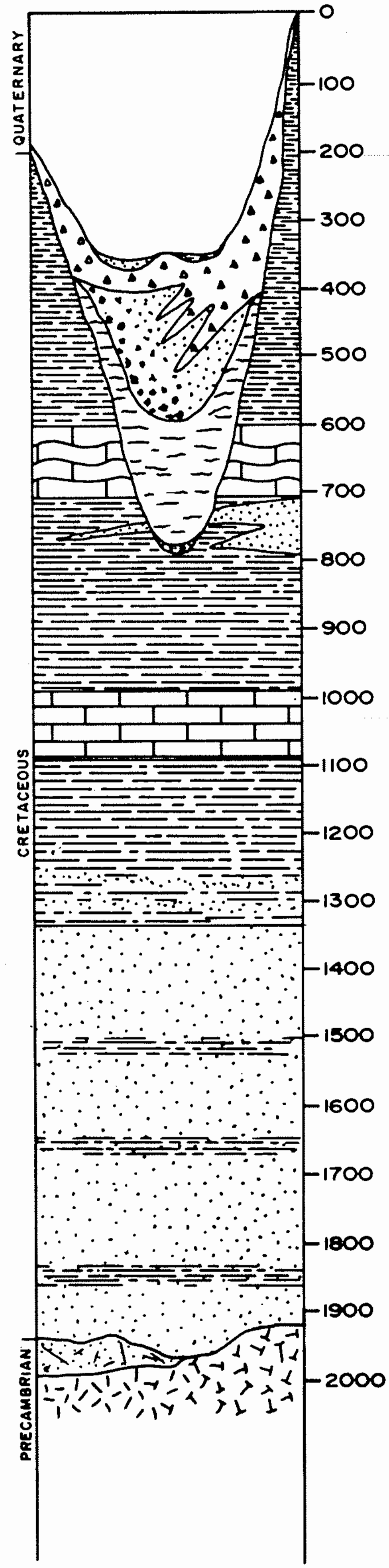

GEOLOGY AND WATER RESOURCES OF BEADLE COUNTY SOUTH DAKOTA

Part II: Water Resources

by

Lewis W. Howells and Jerry C. Stephens
Geological Survey
United States Department of the Interior

Prepared in cooperation with the
South Dakota Geological Survey

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STATE OF SOUTH DAKOTA
Frank Farrar, Governor

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Duncan J. McGregor, State Geologist

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by
Lewis W. Howells, U.S.G.S., and Jerry C. Stephens, U.S.G.S.

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ABSTRACT

The surface-water resources of Beadle County are relatively undeveloped. During 1963, except for about 1,800 acre-feet diverted for irrigation, 2,785 acre-feet diverted for municipal and industrial uses, and small diversions for stock supplies, most of the flow of the James River and other streams was unused. Average net runoff from the surface of the county is more than 25,000 acre-feet per year. Most of the 1.2 million acre-feet of precipitation in an average year is lost as evapotranspiration.

More than 5 million acre-feet of water is stored in three aquifers in surficial deposits. Although the water is somewhat mineralized and of variable quality, about 3,200 acre-feet was pumped from about 700 wells in 1963 for irrigation, stock, domestic, and municipal supplies. The greatest potential for development of high-capacity wells is in areas where the major aquifers are more than 25 feet thick. The aquifers are recharged by infiltration of precipitation in Beadle County and by underflow from adjacent areas. Discharge from the aquifers is mostly by evapotranspiration and through wells.

Two artesian aquifers in bedrock strata are major sources of water for stock, domestic, and municipal use. The aquifer in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale supplies soft water to about 140 wells in the east-central third of the county. The aquifer in the Dakota Formation supplies water to more than 1,060 wells (most of which flow) throughout the county.

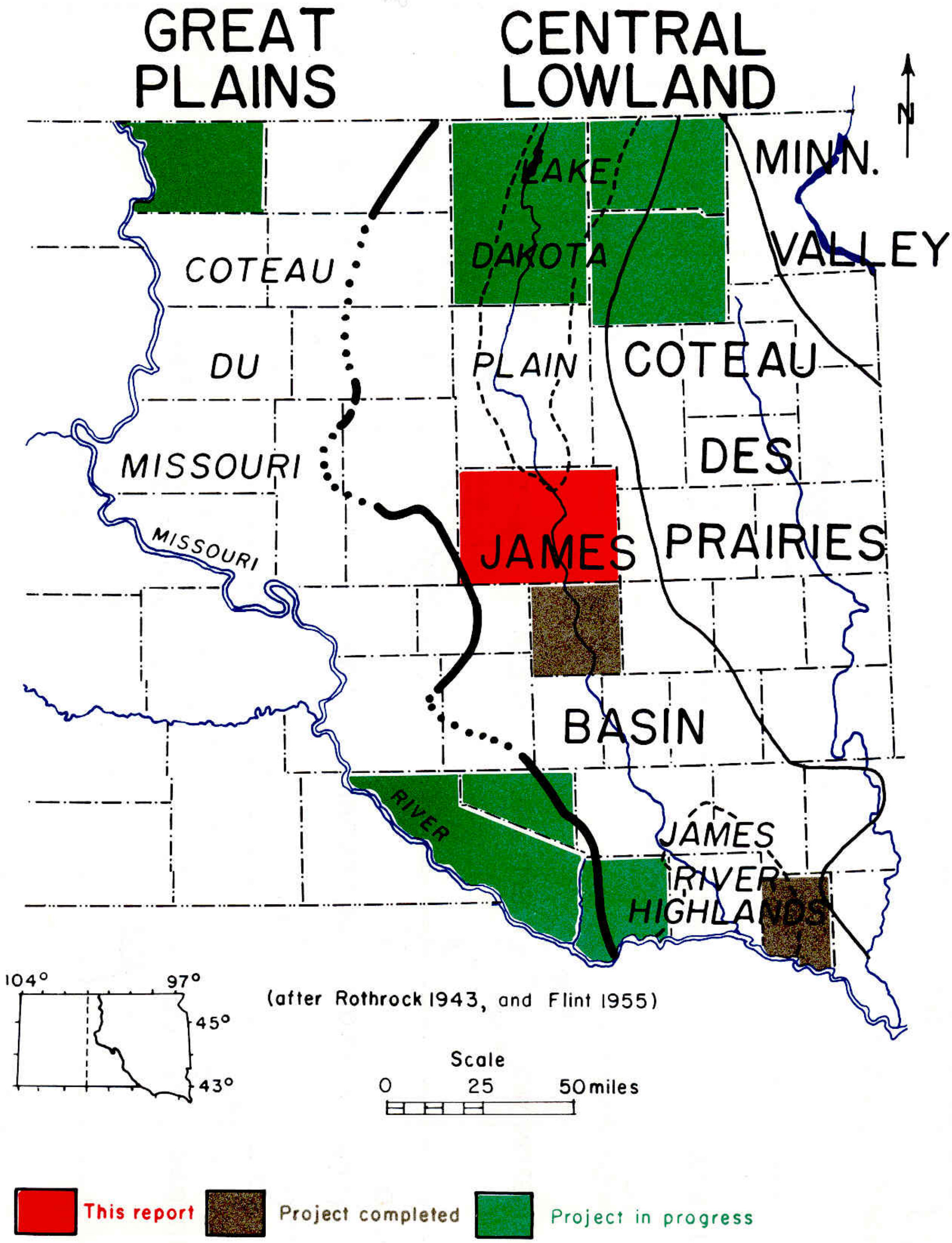

Figure 1.--Index map of eastern South Dakota showing the physiographic divisions (after Flint, 1955, p. 5 and Rothrock, 1943, p. 8) and the locations of Beadle County and the counties studied in other cooperative investigations.

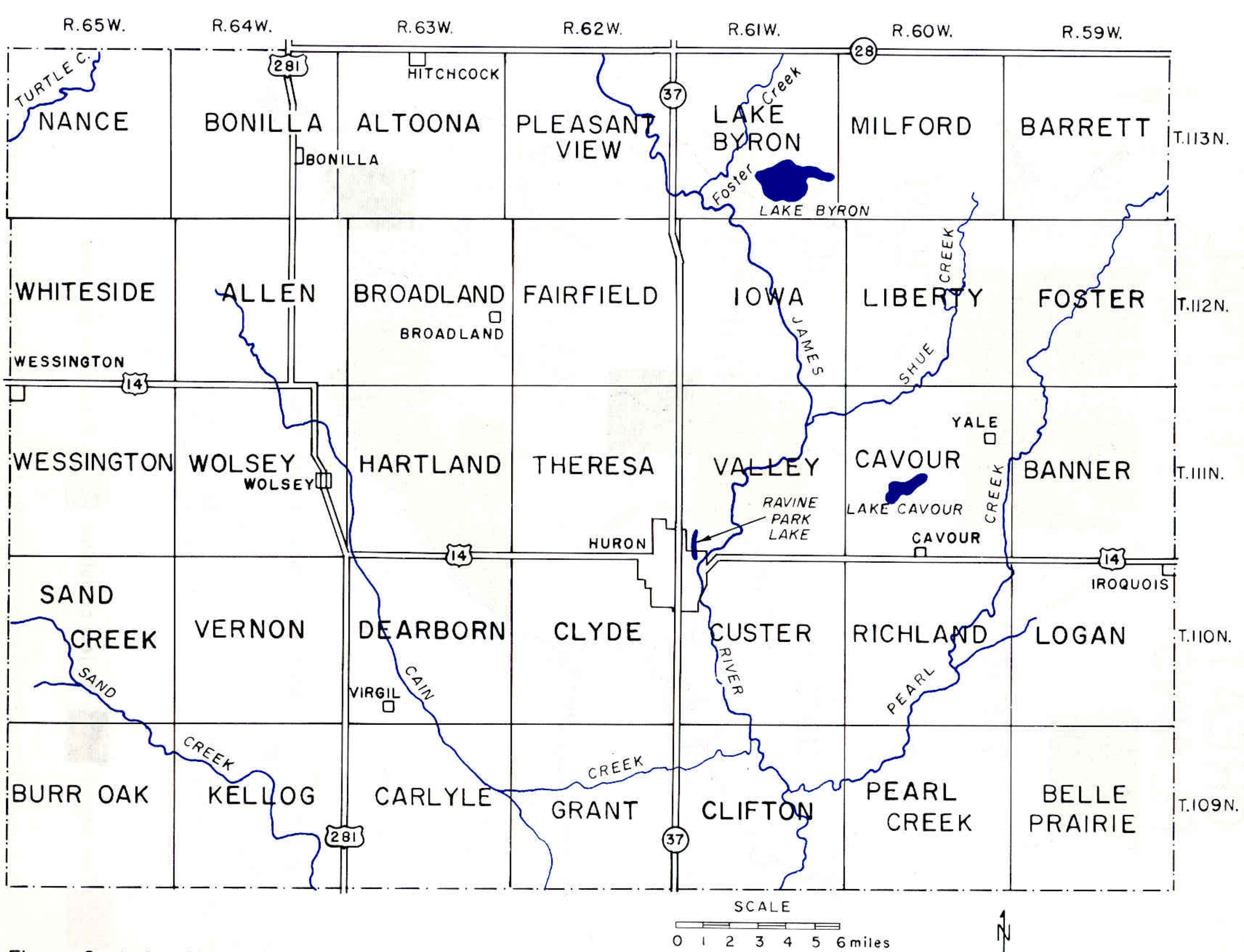

Figure 2. Index Map of Beadle County.

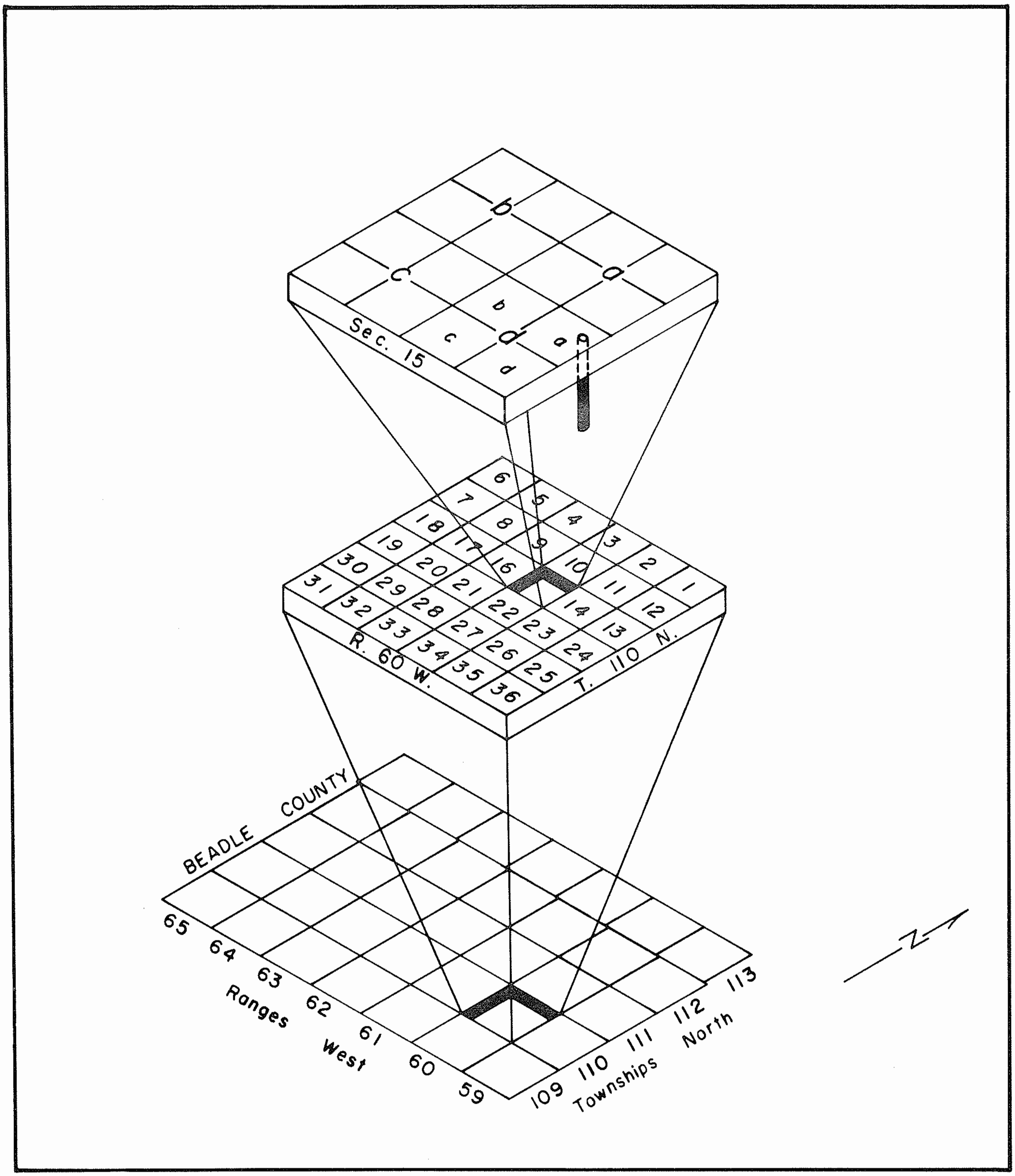

Figure 3.--Well-numbering system. Each well or test hole has been assigned a number based on its location according to the Federal land-survey system used in South Dakota. The number consists of the township, range, and section numbers separated by hyphens; four lowercase letters that indicate respectively the 160, 40, 10, and 2 1/2 acre tract in which the well is located; and a serial number to distinguish between wells in the same 2 1/2 acre tract, where necessary. Thus, well 110-60-15da is in the NE1/4 SE1/4 sec. 15, T. 110 N., R. 60 W.

The authors gratefully acknowledge help from the well drillers, municipal, and town officials, and ranchers and farmers of Beadle County and adjacent areas. Special thanks are due to Dr. Oscar Olson, Station Biochemistry, and Mr. Raymond Ward, Soils Laboratory, of South Dakota State University, for supplying many chemical analyses of water. Much useful information and many valuable comments were supplied by personnel of the U. S. Bureau of Reclamation and the South Dakota Water Resources Commission. Mr. Vernon Moxon and his colleagues of the U. S. Soil Conservation Service gave invaluable assistance in locating and evaluating areas of recharge to aquifers in the drift.

During this investigation, a complete inventory of rural and municipal wells was made; more than 400 test holes were drilled, more than 2,200 partial or field and 200 complete chemical analyses of water were made or collected, and data from 15 aquifer tests were collected and analyzed.

HYDROLOGY

Water in Beadle County occurs in surface streams and reservoirs and in the interstices of surficial deposits and bedrock strata. Most of the surface water and much of the ground water in surficial deposits comes from precipitation in the county. The amount of precipitation that falls, however, is much greater than the amount that runs off from the surface or is added to storage in surface- and ground-water reservoirs. Evaporation from surface-water bodies and from soil and shallow ground-water reservoirs, and transpiration of soil moisture and ground water by vegetation, greatly reduces the amount of water available for man's use.

Normal precipitation in Beadle County is about 1.2 million acre-feet (17.3 inches) annually; annual net runoff is about 0.03 million acre-feet. The remaining 1.17 million acre-feet of precipitation evaporates, is transpired, adds to soil moisture, or is stored on the surface or in ground-water reservoirs in surficial deposits.

Occurrence of Surface Water

Streams

All streams in Beadle County are part of the James River drainage system. The James River is the most "permanent" stream in the county, but it has been dry during many periods of scant rainfall. Nearly all streams tributary to the James are ephemeral--that is, they flow only in direct response to precipitation. Some of the major tributaries, such as Sand, Cain, Pearl, Foster, Turtle, and Shue Creeks (fig. 2) contain intermittent segments where the stream channel is intermittently below the water table.

About one-fourth of the land surface of Beadle County is drained internally--that is, the water remains ponded. Many minor water courses that carry internal drainage discharge water only during the spring snow melt and after heavy rains. Such water courses have little topographic expression; many of them, in fact, are recognizable as drainageways only when they are discharging water.

The distribution with time of net runoff and precipitation in Beadle County for the water years 1951-60 is shown on figure 4. Runoff is greatest in April, whereas precipitation is greatest in June. Almost 75 percent of the annual runoff takes place in April, May, and June, but less than 45 percent of the annual precipitation falls in these three months. The decrease in runoff that occurs while precipitation increases is a result of increasing rates of evapotranspiration. Pengra (1959, p. 41) determined that average daily potential evapotranspiration exceeds average daily precipitation at Huron from May through October. Precipitation in amounts equal to or less than the daily average would, therefore, contribute little to runoff, soil moisture, or storage during this period. The large percentage of runoff in April is a result of snow melt and spring rainfall that occurs before evapotranspiration begins to increase.

Stream discharge from Beadle County consists primarily of surface inflow to the county. Surface runoff from precipitation within the county accounts for the remaining discharge. None of the streams have a base flow; the volume of ground water discharged to streams is too small to sustain flow except in short, discontinuous stream segments. The distribution of average discharge of the James River at Huron and of Sand Creek at a point 3 miles south of the county line in Jerauld County are shown on figure 4. The discharge of these streams does not consist entirely of runoff from Beadle County, but their discharge characteristics probably are typical of most other streams in the county. The greatest increase in James River discharge occurs in March, as a result of precipitation and snow melt in an extensive drainage area to the north of Huron, whereas the greatest increase in Sand Creek discharge, which is derived entirely from local precipitation and snow melt occurs in February.

Reservoirs

Dams on the James River at Huron and in T. 113 N., R. 62 W., about 15 miles north of Huron, create a combined reservoir capacity of about 7,200 acre-feet. Other artificial surface-water impoundments include about 1,500 "dugouts" and other small reservoirs that are used for stock water supplies (part of the water impounded in these reservoirs comes from ground water), and one small irrigation reservoir on an ephemeral stream in T. 113 N., R. 60 W. The total storage capacity of artificial surface-water impoundments in the county probably is about 9,000 acre-feet.

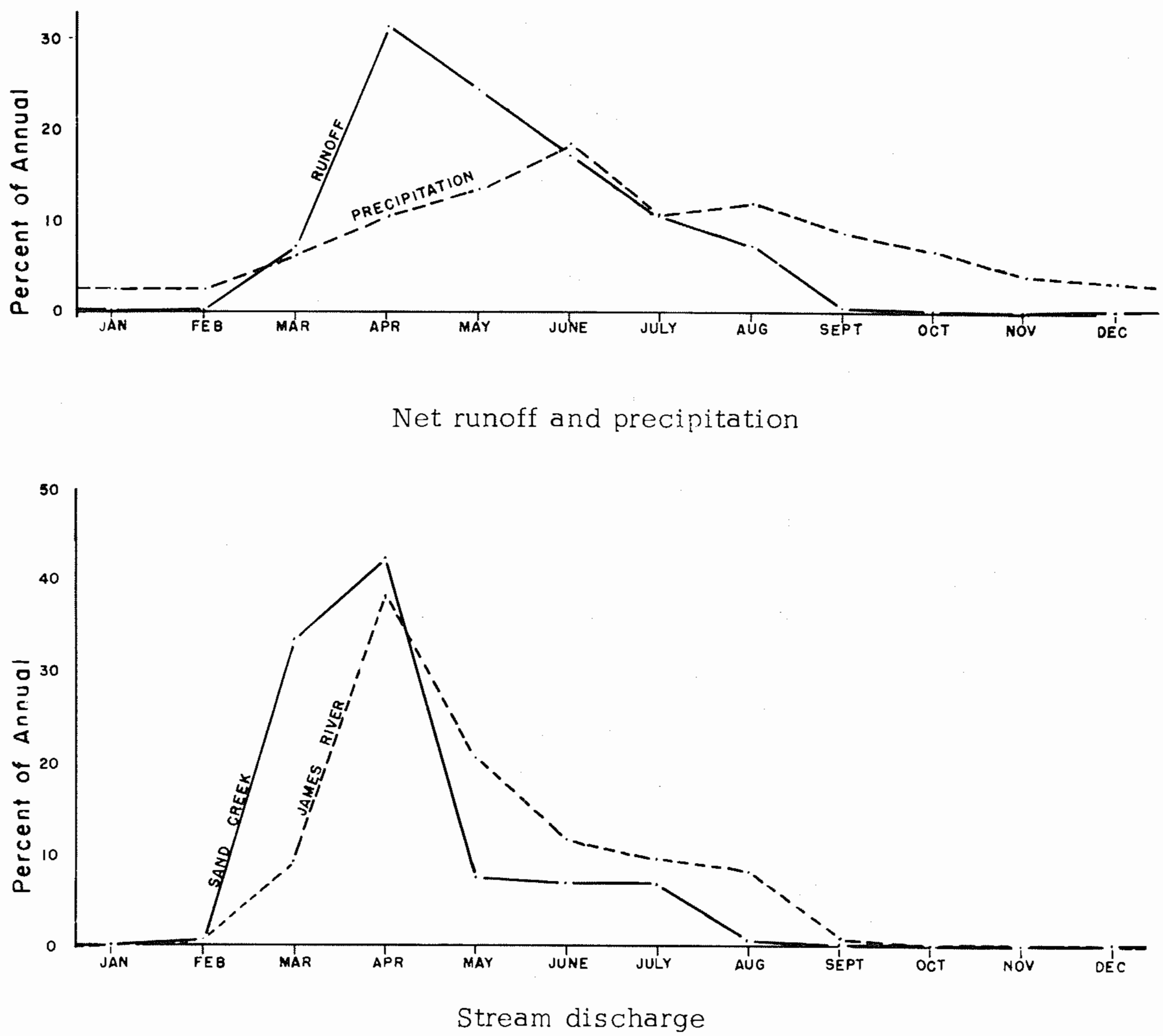

Figure 4.--Distribution of average annual precipitation in and runoff from Beadle County, and discharge of James River at Huron and of Sand Creek near Alpena, for water years 1951-60. (Precipitation data from U. S. Weather Bureau station at Huron; runoff and stream discharge from U. S. Geol. Survey, 1964, p. 472-473.)

Natural surface reservoirs in the county store water only intermittently. Lake Byron, the largest of these reservoirs, has a maximum storage capacity of about 5,000 acre-feet, although it normally contains much less than this amount and was completely dry at times during the 1930's. A small part of the storage capacity of Lake Byron is due to a levee that was built to divert Foster Creek into the lake. Lake Cavour, the second-largest natural reservoir in the county, receives internal drainage only; at its maximum extent it may hold as much as 4,000 acre-feet of water, but the average storage of the lake is probably little more than one-fourth of this amount. Lake Cavour was dry for long periods during the 1930's and 1940's. Internal drainage is collected in a great many natural sloughs and potholes in addition to Lake Cavour. Storage of water in these shallow depressions is intermittent, except in those few where the water table is at the land surface. Total storage capacity in all natural reservoirs, excluding Lake Byron, may be as much as 20,000 acre-feet, but only in an abnormally wet spring does the actual storage volume approach the maximum.

Occurrence of Ground Water

Aquifers in Beadle County are divided into two groups--those in unconsolidated surficial deposits and those in the bedrock. The surficial deposits contain three major and several minor aquifers; the bedrock contains two major and three minor aquifers. Some of the important characteristics of the aquifers and intervening aquicludes are summarized in table 1.

Aquifers in Surficial Deposits

Most surficial deposits in Beadle County are the result of glaciation and collectively are called drift. Along water courses and in sloughs and lakes the drift is covered by deposits of alluvium; locally the drift is covered by windblown sand and silt. The thickness of the surficial deposits is shown on figure 5.

Alluvium in the county consists of poorly sorted, poorly stratified, thin, discontinuous layers of material that range in grain size from clay to boulders. The alluvium underlying the James River floodplain is as much as 25 feet thick, and that along tributary streams and minor water courses generally is less than 10 feet thick. The alluvium of the James River floodplain contains a much higher proportion of silt than does alluvium elsewhere in the county. (See Tipton, 1960, p. 3.)

Drift in Beadle County can be divided into two major types, till and outwash, that differ greatly in physical and hydrologic characteristics. Till, which was deposited directly from or by glacial ice, is a heterogeneous mixture of silt, sand, gravel, and boulders in a matrix of clay. It is the most abundant glacial deposit in the county. Outwash, which was deposited from or by

SYSTEM	FORMATION OR DEPOSIT	SECTION	THICKNESS (feet)1/	MATERIAL	REMARKS
Quaternary	Alluvium		0-350+ / 0-25	Generally brown to gray, medium sand to silt and clay; locally may contain gravel, cobbles, or boulders.	Locally, particularly in the James River trench, may yield adequate water for stock or domestic use. Water varies in quality both areally and seasonally.
Quaternary	Drift: Till and undifferentiated drift.		0-190	Till is a brown to gray heterogeneous mixture of coarse material in a matrix of silt or clay. Undifferentiated drift includes till and relatively fine-grained, poorly sorted, water-laid material.	Relatively impermeable; an aquiclude.
Quaternary	Drift: Outwash and other fluvioglacial deposits.		0-210	Brown to gray, stratified, water-laid beds of gravel, sand, silt, and clay. Mostly beds of sandy gravel, clayey or silty sand, and sand and silty clay.	Constitute the most important sources of water in the drift. Yield small to very large supplies of soft to hard fresh to saline water. Water occurs under both artesian and water-table conditions.
Cretaceous	Pierre Shale		0-600	Light-gray calcareous to blue-black or black non-calcareous shale. Commonly contains thin layers of bentonite.	Relatively impermeable; an aquiclude.
Cretaceous	Niobrara Marl		0-120	Dark-blue, tan or light-gray calcareous shale; commonly contains abundant microfossils.	The Codell Sandstone Member of the Carlile Shale and a permeable zone near the base of the Niobrara comprise a single artesian aquifer. It can yield from 1-300 gpm of soft, saline water to wells. Wells may flow in some low-lying areas.
Cretaceous	Carlile Shale		180-350 / (0-60)	Light-blue to black non-calcareous shale.	Relatively impermeable; an aquiclude.
Cretaceous	Codell Sandstone Member		(0-80)	White to rusty-brown sandstone; loose to tightly cemented, very fine to coarse sand. Locally clayey.	
Cretaceous	Carlile Shale			Light-gray and light-blue to black non-calcareous shale; pyrite and marcasite common. Locally contains thin beds or lenses of sandstone below the Codell.	An aquiclude except for those thin beds or lenses of sandstone that are permeable and can yield small supplies of soft, saline water under artesian pressure.
Cretaceous	Greenhorn Limestone		15-110	Fossiliferous, calcareous shale, locally may contain beds and lenses of sandstone.	A permeable zone, usually near the middle of the formation, contain soft, saline, usually muddy water under artesian pressure. Wells would flow in central two-thirds of county.
Cretaceous	Graneros Shale		140-350	Dark-colored non-calcareous shale; pyrite, marcasite and calcareous concretions common. Locally may contain thin beds or lenses of loose to tightly-cemented sandstone.	An aquiclude except for thin beds of permeable sandstone which may yield small supplies of soft, saline water under artesian pressure.
Cretaceous	Dakota Group		0-600+	Interbedded tan to white sandstone and dark-colored shale. Sandstone is composed of loose to well-cemented, very fine to coarse quartz sand; cement most commonly is calcium carbonate.	Most important aquifer in the bedrock; permeable sandstone beds yield soft to extremely hard saline water. Wells flow in 90 percent of the county and yield from 2 to more than 100 gpm.
Pre-cambrian	Sioux Quartzite			Hard, dense, purple to red orthoquartzite.	Aquicludes; locally might yield water from fractures or joints.
Pre-cambrian	Granite and other crystalline rocks			Red to dark-gray biotite and hornblende granite, light-colored granite, and gray mica schist.	

1/ Based on interpretation and projection of data from electric logs, drillers logs, and test holes.

Table 1.--Generalized stratigraphic column showing aquifers and aquicludes and some of their characteristics.

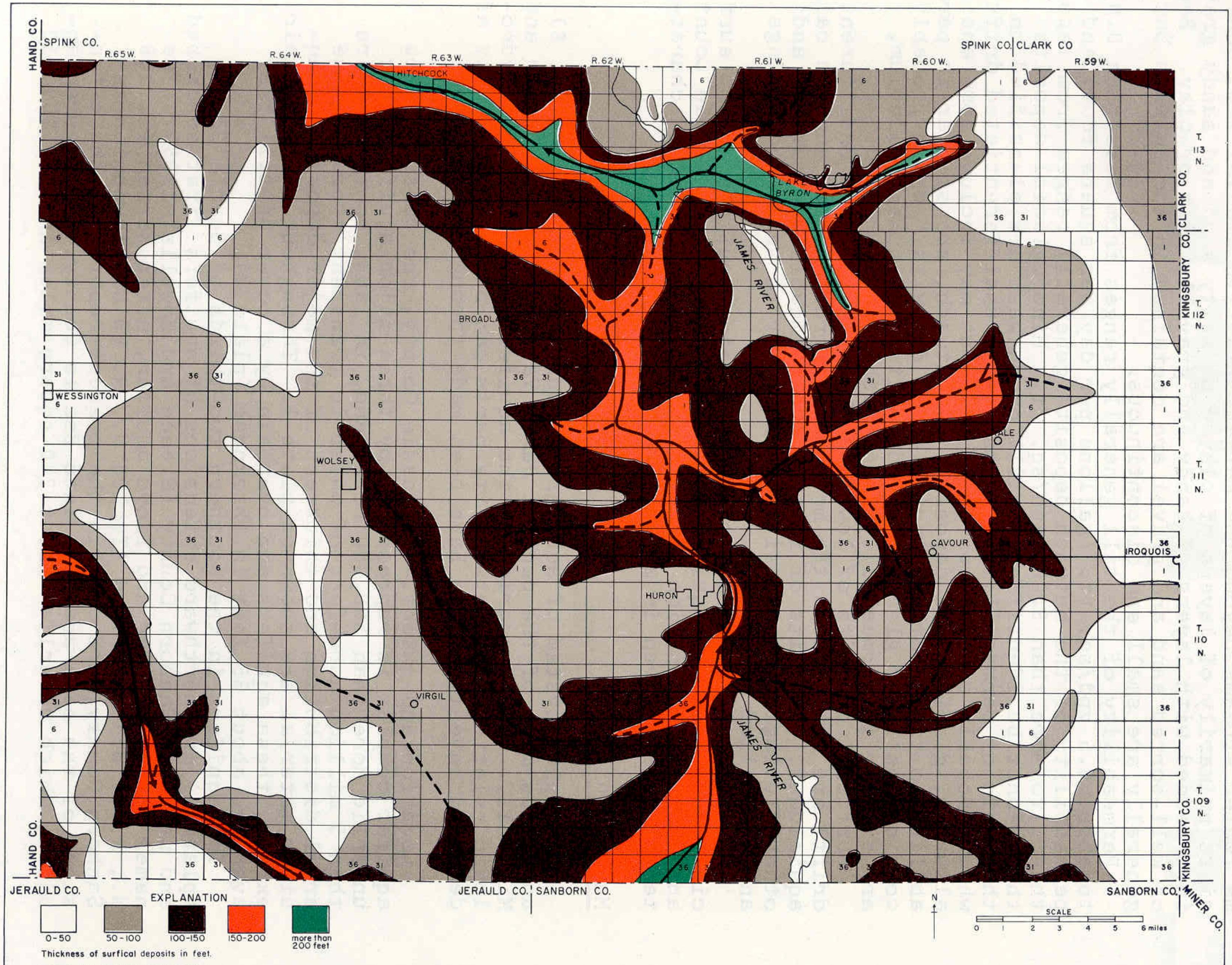

Fig. 5 Thickness of surficial deposits and location of major valleys in bedrock surface.

meltwater streams beyond the margin of active glacial ice, consists primarily of layers of clayey or silty sand and sandy gravel interbedded with layers of sandy and gravelly silt or clay. Beds of well-sorted sand and gravel are contained in the outwash but generally are small and discontinuous.

Permeability of the till generally ranges from less than 0.01 to about 0.5 gpd/sq. ft. (gallons per day per square foot) and permeability of the outwash deposits generally ranges from less than 1 to more than 5,000 gpd/sq. ft. Minor glacial deposits that cannot be identified as till or outwash are classified on the basis of permeability: deposits of "undifferentiated drift," which probably consist mostly of till but may include some ancient alluvium, glacial lake deposits, or outwash, are similar in permeability to till; "other fluvioglacial deposits," which probably consist mostly of glacial lake deposits and ancient alluvium, are similar in permeability to outwash.

Surficial deposits of low permeability (till and undifferentiated drift) are barriers to the movement of ground water and are called aquicludes. Deposits of fairly high permeability (outwash and other fluvioglacial deposits) yield water to wells and springs and are called aquifers.

The hydrologic characteristics of major aquifers in the surficial deposits at 15 aquifer test sites in and near Beadle County and a brief explanation of the significance of selected characteristics are given in appendix B.

Major aquifers

A complex system of aquifers in surficial deposits (fig. 6) underlies much of the central James Valley between Aberdeen and Mitchell. The boundaries of the aquifer complex and the hydrologic relationships between its parts can be determined only after detailed investigations have been made throughout the area.

Location and extent.--In Beadle County, the central James aquifer complex is represented by three major aquifers that underlie more than 500,000 acres and, in 1963, contained more than 5 million acre-feet of water in transient storage. The areal distribution and thickness of the major deposits of aquifer material are shown on plate 1. Throughout most of their extent, these aquifers are overlain by a cover of till that averages about 35 feet in thickness (plate 2).

Two aquifers in the southern two-thirds of Beadle County (plate 1) are northward extensions of aquifers first described and named in Sanborn County (Steece and Howells, 1965). The names Warren aquifer and Floyd aquifer, after Warren (T. 108 N., R. 62 W.) and Floyd (T. 108 N., R. 60 W.) townships in Sanborn County, are used in the present report for the extensions of the same aquifers into Beadle County. The Warren aquifer, which underlies about 240 square miles in Tps. 109-112

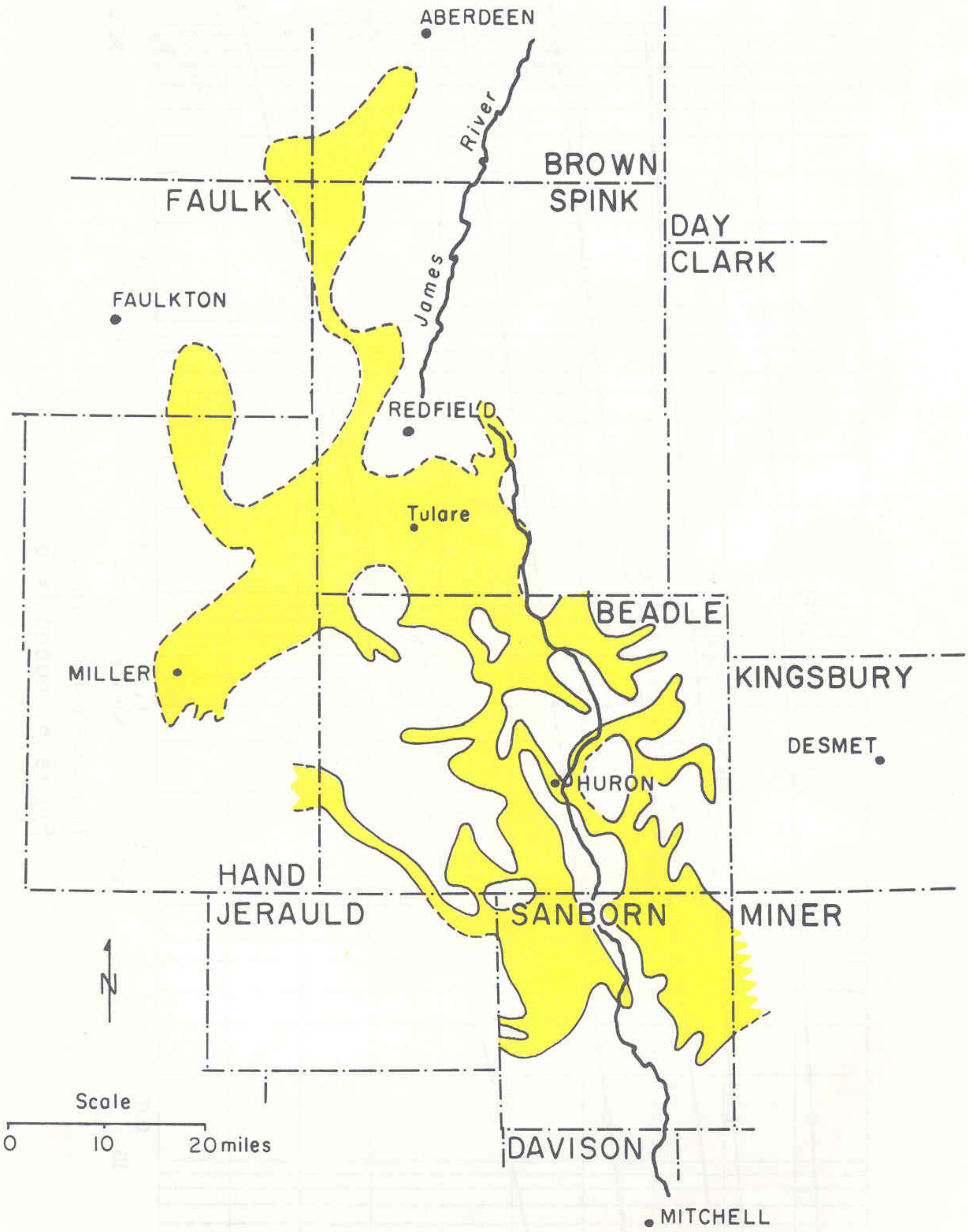

Figure 6. Extent of Central James aquifer complex (modified after Jones, 1956; outline dashed where approximate).

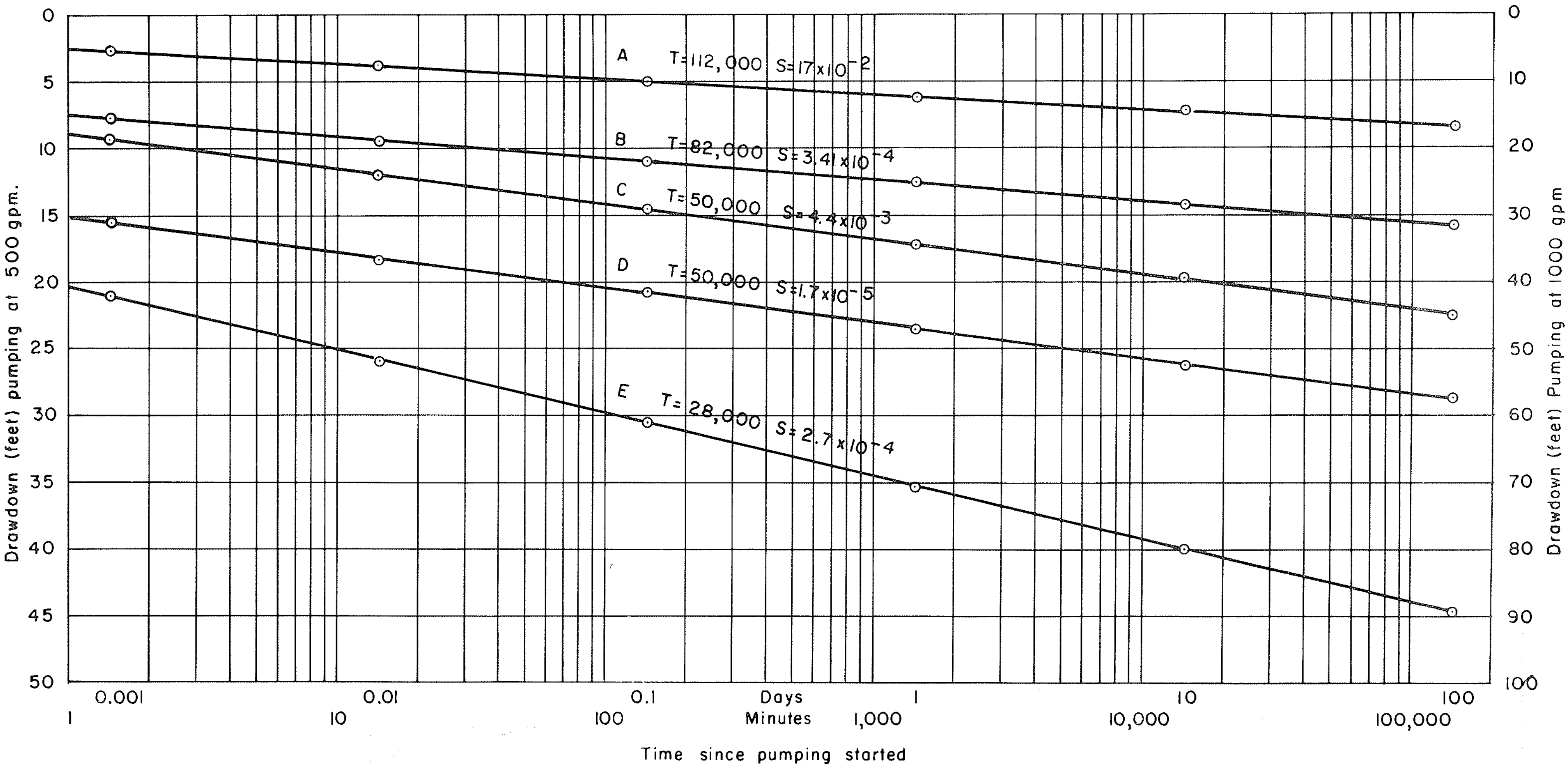

Figure a, appendix b

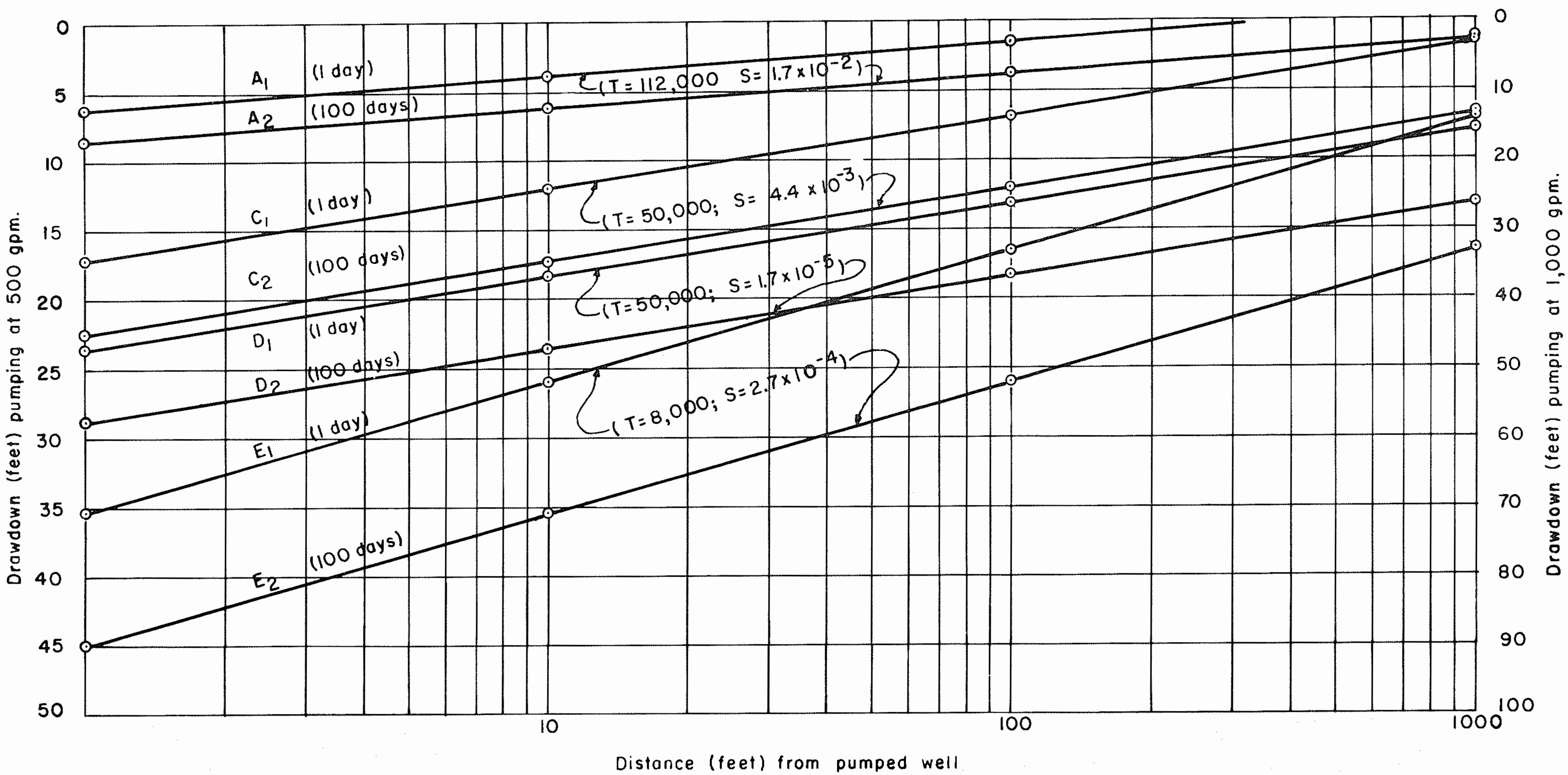

Figure b, appendix b

N., Rs. 61-65 W., contained more than 1,400,000 acre-feet of water in transient storage in 1963. The Floyd aquifer underlies about 265 square miles in Tps. 109-112 N., Rs. 59-62 W., and contained an estimated 1,800,000 acre-feet of water in transient storage.

An aquifer in northern Beadle County, here named the Tulare aquifer, is the southeastern extension of an aquifer that is extensively developed in Tulare (T. 115 N., R. 63 W.) and adjacent townships in southwestern Spink and in northeastern Hand Counties. (See fig. 6.) This aquifer underlies about 260 square miles in Tps. 112 and 113 N., Rs. 60-65 W.; the thickest part of the aquifer overlies a buried bedrock valley (fig. 5 and plate 1) that trends westward across T. 113 N., Rs. 60-63 W. An estimated 1,800,000 acre-feet of water was in transient storage in the aquifer in 1963.

The major aquifers generally are surrounded by areas in which aquifer material is thin and discontinuous or is missing. (See plates 1 and 2.) Thus, there is only limited hydraulic continuity between the aquifers.

Some water may be exchanged between the Warren and Floyd aquifers in the south-central part of T. 111 N., R. 62 W., where more than 25 feet of saturated aquifer material is shown on the map, but this connection probably is not hydrologically significant because of the small extent and relatively low permeability of the connecting material.

Although 25 to 50 feet of aquifer material (plate 1) appears to connect the Warren and Tulare aquifers near Broadland, in T. 112 N., R. 63 W., examination of well and test-hole logs indicates that the aquifers are not actually connected. The aquifer material shown on plate 1 is divided into two unconnected layers, the upper one a part of the Warren aquifer and the lower one a part of the Tulare aquifer. Differences in water quality and water levels between the two aquifers substantiate this interpretation of the logs.

Hydrologic continuity between the Floyd and Tulare aquifers is limited to a narrow "neck" in the southern part of T. 112 N., R. 60 W., where less than 50 feet of permeable material in an area less than 2 miles wide provides a connection (plate 1).

Water levels.--Water in the major aquifers occurs under artesian conditions because the low-permeability till is a confining layer for water moving down gradient from areas of recharge. However, water-table conditions exist locally where the aquifers are exposed at the surface. The general slope of the piezometric surface of water in the aquifers is toward, and southward in, the main buried valley (fig. 5) in Rs. 61 and 62 W. The general configuration of the piezometric surface is distorted locally as a result of variations in recharge, discharge, and hydrologic characteristics of the aquifers. Long-term and regional changes in the configuration are due primarily to climatic fluctuations.

In general, the depth to water in wells completed in the major aquifers is greatest beneath bluffs along deeply-incised stream valleys and beneath other prominent topographic highs, and where permeable deposits are most deeply buried. The depth to water is least beneath stream valleys and other topographic depressions, and where permeable deposits are at the surface. Water levels in the aquifers have been relatively stable or have risen slightly over the past few years; thus, recharge to the aquifers has been equal to or slightly greater than discharge.

Warren aquifer.--Water levels in wells completed in the Warren aquifer generally are less than 40 feet below land surface. Artesian conditions exist throughout most of the aquifer and, locally, the pressure may be high enough to cause wells to flow. For example, small volume, low-pressure flows were obtained from test holes 109-65-2bbab and 2bbbb on the alluvial flat along Sand Creek. In the valleys of Sand Creek and other ephemeral streams, water-table conditions occur in shallow surface materials, and water levels are at or near the land surface.

Pronounced seasonal water-level fluctuations occur in the Warren aquifer. In the abnormally wet spring of 1962, water levels in some wells rose as much as 15 feet, while in the abnormally dry summer of 1964, water levels locally dropped 10 to 15 feet. Hydrographs of four wells completed in the Warren aquifer are shown on figure 7. The fluctuations shown on these hydrographs, except where caused by pumping, are primarily due to seasonal variations in recharge and discharge. The hydrographs of wells 110-62-9bccc$_1$ and 110-62-9bbcd$_1$, observation wells in the city of Huron's West Well Field, show the effects of heavy pumping; wells in this field furnished all or most of Huron's water supply during much of the 1930's, 1940, the last half of 1959, and the first three-quarters of 1960.

The water level in well 109-62-9aadd$_1$ has been measured intermittently since 1935. Fluctuations shown on the hydrograph are in response to both long-term and seasonal variations in recharge and discharge.

Floyd aquifer.--The level of water in wells completed in the Floyd aquifer ranges from land surface to more than 50 feet below land surface. Throughout much of area A, figure 8, and in the deepest stream valleys, water levels are at or within a few feet of the surface in the spring, and even in late fall seldom drop to more than 10 to 15 feet below the surface. Where permeable deposits at the surface are not connected to the aquifer, and where, locally, the aquifer is separated into two parts (as at well 110-60-11bbd) the piezometric surface of water in the deepest part of the aquifer may be as much as 65 feet below land surface.

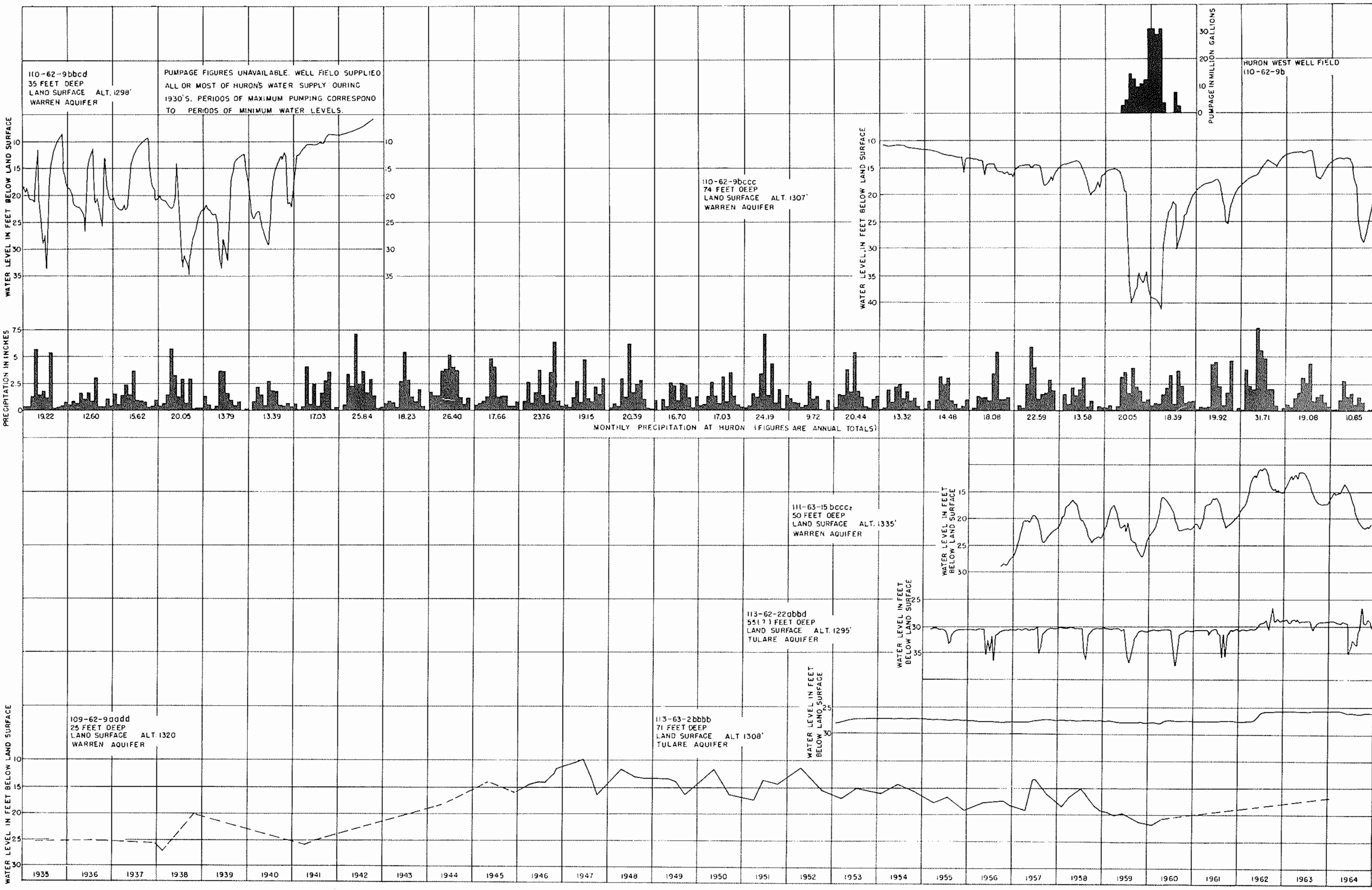

FIGURE 7. HYDROGRAPHS SHOWING PRECIPITATION AT HURON AND WATER-LEVEL FLUCTUATIONS IN SELECTED WELLS COMPLETED IN AQUIFERS IN THE DRIFT, BEADLE COUNTY, SOUTH DAKOTA.

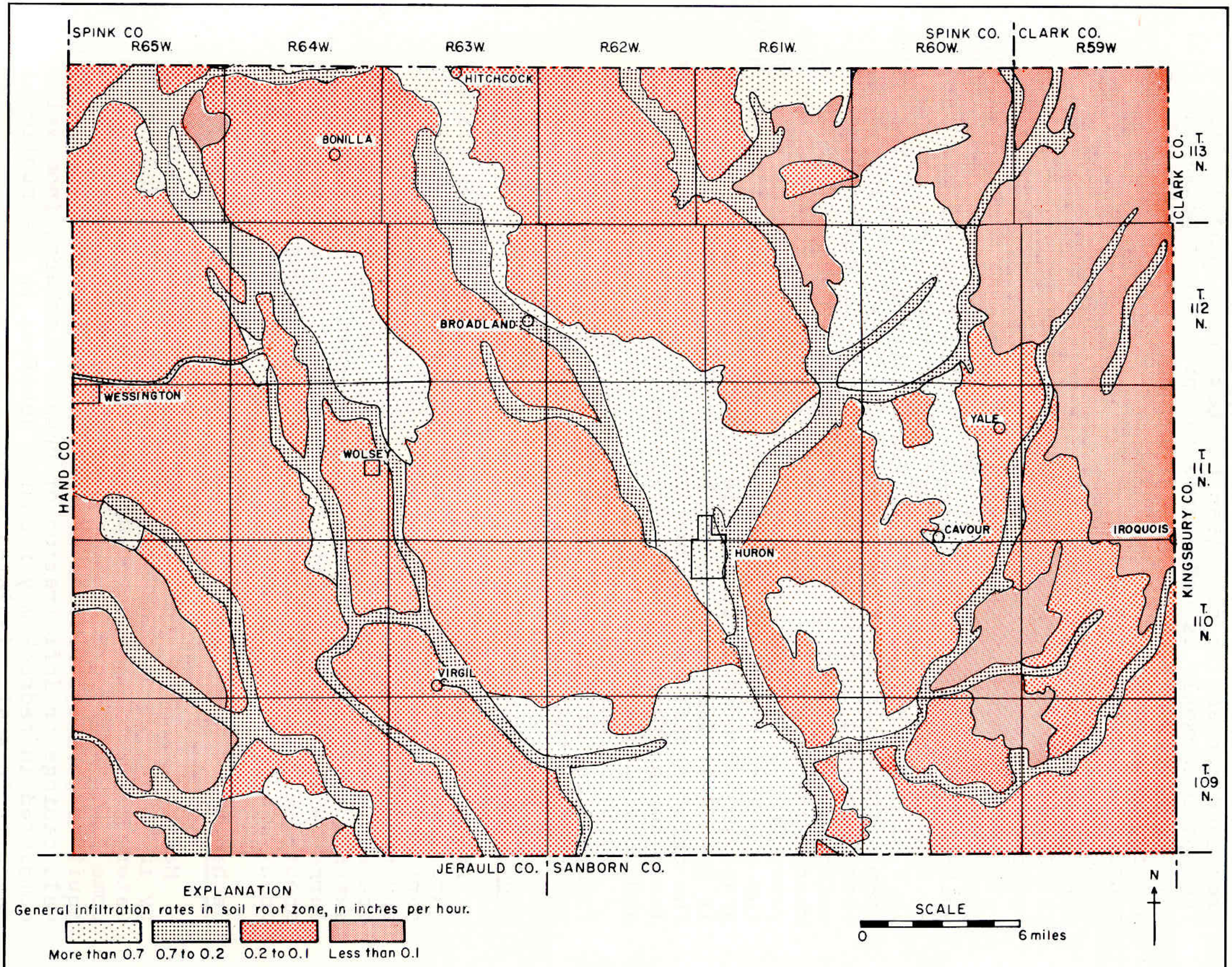

Figure 8. Surface deposits of Beadle County classified by permeability. (modified after Moxon, 1965)

Tulare aquifer.--Water levels in the Tulare aquifer range from land surface to more than 60 feet below land surface. The water commonly is under artesian pressure because the till cover over the aquifer confines the water moving through the aquifer from recharge areas at higher altitude. Water-table conditions are present, however, in some topographic depressions in T. 113 N., Rs. 60-62 W., where the aquifer is at the land surface. Near, and northeast of, Lake Byron, in T. 113 N., Rs. 60 and 61 W., artesian pressure in the aquifer is great enough to cause some wells to flow at altitudes below about 1,270 feet. Some of these wells, such as well 113-60-15ddbb, flow intermittently because of seasonal variations of pressure, while others, such as well 113-61-23cdbb, flow perenially.

Seasonal water-level fluctuations in the Tulare aquifer in T. 113 N., Rs. 62 and 63 W. generally are small. The hydrographs for wells 113-62-22abbd and 113-63-2bbbb (fig. 7), both completed in this aquifer, show very little change in water level as a result of natural seasonal variations in recharge and discharge. Well 112-62-22abbd is located about 200 yards from an irrigation well, and the hydrograph clearly shows the effects of pumping during the summer. However, if the hydrograph is adjusted to compensate for the effects of pumping, it is nearly identical to the hydrograph for well 113-63-2bbbb. The only significant fluctuation is the 2-foot rise in water level during the summer of 1962, when record high snow melt and precipitation occurred.

Except in the area discussed above, seasonal water-level fluctuations in the Tulare aquifer are similar in magnitude to those in the Warren and Floyd aquifers.

Minor aquifers

Discontinuous lenses of outwash and other fluvioglacial material in till yield water to domestic and stock wells in parts of Beadle County, especially in Tps. 109-112 N., Rs. 64 and 65 W. Alluvial deposits in the county (area B, fig. 8) are not widely used for water supplies because of their small extent, thinness, and generally low permeability, and the large variations in quality of the water they contain. Only about six wells are completed in alluvial deposits in the county.

Recharge

Most of the recharge to aquifers in surficial deposits is by infiltration of precipitation in Beadle County and by ground-water inflow from adjacent areas. Minor amounts of recharge come from aquifers in the bedrock that are in contact with aquifers in the surficial deposits. Leakage through ruptured well casings or infiltration of unused discharge from wells completed in bedrock may recharge aquifers in the surficial deposits in small, isolated areas.

Infiltrating water must fill the soil to its moisture-holding capacity before any recharge from precipitation can take place. When the ground thaws in the spring, the amount of water infiltrating from melted snow and from rainfall exceeds the moisture-holding capacity of the soil, and the excess may move downward to recharge the aquifers. The rise of water level each spring, shown on the hydrograph of well 111-63-15bccc$_2$, figure 7, indicates that recharge in the spring is significant. A smaller rise in water level usually occurs in late fall and early winter because of the decrease in discharge of water by evapotranspiration.

Precipitation in summer and fall rarely contributes to the ground-water supply because most of it evaporates, is used by vegetation, or is retained as soil moisture. As noted previously, precipitation in amounts equal to or less than the daily average would be unavailable for either soil-moisture replenishment or recharge from May through October. Average potential evapotranspiration at Huron during this period is 23.24 inches and average precipitation is 13.36 inches (Pengra, 1959, p. 41). In late fall, winter, and early spring, infiltration is prevented by frozen ground and by the occurrence of most precipitation in the form of snow or ice.

The amount of precipitation that infiltrates the soil is governed by the permeability of the soil. Infiltration rates, which are a measure of permeability, range from less than 0.02 to more than 1.0 inch of water per hour in Beadle County soils. (See fig. 8.) Where the most permeable surface materials are present (area A and parts of area B, fig. 8), infiltration of precipitation is most rapid. The soils in these areas range in thickness from less than 10 inches to 5 feet, and in moisture-holding capacity from about 1.25 to about 1.75 inches per foot of thickness (U. S. Soil Conservation Service, 1957). Because of the high infiltration rates, nearly all precipitation and runoff that reaches the permeable areas infiltrates the soil. In the spring, and following heavy or prolonged moderate rainfalls in the summer and fall, the soil moisture-holding capacity is exceeded frequently and aquifers immediately underlying the soil are recharged.

Where a layer of till overlies the aquifers, recharge from infiltration of precipitation is limited by the very low permeability of the till. The maximum infiltration rate in unweathered till in Beadle County is probably less than 0.001 inch per hour (estimated from laboratory and field-test data). Because soil developed on till generally has high moisture-holding capacity (1.75 to 2.20 inches per foot of thickness) and till has very low permeability, little recharge to the aquifers takes place through the till.

Ground-water inflow from areas adjacent to Beadle County is a major source of recharge to aquifers in the drift in parts of the county. Where aquifers that extend outside Beadle County are exposed at the surface, or are overlain by permeable materials, they are recharged by infiltration of precipitation. Water in the aquifers moves down gradient, as does water in a surface stream; where the intake area outside the county is at a higher altitude than the water level of the aquifer in Beadle County, water moves through the aquifer into the country.

Warren aquifer.--Major recharge to the Warren aquifer in Beadle County is from direct infiltration of precipitation and snow melt. Hydrographs of wells completed in the aquifer (fig. 7) indicate that recharge is greatest after the ground thaws each spring. Permeable surficial deposits (area A and parts of area B, fig. 8), although not everywhere hydraulically connected to the buried aquifer, provide an avenue for infiltration of precipitation. In addition, some runoff from areas underlain by relatively impermeable surface materials (area C, fig. 8) is channeled into ephemeral streams and thence to areas where permeable surface deposits permit infiltration. As suggested by Sayre (1935, p. 105) and more recently by Walker (1961, p. 17), outwash and alluvium at the surface near Broadland probably constitute a major intake area for recharge to the Warren aquifer.

Although the sand plain in northwestern Sanborn County is an intake area for much of the recharge to the Warren aquifer (Steece and Howells, 1965), such recharge probably does not move northward into Beadle County. Available data, though inconclusive, indicate that the piezometric surface of water in the aquifer slopes toward the south and southeast in southern Beadle County.

Ground-water inflow from Hand County is a source of some recharge to the aquifer in Tps. 110 and 111 N., R. 65 W. Precipitation, runoff from areas of impermeable surface materials, and snow melt all infiltrate the aquifer where it is exposed at the surface (probably along the eastern flank of the Coteau du Missouri). Movement of this water down gradient toward the southeast and into Beadle County recharges the aquifer.

Some recharge to the Warren aquifer in T. 109 N., Rs. 61 and 62 W., may come from the aquifer in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale. In this area, erosion prior to deposition of the drift nearly cut through the Niobrara Marl (Hedges, 1967). The resulting valley is filled, in part, with permeable drift, some of which is in contact with the aquifer in the Niobrara and Codell. The water level in the Warren aquifer, where the aquifer fills the buried valley in T. 109 N., Rs. 61 and 62 W., is at a minimum altitude of about 1,270 feet. The water level in the aquifer in the Niobrara and Codell in this area is at an altitude of about 1,280 feet. Thus, where they are in contact, movement of water from the aquifer in the Niobrara and Codell into the Warren aquifer may take place. In northern Sanborn County, recharge from the aquifer in the Niobrara and Codell to the aquifer in the drift occurs mostly on the north and west sides of buried bedrock valleys (Steece and Howells, 1965). A similar situation is believed to exist in southern Beadle County.

Floyd aquifer.--A major source of recharge to the Floyd aquifer is direct infiltration of precipitation and runoff into permeable surface deposits in the east-central part of the county. Alluvium (area B, fig. 8) in the valleys of ephemeral streams in eastern Beadle County apparently is in direct contact with the aquifer in many places. (See plate 2.) In addition, surface deposits with high intake rates and low moisture-holding capacities (areas labeled A, fig. 8) directly overlie the aquifer in parts of Tps. 109-111 N., Rs. 60 and 61 W. The slope of the piezometric surface of water in the aquifer is generally southwestward in east-central Beadle County. The quality of water in the most permeable part of the aquifer down gradient from the area underlain by permeable surface deposits is similar to the quality of water in the surface deposits. Thus, the areas underlain by permeable surface deposits apparently are intake areas for much of the recharge to the Floyd aquifer.

The southern part of the aquifer receives recharge by ground-water inflow from Sanborn County. Comparison of water levels in wells completed in the aquifer in northeastern Sanborn County and southeastern Beadle County indicates that ground water probably is moving northward or northwestward in this area. The rather uniform quality of water (specific conductance 2,000-2,400 micromhos) from the Floyd aquifer in Sanborn County appears to continue into Beadle County, at least as far north as the southern part of T. 110 N., Rs. 60 and 61 W.

Tulare aquifer.--The major intake area for recharge to the western part of the Tulare aquifer in Beadle County apparently is in southwestern Spink County. Recharge moves toward the southeast through the aquifer.

A constriction in the aquifer, southeast of Hitchcock, serves to maintain a constant volume of flow through the aquifer and even out, or damp, water-level fluctuations that normally are caused by seasonal changes in volume of recharge and discharge. The constriction is caused by decreases in thickness, width, and permeability of the aquifer. Up gradient from the constriction, changes in the volume of water in transient storage, and hence the water level, are in response to changes in the volume of recharge and discharge; the amount of water in transient storage in the area of constriction, however, remains relatively constant as indicated by the lack of pronounced natural water-level fluctuations in wells 113-62-22abbd and 113-63-2bbbb (fig. 7). If recharge "upstream" from the constriction were greatly reduced for a prolonged period, the amount of water in transient storage would be less than the amount that could pass through the constriction, and water levels in wells 113-62-22abbd and 113-63-2bbbb would decline. When recharge "upstream" exceeds the volume that can pass through the constriction, the excess moves eastward through another part of the aquifer in Spink County.

The Tulare aquifer in T. 113 N., Rs. 60 and 61 W., receives recharge from infiltration of precipitation where the aquifer is at the surface in stream valleys. Some additional recharge to the aquifer in this area may come from the aquifer in the Niobrara Marl and the Codell Sandstone Member of the Carlile Shale. In T. 113 N., R. 60 W., the Carlile Shale is in contact with the Tulare aquifer in the bottom of the buried bedrock valley. (See fig. 5.) The aquifer in the Niobrara and Codell has been completely removed in the bottom of this valley, but where it is in contact with the Tulare aquifer along the valley sides, water moves from one aquifer to the other.

Whether the Tulare aquifer receives recharge from, or discharges to, the aquifer in the Niobrara and Codell depends on the pressure differential. The configuration of the piezometric surface of water in the bedrock aquifer in this area is unknown but the altitude of this surface is known to be above 1,250 feet and may be as high as 1,275 feet. The piezometric surface of water in the Tulare aquifer in the buried valley has a maximum altitude of about 1,270 feet and may be as low as 1,260 feet during times of maximum discharge and minimum recharge. Thus, during periods when the water level in the drift is at its lowest, water may move from the Niobrara and Codell into the drift, whereas during periods of high water levels in the drift, water may move in the opposite direction and recharge the bedrock aquifer.

Minor aquifers.--Recharge to aquifers in alluvium is from infiltration of precipitation and runoff from adjacent areas and, particularly along the James River, from influent seepage from stream channels. Recharge to the minor aquifers in the drift, except where they are exposed at the surface, is by slow infiltration of water through the till.

Discharge

Wells completed in aquifers in surficial deposits in Beadle County discharged an estimated 3,160 acre-feet of water, most of which came from the three major aquifers, in 1963. Of this amount, about 2,200 acre-feet was discharged by 29 irrigation wells. Irrigation use, therefore, accounted for more than two-thirds of the water yielded to wells by aquifers in surficial deposits, and the demand for irrigation water is increasing rapidly. At least 10 new irrigation wells were constructed or scheduled for construction in the county during 1964.

Evaporation and transpiration account for much of the natural ground-water discharge from aquifers in surficial deposits. Except in spring and early summer, when a high water table may result in numerous temporary seeps, discharge to lakes and springs is slight and there is no base flow in streams; in years with scant rainfall even the James River is dry.

Most of the perennial springs in the county are found in 5 areas; (1) on the west side of the James River trench in sections 3 and 10, T. 113 N., R. 62 W.; (2) along both sides of the valley that extends northeast from Lakes Connors and Byron through T. 113 N., R. 60 W.; (3) Pearl Springs, along Pearl Creek, sections 12 and 13, T. 109 N., R. 61 W., and section 18, T. 109 N., R. 60 W.; (4) along Cain Creek, sections 11 and 12, T. 109 N., R. 62 W.; and (5) in T. 109 N., R. 65 W., along the escarpment of the Coteau du Missouri where there are several small seeps and springs (flow generally less than 3 gpm) at or near the contact between the Pierre Shale and the overlying drift. Except for those springs discharging beneath the surfaces of Lakes Connors and Byron, the total discharge of all known springs in the county is less than 100 gpm.

Since 1880, as a result of increasing development of the aquifer in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale, aquifers in the drift probably have begun to discharge water to the Niobrara and Codell, particularly on the southern or eastern margins of deep valleys in the bedrock surface (Steece and Howells, 1965).

Ground-water outflow from Beadle County accounts for some discharge from the major aquifers in the drift. Water moves through the Warren aquifer and into Jerauld County in Rs. 63 and 64 W., and probably into Sanborn County in Rs. 61 and 62 W. The amount of outflow cannot be determined until more quantitative data are available.

Minor aquifers in surficial deposits yield water to wells, but because of their generally small extent, thinness, and poor-quality water, they supply only a very small part of the water used. Minor aquifers surrounded by till are recharged by slow infiltration of water through the till. For this reason, these aquifers are seldom capable of yielding large quantities of water to wells for sustained periods. Minor aquifers exposed at the surface are recharged by direct infiltration of precipitation and by infiltration of runoff from adjacent areas. Where these exposed aquifers have a saturated thickness adequate to provide the necessary volume of storage, they may yield reliable water supplies except during prolonged periods of drought. A municipal well at Wessington obtains as much as 200 gpm from one such exposed aquifer.

Water quality

The quality of water from aquifers in surficial deposits varies widely with time and place, and even with depth at a given time and place. Selected chemical analyses of water from these aquifers are given, together with an explanation of the meaning and relation to use of important chemical properties, in appendix C. Additional analyses are given in Howells, Stephens, and Hedges (1967).

General ranges of some of the more important chemical constituents and properties of water from aquifers in surficial deposits are given below:

Iron (Fe) and manganese (Mn)	0- 15	ppm
Calcium (Ca)	5- 525	ppm
Sodium (Na)	15- 1,500	ppm
Bicarbonate (HCO_3)	150- 800	ppm
Sulfate (SO_4)	80- 5,000	ppm
Nitrate (NO_3)	0- 1,000	ppm
Fluoride (F)	0.04- 1.3	ppm
Boron (B)	0.04- 2.5	ppm
Hardness	10- 6,000	ppm
Total dissolved solids	400- 8,500	ppm
Specific conductance	350-20,000	micromhos
% Sodium	6- 98	
SAR	0.3- 20	

Most of the water from aquifers in surficial deposits contain more than 1 ppm (parts per million) dissolved iron and manganese. The dominant cation in the water commonly is calcium or sodium, and the dominant anion commonly is bicarbonate or sulfate.

The nitrate content of water from surficial deposits varies widely. Wells completed in very shallow aquifers are more susceptible to pollution by organic wastes, resulting in a higher nitrate content, because infiltrating surface water moves more rapidly and directly to the aquifer and consequently is less purified than water in deeper aquifers.

Water in the more permeable parts of the aquifers generally has lower conductance and dissolved solids content than water in the less permeable parts. The rate of water movement through the aquifer determines the amount of time available for the water to dissolve mineral matter from the containing materials. Thus, where permeability is low and water moves slowly, dissolved mineral content increases.

Water from the eastern part of the Floyd aquifer in Beadle County is of better quality (lower dissolved solids content) than water from the western part of the aquifer and from the other major aquifers. Local recharge in the eastern part of the aquifer supplies water with low dissolved solids content that, as it moves down gradient, becomes mixed with water of poorer quality already moving through the aquifer.

Seasonal variations in water quality are in part due to variations in recharge. In the spring, and following heavy rains, water in parts of aquifers that are locally recharged by infiltrating precipitation may be of much poorer than normal quality because some of the soluble salts deposited in the soil during dry periods are flushed downward into the aquifers.

Highly permeable alluvium along ephemeral streams in eastern Beadle County generally contains water of good quality (dissolved solids content less than 600 ppm) but in alluvium that is only slightly permeable and in some deposits overlying Pierre Shale or till, the water often is of very poor quality (dissolved solids content more than 2,500 ppm).

Most of the minor aquifers enclosed by till contain water of poorer quality than that in the major aquifers or in minor aquifers exposed at the surface. Slow recharge allows the water to dissolve large quantities of material from the till through which it passes. Such water often contains more than 3,000 ppm dissolved solids and may contain as much as 15,000 ppm.

Aquifers in the Bedrock

The bedrock strata of Beadle County contain two major and several minor aquifers. One major aquifer is in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale; the other is in the sandstone beds of the Dakota Group. The minor aquifers are in the Greenhorn Limestone, and in permeable sand or sandy shale zones in both the Carlile Shale below the Codell Sandstone Member and the Graneros Shale.

Major aquifers

Aquifers in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale.--The Codell Sandstone Member of the Carlile Shale and a permeable zone at or near the base of the Niobrara Marl comprise a single artesian aquifer. The extent of the aquifer in Beadle County is outlined in figure 9, which also shows the approximate depth to the Codell. The Codell is the lower part of the aquifer and seems to be more uniform in its distribution and hydrologic characteristics than is the upper part in the Niobrara Marl. Throughout most of

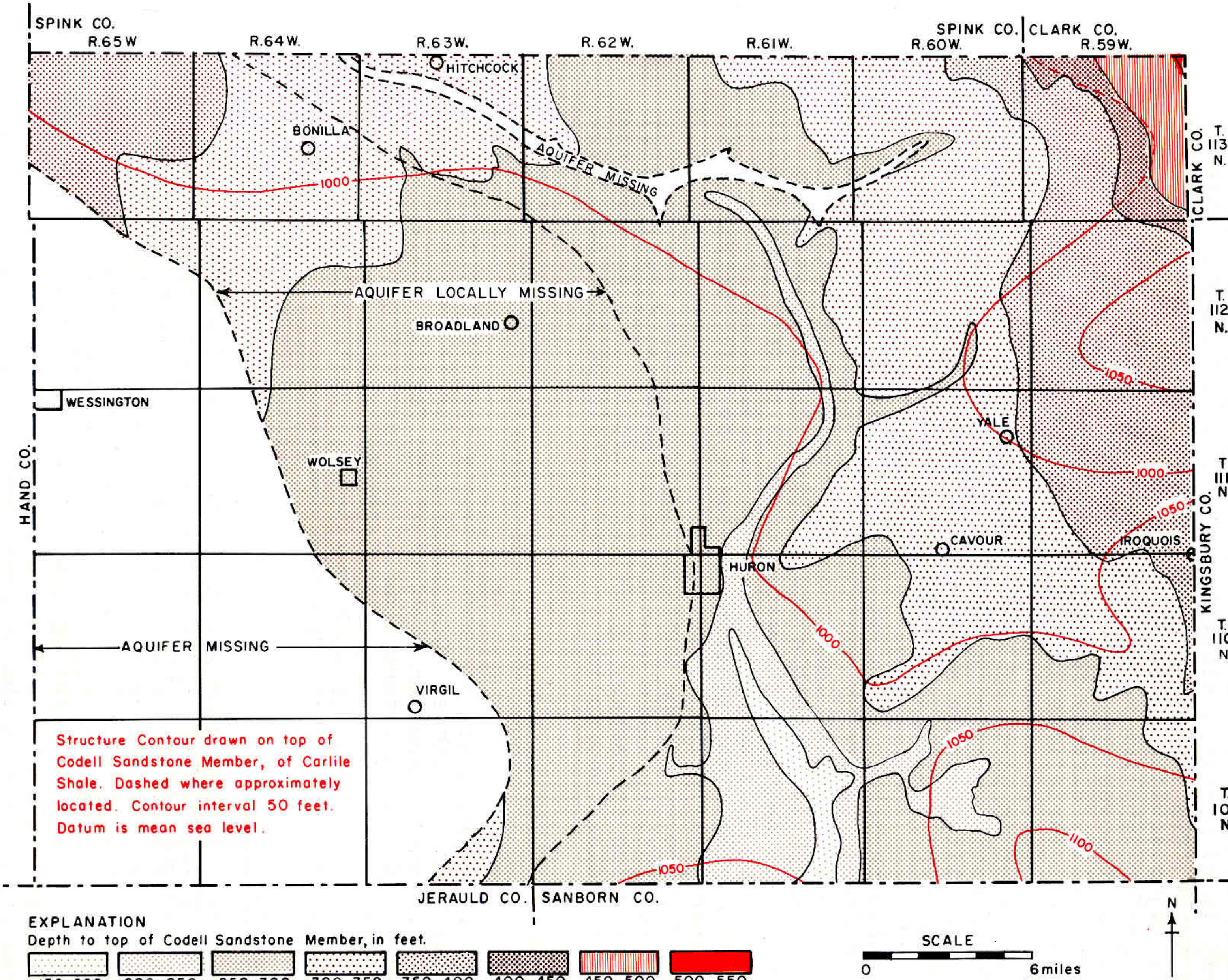

Figure 9. Extent of the aquifer in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale; also shown are contours on and depth to the lower part of the aquifer (Codell Sandstone).

the county the Niobrara and Codell are separated by a shale bed at the top of the Carlile Shale; locally, however, they are in contact.

The artesian head in the aquifer has declined 100 to 150 feet since development began in the late 1880's. The maximum decline in head occurred where development was most intense--an area extending from Mitchell to a few miles north of Huron. In Beadle County most wells tapping the aquifer are concentrated in an area extending 12 miles east from State Highway 37 and 16 miles north from the Sanborn County line. In 1962, the altitude of the piezometric surface was about 1,280 feet two miles north of Huron, and 1,238 feet on the James River floodplain near the Sanborn County line.

Aquifer in the Dakota Group.--In Beadle County, as in much of eastern South Dakota, the sandstone beds of the Dakota Group constitute the most widely-developed aquifer in the bedrock. The hydrology of this aquifer has not yet been fully outlined because of its complexity.

In Beadle County, the Dakota yields water to flowing wells except where the land surface is above an altitude of about 1,350 feet in the east and about 1,495 feet in the southwest. Near the James River at the Sanborn County line the piezometric surface is slightly above 1,300 feet. Thus, flowing wells can be obtained in all but about 125 square miles of the county. The present limits of flow and the depth to the top of the aquifer in the Dakota are shown in figure 10.

The piezometric surface of water in the Dakota has declined as a result of development. When development began, flowing wells could be obtained in all but 2 or 3 square miles in the southwestern corner of the county. Darton (1909), Todd (1904), and Todd and Hall (1904a) indicated that the piezometric surface sloped from west to east or northwest to southeast across the county and, in 1894, was as high as 1,760 feet above sea level in southwestern Beadle County and 1,600 feet at Iroquois. The artesian head is still decreasing, but at a much lower rate in the past.

Minor aquifers

The Carlile Shale below the Codell Sandstone Member and the Graneros Shale contain this lenses or beds of sandstone or permeable sandy shale that locally can yield water to wells. As no wells in Beadle County now yield water from these minor aquifers, little is known about their hydrology. In the 1890's, a few wells were completed in both the Carlile and Graneros Shales; reports by drillers indicated that the piezometric surfaces in both aquifers were above land surface in central Beadle County and the artesian head in the Graneros was greater than that in the Carlile. Early reports also noted that the artesian head declined rapidly and wells commonly stopped flowing within a few years.

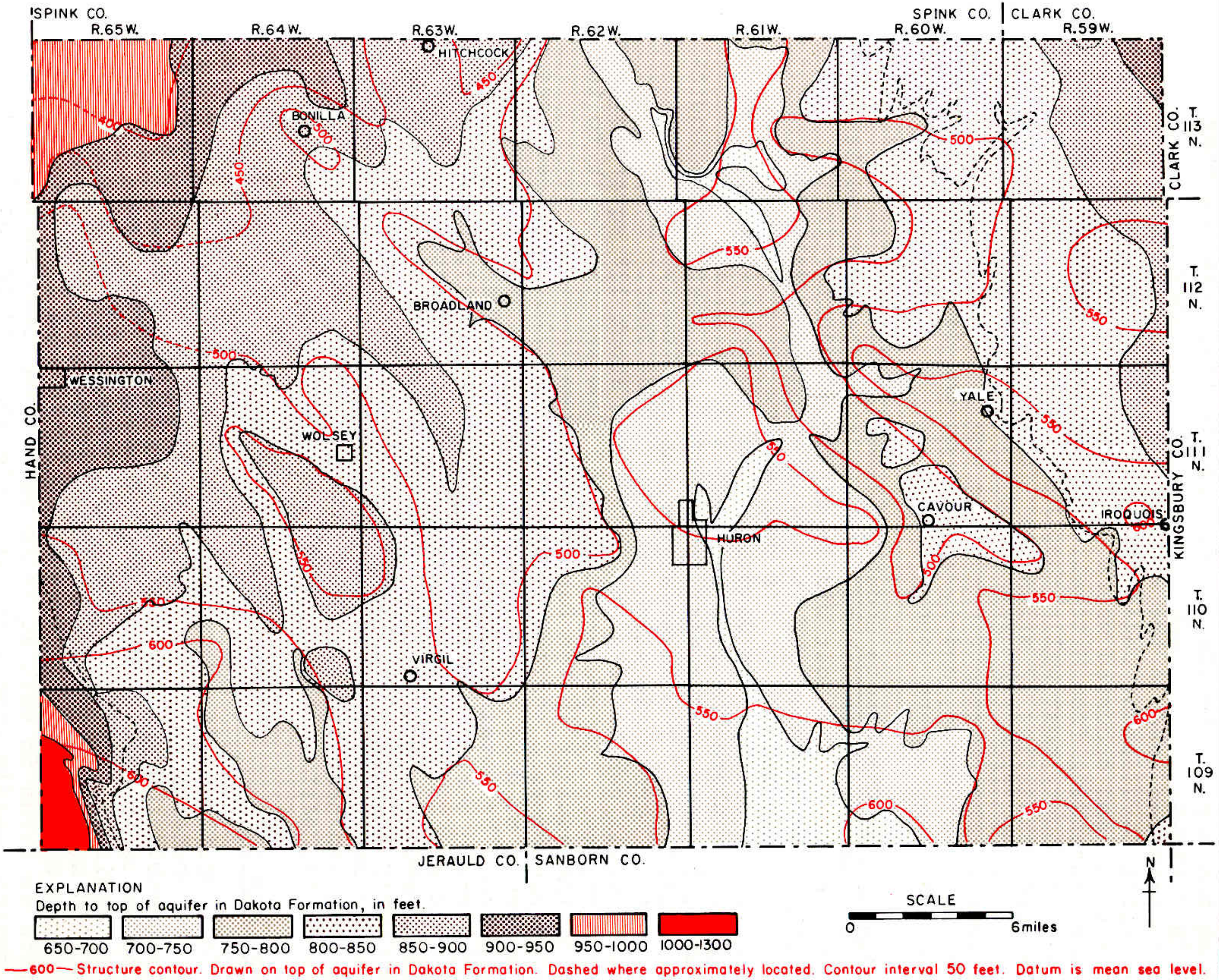

Figure 10. Contours on and depth to the top of the aquifer in the Dakota Formation. The approximate boundary of the area within which wells will flow is shown with a dashed line.

At present (1964) small supplies of water adequate for stock or domestic use could be obtained locally from the Carlile and graneros in the central two-thirds of Beadle County.

A permeable zone near the middle of the Greenhorn Limestone is also an aquifer throughout Beadle County. The depth to this aquifer in the central two-thirds of the county ranges from about 450 to 600 feet.

Although this aquifer, locally called the "mud flow," yields water under artesian conditions, the head is much less now than formerly. Todd and Hall (1904a, p. 5) noted that water in the Greenhorn initially had "sufficient pressure to rise to nearly 1,500 feet above sea level." By 1904, the piezometric surface had declined to about 1,400 feet in the southeastern corner of Beadle County and about 1,300 feet near the James River at the Sanborn County line. In 1963, although the piezometric surface appeared to be no lower than about 1,300 feet in Beadle County, its maximum altitude probably was no more than 1,350 feet. Flowing wells probably could be obtained in about two-thirds of the county.

Recharge

The sources of recharge to aquifers in bedrock strata are unknown. One or more of the aquifers may contain connate water only and not recieve recharge from another aquifer or from infiltration of precipitation. When water is discharged from such an aquifer, whether by natural or man-made means, it is not replaced by natural process.

Major aquifers.--The major source of recharge to the aquifer in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale is unknown. Before development of ground-water supplies began in the 1880's, the Niobrara and Codell probably did not receive much, if any, recharge from overlying aquifers for two reasons: (1) north, east, and west of Beadle County the overlying, nearly impermeable Pierre Shale thickens and serves as a barrier to downward movement of water; and (2) because the piezometric surface of water in the aquifer was about 1,400 feet, or more than 100 feet above the land surface in those parts of the James Valley where permeable drift is in contact with the Niobrara or Codell. Thus the Niobrara and Codell probably discharged water to, rather than received recharge from, the drift before 1880.

Since the 1880's, however, the aquifer probably has begun to receive recharge from aquifers in the overlying drift where buried bedrock valleys (see fig. 5) are deep enough to reach either the lower part of the Niobrara Marl or the Codell Sandstone Member. Such recharge occurs because well development has resulted in a lowering of the piezometric surface from an altitude slightly above 1,400 feet in 1885 to as low as 1,238 feet in 1963. Most of the recharge occurs on the southern or eastern sides of the buried valleys, the "down gradient" sides with respect to the original piezometric surface in the Niobrara and Codell.

The aquifer in the Niobrara and Codell also has received recharge from aquifers in the Greenhorn Limestone and Dakota Group as the result of casing failure of many deep wells.

The source of recharge to the Dakota is unknown; perhaps the water is connate and is released by the expansion of water and compaction of the aquifer than can accompany the release of artesian pressure. Other possible sources of water are dewatering of the confining and contained shale beds in the Dakota Group, or recharge from deeper aquifers where they contain water that is under greater artesian pressure than that in the Dakota. Well drillers report that within the last 20 years the aquifer in the Greenhorn Limestone has begun, in some areas, to supply recharge to the aquifer in the Dakota Group by leakage through failed well casings and down the outsides of casings imperfectly sealed between the Greenhorn and Dakota. Such recharge now occurs because the piezometric surface in the Dakota has declined below that in the Greenhorn.

Minor aquifers.--Little information is available to indicate the source, if any, of recharge to the Greenhorn Limestone or to permeable zones or lenses in the Carlile Shale below the Codell Sandstone Member and to permeable zones or lenses in the Graneros Shale. The close similarity of analyses (some from areas adjacent to Beadle County) of water from the Carlile, Greenhorn, and Graneros to each other and to analyses of water from the topmost part of the Dakota Group may indicate a similar or a common source of water for all four aquifers. The water may be connate, or it may be moving from the Dakota into the Graneros, Greenhorn, and Carlile through fractures or other permeable or slightly permeable connections though no such movement is known to occur in Beadle County. Possibly, also, the aquifers may be in physical contact over or near highs of the Precambrian surface, as Steece and Howells (1965, p. 72) noted in Sanborn County.

Discharge

Major aquifers.--Natural discharge from the aquifer in the Niobrara and Codell probably is small and occurs primarily at the northern and western sides of major bedrock valleys. The water is discharged to permeable deposits in the overlying drift.

In 1963, the aquifer discharged an estimated 170,000 gpd to wells in Beadle County. More than 85 percent of the wells supplied water for domestic use.

The aquifer in the Dakota Group has no known natural discharge in Beadle County. However, it discharges much water through wells and to overlying aquifers through corroded well casings. Discharge of Dakota wells, much of which was unused, was estimated as 7,000,000 gpd in 1963.

Minor aquifers.--The minor aquifers have no known natural discharge in Beadle County. Of these aquifers, only the aquifer in the Greenhorn Limestone is known to discharge water to wells, about 4,000 gpd in 1963. The notable decline in artesian head in the Greenhorn probably has resulted from discharge to other aquifers through failed casings or along poorly-sealed casings, as this aquifer has rarely been used as a source of water. It is at the Greenhorn that casing failure most commonly occurs in wells tapping the aquifer in the Dakota Group.

Water quality

Water from aquifers in the bedrock is saline and usually contains more than 1,500 ppm dissolved solids. Water within each of these aquifers is more uniform in quality than is water within each of the aquifers in the drift.

Major aquifers.--Throughout much of the county, water from the aquifer in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale is soft, commonly contains less than 50 ppm sulfate, has a specific conductance of more than 3,500 micromhos, and is of sodium chloride type. Bicarbonate content increases from about 20 percent of the anions near Cavour to more than 40 percent near the Beadle-Sanborn-Jerauld County lines. Bicarbonate may be the dominant anion southwest of Beadle County. The water analyses for wells 109-60-1baaa and 111-62-13dddd (app. C) probably represent the general quality of water in the aquifer.

Near the buried bedrock valleys shown in figure 5, the proportions of various chemical constituents in the water locally change markedly, especially in the upper part of the aquifer (Niobrara Marl). Water from the aquifer in these areas is soft to very hard, contains less than 300 ppm chloride, has a specific conductance as low as 1,500 micromhos, and is of sodium sulfate type; well 109-60-25dc$_1$ (app. C) yields water in such an area. The changes in proportions of chemical constituents probably are due to recharge of the aquifer in the Niobrara and Codell by water from aquifers in the drift. The normally very hard water from the drift may be softened by an ion exchange in the Niobrara.

Sandstone beds in the Dakota Group yield water of both the sodium sulfate and calcium sulfate types; the total dissolved solids, sulfate, and chloride concentrations are fairly uniform throughout the county, but the concentrations of other constituents vary widely. Water from wells tapping the Dakota can be separated into the following three chemical quality groups: (1) water in the permeable sandstones at or near the top of the Dakota generally is a soft to moderately hard (less than 200 ppm), high-boron, sodium sulfate water that has a specific conductance generally greater than 3,000 micromhos (well 112-61-14cdcd$_2$, app. C); (2) water in the lowest sandstones of the Dakota generally is a very hard (more than 800 ppm), low-boron, calcium sulfate water that has a specific conductance less than 2,600 micromhos (well 113-65-4bcca, app. C); (3) water of intermediate quality occurs in permeable sandstones near the middle of the Dakota Group (well 112-61-14cdcd$_1$, app. C). Wells 112-61-14cdcd$_1$ and 112-61-14cdcd$_2$ are less than 30 yards apart. The latter is completed in the top sandstones of the Dakota and yields sodium sulfate water (96 percent sodium), whereas the former is more than 200 feet deeper and yields sodium-calcium sulfate water (46 percent sodium and 37 percent calcium).

Minor aquifers.--The quality of water from permeable zones in the Carlile Shale or the Graneros Shale is unknown, as no wells in Beadle County are known to obtain water from these zones. The water probably is similar to that obtained from such zones in Sanborn County, where Steece and Howells (1965) reported the water to be soft, of sodium chloride-bicarbonate-sulfate type, and to have a specific conductance greater than 3,000 micromhos. Before 1900 the water was reported to be soft and to contain various salts of soda.

As only two wells in Beadle County are thought to tap the aquifer in the Greenhorn Limestone, an evaluation of water quality throughout the county cannot be made. However, available evidence indicates that the quality of water from the Greenhorn is fairly uniform throughout Beadle County. Drillers report that water from the Greenhorn commonly is muddy and "very salty"; casings of wells tapping the aquifer in the Dakota Group often corrode through at the Greenhorn. Water from well 112-63-14bbad (app. C) is similar in quality (though of higher chloride content) to water from wells tapping the Greenhorn in northern Sanborn County (Steece and Howells, 1965, table 3).

WATER USE

Extent of Use

Surface Water

Although the average surface-water runoff from Beadle County probably exceeds 25,000 acre-feet per year, development of this resource, except from the James River, has been slight. Ravine Lake at Huron and Lake Byron are public recreation areas and other small lakes or ponds provide additional limited recreational opportunities. Water impounded in a draw east of Lake Byron provides an irrigation supply for about 50 acres, and minor diversions of drainage to dugouts provide some stock water throughout the county.

The James River, which furnishes the Huron municipal supply, also supplied about 1,800 acre-feet of water to irrigate about 1,200 acres of crop land in 1964. The city of Huron and the Armour and Company packing house obtain their supplies, about 1.5 million gpd (1,665 acre-feet per year) and 1 million gpd (1,120 acre-feet per year) respectively, from the reservoir of a city-owned dam at Huron. The storage capacity of the city reservoir is 2,320 acre-feet. An additional 4,875 acre-feet can be stored behind a U. S. Bureau of Reclamation dam on the James River about 15 miles north of Huron.

The State Water Resources Commission (1965, written communication) has found that the average summer flow of the James River in Beadle County is fully appropriated.

Ground Water

Use of ground water in Beadle County during 1963 is summarized in table 2, which shows the discharge of water by wells (about 11,200 acre-feet or 10 million gpd); table 3, which shows the estimated consumption of water for various uses from each aquifer; and table 4, which shows the estimated consumption of water from public-supply wells.

Industrial use of ground water is slight in Beadle County. Most industries obtain their water from municipal systems. A few industrial users, mostly those located outside the areas of municipal service, utilize ground water for drinking, lawn irrigation, and other minor uses. Their wells tap aquifers in the drift, in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale, or in the Dakota Group.

Table 2.--Estimated well discharge in 1963.

Type of well	No. of wells	Estimated production Million gallons per day	Acre-feet per year
Flowing	989	6.89	7,710
Non-flowing	942	3.14	3,510
Total	1,931	10.03	11,220

Water-bearing unit	No. of wells	Million gallons per day	Acre-feet per year
Drift and alluvium	699	2.83	3,160
Niobrara Marl and Codell Sandstone Member of the Carlile Shale	140	.17	187
Greenhorn Limestone	2	.004	4.5
Dakota Group	1,061	7.00	7,840
Undetermined	29	.03	28
Total	1,931	10.03	11,220

Table 3.--Estimated use of ground water in 1963.

Water-bearing units	Domestic 1/		Stock 1/		Irrigation		Public Supplies	
	No. wells and springs	Thousand gpd	No. wells and springs	Thousand gpd	No. wells	Thousand gpd	No. wells	Thousand gpd
Drift and alluvium	471	121	563	607	29	1,960	11	30.4
Niobrara Marl and Codell Sandstone Member of the Carlile Shale	118	33	108	121	--	-----	3	11.1
Greenhorn Limestone	2	.6	2	2	--	-----	--	-----
Dakota Group	783	237	956	1,070	1	4	14	103.2
Undetermined	20	6	24	27	--	-----	--	-----
TOTAL	1,394	398	1,643	1,827	30	1,964	28	144

1/ Totals include 1,222 wells and springs that supplied both domestic and stock needs.

Table 4.--Public ground-water supplies in 1963.

		Water-bearing Unit			
		Drift	Niobrara Marl and Codell Sandstone Member of the Carlile Shale	Dakota Group	Total
Cavour[a/] (pop. 151)	No. Wells	--	1	--	1
	1000 gpd	--	11	--	11
Hitchcock (pop. 205)	No. Wells	--	--	2	2
	1000 gpd	--	--	26	26
Huron[b/] (pop.15,085)	No. Wells	2	--	--	2
	1000 gpd	c/	--	--	c/
Iroquois[d/] (pop. 410)	No. Wells	--	--	3	3
	1000 gpd	--	--	29	29
Virgil (pop. 86)	No. Wells	--	--	1	1
	1000 gpd	--	--	6	6
Wessington (pop. 402)	No. Wells	1	--	1	2
	1000 gpd	29	--	2	31
Wolsey (pop. 376)	No. Wells	--	--	4	4
	1000 gpd	--	--	27	27
Yale (pop. 171)	No. Wells	--	--	1	1
	1000 gpd	--	--	13	13
Beadle[e/] County	No. wells	6	2	2	10
	1000 gpd	.4	.1	.2	.7
S. Dakota Dept. Game, Fish & Parks	No. Wells	2	--	--	2
	1000 gpd	1	--	--	1
TOTAL	No. Wells	11	3	14	28
	1000 gpd	30	11	103	144

a/ Populations estimated for 1963.

b/ From 1886 to 1914 Huron's water supply came from wells tapping the Dakota; by 1914 these wells were inadequate and the city began to obtain its water from the James River. In 1934, to provide additional water during periods of drought, 3 wells were drilled to the aquifer in the Niobrara and Codell, but were abandoned after 3 or 4 months as inadequate and of unsuitable quality. The city then had 4 wells drilled to form the West Well Field in 110-62-9b.

c/ In 1959, the wells were pumped at maximum capacity and produced about 900,000 gpd.

d/ All wells are in Kingsbury County.

e/ Eight school wells and two wells at the county courthouse.

Some public-supply wells are maintained as standby or emergency supplies. The city of Huron, for example, uses its wells only when the supply from the river is insufficient, as it was in 1959. The two county wells at the courthouse (one completed in the Dakota, the other in the Niobrara) likewise are standby supplies.

Type of Use

The use made of a water supply is related to the quality of that supply. The general chemical quality of surface and ground water in Beadle County, and the relation of water quality to water use are summarized in appendix C. Of note is the improvement in quality of surface water after the spring thaw.

Municipal and Domestic Use

The chemical quality of municipal-water supplies is shown in appendix C. Of the 10 communities in Beadle County, only Bonilla and Broadland[1/] did not have public-water supplies in 1963.

Water for domestic use should be free not only of harmful bacteria, but also of objectionable taste and odor. The standards for drinking water established by the U. S. Public Health Service (1962) and adopted by the American Water Works Association as criteria of quality for public-water supplies in the United States are shown in table 5. Also shown are the modified standards adopted by the South Dakota Department of Health.

No aquifer in the county yields water that does not have one or more constituents in excess of both standards. The constituents commonly in excess are total dissolved solids and sulfate. In addition, water from aquifers in the drift usually contains excess iron, and water from the Niobrara and Codell, though low in sulfate, contains excess flouride. No ill effects have been attributed to drinking water that contains one or more constituents slightly in excess of the standards.

1/ In March, 1965, the town of Broadland completed a municipal well tapping the aquifer in the Dakota Group. The well is 995 feet deep, has 5 and 2 1/2-inch diameter casing, and is finished with 115 feet of perforated 3-inch casing. Initial flow and pressure were reported as 80 gpm and 50 psi respectively.

Table 5.--Standards for drinking water adopted by the United States Public Health Service and the South Dakota Department of Health.

(Recommended maximum concentration1/)

Constituent	United States Public Health Service (ppm)	South Dakota Department of Health2/ (ppm)
Chloride	250	250
Fluoride	1.13/	.9-1.7
Iron	.3	.3
Maganese	.05	.05
Nitrate	454/	45
Sulfate	250	250
Total dissolved solids	500	1,000

1/ Should not be exceeded where other more suitable supplies are or can be made available.

2/ Written communication, February 5, 1962.

3/ For Beadle County; limit varies for different parts of the United States.

4/ In areas in which the nitrate content of water is known to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.

Agricultural Use

Livestock

Water used by livestock is subject to quality limitations of the same type as those relating to the quality of drinking water for human consumption. Livestock, however, generally can tolerate a greater amount of dissolved solids in their water than can humans. Maximum tolerances of some farm animals to dissolved solids are shown in table 6. All major aquifers yield water suitable for most farm animals. However, water too saline for stock use is found locally in thin, discontinuous lenses of permeable drift, in the less permeable (clayey or very silty) parts of the major aquifers in the drift, and near the eastern and western borders of the county where the water has been in contact with the Pierre Shale. West of Huron, water from the aquifer in the Niobrara and Codell is too saline for poultry and, possibly, for swine.

Irrigation

Characteristics that determine the suitability of water for irrigation are: (1) total dissolved-solids content, (2) amount of boron, (3) relative amounts of some dissolved constitutents, and (4) chemical changes that may take place in the soil and water after the water has been applied.

High concentrations of dissolved solids in irrigation water may adversely affect plant growth. The tolerances of many common crops to the amount of dissolved solids are shown in table 7.

Sodium hazard is a measure of the capacity of irrigation water to permit replacement, on soil particles, of exchangeable calcium and magnesium by sodium. Soil that has a high content of exchangeable sodium is undesirable for agriculture as it tends to deflocculate or "puddle," to develop a hard crust, and to become nearly impermeable to water. This effect may result when the percent sodium in irrigation water rises considerably above 50 (Wilcox, 1949).

Boron is essential to proper plant growth and nutrition but a small excess over the needed amount is toxic to some plants. The tolerances of many common crops to the amount of boron are shown in table 8.

"Black Alkali" or sodium carbonate may form in soils by evaporation of some types of water and result in an unfavorably high soil pH. The tendency for black alkali to form is called the alkali hazard and is related to the residual sodium carbonate in the irrigation water.

Table 6.--Maximum tolerances of some farm animals to dissolved solids in water (from Officers of the Department of Agriculture, 1950).

Animal	Maximum dissolved Solids (ppm)
Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle (dairy)	7,150
Cattle (beef)	10,000
Adult Sheep	12,900

Table 7.--Relative tolerance of crop plants to amount of dissolved solids.
(United States Salinity Laboratory Staff, 1954, p. 7)

[Within each group the least tolerant plants are placed at the top of the column.]

SENSITIVE	MODERATELY TOLERANT	TOLERANT
	Fruit Crops	
Strawberry	Cantaloupe	
Peach	Grape	
Apricot		
Almond		
Plum		
Prune		
Apple		
Pear		
	Vegetable Crops	
Green bean	Cucumber	Spinach
Celery	Squash	Asparagus
Radish	Peas	Kale
	Onions	Garden beet
	Carrot	
	Potato	
	Sweet corn	
	Lettuce	
	Cauliflower	
	Bell pepper	
	Cabbage	
	Broccoli	
	Tomato	
	Forage Crops	
Ladino clover	Sour clover	Birdsfoot trefoil
Red clover	Tall meadow oatgrass	Barley (hay)
Alsike clover	Smooth brome	Western wheat grass
Meadow foxtail	Big trefoil	Canada wildive
White Dutch clover	Reed canary	Saltgrass
	Blue gamma	Alkali sacaton
	Orchardgrass	
	Oats (hay)	
	Wheat (hay)	
	Rye (hay)	
	Alfalfa	
	Sudan grass	
	Dallis grass	
	Strawberry clover	
	Perennial ryegrass	
	Yellow sweet clover	
	White sweet clover	
	Field Crops	
Field bean	Castorbean	Rape
	Sunflower	Sugar beet
	Flax	Barley (grain)
	Corn (field)	
	Sorghum (grain)	
	Oats (grain)	
	Wheat (grain)	
	Rye (grain)	

Table 8.--Relative tolerance of crop plants to boron (United States Salinity Laboratory Staff, 1954, p. 67)

[The least tolerant plants are placed at the tops of the columns.]

SENSITIVE	SEMI-TOLERANT	TOLERANT
Thornless blackberry	Lima bean	Carrot
Apricot	Bell pepper	Lettuce
Peach	Pumpkin	Cabbage
Cherry	Zinnia	Turnip
Persimmon	Oats	Onion
Apple	Milo	Broadbean
Pear	Corn	Gladiolus
Plum	Wheat	Alfalfa
American elm	Barley	Garden beet
Navy bean	Field pea	Sugar beet
English walnut	Radish	Asparagus
Black walnut	Sweet pea	
	Tomato	
	Potato	
	Sunflower (native)	

Residual sodium carbonate is the amount of carbonate and bicarbonate expressed in equivalents per million (epm) that would remain in solution if all the calcium and magnesium were precipitated as carbonate. Eaton (1950) concluded that carbonate and bicarbonate concentration must exceed calcium and magnesium concentration by more than 1.25 epm before soil structure will deteriorate.

Water from aquifers in the drift ranges from good to unsuitable for irrigation. Water generally is classified as unsuitable because of high salinity hazard or high sodium hazard. Figure 11 shows how water from 100 wells tapping the drift rarely contains a high boron concentration, high residual sodium carbonate is not uncommon.

Water from aquifers in the bedrock is unsuitable for irrigation because it has a high or very high salinity hazard. Much of the water also has a very high sodium hazard, high residual sodium carbonate, or high boron content.

CONCLUSIONS

Aquifers in Surficial Deposits

Aquifers in surficial deposits have greater potential for development than do the aquifers in the bedrock, because they contain the only water suitable for irrigation, and contain more water in transient storage (an estimated 5.2 million acre-feet). The fullest realization of an aquifer's potential for development, however, depends not only on the quality and quantity of water in the aquifer, but also upon the rates of withdrawal and recharge and the effectiveness with which withdrawn water is used.

About 62 percent of the area of Beadle County is underlain by 10 feet or more of aquifer material in surficial deposits. Water levels in the aquifers fluctuate in response to recharge and discharge; in Beadle County, average water levels generally have been stable or rising slightly during the past 10 years, indicating that recharge is equal to or slightly in excess of discharge.

The Warren and Floyd aquifers are recharged primarily by infiltration within the county; some subsurface recharge comes from adjacent counties, but the amount is undetermined. The western part of the Tulare aquifer is recharged primarily by ground-water inflow from Spink County; the eastern part receives a major portion of its recharge from local infiltration of precipitation.

Wells completed in aquifers in surficial deposits discharged slightly more than 3,100 acre-feet of water in 1963. Of this amount, more than two-thirds came from 29 irrigation wells. Total discharge from springs in the county probably averages less than 100 gpm (about 17 acre-feet per year), although, during the spring, discharge from numerous temporary

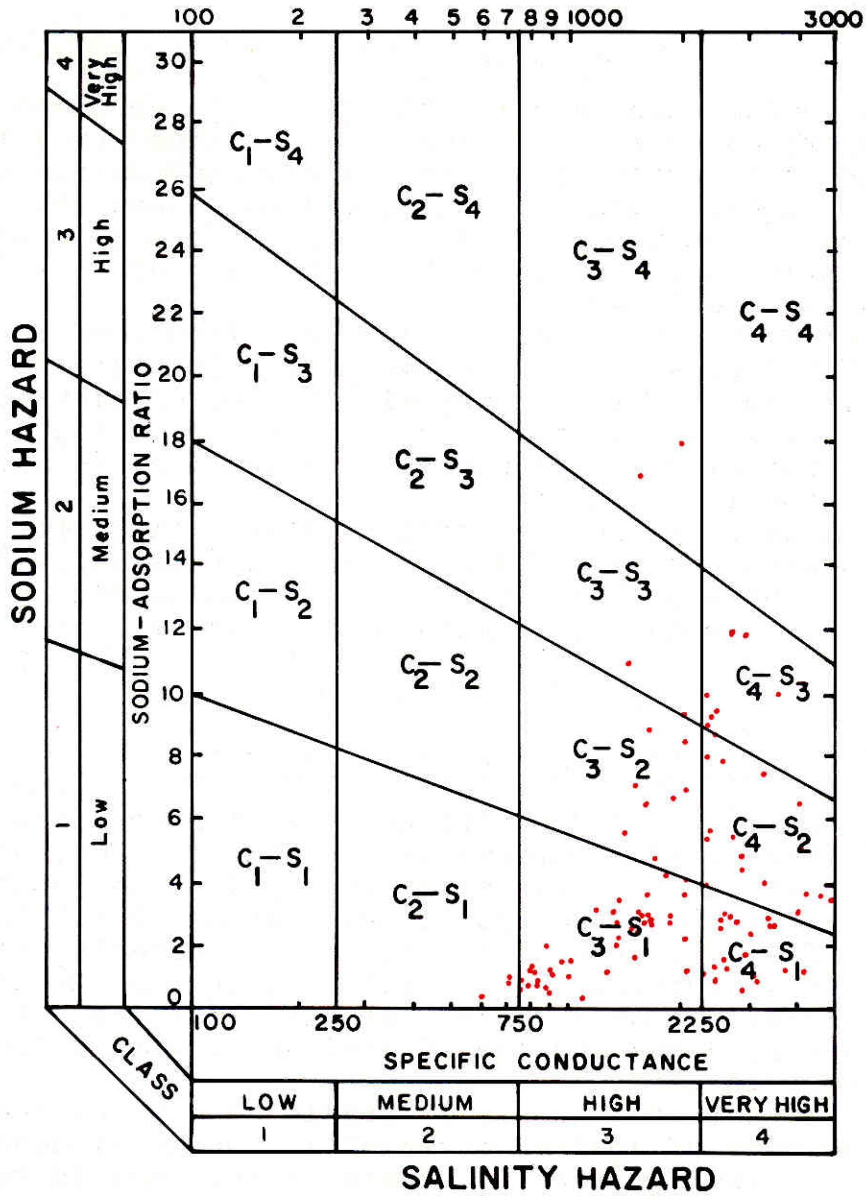

Figure 11.--Diagram for classifying irrigation water with respect to salinity hazard and sodium hazard. Dots represent the classification of water from 100 wells completed in the drift. Salinity hazard classes are indicated by the letter "C" and a subscript, and sodium hazard classes are indicated by the letter "S" and a subscript; in both classes, a higher hazard is indicated by a higher subscript. Thus, water classified as C_1-S_1, under average conditions, is more suitable for irrigation than water classified as C_4-S_4.

springs and seeps caused by the high water table may increase this average.

Except for flow from springs, natural discharge (evaporation, transpiration, leakage to aquifers in the bedrock, ground-water outflow to adjacent areas) cannot be determined from available data. Evapotranspiration is greatest where the aquifers are at the land surface and the water table is at or near the surface, and normally decreases with increasing depth to water. Where the aquifers are covered by a layer of till, evapotranspiration probably is small. Leakage of water from aquifers in the drift to aquifers in the bedrock accounts for only a small part of the total discharge. This transfer of water takes place only locally along buried valleys in the bedrock and may occur only for short periods during the year. Ground-water outflow accounts for much of the discharge of the Warren aquifer in Beadle County, but probably affects the Floyd and Tulare aquifers only slightly, if at all.

Beadle County contains less than one-third of the central James aquifer complex, which also underlies parts of Miner, Sanborn, Jerauld, Hand, Faulk, Spink, and Brown Counties. An estimate of recharge and discharge cannot be made until data are available for the whole aquifer complex.

Water from aquifers in the drift frequently is of "borderline" quality for irrigation, and certain chemical constituents may be present locally in amounts in excess of desirable limits for uses other than irrigation. The water generally is hard and has a high content of iron, but other important chemical properties vary so widely that a general statement of water quality is impossible.

For the fullest realization of the potential of aquifers in the drift, development of new supplies should be coordinated with, and dependent upon, the acquisition of more detailed data upon which quantitative determination of physical and hydrologic characteristics, recharge, discharge, and water quality can be based. Because of the extreme areal variations of the hydrologic characteristics of the aquifer material, individual wells should be designed on the basis of characteristics determined at the site. The most desirable well spacing and discharge rates can only be determined from the characteristics of the aquifer in the immediate area of the wells. Development of new supplies should take into consideration the normal water quality, as well as variations in quality with time and depth, at the prospective site.

Aquifers in the Bedrock

Aquifers in the bedrock may not be subsurface reservoirs with constantly renewed supplies of water, but may resemble mines or oil pools in that water removed from storage is "mined" and not replaced. Even so, the aquifers in the bedrock have a considerable potential for development.

Conservation or good management of a depletable or vanishing resource does not mean that the resource should not be developed, but that the resource should be developed to achieve the maximum beneficial use.

All aquifers in the bedrock yield water containing more than 2,000 ppm dissolved solids, though the aquifer in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale locally yields less saline water near buried bedrock valleys. Sodium is the predominant cation in water from all aquifers except the lowest sandstone beds of the Dakota Group where calcium and magnesium predominate. Sulfate is the major anion in the water in all aquifers except the Niobrara and Codell, where chloride is the major anion.

The aquifer in the Niobrara Marl and Codell Sandstone Member of the Carlile Shale underlies more than half of Beadle County and could provide much more water for use than was withdrawn in 1963. Little water from this aquifer is wasted because very few of the wells flow.

Increased development will further lower the piezometric surface in the Niobrara and Codell and induce greater recharge of hard water from the drift. Future development of the aquifer therefore should emphasize domestic use in preference to other uses. Thus softness, the most desirable attribute of water from the aquifer, could be preserved longer.

Permeable zones in the Carlile Shale below the Codell Sandstone Member and in the Graneros Shale have slight potential for development, though locally they might yield adequate domestic or stock supplies of soft, saline water.

Although the aquifer in the Greenhorn Limestone has far less potential than do aquifers in the Dakota or the Niobrara and Codell, it could supply much more water than was withdrawn in 1963. Unfortunately, water from the Greenhorn often contains much suspended clay and therefore may be unsuitable for domestic or stock use.

The Dakota Group could furnish all stock and domestic water supplies for Beadle County for many years--if the water were not being wasted by uncontrolled flowing wells. In 1963, the total estimated consumption of water for domestic and stock use in the county was 4,320 acre-feet (3,850,000 gpd), which is only slightly over one-half the discharge of the Dakota.

About 80 percent of the 7,840 acre-feet of water discharged to wells in 1963 by the Dakota Group was wasted by unrestricted flow from wells. Waste of water since 1886 has resulted in a rapid decline of artesian pressure and in decreased yield from wells (Steece and Howells, 1965, Davis, Dyer, and Powell, 1961), and, if continued, may result in cessation of all flow within the near future. Because of the decline in artesian pressure, wells no longer flow in more than 125 square miles (10 percent) of Beadle County.

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APPENDIX A.--GLOSSARY AND LIST OF ABBREVIATIONS

Acre-foot.--A unit for measuring the volume of water; the quantity of water required to cover 1 acre to a depth of 1 foot; equal to 43,560 cubic feet or 325,851 gallons.

Alluvial deposits.--Sand, gravel, and other material that has been transported by streams and deposited at places where the velocity of flow was not sufficient to maintain the materials in motion. Material deposited by existing streams is known as alluvium.

Anion.--An ion that moves, or that would move, toward an anode; hence, nearly always synonymous with negative ion. Common anions in water are bicarbonate (HCO_3^-), sulfate ($SO_4^=$), chloride (Cl^-), nitrate (NO_3^-), and fluoride (F^-).

Aquiclude.--A formation, group of formations, or part of a formation that, although porous and capable of absorbing and transmitting water slowly, will not yield an appreciable supply for a well or spring. An aquiclude generally is a confining bed or barrier to the movement of ground water.

Aquifer.--A formation, group of formations, or part of a formation that is water bearing. The term water-bearing formation is a relative term used to designate a formation that contains considerable gravity ground water. Few, if any, formations are entirely devoid of gravity ground water, but those that do not contain enough to be of consequence as a source of supply are not rated as water bearing.

Aquifer test.--A means for determining the hydrologic properties of an aquifer. Conducted by pumping a well while measuring discharge and drawdown in the pumped well and drawdown in observation wells, then stopping the pump and measuring recovery in all of the wells.

Artesian.--Refers to ground water under sufficient pressure to rise above the top of the aquifer in which it is contained.

Artesian condition.--Condition under which water in an aquifer is confined by overlying, relatively impermeable strata and as a result is under sufficient pressure to rise above the top of the aquifer.

Base flow.--Sustained or fair weather flow is composed largely of ground water discharged into stream channels.

Basement rocks.--A term commonly applied to metamorphic or igneous rocks underlying the sedimentary rock sequence.

Bedrock.--Any consolidated rock exposed at the surface of the earth or overlain by unconsolidated materials.

Cation.--An ion that moves, or that would move, toward a cathode; hence, nearly always synonymous with positive ion. Common cations in water are calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^+), and potassium (K^+).

Coefficient of permeability.--The rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at a temperature of 60 degrees F. In field practice the adjustment to the standard temperature is commonly ignored and permeability is then understood to be a field coefficient at the prevailing water temperature.

Coefficient of storage.--The volume of water released from or taken into storage in an aquifer per unit surface area of the aquifer per unit change in the component of head normal to that surface. For an artesian aquifer the water released from or taken into storage, in response to a change in head, is attributed solely to compressibility of the aquifer material and of the water; although rigid limits cannot be established, storage coefficients of artesian aquifers range from about 0.00001 to 0.001. For a water-table aquifer, the water released from or taken into storage, in response to a change in head, is attributed partly to gravity drainage or refilling of the zone through which the water table moves, and partly to compressibility of the water and aquifer material in the saturated zone; storage coefficients of water-table aquifers range from about 0.05 to 0.30.

Coefficient of transmissibility.--The average field coefficient of permeability multiplied by the aquifer thickness in feet; expressed as the rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 100 percent.

Connate water.--Water entrapped in the interstices of a sedimentary rock at the time the rock was deposited.

Drawdown.--Lowering of the water table or piezometric surface by pumping or by artesian flow.

Drift.--Rock material, such as boulders, till, gravel, sand, or clay, transported by a glacier and deposited by or from the ice or by or in water derived from the melting of the ice.

Ephemeral stream.--A stream that flows only in direct response to precipitation. It receives little or no water from springs, and no long-continued supply from melting snow or other sources. Such streams are dry for part of the year.

epm.--Abbreviation of equivalents per million.

Equivalents per million.--Relates to the chemical equivalency of ions in solution; equal to the product of the ionic concentration times the reciprocal of the combining (atomic) weight of the ion. In an analysis expressed in equivalents per million, unit concentrations of all ions are chemically equivalent.

Evapotranspiration.--Water withdrawn from a land area by evaporation from water surfaces and moist soil, and by plant transpiration.

Floodplain.--The part of the floor of a river valley, adjacent to the river channel, that is underlain by sediments deposited during the present regimen of the stream and is covered with water when the river overflows its banks at flood stage.

Fluvioglacial.--Pertaining to streams flowing from glaciers or to the deposits made by such streams.

Fossil.--The remains or traces of animals or plants that have been preserved by natural causes in the earth's crust, exclusive of organisms which have been buried since the beginning of historic time.

Fresh water.--Water containing less than 1,000 parts per million dissolved solids.
gpd.--Abbreviation of gallons per day.
gpd/sq. ft.--Abbreviation of gallons per day per square foot. (See coefficient of permeability.)
gpm.--Abbreviation of gallons per minute.
Ground water.--Water in the ground that is in the zone of saturation, from which wells, springs, and ground-water runoff are supplied.
Hardness of water.--A property of water generally related to its soap-consuming power; caused by the presence in the water of cations that form insoluble compounds with soap. Hardness commonly is reported in terms of an equivalent quantity of calcium carbonate ($CaCO_3$). The following terminology is used in this report:

Hardness, as $CaCO_3$ (ppm)	(grains per gallon) (approximate)	Classification
0- 60	0- 3.5	Soft
61-120	3.5- 7.0	Moderately hard
121-180	7.0-10.5	Hard
more than 180	more than 10.5	Very hard

Hydrograph.--A graph showing stage, flow, velocity, or other property of water with respect to time.
Infiltration.--The flow of a fluid into a substance through pores or small openings. Rate of infiltration is expressed in inches of water per hour under a hydraulic gradient of 100 percent; an infiltration rate of 1 in./hr. equals a permeability coefficient of 14.96 gpd/sq. ft.
Intermittent streams.--A stream that flows only at certain times of the year when it receives water from springs or from some surface source.
Internal drainage.--The condition in which surface runoff accumulates in small depressions that have no outlets to through-flowing streams. When the volume of runoff is exceptionally large, water may overflow the smaller depressions, but under normal climatic conditions, water that flows into the depressions remains there until it evaporates, transpires, infiltrates, or is withdrawn by artificial means.
Ion.--An atom or group of atoms with an electric charge.
Lithology.--Physical character of a rock, generally as determined by visual examination without magnification of the sample.
lsd.--Abbreviation of land surface datum; surface from which depth is measured.
Outwash.--Stratified, sorted material deposited from or by melt-water streams beyond the margin of active glacial ice. In Beadle County, outwash generally is composed of layers of clayey and silty sand or sandy gravel.
Parts per million.--A unit for expressing the concentration by weight of a chemical constituent, usually as milligrams of

constituent per kilogram of solution or as grams of constituent per million grams of solution.

Permeability.--The capacity of a material for transmitting a fluid; depends upon size and shape of pores and size, shape, and extent of pore connections. (See coefficient of permeability.)

Physiography.--Description of the physical features of the earth's surface and the processes by which they are formed.

Piezometric surface.--An imaginary surface that everywhere coincides with the static level of the water in the aquifer. It is the surface to which the water from the aquifer will rise under its full head.

Potential evapotranspiration.--Water loss that will occur if there is never a deficiency of water in the soil for use of vegetation.

ppm.--Abbreviation of parts per million.

Recharge.--The processes by which water is absorbed and added to the zone of saturation; also, the quantity of water that is so added.

Recovery.--Difference between observed water level in a well after pumping has stopped and lowest level reached during pumping.

Regimen of a stream.--The system or order characteristic of a stream; in other words, its habits with respect to velocity and volume, form of and changes in channel, capacity to transport sediment, and amount of material supplied for transportation.

Saline water.--Water containing more than 1,000 ppm dissolved solids. For the purpose of comparison, sea water has about 35,000 ppm dissolved solids.

Salinity hazard.--The injury-causing potential (to soil or crops) of the total dissolved solids in water. The four classes of salinity are based upon the specific conductance of water.

SAR.--Abbreviation of sodium-adsorption-ratio.

Sodium-adsorption-ratio.--Related to the adsorption of sodium from water by the soil to which the water is added; determined by the following relation where sodium (Na), calcium (Ca), and Magnesium (Mg) ion concentrations are expressed in equivalents per million:

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

Sodium hazard.--The injury-causing potential (to soil or crops) of the sodium ions dissolved in water. The four classes of hazard are based upon the sodium-adsorption-ratio (SAR).

Soft water.--(See hardness of water.)

Soil moisture-capacity.--The amount of moisture that a soil can hold in the plant root zone against gravity; moisture available for plant use.

Specific conductance.--The ability of one cubic centimeter of water or a water solution of mineral matter to conduct electricity. Because conductance is the reciprocal of resistance, specific conductance is reported in terms of reciprocal ohms (units of electrical resistance) or "mhos." To avoid the use of inconvenient decimals, specific conductance values are reported in millionths of mhos or micromhos. Because specific conductance varies with temperature, all values are referred to a temperature standard of 25 degrees C.

Surface water.--Water on the earth's surface, such as rivers, lakes, and ponds.

Surficial deposits.--Unconsolidated residual, alluvial, or glacial deposits lying on the bedrock.

Till.--Unstratified, unsorted material deposited directly from or by glacial ice. In Beadle County, till is a heterogeneous mixture of silt, sand, gravel, and boulders in a matrix of clay.

Transient storage.--Refers to gravity ground water contained in an aquifer at any given time; such water is moving from a recharge area to a discharge area.

Water table.--The upper surface of the zone of saturation except where that surface is formed by an impermeable barrier.

Water-table condition.--Condition under which the water in an aquifer is not confined by overlying, relatively impermeable strata. Under these conditions, water can be obtained from storage in the aquifer by gravity drainage--that is, by lowering the water level, as in a pumped well.

Water year.--The 12-month period beginning October 1 and ending September 30; designated by calendar year in which it ends and which includes 9 of the 12 months.

Zone of saturation.--The zone in which the rocks are saturated with water under hydrostatic pressure.

APPENDIX B.--HYDROLOGIC CHARACTERISTICS OF MAJOR AQUIFERS IN SURFICIAL DEPOSITS

Aquifer Test Results

TEST NO.	LOCATION	AQUIFER (see plate 1)	COEFFICIENT OF TRANS-MISSIBILITY (T)	COEFFICIENT OF STORAGE (S)	AQUIFER THICKNESS (Feet)	COEFFICIENT OF PERME-ABILITY (P)
Sanborn Co.						
1	108-61-17aacc	W	50,000	$1.7X10^{-5}$	42	1,190
Beadle Co.						
2	109-63-34acab	W	425,000	----	85	5,000
3	110-60-11bbd	F	33,000	$4X10^{-2}$	55	600
4	$-61-6acdd_2$ a/	F	29,000	$3.5X10^{-4}$	24(?)	1,200
5	$111-59-6bbbb_2$	F	110,000	$1.7X10^{-4}$	33	3,330
6	$112-59-31cccd_1$	F	112,000	$1.7X10^{-2}$	40	2,800
7	$-32dddd_2$	F	69,000	$3.9X10^{-4}$	40	1,730
8	$113-62-5ddbb_1$	T	175,000	----	50	3,500
9	$-18bcad_1$	T	28,000	$2.7X10^{-4}$	42	660
10	$-22abba_2$	T	82,000	$3.4X10^{-4}$	43	1,900
11	$-22abba_4$	T	82,000	$3.3X10^{-4}$	43	1,900
12	$-34cdcc_2$	T	50,000	$4.4X10^{-3}$	49	1,030
13	$-36dcdb_1$	T	48,000	$3.9X10^{-4}$	30	1,600
Spink Co.						
14	$114-63-24cbaa_1$	T	695,000	----	65	10,690
15	$-26acaa_1$	T	250,000	----	60	4,160

a/ Probably includes some alluvium.

EXPLANATION

TEST NO.: Test No. 1 from Steece and Howells, 1965; Test No. 4 conducted cooperatively with City of Huron; Tests No. 5-15 conducted cooperatively with United States Bureau of Reclamation, analyzed by G. A. LaRocque, Jr., United States Geological Survey.

AQUIFER: W - Warren Aquifer; F - Floyd Aquifer; T - Tulare Aquifer.

COEFFICIENTS OF TRANSMISSIBILITY (T), STORAGE (S), AND PERMEABILITY (P): See Ferris and others, 1962, for detailed discussion.

(T): Rate of flow of water, in gallons a day, at the prevailing water temperature and under a unit hydraulic gradient, through each vertical strip of the aquifer one foot wide having a height equal to the thickness of the aquifer.

(A): Volume of water released from or taken into storage in each vertical column of the aquifer having a base of one foot square when the water table or other piezometric surface declines or rises one foot. In an artesian aquifer, the volume of water released from or taken into storage in response to a change in head is entirely determined by the compressibility of the aquifer and of the water; storage coefficients of artesian aquifers may range from about 0.00001 to 0.001. In a water-table aquifer, the volume of water released from or taken into storage is determined partly by the compressibility of the saturated part of the aquifer and of the water and partly by gravity drainage from the zone through which the water table moves; storage coefficients in water-table aquifers range from about 0.05 to 0.30.

(P): Rate of flow of water, in gallons a day, at the prevailing water temperature, through a cross section of one square foot of material under a unit hydraulic gradient. P, thus defined, is commonly called the field coefficient of permeability; it is equal to the coefficient of transmissibility (T) divided by the thickness of the aquifer.

All definitions are based on the assumption that materials and conditions are uniform throughout the aquifer, both vertically and laterally, and that the areal extent of the aquifer is infinite. Because these ideal conditions do not prevail in the field, values from the table can be used only as approximate values for the area surrounding each test. The coefficients are averages for the entire aquifer at the test site.

DISCUSSION OF GRAPHS (a) AND (b)

The amount of drawdown, or decline of water level, at and near a discharging well is determined by the rate at which water moves through the aquifer (T) and by the amount of water released from storage as the water level declines (S). Comparison of curves C and D, figure a, reveals the dependence of drawdown on storage coefficient; although T is the same for both curves, the lower S value of curve D results in more than six feet of additional drawdown at all points along the curve, as compared to curve C. In practical terms, the curves show that, although water moves through the aquifer at the same rate at both locations, the aquifer at location C will yield less water from storage per unit volume of aquifer material, and consequently, to obtain the same volume of water from storage, the water level must decline by a greater amount (in this case, more than six feet) at location C than at location D.

Comparison of curves B and E, figure a, reveals the relationship between drawdown and coefficient of transmissibility; S is similar at both locations, but because the rate of movement is less at location E, as indicated by the lower T value, water cannot move to the discharging well at location E as fast as it can at location B; consequently, drawdown is greater for the well at location E than for the well at location B. The curves in figure b indicate that conditions similar to those shown by figure a prevail as the distance from the discharging well increases.

Because ideal conditions do not exist in the field, the drawdown values from the curves in figures a and b can be used only as approximations to the actual values which might be obtained under field conditions. The effect of impermeable boundaries, such as the termination of the aquifer at the sides of a buried valley or at a relatively impermeable till deposit, greatly changes the shape of the drawdown curve and limits the extent of the area in which the discharging well causes the water level to decline. The coefficients for each aquifer test can be applied accurately only to that portion of the aquifer in which the water level was influenced by the well during pumping.

APPENDIX C.--WATER QUALITY AND ITS SIGNIFICANCE

A summary of the quality-of-water data collected during the investigation, the general quality of water in the various aquifers as shown by selected laboratory analyses, and the significance of dissolved mineral constituents and physical properties are shown in the following tables. Because of local conditions, the quality of water from some wells may differ greatly from the quality of water usually obtained from a given aquifer. Such conditions include: contamination by surface pollutants, leakage from another aquifer through the corroded casing of a nearby well, and local variations in lithology or composition of the aquifer.

Many analyses were obtained from the files and published reports of State and Federal agencies. Field analyses included measurements of specific conductance and determination of hardness, chloride, and pH.

Water-bearing Unit	Laboratory Analyses Complete	Laboratory Analyses Partial	Field Analysis	Total
Drift	128	492	611	1,231
Niobrara Marl and Codell Sandstone Member of the Carlile Shale	18	---	125	143
Greenhorn Limestone	1	---	2	3
Dakota Group	81	8	1,019	1,108
Undetermined	1	4	25	30
Total	229	504	1,782	2,515

SIGNIFICANCE OF CHEMICAL AND PHYSICAL PROPERTIES OF WATER

Constituent of physical Property	Significance
Silica (SiO_2)	Forms hard scale in pipes and boilers and may form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Forms rust-colored sediment; stains laundry, utensils, and fixtures reddish brown. Objectionable for food and beverage processing.
Manganese	Causes gray or black stains on porcelain, enamel, and fabrics. Can promote growth of certain kinds of bacteria.
Calcium (Ca) and Magnesium (Mg)	Cause most of the hardness and scale-forming properties of water (See hardness).
Sodium (Na) and Potassium (K)	Large amounts may limit use of water for irrigation and industrial use and, in combination with chloride, give water a salty taste. Abnormally high concentrations may indicate natural brines, industrial brines, or sewage.
Bicarbonate (HCO_3)	In combination with calcium and magnesium forms carbonate hardness.
Sulfate (SO_4)	Sulfates of calcium and magnesium form hard scale. Large amounts of sulfate have a laxative effect on some people, and in combination with other ions, give water a bitter taste.
Chloride (Cl)	Large amounts increase the corrosiveness of water and, in combination with sodium, give water a salty taste.
Fluoride (F)	Reduces incidence of tooth decay when optimum fluoride content is present in water consumed by children during the period of tooth calcification. Excessive amounts of fluoride may cause mottling of teeth.

Constituent or physical Property	Significance
Nitrate (NO_3)	Concentrations higher than local average may indicate pollution by sewage or organic fertilizers. Concentrations higher than 45 ppm may be injurious when used in infant feeding (Maxcy, 1950).
Boron (B)	May be toxic to crops when present in excessive concentrations in irrigation water (Wilcox, 1955).
Dissolved solids	The total of all dissolved mineral constituents, usually expressed in parts per million of weight. The concentration of dissolved solids may affect the taste of water. Water that contains more than 1,000 ppm is unsuitable for many industrial uses. Some dissolved mineral matter is desirable, otherwise the water would have a flat taste.
Hardness as $CaCO_3$	Related to the soap consuming power of water; results in formation of scum when soap is added. May cause deposition of scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate in water is called carbonate hardness; hardness in excess of this amount is called noncarbonate hardness. Water that has a hardness less than 61 ppm is considered soft; 61-120 ppm, moderately hard; 121-180 ppm, hard; and more than 180 ppm, very hard.
Specific conductance	A measure of the ability of a unit cube of water to conduct an electric current; varies with temperature, therefore reported at 25°C. Values reported in micromhos. Magnitude depends on concentration, kind, and degree of ionization of dissolved constituents; can be used to determine the approximate concentration of dissolved solids.

Constituent or physical Property	Significance
pH	A measure of the hydrogen ion concentration; pH of 7.0 indicates a neutral solution, pH values lower than 7.0 indicate acidity, pH values higher than 7.0 indicate alkalinity. Water generally becomes more corrosive with decreasing pH; however, excessively alkaline water may be corrosive.
Percent Sodium (% Na)	Ratio of sodium to total cations in equivalents per million (epm) expressed as a percentage. Important in irrigation waters; the higher the percent sodium, the less suitable the water for irrigation.
Sodium-adsorption-ratio (SAR)	A ratio used to express the relative activity of sodium ions in exchange reactions with soil. Important in irrigation water; the higher the SAR, the less suitable the water for irrigation.
Temperature	Affects the usefulness of water for many purposes. Generally, users prefer water of uniformly low temperature. Temperature of ground water tends to increase with increasing depth to the aquifer. In Beadle County water temperature probably reflects aquifer temperature if the well flows more than 1.5 gpm or is pumped at a rate of at least 3 gpm for 5 minutes prior to measurement.

SELECTED CHEMICAL ANALYSES REPRESENTING THE GENERAL CHEMICAL QUALITY OF WATER IN BEADLE COUNTY. SOUTH DAKOTA.

Additional analyses are published in Howells, Stephens, and Hedges (1967) table 3.

Laboratory: a, U.S. Geol. Survey, Lincoln, Nebr.; b, Station Biochemistry Department, South Dakota State Univ., Brookings; c, Soils Laboratory, South Dakota State Univ., Brookings; d, South Dakota Dept. Health, Pierre.

[Results in parts per million except as indicated.]

Location	Date of collection	Depth of well (feet)	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos)	pH	Percent sodium (%Na)	Sodium adsorption ratio (SAR)	Residual sodium carbonate (RSC)	Laboratory
GROUND WATER PRIVATE WELLS																											
Aquifers in the drift																											
109-60-23adaa	12-6-63	150(?)	50.5	18	0.96	0.11	121	42	405	11.	324	0	772	182	0.4	7.9	2.2	1,720	1,770	476	210	2,500	7.4	64	8.1	0.0	a
109-62-20dcdd	4-17-63	59	40	23	.26	.04	131	89	24	8.8	506	0	257	33	.5	26	.05	842	865	691	276	1,260	7.6	7	.4	0.0	a
109-65-31cddc	12-6-63	---	50	11	1.2	.01	24	6.3	353	13	415	0	327	120	.4	2.2	2.5	1,060	1,090	86	0	1,710	7.9	88	17	5.08	a
110-59-26cdcd$_1$	12-6-63	---	----	29	.01	.01	63	39	45	2.7	381	0	93	4.2	.4	4.0	.17	46	452	319	7	741	7.7	23	1.1	.0	a
110-62-12acba	5-15-59	50	----	--	2.75	.21	394	143	216	20	633	0	1,430	19	.04	---	---	2,540	2,780	1,590	1,060	3,020	7.2	23	2.4	.0	b
110-64-21abba	4-17-63	60	----	32	.87	.05	90	31	246	12	809	0	174	34	.3	20	.63	1,040	1,010	350	0	1,570	7.8	59	5.7	0.22	a
111-59-12addb$_1$	11-21-63	20	48	32	.27	.04	301	136	228	16	499	0	1,020	140	.3	156	.57	2,280	2,370	1,310	901	2,800	7.8	27	2.7	0.0	a
111-63-23bbbb	9-24-63	72	63	13	.38	.40	317	486	432	16	333	0	3,140	89	.3	5.7	.48	4,660	5,180	2,790	2,520	5,070	7.3	25	3.6	.0	a
-24dddd	9-24-63	64	59	12	.19	1.0	63	33	77	14	262	0	212	24	.1	.2	.32	566	605	292	77	909	7.2	35	2.0	.0	a
112-59-31cccd$_1$	5-25-54	70	----	27	.05	---	110	36	74	6.8	295	0	293	30	.2	2.1	.16	754	----	421	179	1,070	7.6	27	1.6	.0	a
112-62-34bc	6-2-47	16	----	25	.33	---	174	156	125	10	302	8	715	92	.5	276	.30	1,730	----	1,080	819	2,140	8.6	20	1.7	.0	a
112-65-1bbbb$_2$	4-24-63	47	----	29	.19	0	42	11	317	8.6	588	0	209	118	.5	3.0	.64	1,030	1,050	152	0	1,620	8.2	81	11	6.6	a
113-59-1abaa	12-20-63	140	45	36	1.4	.21	88	31	500	9.2	388	0	1,000	50	.3	11	1.8	1,920	1,980	345	27	2,860	7.7	75	12	.0	a
113-62-5ddbb	7- -53	64	----	--	---	---	141	44	140	11	458	0	370	54	---	---	.46	985	----	533	157	1,490	7.7	36	2.6	.0	a
113-65-6dccc	4-24-63	52	58	29	.9	.46	175	71	228	13	545	0	650	77	.3	18	.67	1,530	1,580	728	281	2,130	7.6	40	3.7	.0	a
Aquifer in the Niobrara Marl and the Codell Sandstone Member of the Carlile Shale																											
109-60-1baaa	11-16-59	200	----	--	---	---	13.2	4.13	772	5.86	431	22.8	37.5	976	---	---	---	2,040	2,130	50[1/]	0	3,600	7.8	97	48.	6.84	c
-25dbcd$_1$	4-16-63	230	----	10	.14	.01	15	5.2	313	4.9	416	0	209	148	1.0	6.2	3.4	921	944	59	0	1,540	7.9	91	18.	5.64	a
111-62-13dddd	12-4-62	180	56	8.6	.26	.00	16	3.6	1,030	24	858	0	312	875	1.0	.2	4.8	2,700	2,710	55	0	4,500	7.8	96	60	13.0	a
113-61-11cccb	12-23-63	140	53	13	.03	.01	13	5.0	452	5.4	437	0	513	88	.7	7.2	2.0	1,310	1,350	53	0	2,140	8.1	94	27	6.10	a
Aquifer in the Greenhorn Limestone																											
112-63-14bbad	1-14-64	550	57	10	.24	.00	33	11	800	12	390	0	448	766	3.1	5.7	5.2	2,290	2,280	128	0	3,770	7.3	92	31	3.8	a
Aquifer in the Dakota Group																											
109-59-22bccc$_2$	12-6-63	784	----	9.8	2.1	.10	8.7	1.8	676	4.5	212	0	1,100	119	1.8	6.8	1.2	2,030	2,050	29	0	3,000	7.6	98	55	2.69	a
109-65-21cdcd$_2$	1-6-64	956	61	13	1.1	.03	230	64	318	19	140	0	1,210	105	2.0	8.4	.73	2,040	2,130	839	724	2,650	7.0	44	4.8	.0	a
110-62-7bdbc	12-6-63	822	67	11	1.2	.06	166	49	410	18	136	0	1,130	136	1.7	.2	.85	1,990	2,060	616	504	2,730	6.9	58	7.2	.0	a
112-61-14cdcd$_1$	4-25-63	1,000	66	11	1.2	.09	231	58	326	19	177	0	1,230	122	1.7	1.1	.99	2,090	2,190	813	668	2,760	7.6	46	5.0	.0	a
-14cdcd$_2$	4-25-63	770	61	10	.23	.03	16	2.4	650	8.6	260	0	985	182	1.9	10	1.8	2,000	1,970	50	0	2,950	7.6	96	40	3.26	a
113-59-12adaa$_2$	1-7-64	1,002	54	10	6.3	.07	6.9	2.9	862	4.9	524	0	965	294	8.0	7.5	4.8	2,430	2,500	29	0	3,700	8.0	98	70	8.0	a
113-65-4bcca	4-24-63	1,000	71	11	2.3	.14	369	85	154	22	161	0	1,280	98	2.7	4.0	.33	2,110	2,210	1,270	1,140	2,510	7.2	21	1.9	.0	a

1/ Calculated

SELECTED CHEMICAL ANALYSES REPRESENTING THE GENERAL CHEMICAL QUALITY OF WATER IN BEADLE COUNTY, SOUTH DAKOTA.

Additional analyses are published in Howells, Stephens, and Hedges (1967) table 3.

Laboratory: a, U. S. Geol. Survey, Lincoln, Nebr.; b, Station Biochemistry Department, South Dakota State Univ., Brookings; c, Soils Laboratory, South Dakota State Univ., Brookings; d, South Dakota Dept. Health, Pierre.

[Results in parts per million except as indicated.]

Location	Date of collection	Depth of well (feet)	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Non-carbonate	Specific conductance (micromhos)	pH	Percent sodium (%Na)	Sodium adsorption ratio (SAR)	Residual sodium carbonate (RSC)	Laboratory
GROUND WATER — MUNICIPAL WELLS																											
Aquifers in the drift																											
Huron, Wells 1 and 2																											
110-62-9bcc$_1$	5- -59	82 & 84	----	--	2.3	.3	54	12	345	12.9	571	0	401	34	.4	4.0	---	1,190	----	190	0	-----	7.7	8	11	5.67	d
City of Wessington																											
111-65-6bbbb$_1$	7- -56	32	----	--	.1	.0	206	123	155	7.2	459	-	787	110	.5	53.2	---	1,890	----	1,020	645	-----	7.6	25	2.1	.0	d
Aquifer in the Niobrara Marl and the Codell Sandstone Member of the Carlile Shale																											
City of Cavour																											
111-60-33ddca	3- -57	200	----	--	.0	.0	25	4	543	9.4	332	-	665	223	1.0	.4	---	1,630	1,630	80	0	-----	8.0	92	27	3.86	d
Aquifer in the Dakota Group																											
Iroquois																											
110-58-6cbbb	10- -60	1,008	----	--	2.9	.6	143	34	630	14.9	334	-	1,430	100	2.6	1.5	---	2,520	2,550	506	224	-----	7.4	72	12	.0	d
110-58-6bbba	2- -59	980	----	--	.2	.0	10	2	736	9.4	332	-	1,130	150	4.2	.0	---	2,200	2,220	33	0	-----	8.3	97	56	4.78	d
City of Virgil																											
110-63-32acdd	3- -54	800	----	--	1.0	--	273	65	325		144	-	1,240	153	2.4	.8	---	2,130	2,270	950	831	-----	7.2	43	4.6	.0	d
City of Yale																											
111-60-12cbad$_1$	12- -56	850	----	--	.6	.0	14	4	731	9.5	276	-	1,140	135	2.5	2.5	---	2,180	2,160	55	0	-----	7.6	97	44	3.49	d
City of Wolsey																											
111-64-24bbcd$_3$	2-24-59	930	----	9.6	4.8	.06	136	39	458	17	193	0	1,050	159	2.6	.1	1.7	1,970	2,050	500	343	2,810	7.4	66	8.9	.0	a
-24bbcd$_5$	2-14-63	1,220	----	--	1.4	.10	364	74	178	22	149	-	1,301	108	2.7	.0	---	2,120	2,290	1,220	1,090	2,580	7.4	24	2.0	.0	d
City of Wessington																											
111-65-6bbbc	7- -37	1,100 1,180	----	40	1.4	--	257	73	193		144	-	1,150	30	3.	---	---	1,820	2,170	942	824	-----	---	31	2.7	.0	a
City of Hitchcock																											
113-63-4badc$_1$	11- -53	1,040	----	--	1.8	--	374	83	177		173	-	1,280	99	2.7	.0	---	2,100	2,290	1,280	1,130	-----	---	23	2.2	.0	d
SURFACE WATER																											
James River at Huron 2/	12-1-59	---	----	17	.02	--	84	58	195	17	313	0	483	94	.4	4.2	.96	1,110	1,170	448	191	1,670	7.1	47	4.0		a
James River at Huron 3/	3-30-60	---	----	7.2	.08	--	22	8.5	15	8.9	86	0	44	8.0	.0	7.4	.15	----	172	90	19	282	7.2	24	.7		a
111-64-12cc (dugout)	3-27-61	---	----	--	.1	--	10	.0	40	2.0	100	0	25	5.0	--	---	---	137	----	50	0	250	---	64	2.5	1.0	b
111-65-32a (dugout)	8-19-59	---	----	--	---	--	400	1,040	2,500		---	-	8,800	650	--	---	---	13,400	----	5,300	-----	18,000	---	45	12	.0	b
Lake Byron 2/	3-9-60	---	----	108	6.9	--	550	656	2,090	169	2,230	0	5,650	860	.7	3.0	5.7	11,200	11,800	4,070	2,240	12,900	7.6	51	14		a
Lake Byron 3/	4-6-60	---	----	8.1	.20	--	14	5.1	9.6	11	58	0	31	4.0	.1	8.3	.09	----	138	56	8	213	6.6	23	.6		a

2/ Sampled during the winter when water surface frozen. 3/ Sampled after spring thaw, during annual period of high precipitation and runoff.