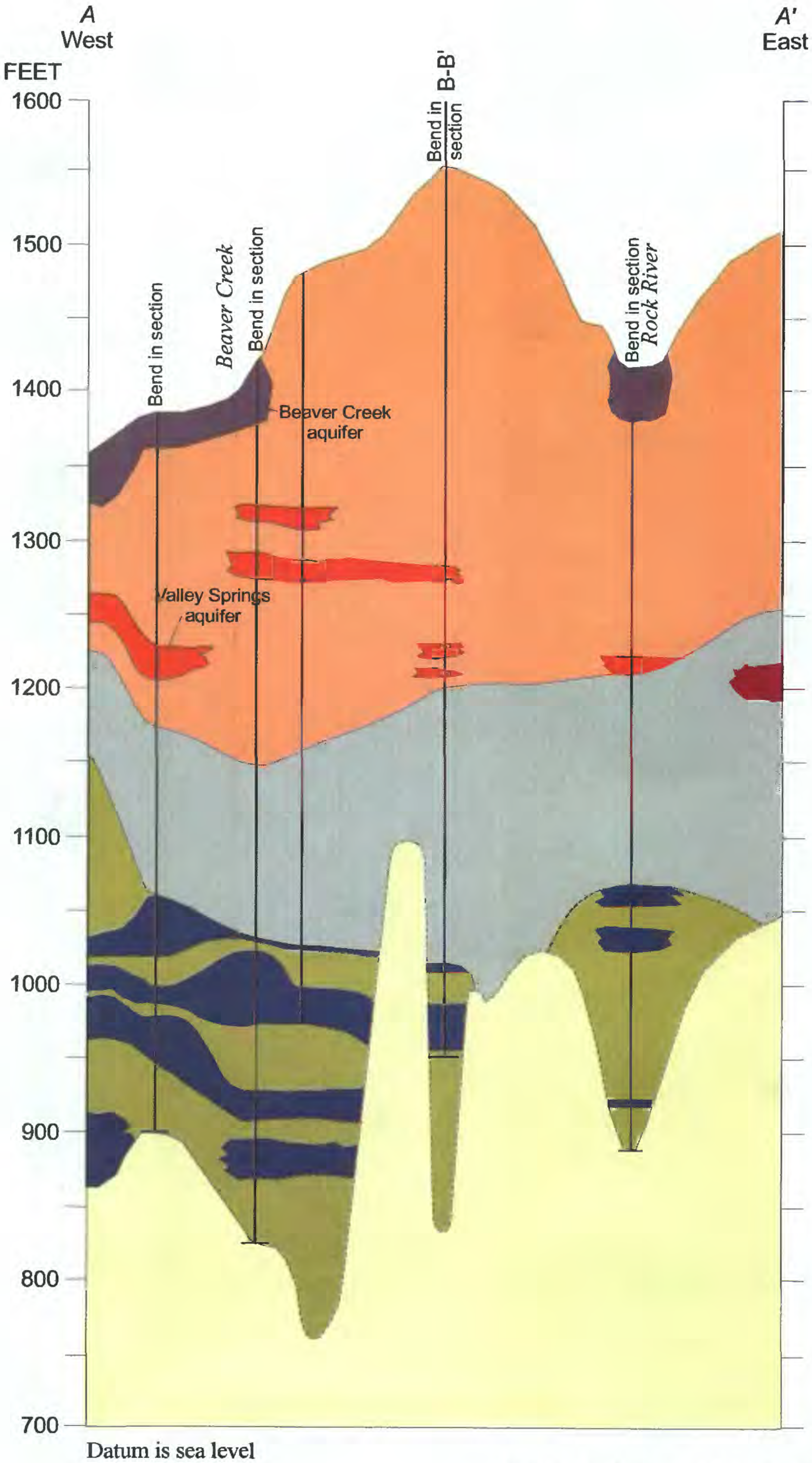
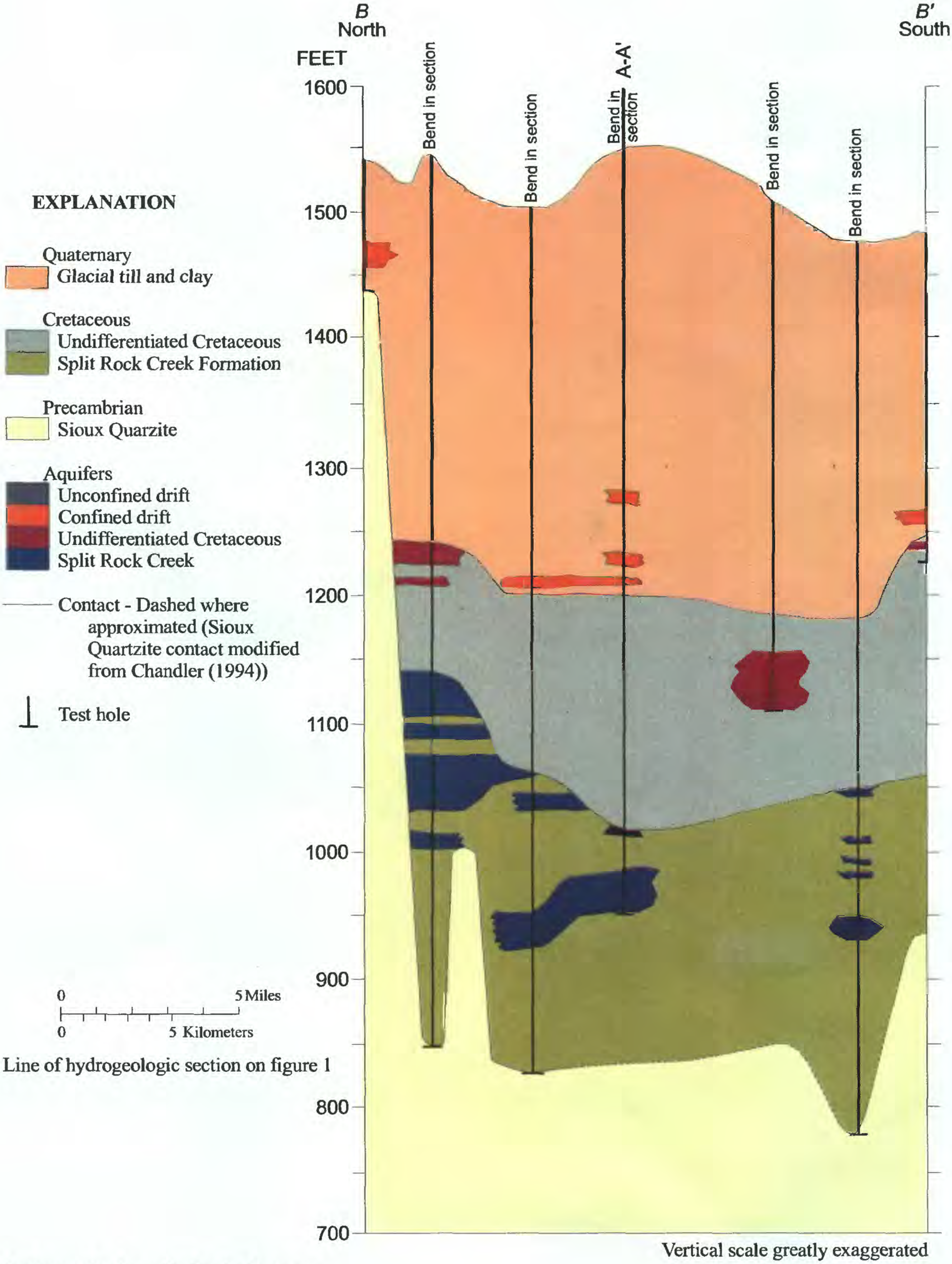


Figure 3. Hydrogeologic sections showing



hydrogeologic units in study area.

Table 1.—Thicknesses of confined drift, undifferentiated Cretaceous, and Split Rock Creek aquifers

[Aquifer thickness is in feet. Number in parentheses is number of sand layers, if more than one. (+) indicates full thickness of aquifer was not penetrated by test hole or well boring. (?) indicates aquifer designation of sand layer is uncertain]

Identification label (figure 2)	Location	Cumulative sand thickness		
		Confined drift aquifer	Undifferentiated Cretaceous aquifer	Split Rock Creek aquifer
1	101N44W15DDDABA			2+
2	101N44W21AABBCA	4+		
3	101N44W22ADBDBD			12 (3)
4	101N45W07CBCCAC		46+	
5	101N45W08CBBACD	28+		
6	101N45W12DBADAD			31 (3)
[1]7	101N46W14CDDDDC			40 (5)
8	101N46W20ADDACA	8+		
9	101N46W28AAACBC	11	6	
10	101N46W28ABABAA	12		
11	101N47W05DAAAAA			37 (3)
12	101N47W08AAAAAA	6		78 (2)
13	101N47W09AAAAAA	11		105
14	101N47W18DAAAAA			114 + (2)
15	101N47W24DDCADD		7+	
16	102N44W02AAADCD	2+		
17	102N44W17BAAACA		25+	
18	102N44W17BAADBB	7		
[2]19	102N45W03DCCCDC			26 (2)
20	102N45W07BAABAC	14+		
21	102N45W09DAAADB	32+		
22	102N45W16AABDCC	9+		
[1]23	102N45W23CCDCCD	13		
				44 (3)
24	102N45W26AADABC	15 + (2)		
[1]25	102N46W01DCDDDD	7		49 (3)
[1]26	102N46W06BBABAA		?5	
27	102N46W09CCADDB	5+		
28	102N46W14AAAABB	7		
			17 (2)	
[1]29	102N46W17ADADAA	33 (2)		
				50 (4)
[2]30	102N46W24DABBBA	15 (3)		
				38 (2)
31	102N46W28BADBDA	30 (2)		
32	102N46W28BDAAAD			25+
[1]33	102N46W29CDAACB	30 (2)		
				110 (6)
34	102N47W29CCCCCC			53

Table 1.—Thicknesses of confined drift, undifferentiated Cretaceous, and Split Rock Creek aquifers--Continued

Identification label (figure 2)	Location	Cumulative sand thickness		
		Confined drift aquifer	Undifferentiated Cretaceous aquifer	Split Rock Creek aquifer
35	102N47W32DCCCCC01	26 (2)		
36	102N47W32DCCCCC02			168 (3)
37	102N47W33AAAAAA	25		
				88
38	102N47W34CCCCCB	18		
				105 (5)
[1]39	102N47W35AADDDA			91 (3)
40	102N47W35AADDDC01	18		
41	102N47W35AADDDC02			81 (6)
42	103N44W02ADDDDC	5		
43	103N44W21ACABAC		30	
44	103N44W32BBBCDB	24 + (2)		
45	103N45W19CCADAA	22		
[2]46	103N45W32ABAAAA		27 (2)	
				128.5(5)

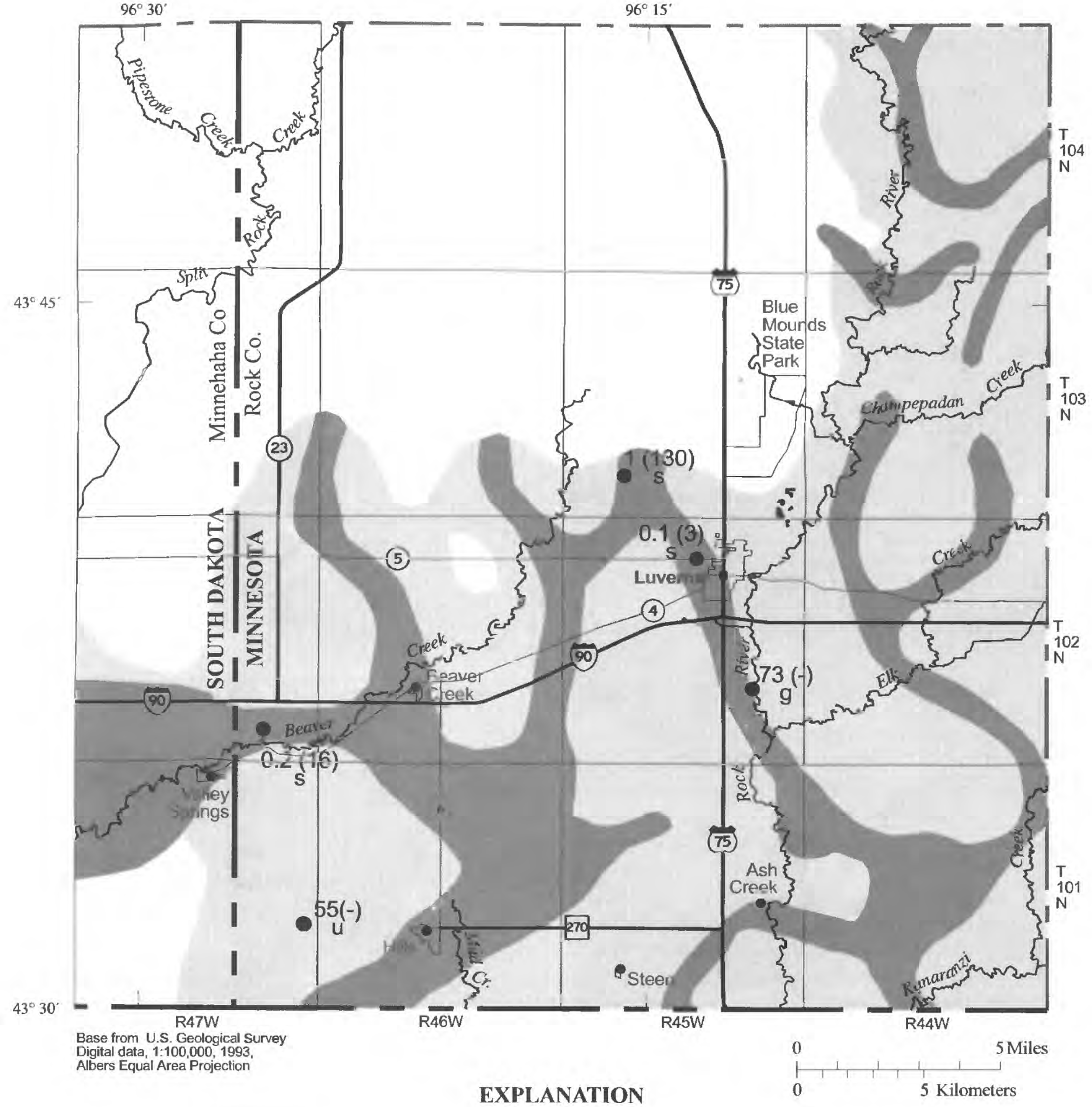
[1]Test hole drilled for this study.
[2]Well installed for this study.

term average recharge rates in the Bemidji-Bagley area in north-central Minnesota of (1) 4 to 8 in./yr in areas where sandy Wadena lobe (Hewitt) till is exposed at land surface, and (2) 0 to 4 in./yr in areas where clayey Des Moines lobe till is exposed at land surface. Leakage rates through till of 0.06 to 1.60 in./yr were computed at nine sites in the Brooten-Belgrade area in west-central Minnesota by Delin (1988). Delin (1990) reported that recharge rates of 0 to 2.5 in./yr in areas where the thickness of glacial deposits is greater than 100 ft produced the best match between measured and simulated hydraulic heads in the Rochester area in southeastern Minnesota.

Recharge to the confined drift aquifers may also be derived from hydraulic connection to the Sioux Quartzite aquifer as infiltrated precipitation moves through the fractures and joints of the Sioux Quartzite in areas where the confined drift aquifers abut or are in close proximity to the sides of the buried valleys incised in the Sioux Quartzite surface. Lindgren and Niehus (1992, p. 58) indicated that recharge to a confined drift aquifer in Minnehaha County, South Dakota is from movement of water through fractures in the Sioux Quartzite and then into the directly overlying confined drift aquifer.

Discharge from the confined drift aquifers in Rock County is primarily to domestic and municipal wells. Some discharge from the confined drift aquifers may occur by downward leakage to underlying aquifers. The confined drift aquifer penetrated at 101N46W28ABABAA (site 10 on fig. 2) is separated from the underlying undifferentiated Cretaceous aquifer by 18 ft of till and clay. Lindgren and Niehus (1992) reported that the Valley Springs aquifer may discharge to the underlying Split Rock Creek aquifer, particularly near the northwest corner of T. 101 N., R. 47 W.

Depths to static water levels were measured in five wells screened in confined drift aquifers within or near buried-valley deposits (fig. 5). The five-point measurements indicate that the general directions of flow in the aquifers are to the south and west (high to low water-level elevations). In southwestern Rock County the direction of flow is to the west (fig. 5). This flow direction is consistent with a southwest direction of ground-water flow for the Valley Springs aquifer reported by Lindgren and Niehus (1992).



EXPLANATION

Area where Sioux Quartzite is at or near land surface

Maximum probable extent of Cretaceous rocks. Boundary in Rock County from Chandler (1994), in Minnehaha County from Tomhave (1994).

Buried valley. Modified from Chandler (1994).

● 0.2 (16) s — Specific-capacity or slug test site. Number indicates horizontal hydraulic conductivity in ft /d. Number in parentheses is transmissivity in ft^2/d "-" indicates that well borehole did not penetrate full thickness of aquifer; "g" indicates confined drift aquifer; "u" indicates undifferentiated Cretaceous aquifer; "s" indicates Split Rock Creek aquifer.

Figure 4. Slug-test and specific-capacity information sites and horizontal hydraulic conductivity and transmissivity values for confined drift, undifferentiated Cretaceous, and Split Rock Creek aquifers.

Table 2.--Hydraulic properties of confined drift, undifferentiated Cretaceous, and Split Rock Creek aquifers

[ft/d. feet per day; ft^2/d. feet squared per day; --. transmissivity cannot be calculated because well boring did not penetrate full thickness of aquifer.]

Location (aquifer)	Type of test	Horizontal hydraulic conductivity (ft/d)	Transmissivity[1] (ft^2/d)	Transmissivity[2] (ft^2/d)
102N45W26AADABC (confined drift)	Specific-capacity	73	--	--
101N47W24DDCADD (Undifferentiated Cretaceous)	Specific-capacity	55	--	--
102N45W03DCCCDC (Split Rock Creek)	Slug	[3]0.1	3	0.6(28.5)
	Slug	[3]0.2	16	10(42)
103N45W32ABAAAA (Split Rock Creek	Slug	[3]1	130	12(66.5)

[1]Transmissivity calculated as horizontal hydraulic conductivity (calculated using method described by Bouwer and Rice [1976]) multiplied by total aquifer thickness.

[2]Transmissivity calculated using method described by Cooper, Bredehoft, and Papadopulos (1967). The number in parentheses is the thickness of the sand layer that is screened. in feet.

[3]Horizontal hydraulic conductivity calculated using method described by Bouwer and Rice (1976) and Bouwer (1989).

Undifferentiated Cretaceous Aquifers

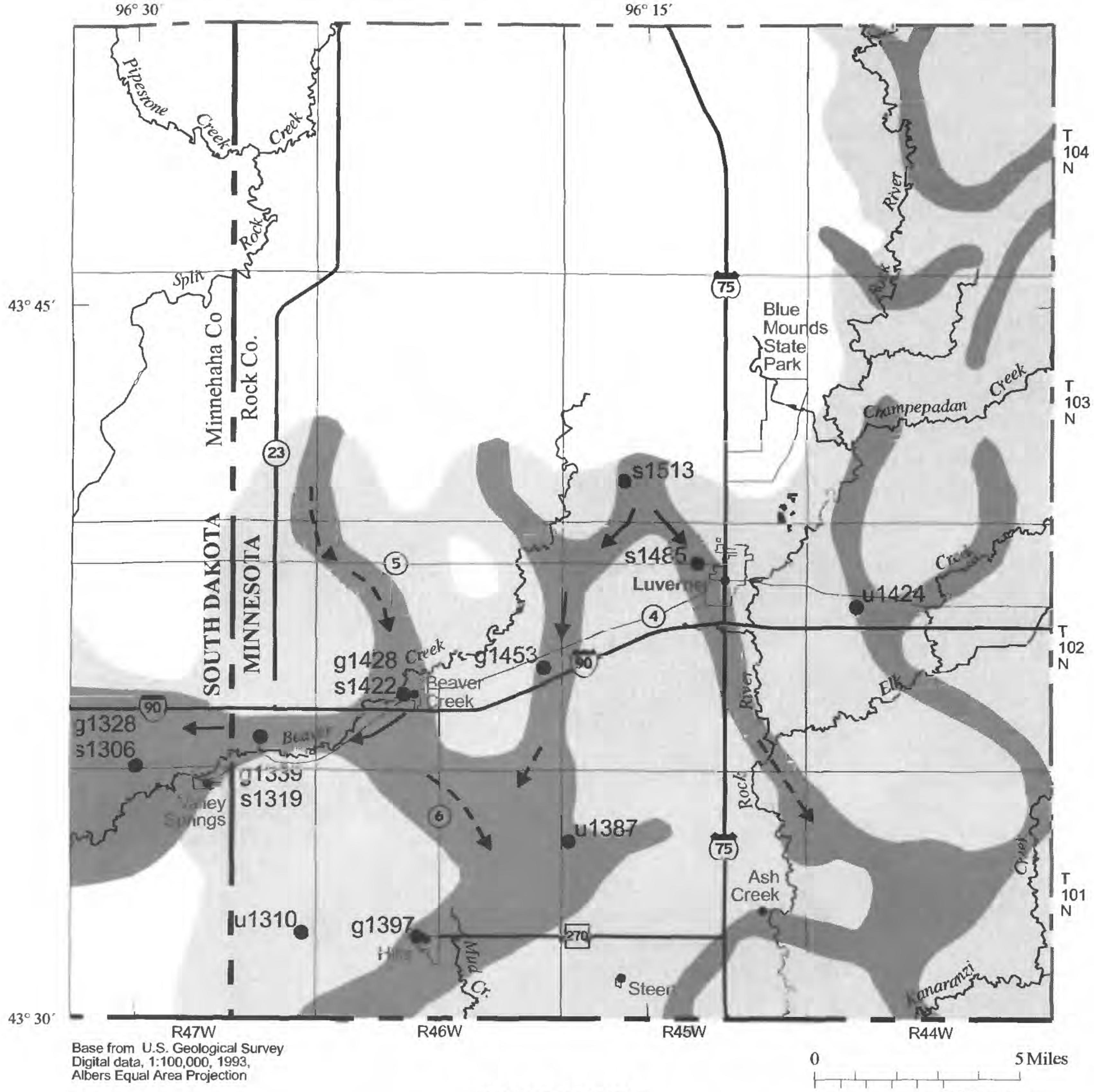
No major (thickness greater than 5 ft) undifferentiated Cretaceous aquifers were penetrated in the 10 test holes drilled for this study. Geologic logs from the files of the MGS indicated that four domestic wells were screened in undifferentiated Cretaceous aquifers in Rock County (fig. 1). Two of the wells were located within the boundaries of the buried valleys and two were located in areas outside the buried valleys (fig. 2). Thicknesses of the undifferentiated Cretaceous aquifers range from at least 7 ft to greater than 46 ft (table 1. fig. 2). The available information is insufficient to determine any areal patterns in the distribution and thicknesses of the aquifers.

Specific-capacity information was available for one well screened in an undifferentiated Cretaceous aquifer (fig. 4, table 2). The estimate for horizontal hydraulic conductivity derived from specific-capacity information was 55 ft/d. Transmissivity could not be estimated because the well boring did not penetrate the entire aquifer thickness. The water yielding potential from undifferentiated Cretaceous aquifers present in buried-valley deposits in Rock County appears to be minimal; no aquifer thickness greater than 5 ft was penetrated in the 10 test holes drilled for this study.

Recharge to the undifferentiated Cretaceous aquifers is by leakage of water through confining units from overlying confined drift aquifers. Recharge to the undifferentiated Cretaceous aquifers may also be derived from hydraulic connection to the laterally adjacent Sioux Quartzite aquifer as infiltrated precipitation moves through the fractures and joints of the Sioux Quartzite (fig. 3, section B-B'). Discharge from the undifferentiated Cretaceous aquifers is to domestic wells and possibly to the underlying Split Rock Creek aquifer.

Depths to static water levels were measured in three wells screened in undifferentiated Cretaceous aquifers (fig. 5). The three water-level measurements indicate that the regional direction of flow in the aquifers is probably to the south and southeast away from the Sioux Quartzite high. Similarly, Woodward and Anderson (1986) reported that regional ground-water flow in the Cretaceous aquifer in southwestern Minnesota is southward and eastward away from the Sioux Quartzite Ridge

During the test drilling of 102N47W35 (sites 39 and 41, fig. 2) there was a flow to the land surface (hydraulic head greater than land elevation). The flow was from a hard black shale in the upper part of the undifferentiated Cretaceous deposits. The hard black shale was 37 ft thick, beginning at an altitude of about 1,175 ft. A hard black shale in the upper part of the undifferentiated Cretaceous deposits was penetrated in five of the other test holes drilled for this study. However, the shale unit did not produce flow and did not appear to be water-bearing at any other location. Also, no supply wells are known to be screened in this unit in Rock County or in Minnehaha County, South Dakota. Therefore, the unit is not considered a major aquifer.



EXPLANATION

Area where Sioux Quartzite is at or near land surface

Maximum probable extent of Cretaceous rocks. Boundary in Rock County from Chandler (1994), in Minnehaha County from Tomhave (1994).

Buried valley. Modified from Chandler (1994).

Generalized direction of ground-water flow in Split Rock Creek aquifer. Dashed where inferred.

u1387 Water-level measurement site. Number indicates water-level altitude, in feet above sea level; "g" indicates confined drift aquifer; "u" indicates undifferentiated Cretaceous aquifer; "s" indicates Split Rock Creek aquifer.

Figure 5. Water levels in confined drift, undifferentiated Cretaceous, and Split Rock Creek aquifers, November 1995, and directions of ground-water flow in the Split Rock Creek aquifer.

Split Rock Creek Aquifer

The Split Rock Creek aquifer in Minnehaha County, South Dakota consists of fine- to coarse-grained, well-sorted quartzose sand (Lindgren and Niehus, 1992). The test holes drilled for this study indicated that the Split Rock Creek aquifer in Rock County consists of finer-grained sand, predominantly very fine to fine sand. All but one of the 10 test holes penetrated the Split Rock Creek aquifer. Geologic logs from the files of the MGS indicated that three domestic wells and one municipal well were screened in the Split Rock Creek aquifer in Rock County (fig. 1). The town of Beaver Creek uses a well screened in the Split Rock Creek aquifer as a backup water supply.

Cumulative sand thicknesses for the Split Rock Creek aquifer in the 10 test holes drilled for this study ranged from zero to 128.5 ft (table 1, fig. 2). The number of Split Rock Creek aquifer sand layers penetrated in the test holes ranged from 2 to 6, excluding the test hole where no Split Rock Creek Formation material was penetrated. The test hole at 102N46W06BBABAA (site 26, fig. 3), where no Split Rock Creek Formation material was penetrated, may have been drilled outside the boundaries of the buried valley or may have encountered a large quartzite boulder and the Sioux Quartzite surface may not have been reached. The largest cumulative sand thickness penetrated by the four domestic and municipal wells was 31 ft. None of the domestic and municipal well borings penetrated the entire thickness of the Split Rock Creek Formation. The Split Rock Creek aquifer is greater than 90 ft thick northwest of Luverne and between the town of Beaver Creek and the Minnesota-South Dakota State line (table 1, fig. 2). The cumulative sand thicknesses for the Split Rock Creek aquifer for the rest of Rock County were generally smaller than the cumulative sand thicknesses for the Split Rock Creek aquifer in the Brandon Embayment in South Dakota (table 1, fig. 2). The comparatively large cumulative sand thicknesses near the southern margin of the Sioux Quartzite high and in the relatively narrow Brandon Embayment in southeastern Minnehaha County and its extension into Rock County are probably due to a high-energy depositional environment.

Slug tests were conducted for this study at three wells screened in the Split Rock Creek aquifer in Rock County. The estimated horizontal hydraulic conductivities derived from analysis of the slug tests using the method described by Bouwer and Rice (1976) and Bouwer (1989) were 0.1, 0.2, and 1 ft/d (table 2; fig. 4). The corresponding aquifer transmissivities, calculated as the horizontal hydraulic conductivity multiplied by the cumulative sand thickness, were 3, 16, and 130 ft^2/d. Transmissivities derived from analysis of the same three slug tests using the method described by Cooper and others (1967) were 0.6, 10, and 12 ft^2/d for screened sand layers 28.5, 42, and 66.5 ft thick, respectively (table 2). The range of transmissivities determined from six aquifer tests conducted in Minnehaha County ranged from 600 to 5,700 ft^2/d with the most common value around 3,000 ft^2/d (Stan Pence, South Dakota Geological Survey, written commun., 1996). Transmissivity values of 200 to 12,700 ft^2/d with a mean of 2,100 ft^2/d were used in a numerical ground-water-flow model constructed to simulate flow in the Split Rock Creek aquifer in southeastern Minnehaha County and R. 47 W. in Rock County (L.D. Putnam, U.S. Geological Survey, written commun., 1996).

The transmissivity values derived from slug tests for the Split Rock Creek aquifer in Rock County were lower than the transmissivity values derived from aquifer tests for the Split Rock Creek aquifer in Minnehaha County, probably due to the finer grain size of the aquifer material (very fine- to fine-grained sand compared to the medium-grained sand for much of the aquifer in Minnehaha County). However, slug-test results and aquifer-test results may not be directly comparable. Slug-test results represent aquifer material in the immediate vicinity of a borehole, whereas aquifer tests represent aquifer material in a larger area surrounding the borehole. Estimated transmissivities derived from aquifer tests are probably more representative of the aquifer as a whole.

The greatest horizontal hydraulic conductivity and transmissivity estimates derived from the three slug tests in Rock County were the site 103N45W32ABAAAA (site 46, fig. 2) near the Sioux Quartzite high. This site has a greater cumulative sand thickness and coarser-grained aquifer material than the other two sites. The water-yielding potential of the Split Rock Creek aquifer in Rock County is generally limited by the low transmissivity of the aquifer due to the fineness of the aquifer material (generally very fine- to fine-grained sand). The water-yielding potential is greatest near the southern margin of the Sioux Quartzite high and in the extension of the Brandon Embayment eastward in to Rock County.

Most recharge to the Split Rock Creek aquifer is thought to be derived from infiltration of precipitation through fractures and joints of the Sioux Quartzite. Lindgren and Niehus (1992) reported that recharge to the Split Rock Creek aquifer in Minnehaha County, South Dakota is from infiltration of precipitation that falls on Sioux Quartzite outcrops and subsequently moves through fractures in the quartzite and into the Split Rock Creek aquifer. The recharge area for the Sioux Quartzite in Rock County probably is in the northern and western parts of the county (fig. 3, section B-B'), where the Sioux Quartzite outcrops or is overlain by thin permeable sediments. Inflow to the Split Rock Creek aquifer from the Sioux Quartzite probably occurs near the buried-valley boundaries where the Split Rock Creek aquifer abuts the steeply-dipping buried-valley walls (fig. 3, section A-A'). Recharge to the Split Rock Creek aquifer may also occur by downward leakage from undifferentiated Cretaceous aquifers. The aquifer may also receive recharge from the Valley Springs aquifer in Minnehaha County (Lindgren and Niehus, 1992, p. 62).

Discharge from the Split Rock Creek aquifer in Rock County is to domestic and municipal wells. Discharge from the aquifer probably also occurs as subsurface flow to the Sioux Quartzite or permeable deposits overlying the Sioux Quartzite.

The Sioux Quartzite is a source of both recharge to and discharge from the Split Rock Creek aquifer. Ground water moves from the Sioux Quartzite into the Split Rock Creek aquifer at the upgradient (for the potentiometric surface of the Sioux Quartzite aquifer) side of a buried valley. Ground water moves from the Split Rock Creek aquifer into the Sioux Quartzite at the downgradient side of a buried valley. Regional ground-water flow in the Sioux Quartzite in Minnehaha County, South Dakota and western Rock County is to the south and southwest following the regional dip of the quartzite with alterations by hydraulic connections to alluvial aquifers overlying the valleys in the quartzite (L.D. Putnam, U.S. Geological Survey, written commun., 1996).

Depths to static water levels were measured in five wells screened in the Split Rock Creek aquifer (fig. 5). The regional directions of flow in the aquifer are to the south away from the Sioux Quartzite high and to the west in the Brandon Embayment in Minnehaha County and its east-west trending extension into Rock County. Flow directions in eastern Rock County are unknown due to a lack of water-level information, but may be inferred to be to the east and south away from the Sioux Quartzite high. Based on the available water-level measurements, the horizontal hydraulic gradient in the aquifer is about 7 ft/mi near the Sioux Quartzite high and about 2-3 ft/mi in the Brandon Embayment in Minnehaha County and its east-west trending extension into Rock County.

GROUND-WATER QUALITY

The chemical nature of water is determined by the type and quantity of substances dissolved in it. Chemical constituents dissolved in ground water are derived mainly from the materials (soil, unconsolidated materials, and rock) through which water flows; the remainder comes mostly from constituents dissolved in precipitation. Ground-water quality varies in response to changes in residence time, length of flow path, temperature, precipitation, and chemical reactions with geologic materials. Ground-water quality can also be influenced by chemicals introduced by human activity such as direct discharges of chemicals to the ground-water system or nonpoint sources of chemicals related to land-use activities. Chemical constituents that are present naturally in ground water can, in some instances, be the same as those introduced from human activities. For example, most chloride in ground water is dissolved from natural sources; however, elevated concentrations of chloride may be caused by human activities, such as highway deicing, fertilizing, and septic-system drainage. Other chemicals, particularly man-made organic chemicals such as pesticides, herbicides, and solvents, have no naturally occurring source, and can be solely attributed to specific human activities.

The U.S. Environmental Protection Agency (USEPA) has set maximum contaminant levels (MCL's) and secondary maximum contaminant levels (SMCL's) for some constituents in drinking water (U.S. Environmental Protection Agency, 1986) (table 3). MCL's generally are set because elevated concentrations of these constituents may cause adverse health effects. SMCL's generally are set for aesthetic reasons; elevated concentrations of these constituents may impart an undesirable taste or odor to water.

Water samples were collected from domestic, municipal, and observation wells screened in confined drift, undifferentiated Cretaceous, and Split Rock Creek aquifers in Rock County (fig. 6). The ground-water samples were analyzed for common cations and anions to determine the water-quality characteristics of the aquifers.

A description of the water-quality characteristics of ground water includes general properties, concentrations of major and minor constituents, and its suitability for various uses. General properties of water include specific conductance, dissolved solids, pH, alkalinity, and hardness. Specific conductance, pH, and alkalinity are generally determined on site at the time a water sample is taken. Hardness of water is caused by the presence of alkaline earth elements, chiefly calcium and magnesium. Hardness is classified by Durfor and Becker (1964, p. 27) as: soft, 0-60 mg/L; moderately hard, 61-120 mg/L; hard, 121-180 mg/L; very hard, more than 180 mg/L.

Confined Drift Aquifers

Calcium and magnesium are the dominant cations in both unconfined drift and confined drift aquifers in southwestern Minnesota (Ruhl, 1987). Bicarbonate and

Table 3.--Water-quality data for wells screened in confined drift, undifferentiated Cretaceous, and Split Rock Creek aquifers

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; --, not analyzed; field, value determined at sampling site; lab, value determined in a laboratory; MCL, Maximum Contaminant Level established by the U.S. Environmental Protection Agency (1986); SMCL, Secondary Maximum Contaminant Level established by the U.S. Environmental Protection Agency (1986)]

Constituent or property	Confined drift aquifers		
	Location		
	101N46W28ABABAA	102N46W28BADBDA	102N47W35AADDDC01
Specific conductance, field (µS/cm)	2,320	671	722
Specific conductance, lab (µS/cm)	1,930	713	748
pH, field (standard units)	6.8	7.3	7.2
pH, lab (standard units)	7.2	7.4	7.4
Hardness, total (mg/L as $CaCO_3$)	980	310	310
Calcium, dissolved (mg/L)	240	83	86
Magnesium, dissolved (mg/L)	92	24	23
Sodium, dissolved (mg/L)	94	24	27
Sodium adsorption ratio	1	0.6	0.7
Sodium, percent	17	14	15
Potassium, dissolved (mg/L)	9.8	7.9	10
Alkalinity, field (mg/L as $CaCO_3$)	--	329	320
Alkalinity, lab (mg/L as $CaCO_3$)	309	324	316
Sulfate, dissolved (mg/L) (SMCL - 250 mg/L)	850	57	82
Chloride, dissolved (mg/L)	10	2.3	2.2
Fluoride, dissolved (mg/L) (MCL - 4 mg/L) (SMCL - 2 mg/L)	0.2	0.4	0.4
Silica, dissolved (mg/L)	35	57	27
Solids, sum of constituents, dissolved (mg/L) (SMCL - 500 mg/L)	1,520	450	448

Table 3.--Water-quality data for wells screened in confined drift, undifferentiated Cretaceous, and Split Rock Creek aquifers--Continued

Constituent or property	Confined drift aquifers		
	Location		
	101N46W28ABABAA	102N46W28BADBDA	102N47W35AADDDC01
Boron, dissolved µg/L)	440	140	280
Iron, dissolved (µg/L) (SMCL - 300 µg/L)	1,400	81	220
Manganese, dissolved (µg/L) (SMCL - 50 µg/L)	580	500	910
Zinc, dissolved (µg/L) (SMCL - 5 mg/L)	10	15	2.4

Constituent or Property	Undifferentiated Cretaceous aquifers	
	Location	
	101N45W07CBCCAC	101N47W24DDCADD
Specific conductance, field, (µS/cm)	3,500	869
Specific conductance, lab (µS/cm)	3,050	853
pH, field (standard units)	6.8	7.0
pH, lab (standard units)	7.1	7.3
Hardness, total (mg/L as $CaCO_3$)	1,900	430
Calcium, dissolved (mg/L)	440	120
Magnesium, dissolved (mg/L)	190	32
Sodium, dissolved (mg/L)	120	30
Sodium, adsorption ratio	1	0.6
Sodium, percent	12	13
Potassium, dissolved (mg/L)	14	6.2
Alkalinity, field (mg/L as $CaCO_3$)	--	--
Alkalinity, lab (mg/L as $CaCO_3$)	326	316

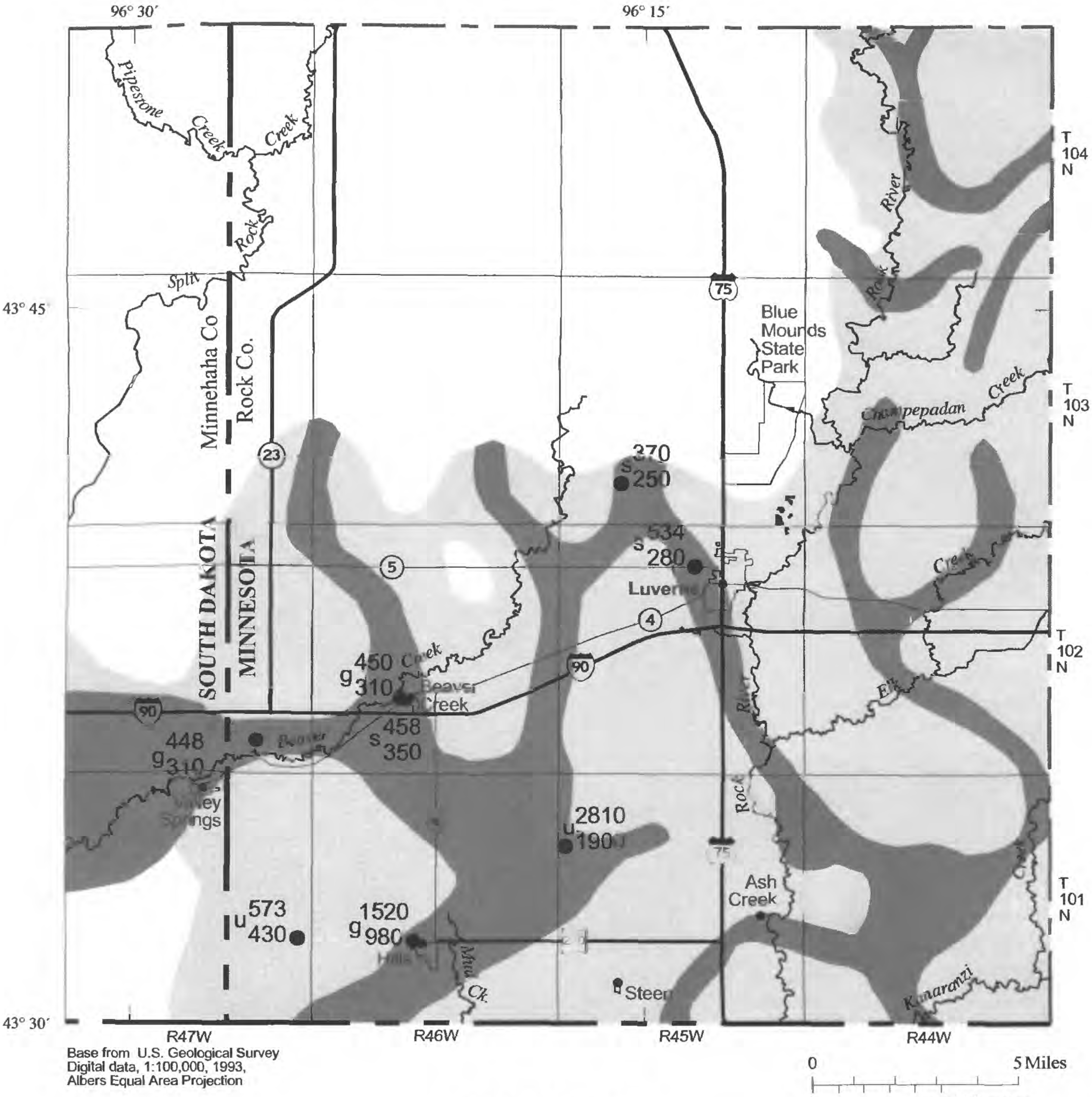
Table 3.--Water-quality data for wells screened in confined drift, undifferentiated Cretaceous, and Split Rock Creek aquifers--Continued

Undifferentiated Cretaceous aquifers		
Constituent or property	Location	
	101N45W07CBCCAC	101N47W24DDCADD
Sulfate, dissolved (mg/L) (SMCL - 250 mg/L)	1,800	170
Chloride, dissolved (mg/L)	7.5	5.4
Fluoride, dissolved (mg/L) (MCL - 4 mg/L) (SMCL - 250 mg/L)	0.1	0.4
Silica, dissolved (mg/L)	27	16
Solids, sum of constituents, dissolved (mg/L) (SMCL - 500 mg/L)	2,810	573
Boron, dissolved (μg/L)	750	180
Iron, dissolved (μg/L) (SMCL - 300 μg/L)	12,000	2,700
Manganese, dissolved (μg/L) (SMCL - 50 μg/L)	520	250
Zinc, dissolved (μg/L) (SMCL - 5 mg/L)	40	10

Split Rock Creek aquifer			
Constituent or property	Location		
	102N46W28BDAAAD	103N45W32ABAAAA	102N45W03DCCCDC
Specific conductance, field (μS/cm)	865	600	852
Specific conductance, lab (μS/cm)	716	600	897
pH, field (standard units)	7.0	7.4	8.6
pH, lab (standard units)	7.2	7.3	8.3
Hardness, total (mg/L as $CaC0_3$)	350	250	280
Calcium, dissolved (mg/L)	96	70	68

Table 3.--Water-quality data for wells screened in confined drift, undifferentiated Cretaceous, and Split Rock Creek aquifers--Continued

Split Rock Creek aquifer			
Constituent or property	Location		
	102N46W28BDAAAD	103N45W32ABAAAA	102N45W03DCCCDC
Magnesium, dissolved (mg/L)	27	19	26
Sodium, dissolved (mg/L)	22	29	67
Sodium adsorption ratio	0.5	0.8	2
Sodium, percent	12	20	33
Potassium, dissolved (mg/L)	7.4	3.0	11
Alkalinity, field (mg/L as $CaC0_3$)	327	182	154
Alkalinity, lab (mg/L as $CaC0_3$)	320	211	163
Sulfate, dissolved (mg/L) (SMCL - 250 mg/L)	85	110	190
Chloride, dissolved (mg/L)	2.0	3.5	69
Fluoride, dissolved (mg/L) (MCL - 4 mg/L) (SMCL - 2 mg/L)	0.4	0.5	0.7
Silica, dissolved (mg/L)	24	19	4.1
Solids, sum of constituents, dissolved (mg/L) (SMCL - 500 mg/L)	458	370	534
Boron, dissolved (µg/L)	170	80	210
Iron, dissolved (µg/L) (SMCL - 300 µg/L)	1,300	11	11
Manganese, dissolved (µg/L) (SMCL - 50 µg/L)	170	110	19
Zinc, dissolved (µg/L) (SMCL - 5 mg/L)	290	6,500	410



EXPLANATION

Area where Sioux Quartzite is at or near land surface

Maximum probable extent of Cretaceous rocks. Boundary in Rock County from Chandler (1994), in Minnehaha County from Tomhave (1994).

Buried valley. Modified from Chandler (1994).

● s 458 / 350 — Water-quality sampling site. Upper value is dissolved-solids concentration, in mg/L. Lower value is hardness concentration, in mg/L. "g" indicates confined drift aquifer; "u" indicates undifferentiated Cretaceous aquifer; "s" indicates Split Rock Creek aquifer.

Figure 6. Water-quality sampling locations and dissolved-solids and hardness concentrations for confined drift, undifferentiated Cretaceous, and Split Rock Creek aquifers.

sulfate are the dominant anions in the unconfined drift and confined drift aquifers, respectively. Sodium chloride, sodium bicarbonate, and sodium sulfate waters are also common locally in southwestern Minnesota (Winter, 1974). Sulfate-type waters are common in the confined drift aquifers of southwestern Minnesota because of the abundance of soluble, sulfur-containing minerals, such as gypsum and pyrite, that react with the ground water to form sulfate ions (Ruhl, 1987). Sources of these minerals are Cretaceous sediments mixed with the younger glacial-drift deposits. The predominant chemical constituents in water from the Valley Springs confined drift aquifer in southeastern Minnehaha County in South Dakota are calcium and bicarbonate (Lindgren and Niehus, 1992). Concentrations of dissolved solids ranged from 450 to 920 mg/L and averaged 620 mg/L. Hardness concentrations (as $CaCO_3$) ranged from 320 to 640 mg/L and averaged 440 mg/L.

Water from glacial-drift aquifers in Minnesota generally is of acceptable quality for most uses, including household supply, industrial supply, and irrigation. Adolphson (1983) reported that, in general, water from the unconfined drift aquifers in southwestern Minnesota is suitable for domestic uses, although it is very hard and, locally, sulfate concentrations may exceed 250 mg/L. Ruhl (1987) reported that the concentration of sulfate exceeded the USEPA's SMCL of 250 mg/L in samples from wells completed in confined drift aquifers throughout the southwestern part of Minnesota.

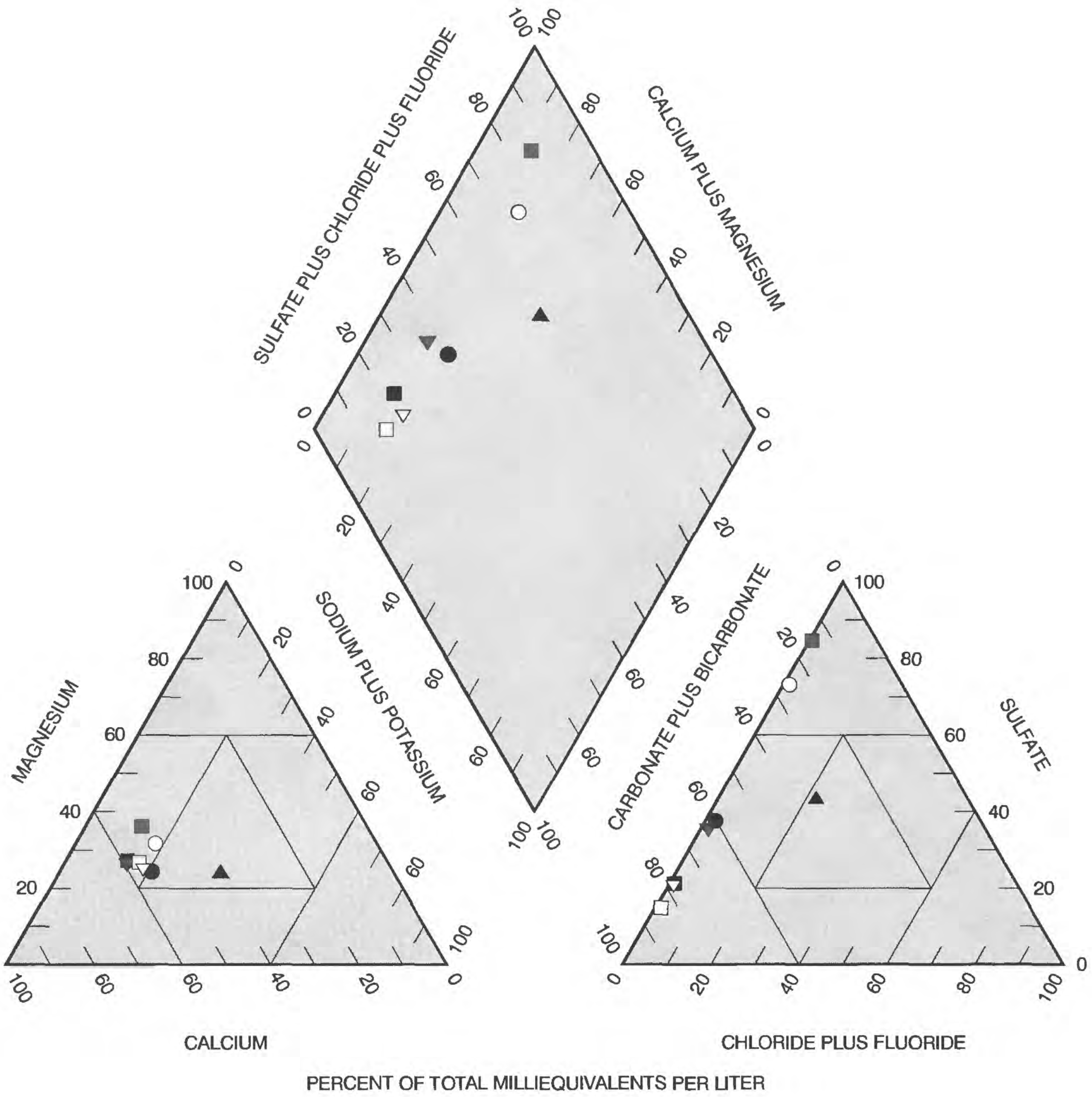
Water samples were collected for this study from three wells screened in confined drift aquifers within buried-valley deposits in Rock County. Specific conductance is a measurement of the ability of water to conduct an electric current. Specific conductance is directly related to the concentration of dissolved solids; the greater the concentration of dissolved solids, the higher the specific conductance. High concentrations of dissolved solids in ground water can cause well-screen encrustation and reduced yields to wells. Specific conductance and dissolved-solids concentration for two of the three sampled wells screened in confined drift aquifers were similar, but specific conductance and dissolved-solids concentration for well 101N46W28ABABAA at Hills were much greater (fig. 6, table 3). The much greater specific conductance and dissolved-solids concentration for water from the well at Hills is probably due to the greater depth of burial of the aquifer. Longer flow paths increase the water-mineral contact time, thereby increasing mineral dissolution and the concentrations of chemical constituents in the ground water. The pH and alkalinity of water from all three sampled wells screened in confined drift aquifers were similar (table 3). Water from all three of the sampled wells screened in confined drift aquifers was very hard (fig. 6, table 3).

A common graphical technique for presenting water-chemistry data is a Piper diagram (Freeze and Cherry, 1979) (fig. 7). The points representing cation and anion data from two separate trilinear diagrams are extended to the parallelogram (Freeze and Cherry, 1979) to characterize the general type of water indicated by concentrations of cations and anions.

The predominant ions in water from well 102N46W28BADBDA at the town of Beaver Creek and well 102N47W35AADDDC01 near Valley Springs, screened in confined drift aquifers, were calcium and bicarbonate. Well 102N47W35AADDDC01 is screened in the Valley Springs aquifer described by Lindgren and Niehus (1992). Calcium and bicarbonate are derived primarily from soil and rock weathering (Hem, 1985). The predominant ions in water from well 101N46W28ABABAA at Hills, screened in a confined drift aquifer, were calcium and sulfate. The chemical characteristics of water from this well are more similar to the chemical characteristics of water from the wells screened in the undifferentiated Cretaceous and Split Rock Creek aquifers than to water from the other two wells screened in confined drift aquifers (fig. 7, table 3). At the Hills site the confined drift aquifer is separated from the underlying undifferentiated Cretaceous aquifer by only 18 ft of till and clay, and some mixing of water between the confined drift and underlying bedrock aquifers may occur.

Metals and other trace constituents typically are present in concentrations less than 1 mg/L in natural waters (Hem, 1985). Concentrations of iron and boron were substantially greater in water from well 101N46W28ABABAA at Hills than in water from the other sampled wells screened in confined drift aquifers (table 3). The concentration of manganese in water from well 102N47W35AADDDC01 was substantially greater than in water from the other sampled wells. Concentrations of zinc were relatively low in samples from all three wells.

Water collected for this study from well 101N46W28ABABAA at Hills screened in a confined drift aquifer had dissolved-solids (1,520 mg/L) and sulfate (850 mg/L) concentrations exceeding the USEPA's SMCL's for dissolved-solids (500 mg/L) and sulfate (250 mg/L) (table 3). The USEPA SMCL for manganese (50 µg/L) was exceeded in water from all three sampled wells. The USEPA SMCL for iron (300 µg/L) was exceeded in water from well 101N46W28ABABAA.



EXPLANATION

- ○ Well 101N46W28ABABAA screened in confined drift aquifer
- □ Well 102N46W28BADBDA screened in confined drift aquifer
- ▽ Well 102N47W35AADDDC01 screened in confined drift aquifer
- ■ (gray) Well 101N45W07CBCCAC screened in undifferentiated Cretaceous aquifer
- ▼ (gray) Well 101N47W24DDCADD screened in undifferentiated Cretaceous aquifer
- ▲ Well 102N45W03DCCCDC screened in Split Rock Creek aquifer
- ■ Well 102N46W28BDAAAD screened in Split Rock Creek aquifer
- ● Well 103N45W32ABAAAA screened in Split Rock Creek aquifer

Figure 7. Major-ion chemical characteristics of water in confined drift, undifferentiated Cretaceous, and Split Rock Creek aquifers.

Undifferentiated Cretaceous Aquifers

Water from Cretaceous aquifers in southwestern Minnesota has relatively high dissolved-solids, chloride, and sulfate concentrations (Woodward and Anderson, 1986). The predominant water type in Rock County for Cretaceous aquifers shown by Woodward and Anderson (1986, fig. 16) is calcium magnesium sulfate, except in the southeastern part of the county, where multiple water types are prevalent.

Water samples were collected from two wells screened in undifferentiated Cretaceous aquifers in Rock County (fig. 6). One well was screened in an undifferentiated Cretaceous aquifer within the deposits filling a buried valley northeast of Hills and one well was located outside the boundaries of the buried valleys. Specific conductance, dissolved-solids concentration, and hardness were all 3.5 to 5 times greater for water from well 101N45W07CBCCAC screened in the buried-valley deposits northeast of Hills than for water from well 101N47W24DDCADD outside the boundaries of the buried valleys (table 3). The well outside the boundaries of the buried valleys is comparatively near areas to the west where the Sioux Quartzite is near land surface, areas of recharge to the Sioux Quartzite. Also, the buried valleys in southern Rock County are comparatively broad and not well defined, with probably a lesser hydraulic connection with the Sioux Quartzite as a source of recharge than the buried valleys near the southern edge of the Sioux Quartzite high. Alkalinity and pH were similar for the two wells (table 3). Water from both wells was very hard.

The predominant ions in water from well 101N45W07CBCCAC located within a buried valley were calcium and sulfate (fig. 7). The predominant ions in water from well 101N47W24DDCADD located outside the boundaries of the buried valleys were calcium and bicarbonate (fig. 7). The difference in water types between the two wells may be due to mixing of water from the undifferentiated Cretaceous aquifer and recharge water from the Sioux Quartzite aquifer in the area between well 101N47W24DDCADD and the Sioux Quartzite high to the west of the well. Lindgren and Niehus (1992) reported that bicarbonate percentages are greatest (greater than 60 percent) and sulfate percentages are lowest (less than 30 percent) in the Sioux Quartzite aquifer in Minnehaha County, South Dakota near the Sioux Quartzite outcrop areas. The percentages of bicarbonate and sulfate decrease to less than 40 percent and increase to more than 50 percent, respectively, as distance from the outcrop areas increases. The concentration of sulfate (1,800 mg/L) in water collected for this study from well 101N45W07CBCCAC greatly exceeded the USEPA SMCL for sulfate (250 mg/L) (table 3).

The concentrations of iron, manganese, zinc, and boron were much greater in water from well 101N45W07CBCCAC, located within a buried valley, than in water from well 101N47W24DDCADD, located outside the boundaries of the buried valleys. The USEPA SMCL's for iron (300 µg/L) and manganese (50 µg/L) were exceeded in both sampled wells screened in undifferentiated Cretaceous aquifers (table 3).

Split Rock Creek Aquifer

Lindgren and Niehus (1992) reported that the predominant ions in water from the Split Rock Creek aquifer in Minnehaha County, South Dakota, were calcium and sulfate. Concentrations of dissolved solids ranged from 230 to 2,300 mg/L and averaged 890 mg/L. Hardness concentrations (as $CaCO_3$) ranged from 180 to 1,700 mg/L and averaged 620 mg/L.

Water samples were collected for this study from three wells screened in the Split Rock Creek aquifer in Rock County. Specific conductance, dissolved-solids concentration, and hardness were all lower for water from well 103N45W32ABAAAA than for water from the other two wells (table 3). Well 103N45W32ABAAAA is located nearer the southern edge of the Sioux Quartzite high and the water is probably more diluted by mixing with recharge water from the Sioux Quartzite aquifer than the water of the other two sampled wells screened in the Split Rock Creek aquifer. Lindgren and Niehus (1992) reported that concentrations of dissolved solids in the Split Rock Creek aquifer in Minnehaha County in South Dakota generally are lower in areas of the aquifer near Sioux Quartzite outcrops, indicating comparatively rapid recharge through fractures in the Sioux Quartzite. Water from all three of the sampled wells was very hard.

The predominant ions in water from two of the three sampled wells screened in the Split Rock Creek aquifer were calcium and bicarbonate (fig. 7). The predominant ions in water from well 102N45W03DCCCDC were calcium and sulfate. Sodium and chloride concentrations were also significantly higher in well 102N45W03DCCCDC than in the other two wells (table 3, fig. 7). A possible reason for the higher sulfate, sodium, and chloride concentrations in water from well 102N45W03DCCCDC compared to the other sampled wells screened in the Split Rock Creek aquifer is mixing with water from undifferentiated Cretaceous aquifers to the east of well 102N45W03DCCCDC. Woodward and Anderson (1986) reported that sodium chloride type water is present in the Cretaceous aquifers in southwestern Minnesota, partially as a result of inflow from South Dakota (Adolphson and others, 1981) and partially from unknown sources. The dissolved-solids concentration in water from well 102N45W03DCCCDC (534 mg/L) exceeded the USEPA SMCL for dissolved solids (500 mg/L). Sulfate concentrations in water from all three sampled wells screened in the Split Rock Creek aquifer were less than the USEPA SMCL for sulfate (250 mg/L).

Concentrations of iron in water from wells screened in the Split Rock Creek aquifer in Minnehaha County, South Dakota ranged from 5 to 8,000 µg/L and averaged 2,730 µg/L (Lindgren and Niehus, 1992). Concentrations of manganese in water from wells screened in the Split Rock Creek aquifer in Minnehaha County ranged from less than 1 to 2,200 µg/L and averaged 670 µg/L (Lindgren and Niehus, 1992). Iron and manganese concentrations in water from three wells sampled for this study screened in the Split Rock Creek aquifer in Rock County were all less than the average values for iron and manganese concentrations for the Split Rock Creek aquifer in Minnehaha County (table 3). Water from well 102N46W28BDAAAD screened in the Split Rock Creek aquifer at the town of Beaver Creek had an iron concentration two orders of magnitude greater than the iron concentrations in water from the other two Split Rock Creek aquifer wells sampled in Rock County (table 3). Water from well 103N45W32ABAAAA screened in the Split Rock Creek aquifer near the southern edge of the Sioux Quartzite high had a zinc concentration one order of magnitude greater than the zinc concentrations in water from the other two Split Rock Creek aquifer wells sampled in Rock County (table 3). The iron concentration in water from well 102N46W28BDAAAD exceeded the USEPA SMCL for iron (300 µg/L) (table 3). The manganese concentrations in water from wells 102N46W28BDAAAD and 103N45W32ABAAAA exceeded the USEPA SMCL for manganese (50 µg/L) (table 3). The zinc concentration in well 103N45W32ABAAAA exceeded the USEPA SMCL for zinc (5 mg/L) (table 3).

SUMMARY AND CONCLUSIONS

The Quaternary and Cretaceous deposits in the southwestern, south-central, and eastern parts of Rock County are thick but largely unexplored sequences that could contain aquifers. The U.S. Geological Survey, in cooperation with the Minnesota Department of Natural Resources, conducted a three-year study (October 1993 to September 1996) to evaluate confined aquifers present within Quaternary and Cretaceous deposits filling buried valleys in the Sioux Quartzite surface in Rock County in southwestern Minnesota.

Hydrogeologic units present within buried-valley deposits in Rock County include unconfined and confined drift aquifers, undifferentiated Cretaceous aquifers, the Split Rock Creek aquifer, and interbedded confining units. The distribution of confined drift aquifers and the availability of water from these aquifers is generally poorly defined. The undifferentiated Cretaceous aquifers consist of sandstone layers within interbedded claystone and siltstone overlying the Split Rock Creek Formation or Sioux Quartzite. The Split Rock Creek Formation, consisting of sand units (comprising the Split Rock Creek aquifer) and interbedded layers of siltstone and claystone, is present in buried valleys incised in the Sioux Quartzite surface in southern and possibly northeastern Rock County.

Confined drift aquifers with thicknesses greater than 5 ft were penetrated in 6 of the 10 test holes drilled for this study. Single-layer thicknesses of the confined drift aquifers in Rock County range from at least 2 to greater than 32 ft. The greatest number of confined drift aquifers are present near the southern and eastern margins of the Sioux Quartzite high, probably due to a high-energy depositional environment in these areas. The estimate for horizontal hydraulic conductivity derived from specific-capacity information for one well screened in a confined drift aquifer was 73 ft/d.

Recharge to ground water is predominantly from precipitation that percolates downward to the saturated zone. Recharge to confined drift aquifers occurs by the vertical movement of water through confining units. Recharge to the confined drift aquifers may also be derived from hydraulic connection to the Sioux Quartzite aquifer as infiltrated precipitation moves through the fractures and joints of the Sioux Quartzite in areas where the confined drift aquifers abut or are in close proximity to the sides of the buried valleys incised in the Sioux Quartzite surface. Discharge from the confined drift aquifers in Rock County is primarily to domestic and municipal wells. Some discharge from the confined drift aquifers may occur by downward leakage to underlying aquifers.

Depths to static water levels were measured in five wells screened in confined drift aquifers within or near buried-valley deposits. The five point measurements indicate that the general directions of flow in the aquifers are to the south and west.

No major (thickness greater than 5 ft) undifferentiated Cretaceous aquifers were penetrated in the 10 test holes drilled for this study. Thicknesses of undifferentiated Cretaceous aquifers from 4 domestic well logs range from at least 7 ft to greater than 46 ft. The available information is insufficient to determine any areal patterns in the distribution and thicknesses of the aquifers. The estimate for horizontal hydraulic conductivity derived from specific-capacity information for one well screened in an undifferentiated Cretaceous aquifer was 55 ft/d.

Recharge to the undifferentiated Cretaceous aquifers is by leakage of water through confining units from overlying confined drift aquifers. Recharge to the undifferentiated Cretaceous aquifers may also be derived from hydraulic connection to the laterally adjacent Sioux Quartzite aquifer as infiltrated precipitation moves through the fractures and joints of the Sioux Quartzite. Discharge from the undifferentiated Cretaceous aquifers is to domestic wells and possibly to the underlying Split Rock Creek aquifer.

Depths to static water levels were measured in three wells screened in undifferentiated Cretaceous aquifers. The three water-level measurements indicate that the regional direction of flow in the aquifers is probably to the south and southeast away from the Sioux Quartzite high.

The test holes drilled for this study indicated that the Split Rock Creek aquifer, penetrated in 9 of the 10 test holes, in Rock County consists of predominantly very fine- to fine-grained sand. Cumulative sand thicknesses for the Split Rock Creek aquifer in the 10 test holes ranged from zero to 128.5 ft in 2 to 6 layers. The aquifer is greater than 90 ft thick northwest of Luverne and between the town of Beaver Creek and the Minnesota-South Dakota State line. The comparatively large cumulative sand thicknesses near the southern margin of the Sioux Quartzite high and in the relatively narrow Brandon Embayment in southeastern Minnehaha County and its extension into Rock County are probably due to a high-energy depositional environment.

Slug tests were conducted for this study at three wells screened in the Split Rock Creek aquifer in Rock County. The estimated horizontal hydraulic conductivities derived from analysis of the slug tests were 0.1, 0.2, and 1 ft/d. The corresponding aquifer transmissivities, calculated as the horizontal hydraulic conductivity multiplied by the cumulative sand thickness, are 3, 16, and 130 ft^2/d. The greatest horizontal hydraulic conductivity and transmissivity estimates were for site 103N45W32ABAAAA near the Sioux Quartzite high. This site has a greater cumulative sand thickness and coarser-grained aquifer material than the other two sites.

Most recharge to the Split Rock Creek aquifer is thought to be derived from infiltration of precipitation through fractures and joints of the Sioux Quartzite. Recharge to the Split Rock Creek aquifer may also occur by downward leakage from undifferentiated Cretaceous aquifers.

Discharge from the Split Rock Creek aquifer in Rock County is to domestic and municipal wells. Discharge from the aquifer probably also occurs as a subsurface flow to the Sioux Quartzite or permeable deposits overlying the Sioux Quartzite.

Depth to static water levels were measured in five wells screened in the Split Rock Creek aquifer. The regional directions of flow in the aquifer are to the south away from the Sioux Quartzite high and to the west in the Brandon Embayment in Minnehaha County and its east-west trending extension into Rock County. Based on the available water-level measurements, the horizontal hydraulic gradient in the aquifer is about 7 ft/mi near the Sioux Quartzite high and about 2-3 ft/mi in the Brandon Embayment in Minnehaha County and its east-west trending extension into Rock County.

Water samples were collected from three wells screened in confined drift aquifers within buried-valley deposits in Rock County. Specific conductance and dissolved-solids concentration for well 101N46W28ABABAA at Hills were much higher than for the other 2 wells, probably due to the greater depth of burial of the aquifer. Water from all three of the sampled wells was very hard. The predominant ions in water from 2 of the wells screened in confined drift aquifers were calcium and bicarbonate. The predominant ions in water from the third well screened in a confined drift aquifer were calcium and sulfate, probably due to mixing with water from the underlying Cretaceous deposits. Water collected from well 101N46W28ABABAA, screened in a confined drift aquifer, had dissolved-solids, sulfate, and iron concentrations exceeding the USEPA's SMCL's (500 mg/L, 250 mg/L, and 300 µg/L, respectively). The USEPA SMCL for manganese (50 µg/L) was exceeded in water from all three sampled wells.

Water samples were collected from two wells screened in undifferentiated Cretaceous aquifers in Rock County. Specific conductance, dissolved-solids concentration, and hardness were all 3.5 to 5 times greater for water from the well screened in the buried-valley deposits northeast of Hills than for water from the well outside the boundaries of the buried valleys. Water from both wells was very hard. The predominant ions in water from the well screened in an undifferentiated Cretaceous aquifer within buried-valley deposits were calcium and sulfate. The predominant ions in water from the well screened in an undifferentiated Cretaceous aquifer outside the boundaries of the buried valleys were calcium and bicarbonate. The concentration of sulfate in water from one well greatly exceeded the USEPA SMCL for sulfate (250 mg/L). The USEPA SMCL's for iron (300 µg/L) and manganese (50 µg/L) were exceeded in both sampled wells screened in undifferentiated Cretaceous aquifers.

Water samples were collected from three wells screened in the Split Rock Creek aquifer in Rock County. Specific conductance, dissolved-solids concentration, and hardness were all lower for water from well 103N45W32ABAAAA than for water from the other two wells. Well 103NW32ABAAAA is located nearer the southern edge of the Sioux Quartzite high and the water is probably more diluted by mixing with recharge water from the Sioux Quartzite aquifer than the water of the other two sampled wells screened in the Split Rock Creek aquifer. Water from all three of the sampled wells was very hard. The predominant ions in water from two of the three sampled wells screened in the Split Rock Creek aquifer were calcium and bicarbonate. The predominant ions in water from well 102N45W03DCCCDC were calcium and sulfate. Sodium and chloride concentrations were also significantly higher in this well than in the other two wells. A possible reason for the higher sulfate, sodium, and chloride concentrations in water from well 102N45W03DCCCDC compared to the other sampled wells screened in the Split Rock Creek aquifer is mixing with water from undifferentiated Cretaceous aquifers to the east of this well. The dissolved-solids concentration in water from one well exceeded the USEPA SMCL (500 mg/L). The USEPA SMCL's for iron (300 μg/L), manganese (50 μg/L), and zinc (5 mg/L) were exceeded in 1, 2, and 1 of the sampled wells, respectively.

The water-yielding potential from the confined drift aquifers present in buried-valley deposits in Rock County appears to be greatest in the southwestern part of the county from east of the town of Beaver Creek extending southwestward to near the town of Valley Springs, where areally persistent confined drift aquifers at similar altitudes are present. Existing municipal and domestic wells currently withdraw water from confined drift aquifers in this area. The water-yielding potential from undifferentiated Cretaceous aquifers present in buried-valley deposits in Rock County appears to be minimal. No aquifer thickness greater than 5 ft was penetrated in the 10 test holes drilled for this study. The scope of the conclusions derived from this study for the confined drift and undifferentiated Cretaceous aquifers are limited by the relatively sparse amount of data and the extensive area of the aquifers outside the boundaries of the buried valleys. The Split Rock Creek aquifer was penetrated in 9 of the 10 test holes drilled for this study, indicating it is generally present in the buried-valley deposits. However, the water-yielding potential of the aquifer in Rock County is generally limited by low transmissivity due to the fineness of the aquifer material (generally very fine- to fine-grained sand). The water-yielding potential from the Split Rock Creek aquifer is greatest near the southern margin of the Sioux Quartzite high and in the extension of the Brandon Embayment eastward into Rock County. Additional test drilling in these areas may be productive in locating new sources of water supply.

Water from the confined drift, undifferentiated Cretaceous, and Split Rock Creek aquifers in Rock County generally is of acceptable quality for most uses. The chemical analyses of five water samples from the confined drift and undifferentiated Cretaceous aquifers indicated that the water-quality characteristics for these aquifers in Rock County are similar to the water-quality characteristics of the same aquifers throughout southwestern Minnesota. The water-use potential of the aquifers is limited by high dissolved-solids and sulfate concentrations in some areas. The water-quality characteristics of water from the Split Rock Creek aquifer in Rock County are similar to those of the Split Rock Creek aquifer in Minnehaha County, South Dakota, based on chemical analyses of three samples analyzed for this study. The water-use potential of the Split Rock Creek aquifer in Rock County is limited by high dissolved-solids concentrations in some areas. Water from all three aquifers is very hard. The scope of the water-quality results presented in this report are limited by the small number of samples analyzed. However, the results are similar to previously published data in southwestern Minnesota and Minnehaha County, South Dakota.

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