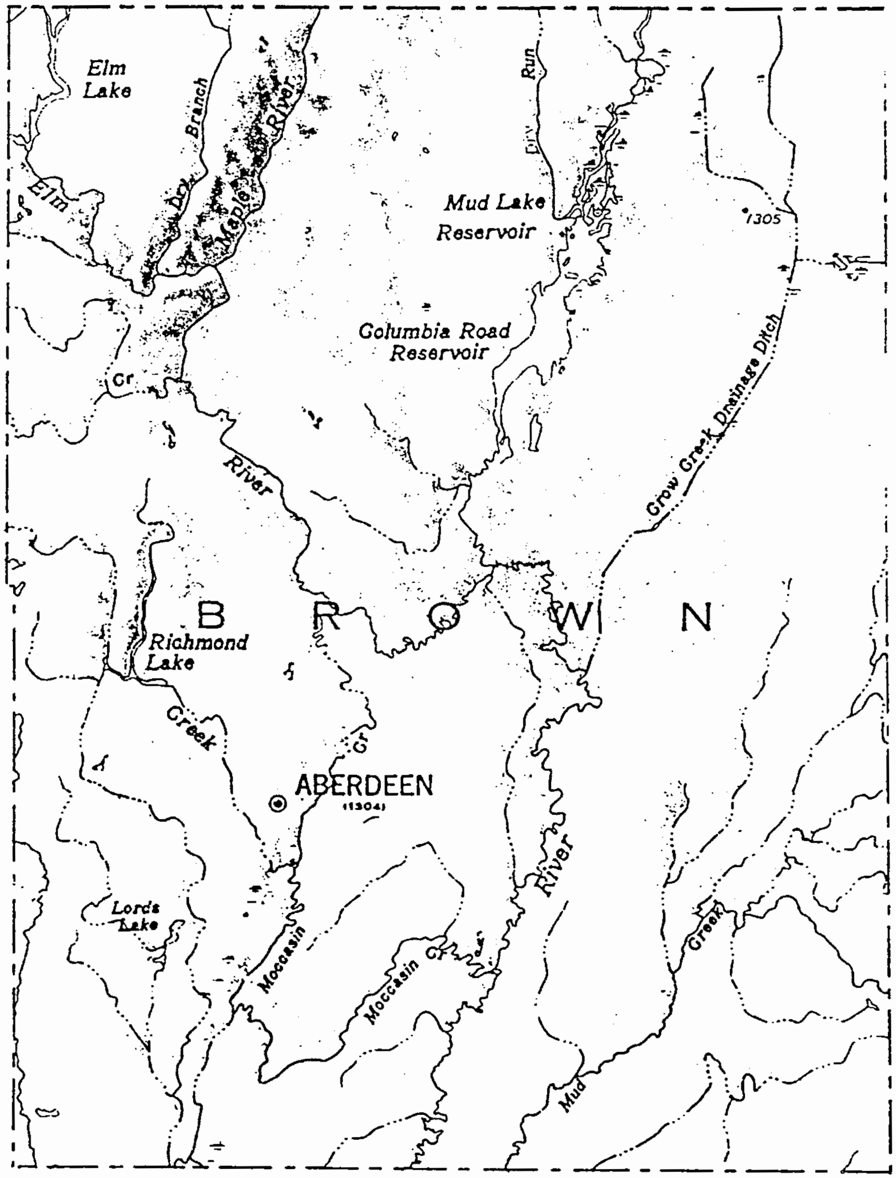
BULLETIN 25

GEOLOGY AND WATER RESOURCES OF BROWN COUNTY, SOUTH DAKOTA



PART II: WATER RESOURCES

by Neil C. Koch and Wendell Bradford

United States Department of the Interior-Geological Survey

Prepared in cooperation with the S. D. Geological Survey, Brown County, and the Oahe Conservancy Sub-District

DEPARTMENT OF NATURAL RESOURCE DEVELOPMENT
SOUTH DAKOTA GEOLOGICAL SURVEY-1976

STATE OF SOUTH DAKOTA
Richard Kneip, Governor

DEPARTMENT OF NATURAL RESOURCE DEVELOPMENT
Vern W. Butler, Secretary

GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

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ABSTRACT

Brown County, an agricultural County in northeastern South Dakota, has an area of 1,683 square miles (4,359 square kilometres).

Glacial outwash is an important water-bearing deposit in Brown County. Such deposits contain three major aquifers, the Deep James, Middle James, and Elm. Where 40 feet (12 metres) or more thick, these aquifers can provide yields of 500 gallons per minute (32 litres per second) or more.

The quality of water from aquifers above the bedrock surface varies from good to very poor for irrigation use.

The Deep James aquifer, an interconnected system of buried stream channels, underlies about 250 square miles (648 square kilometres) in the County, is from 125 to 390 feet (38 to 119 metres) below land surface, and contains water under artesian conditions.

The Middle James aquifer underlies about 530 square miles (1,373 square kilometres) in the County, is from 40 to 250 feet (12 to 76 metres) below land surface, and contains water under artesian conditions.

The Elm aquifer underlies 390 square miles (1,010 square kilometres) of the west-central part of the County, and is from 15 to 100 feet (5 to 30 metres) below land surface. Water in the western part of the aquifer is under water-table conditions and in the eastern part is under artesian conditions.

Recharge to these glacial drift aquifers is by infiltration and percolation of snowmelt and precipitation through overlying materials and by subsurface inflow from Spink and Marshall Counties.

The major bedrock aquifers thus far developed are in the Dakota, Fall River, and Sundance Formations. Wells tapping these aquifers are from 850 to 1,450 feet (259 to 442 metres) deep. Water from the Sundance aquifer recharges the Fall River aquifer which in turn recharges the Dakota aquifer.

The chemical quality of water from the Dakota, Fall River, and Sundance aquifers varies from fair to poor. Specific conductance ranges from 2,470 micromhos per centimetre at 25°C in the Sundance to as much as 4,780 micromhos per centimetre at 25°C in some parts of the Dakota. Major chemical constituents are calcium, sodium, and sulfate in the Sundance and in the Fall River where it is recharged by the Sundance but sodium and sulfate are dominant in the Fall River where it has not received such recharge. In the Dakota sodium and sulfate dominate where it receives recharge from the Fall River, but sodium chloride where it does not.

Most streamflow, and any flooding, in Brown County occurs in the spring and early summer from snowmelt and precipitation. Except for the Elm River, most streams commonly have no flow in the late summer, fall, and winter. The James River between Columbia and Stratford loses water at an average rate of 3,000 acre-feet (3.7 million cubic metres) per year by evaporation. During major flooding from 1950 to 1970 five periods of major stream loss occurred, ranging from 16,000 to 40,000 acre-feet (19.7 to 49.3 million cubic metres).

The dissolved solids concentration of water from streams during periods of high flow may be less than 300 milligrams per litre, but during periods of low flow it may be more than 2,000 milligrams per litre.

INTRODUCTION

Purpose and Scope

In July 1967, the South Dakota State Geological Survey and the U.S. Geological Survey began a 5-year study of the geology and water resources of Brown, Marshall, and Day Counties. This is part of a cooperative program of water-resources evaluation in South Dakota. The progress of that program is shown in figure 1. This report presents the results of the study made in Brown County.

The report provides information that can be used to plan the development of water supplies. It is a general appraisal of water resources; any large-scale development of ground water should be preceded by test drilling and by determination of local aquifer characteristics.

Work performed included preparation of a geologic map (Part I of this Bulletin), compilation and evaluation of data concerning the geology and hydrology of the area, well inventories, collection and analysis of water samples, measurement of water levels in wells, and test drilling.

The basic data collected and used in the preparation of this report are being published in separate reports (Part IIIA and IIIB of this Bulletin) that will contain well records, chemical analyses, water-level records, and well logs.

For those readers interested in using the metric system, metric equivalents of English units of measurements are given in parentheses. The English units used may be converted to metric units by the following conversion factors.[1]

Acknowledgments

Appreciation is expressed to the residents of Brown County and to the managers of municipal water supplies for providing needed information. Valuable information about the water-bearing zones provided by local well drillers is greatly appreciated.

Previous Investigations

A statewide report by Darton (1909) contained information on artesian aquifers in the County. Ground-water hydrology was described for the southern third of the County by Todd (1909), for the Lake Dakota Plain area by Hopkins and Petri (1963), and for the Crow Creek-Sand Lake area by Koopman (1957). Studies were completed for Aberdeen by Sayre (1936) and by Black and Veatch (1956), for Claremont by Baker (1963), and for Columbia by Barari and Brinkley (1970). A report of basic data was compiled by Hopkins and Petri (1962). For a list of references on the geology of Brown County see Leap (in preparation).

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[1]

From		Multiply by	To obtain	
Unit:	*Abbreviation:*		*Unit:*	*Abbreviation:*
Inches	(in)	25.40	Millimetres	(mm)
Inches	(in)	2.54	Centimetres	(cm)
Feet	(ft)	.3048	Metres	(m)
Square miles	(mi^2)	2.590	Square kilometres	(km^2)
Gallons	(gal)	3.785	Litres	(l)
Gallons	(gal)	.003785	Cubic metres	(m^3)
Miles	(mi)	1.609	Kilometres	(km)
Acre-feet	(acre-ft)	1233	Cubic metres	(m^3)
Acres		.4047	Hectares	(ha)
Gallons per minute	(gal/min)	.06309	Litres per second	(l/s)
Pounds per square inch	(lb/in^2)	.07031	Kilograms per square centrimetre	(kg/cm^2)
Feet per mile	(ft/mi)	.1894	Metres per kilometre	(m/km)
Cubic feet per second	(ft^3/s)	.02832	Cubic metres per second	(m^3/s)

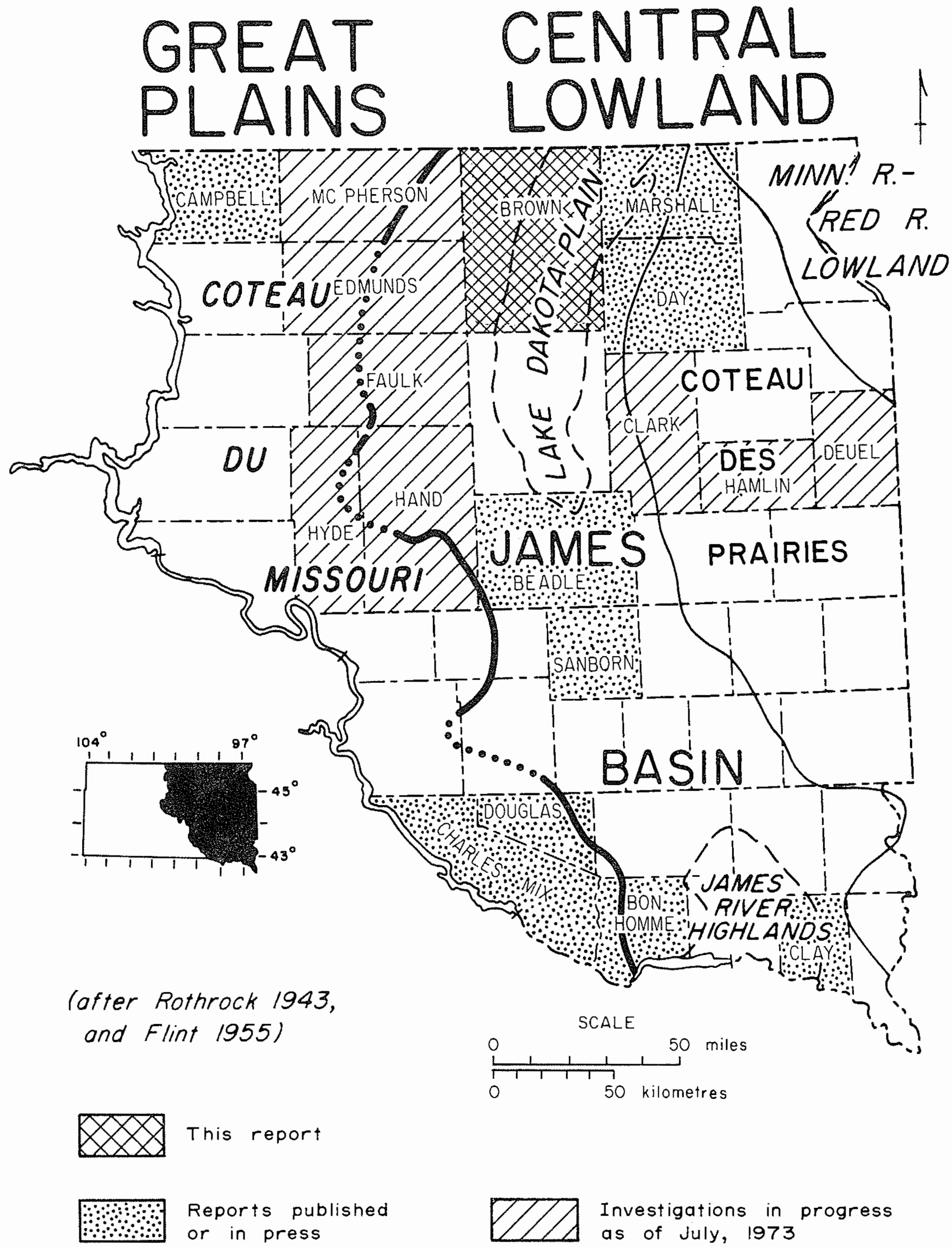

Figure 1. Index map of eastern South Dakota showing area of this report, status of county investigations, and major physiographic divisions.

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Well- and Station-Numbering System

The wells and test holes are numbered according to a system based on the Federal land-survey of eastern South Dakota (fig. 2). The well number consists of township followed by "N", range followed by "W", and section number, followed by a maximum of four upper-case letters that indicate, respectively, the 160-, 40-, 10-, and 2½-acre (65-, 16-, 4-, and 1-ha) tract in which the well is located. These letters are assigned in a counterclockwise direction beginning with "A" in the northeast quarter. A serial number following the last letter is used to distinguish between wells in the same tract. Thus, well 126N62W15DAAA (fig. 2) is in the NE¼NE¼NE¼SE¼, sec. 15, T. 126 N., R. 62 W.

The station-numbering system of the U.S. Geological Survey is based on the grid system of latitude and longitude. The number consists of 15 digits. The first six digits denote the degrees, minutes, and seconds of latitude. The next seven digits denote degrees, minutes, and seconds of longitude. The last two digits are sequential numbers for wells within a 1-second grid. The system provides the geographic location of the well and a unique number for each well.

GEOGRAPHY

Brown County in the northeastern part of the State (fig. 1), is rectangular in shape, and has an area of 1,683 mi^2 (4,359 km^2), including about 10 mi^2 (26 km^2) of lakes.

The city of Aberdeen, the principal shopping and trading center, had a population of 26,476 in 1970. The total population of the County in 1970 was 36,920.

The principal industry is agriculture. Corn, wheat, oats, barley, and hay, the major crops, are used mostly to feed cattle, the major product exported from the area.

Physiography and Topography

Brown County is in the James River Lowland physiographic division (fig. 1). The major landforms are of three general types (fig. 3): lake plain, glacial uplands, and alluvial flood plains.

The eastern two-thirds of the County is a nearly flat plain that lies between 1,290 to 1,310 ft (393 to 399 m) above mean sea level. The plain is the former bed of an extensive, but shallow and short-lived, glacial lake known as Lake Dakota. Lake Dakota was about 90 mi (145 km) long and 27 mi (43 km) wide; it extended from southern Spink County to about 15 mi (24 km) north of the North Dakota-South Dakota State line. The lake plain does not have a well-developed natural drainage system; prior to construction of drainage facilities by man, most of the lake plain was swampland.

The glacial uplands lie west of the lake plain and in the southeastern corner of the County; they consist of deposits of till that form smoothly rolling hills. These uplands range in altitude from 1,310 ft (399 m) on the east to 1,525 ft (465 m) in the northwestern part of the County. In the glacial uplands west of the lake plain are a series of southwest-trending shallow depressions, many of which contain small streams. These shallow depressions probably formed along the ice margin whenever the retreating continental glacier stopped long enough for a drainage system to develop.

Flood plains have developed along the major streams--the James, Elm, and Maple Rivers, and Moccasin Creek. The James River flood plain is 15 to 20 ft (5 to 6 m) below the level of the Lake Dakota plain and ranges from 0.25 to 0.75 mi (0.07 to 0.2 m) in width. The Elm and Maple Rivers occupy valleys far larger and wider than the present flow and erosive power of these streams. This is because the valleys were formed during late glacial time by great streams of glacial meltwater. Those glacier-fed rivers cut wide valleys and deep channels. Today we find minor streams occupying these large valleys.

Drainage

The James River and its tributaries form the natural drainage network of Brown County. The James River flows southward at low gradient (averages 0.26 ft/mi or 0.08 m/km) across the County and joins the Missouri River in the southeastern part of the State. From the North Dakota State line to Columbia the river flows near the west side of the Lake Dakota plain. South of Columbia, its course is in the center of the plain. The low-water channel is 20 to 30 ft (6 to 9 m) wide with abrupt banks 5 to 10 ft (2 to 3 m) high.

The principal tributaries to the James River within Brown County are the Elm River and Moccasin Creek, both of which join the James River from the west (fig. 3). Elm River enters the County near the northwest corner and flows southeast across the glacial uplands at a gradient of about 3.1 ft/mi (0.94 m/km). The head of Moccasin Creek is near Elm River and during times of flooding, water from the Elm flows into Moccasin Creek.

Mud Creek, which drains the southeastern part of Brown County, joins the James River from the east, in Spink County.

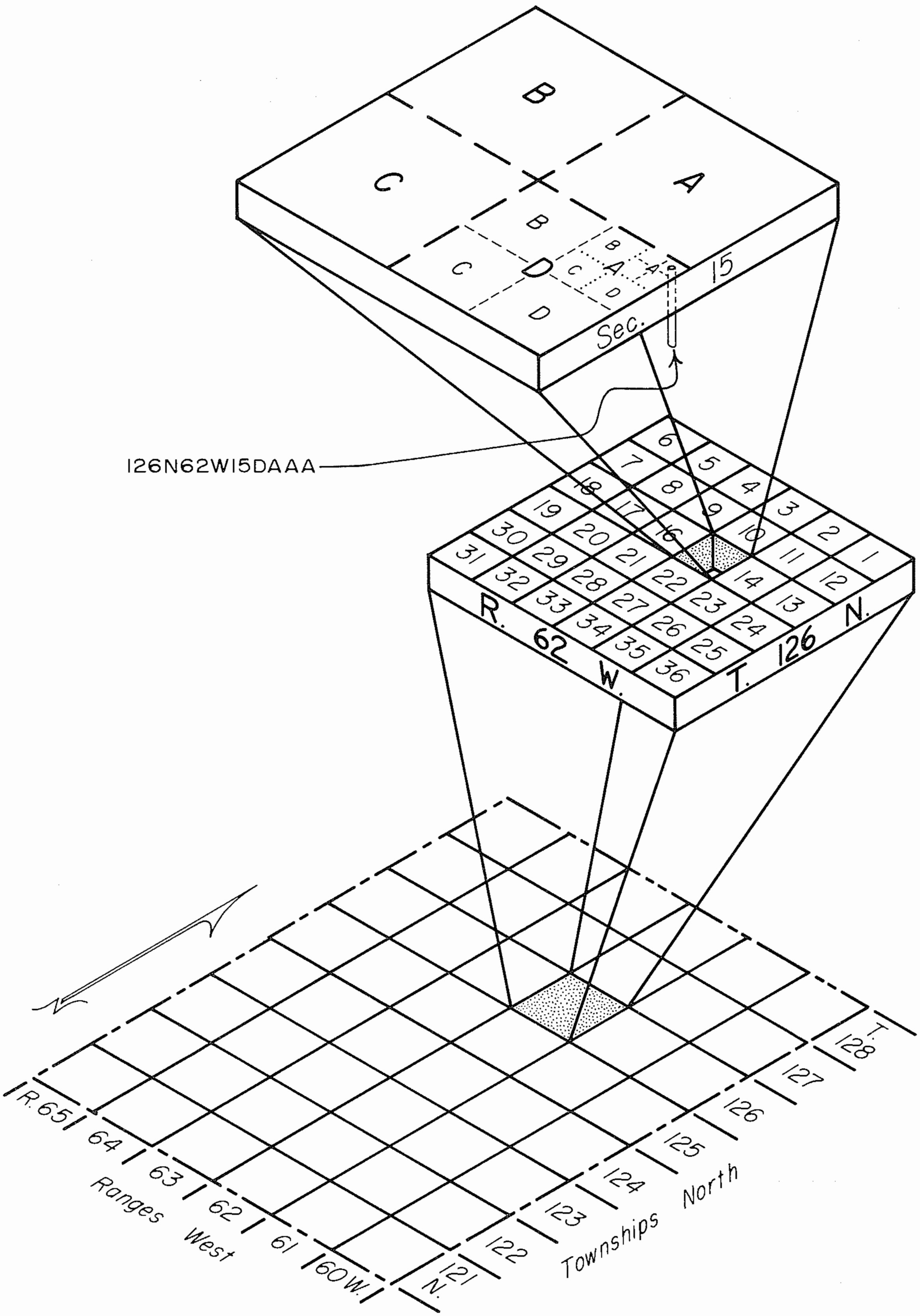

Figure 2. Well numbering diagram showing location of 126N62W15DAAA.

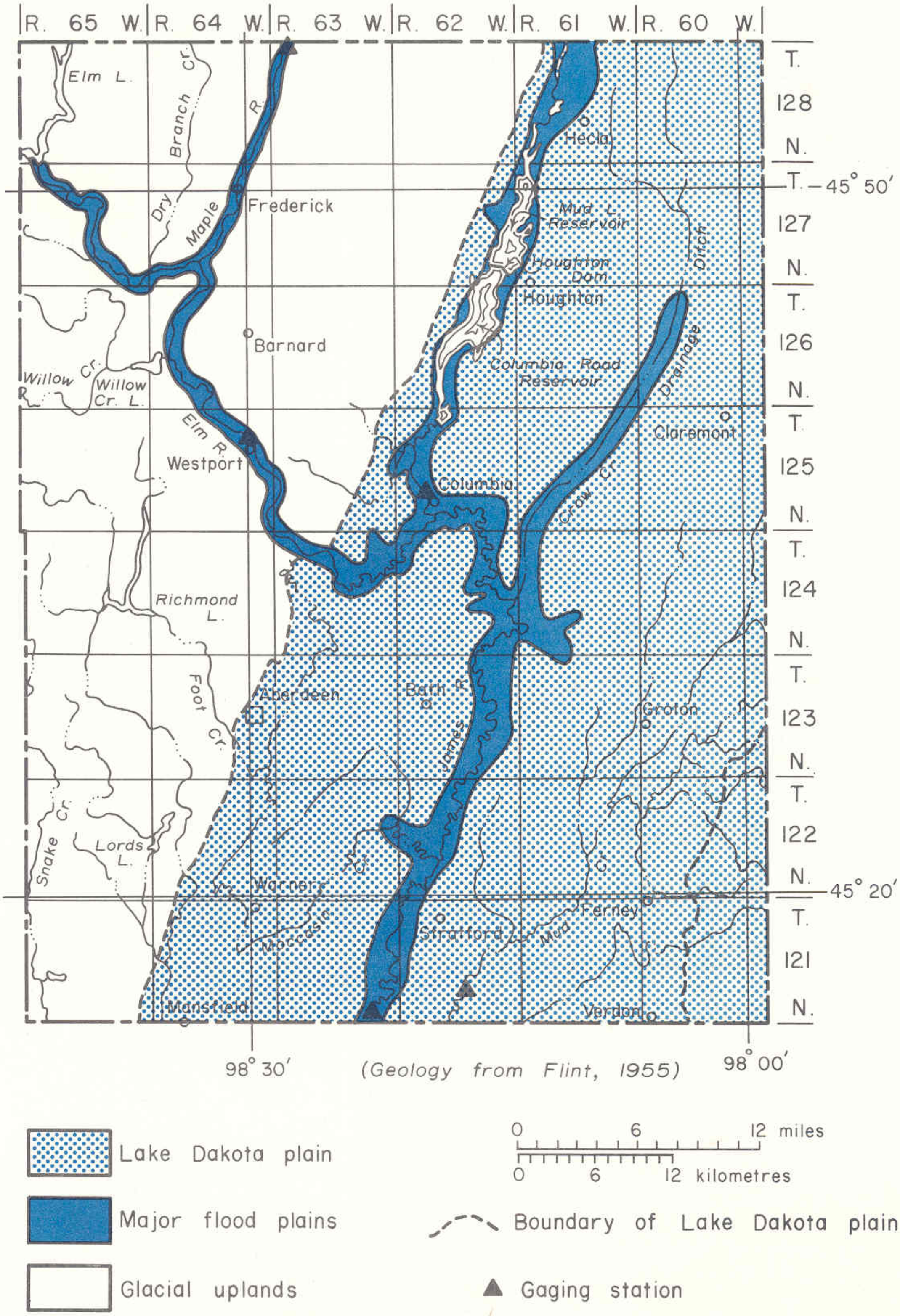

Figure 3. Index map of Brown County showing major landforms, streams, lakes, and reservoirs, and locations of gaging stations.

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Climate

Brown County is subhumid and has a continental climate with short, hot summers and long, cold winters. Below zero temperatures are common in winter and temperatures of 100°F (Fahrenheit) [38°C (Celsius)] are normally experienced at least once each summer. The temperature is greater than 90°F (32°C) about 28 days per year, below 32°F (0°C) about 175 days per year, and below zero°F (-18°C) about 42 days per year. At the U.S. Weather Bureau Station at Aberdeen the average annual temperature is 43.2°F (6.4°C).

Precipitation varies widely from year to year, but usually about 75 percent of the annual precipitation occurs during the growing season. During the period of record (1890-1972) annual precipitation has ranged from 12.43 in (315.7 mm) in 1958 to 38.39 in (975.1 mm) in 1896. About one-quarter of the annual precipitation is snow. Seasonal snowfall generally ranges from 18 to 68 in (460 to 1,730 mm), although in the winter of 1936-37 almost 110 in (2,790 mm) of snow fell. The average annual precipitation is 19.18 in (487.2 mm).

WATER RESOURCES

Water in Brown County occurs in surface streams, ponds, reservoirs, and aquifers in glacial deposits and bedrock strata. Most of the streamflow is derived from snowmelt and spring rains from about 10,000 mi^2 (26,000 km^2) of drainage area. Ground water in surficial deposits originates as precipitation in or near the County. The amount of precipitation, however, is much greater than the amount of water that runs off from the surface or is added to storage in surface- and ground-water reservoirs. Most of the precipitation is returned to the atmosphere by evaporation and transpiration.

Normal precipitation in Brown County is about 1.8 million acre-ft (2.2 billion m^3) annually. Of this amount, about 23,000 acre-ft (28 million m^3) leaves the area as surface runoff and 40,000 acre-ft (49 million m^3) is evaporated from reservoirs and ponds. Evapotranspiration from vegetation and soil (not including aquifers) accounts for about 1.6 million acre-ft (2 billion m^3). The remaining 137,000 acre-ft (169 million m^3) recharges the aquifers in the surficial deposits. The natural discharge from the aquifers is by evapotranspiration and subsurface outflow.

The surface water leaves the area through the James River and its tributaries. In Brown County most streamflow and floods occur in the spring and early summer from snowmelt and precipitation. The average annual discharge of the James River at the mouth of Elm River (includes combined discharges at gaging stations on Elm River at Westport and James River at Columbia) is about 113,000 acre-ft (139 million m^3) and at the gaging station near Stratford about 94,000 acre-ft (116 million m^3). This amounts to an average annual loss of 19,000 acre-ft (23 million m^3), which is the result of evaporation and major flooding (Koch, 1970).

Ground water in Brown County is obtained from confined bedrock deposits and from confined and unconfined aquifers in glacial drift. Aquifers in the glacial drift contain about 3.6 million acre-ft (4.4 billion m^3) of water in storage. They are separated or confined by a pebbly clay till. The till deposits are often discontinuous and lenticular. This situation results in varying degrees of permeabilities between the Elm, Middle James, and Deep James aquifers. The confined Dakota, Fall River and Sundance (bedrock) aquifers may contain about 61 million acre-ft (75 billion m^3) of water in storage.

Recharge to the aquifers in glacial drift is mainly by infiltration of precipitation. In several areas in the County, the Elm aquifer discharges water to the Middle James aquifer and in several areas the Middle James aquifer discharges water to the Deep James aquifer. Natural discharge from the Deep James aquifer is by subsurface outflow into North Dakota and locally by upward leakage into the till. Natural discharge from the Middle James aquifer is by eastward flow into the lake sediments and by upward leakage into the till. Natural discharge from the Elm aquifer is into Elm River and Foot Creek, by evapotranspiration, and by eastward flow into lake sediments. Natural discharge from the lake sediments is mostly by evapotranspiration and partly into the James River and other surface drainages. The confined bedrock aquifers are recharged by subsurface inflow (water in the aquifer entering the County from an adjacent county) and from underlying bedrock aquifers. Natural discharge is by subsurface outflow (water in the aquifer leaving the County).

Surface Water, Quantity and Quality

Streamflow Characteristics

Records of streamflow in Brown County have been collected since 1945. The locations of data-collection sites, the lengths of periods of record, a summary of the measurements of stream discharge, and other data for each site are shown in figure 4.

Variability

The rate, volume, and distribution of runoff depend upon climate and upon the physical characteristics of the watershed. Seasonal variations in streamflow, which are closely related to climate,

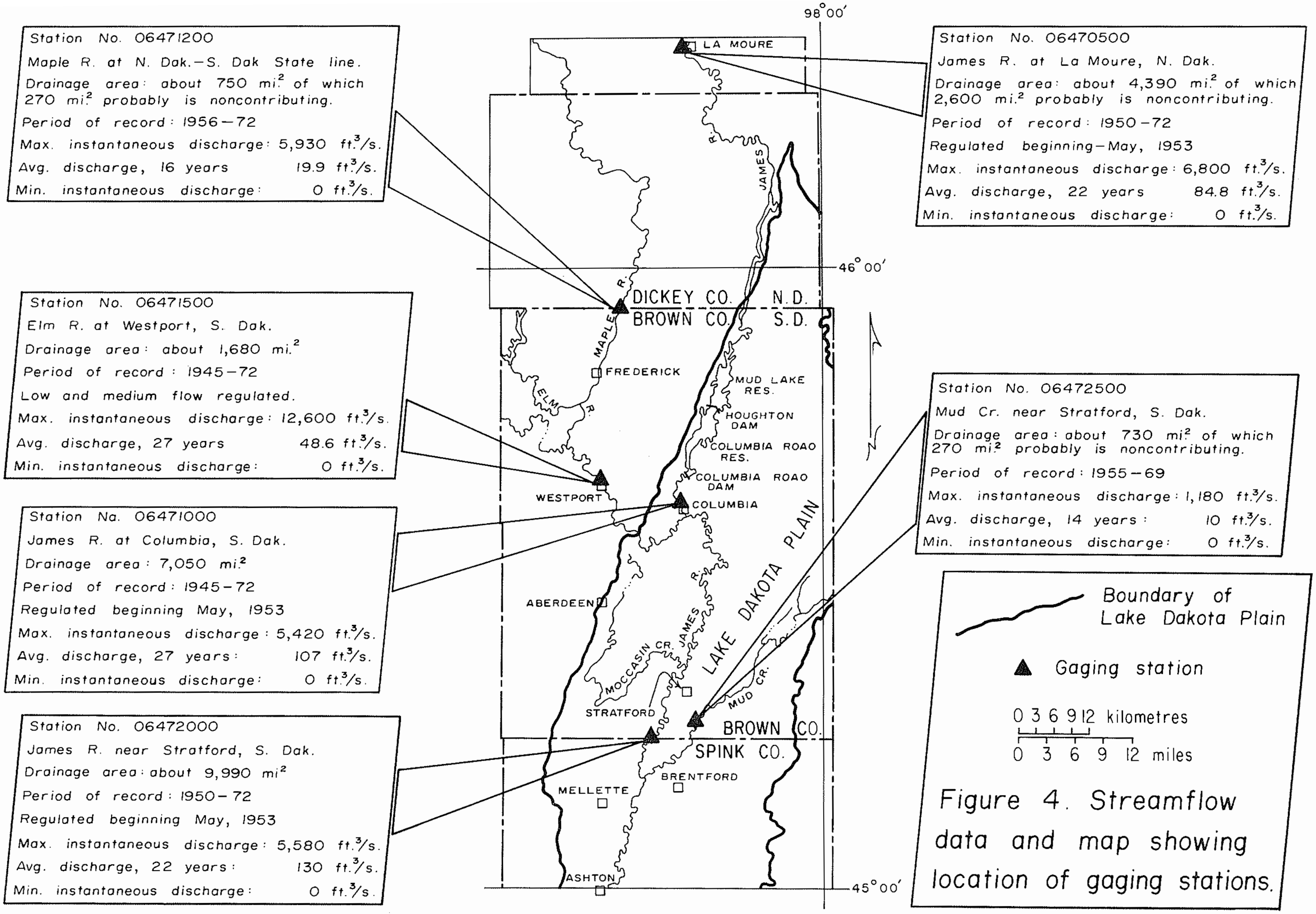

Figure 4. Streamflow data and map showing location of gaging stations.

have similar patterns over relatively large areas. In Brown County most streamflow and any floods occur in the spring and early summer from snowmelt and precipitation. Except for the Elm River, which receives discharge from ground-water storage and reservoir releases for the city of Aberdeen water supply, the major streams commonly have no flow in late summer, fall, and winter (fig. 5). Minor streams are usually dry from June to March unless an unusually heavy rainstorm causes short-lived streamflow.

Throughout much of the year the James River loses water by evaporation. Between the Columbia and Stratford gaging stations water loss is at the rate of 3,000 acre-ft (3.7 million m^3) a year and between the LaMoure, North Dakota and the Columbia station from 6,000 to 12,000 acre-ft (7.4 to 14.8 million m^3) a year (Koch, 1970). The larger stream loss above the Columbia station is caused by evaporation from the Columbia Road and Mud Lake reservoirs.

Flow Duration

Flow-duration data that indicate the percent of time that a given flow was equaled or exceeded can be used to determine the suitability of a stream for water supply. Flow-duration curves for the gaging stations on James, Elm, and Maple Rivers, and Mud Creek are shown in figure 6. The shape of the curve for a given stream is greatly influenced by the geologic and hydrologic characteristics of its basin. Thus an experienced hydrologist can use such curves to deduce many of the basic features of the hydrologic environment of a selected drainage basin. For example, where most of the streamflow is direct runoff the curve will be steep. Where there is a large amount of surface or underground storage stabilizing the streamflow, the curve will be relatively flat. Note that all streams have similar curves except for the Elm River, the curve for which flattens below a discharge of 4 ft^3/s (0.113 m^3/s). Among the causes of such a broadening is a persistence of streamflow from release of water from storage in two reservoirs and from natural storage; in this instance, from water stored in and discharged by an aquifer.

Floods

Patterson (1966, p. 3-9) presented a method of estimating the probable magnitude and frequency of floods in the James River basin. Regional flood-frequency curves applicable to Brown County can be used to estimate the magnitude of floods for recurrence intervals of 1.1 to 50 years. Recurrence interval is the average interval of time within which the given flood will be equaled or exceeded once. Thus, a 10-year flood has a 10 percent chance of occurring in any year, and a 50-year flood has a 2 percent chance of occurring in any year. The mean annual flood is a flood having a recurrence interval of 2 years. Figure 7 shows the relation of the mean annual flood to the size of the drainage area. Figure 8 shows the relation between the recurrence interval and the ratio of discharge to mean annual flood.

The discharge of a 10-year flood at the gaging station on the Elm River at Westport can be determined as follows:

1. Determine the size of the drainage area. (Fig. 4 shows a drainage area of 1,680 mi^2 (4,351 km^2)).

2. Determine from figure 7 the discharge of the mean annual flood for this size drainage area. (The discharge for the mean annual flood for 1,680 mi^2 (4,351 km^2) is about 1,020 ft^3/s (29 m^3/s)).

3. Determine from figure 8 the ratio of the flood of the selected recurrence interval to the mean annual flood. (The ratio for a flood with a 10-year recurrence interval to the mean annual flood is 4.3).

4. Multiply the discharge for the mean annual flood obtained in step 2 by ratio obtained in step 3. (The discharge of the 10-year flood on the Elm River at the Westport gaging station is 1,020 times 4.3, which is 4,386 ft^3/s (124 m^3/s)).

Figure 9 shows flood-discharge frequency at gaging stations on Elm River, James River, Maple River, and Mud Creek. The Elm and James Rivers curves are based on data after the reservoirs were in use.

The frequency with which a given flood stage can occur is dependent upon the width, depth, velocity of flow within the stream channel and on the flood plain; and upon channel controls such as bridges, dams, ice jams, and natural constrictions. Figure 10 shows the frequencies of various flood stages at gaging stations on Mud Creek and on the Elm, James, and Maple Rivers. These flood-stage diagrams should be used to estimate the flood risks near the gaging stations only, because many of the factors controlling flood stage probably are different at other locations.

During major floods on the James River there is major loss of streamflow between the Columbia and Stratford gaging stations. Major floods overtop or break through the levee system along the river and, as the flood recedes, some of the floodwater is trapped and remains ponded until it evaporates or seeps into the ground (Koch, 1970). Five major incidents of such loss of streamflow occurred between 1950 and 1970; loss of streamflow ranged from 16,000 to 40,000 acre-ft (19.7 to 49.3 million m^3).

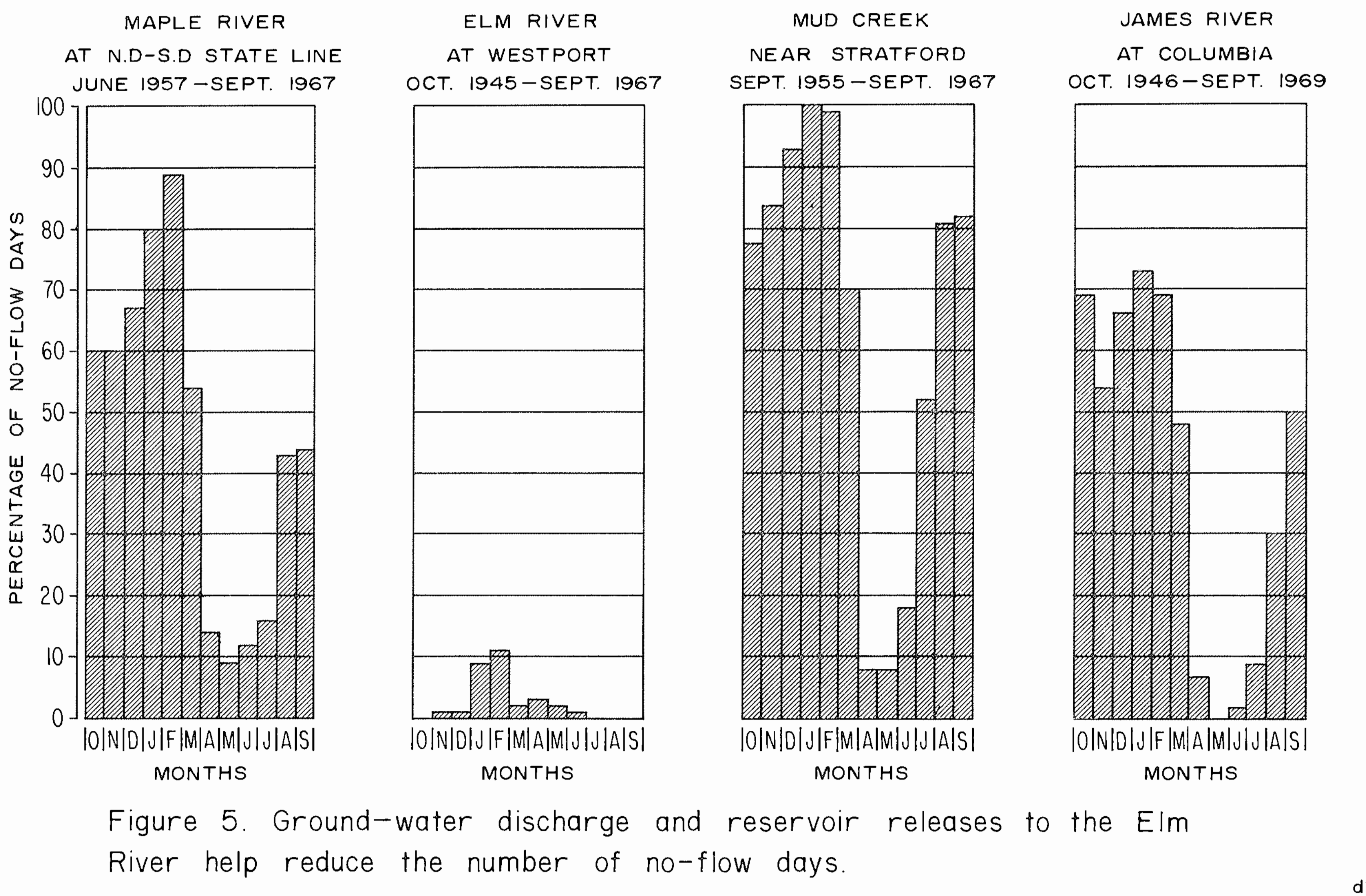

Figure 5. Ground-water discharge and reservoir releases to the Elm River help reduce the number of no-flow days.

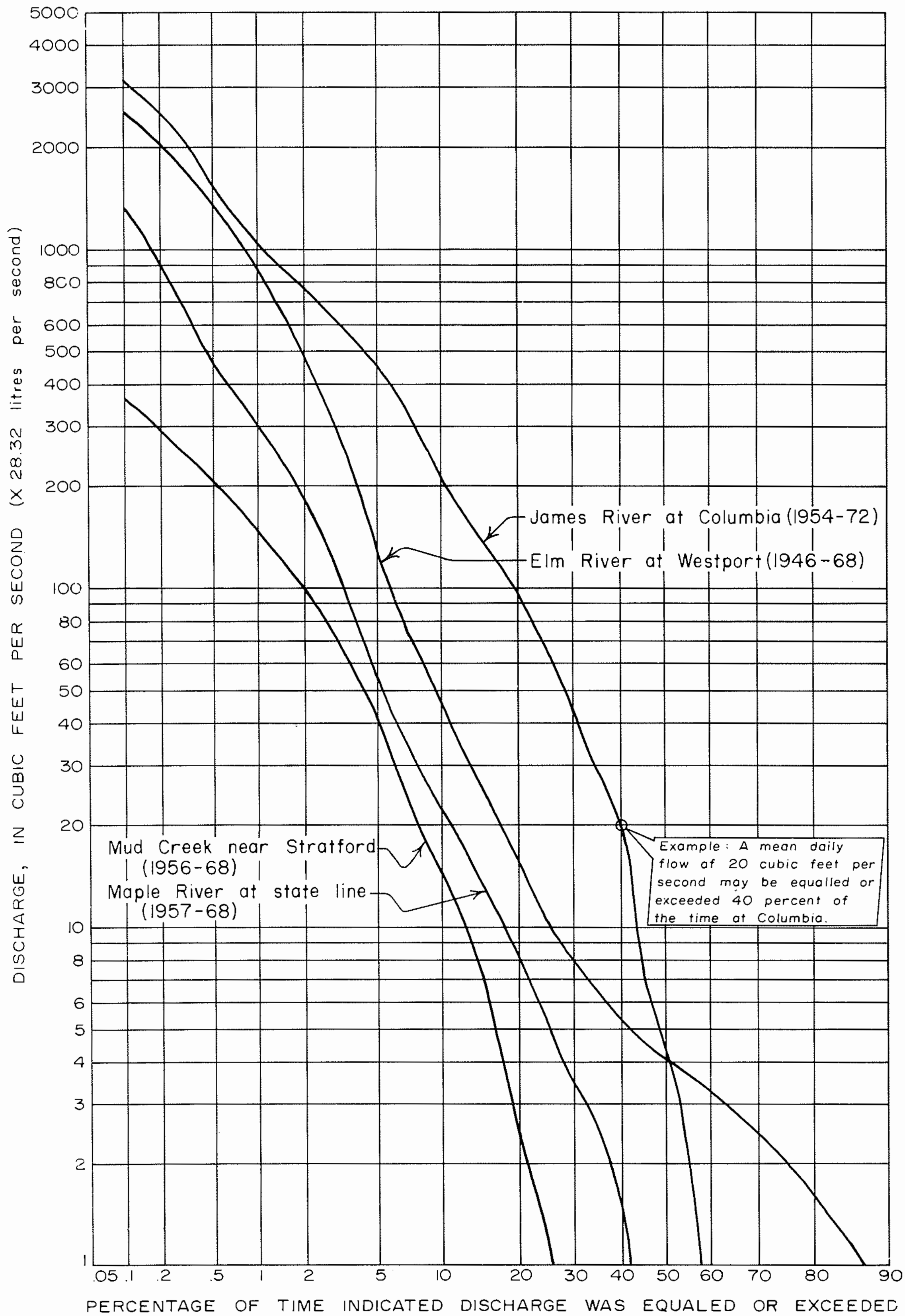

Figure 6. Graph showing flow duration curves for continuous record gaging stations on Mud Creek and on the Maple, Elm, and James Rivers.

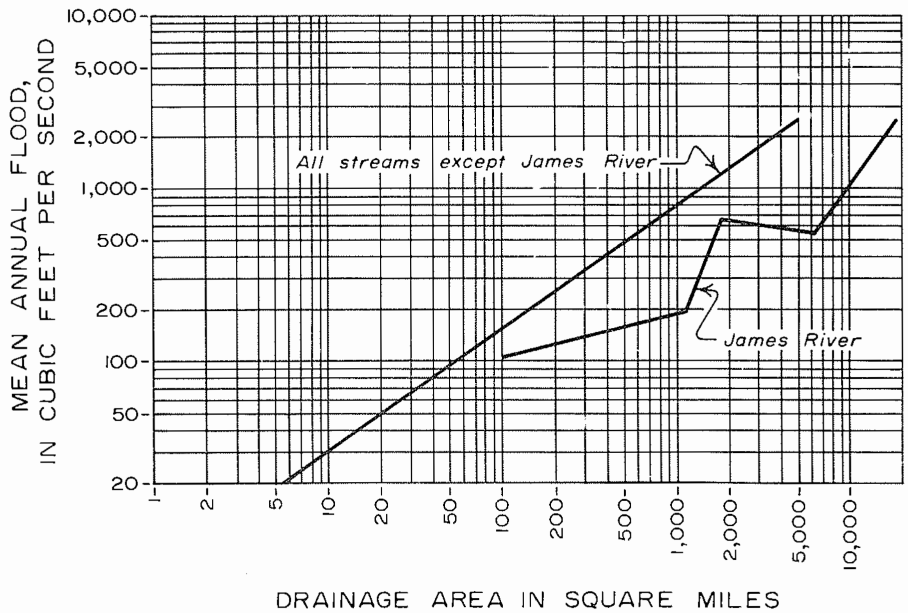

Figure 7. Graph showing variation of mean annual flood with drainage area (after Patterson, 1966).

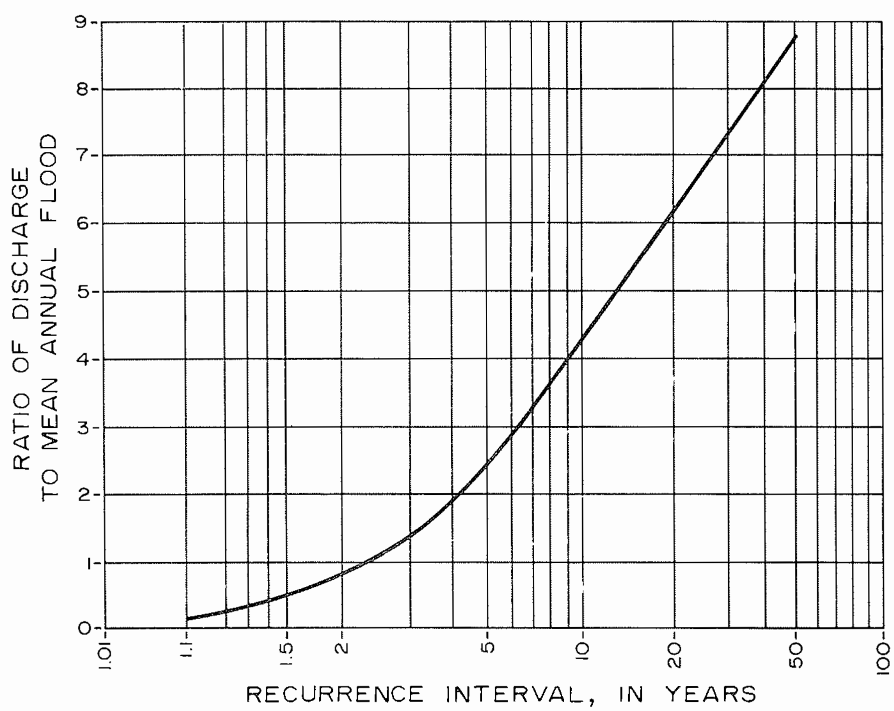

Figure 8. Graph showing variations of flood discharge with recurrence interval (after Patterson, 1966).

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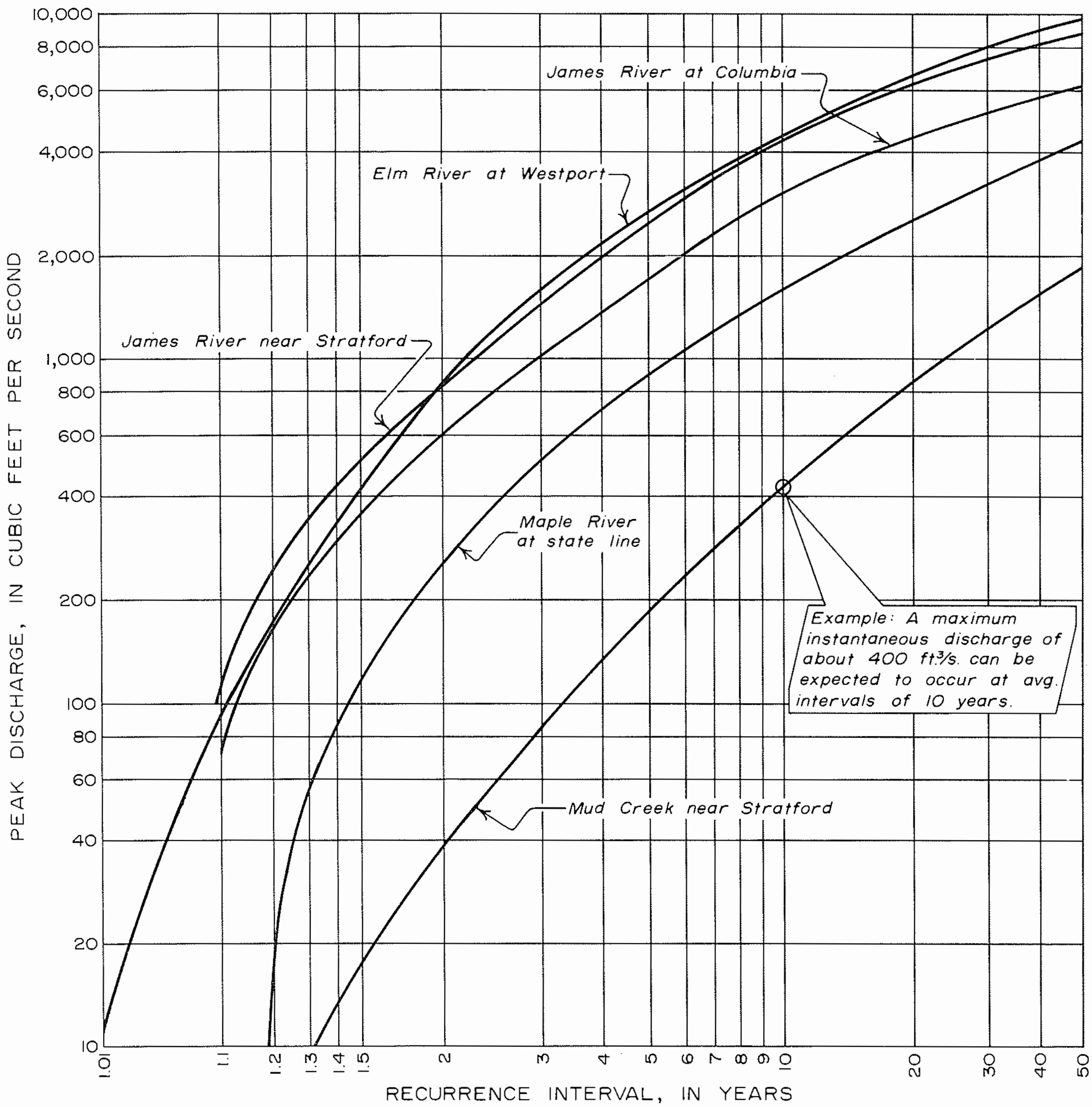

Figure 9. Graph showing flood-discharge frequency at gaging stations on Mud Creek and on the James, Elm, and Maple Rivers.

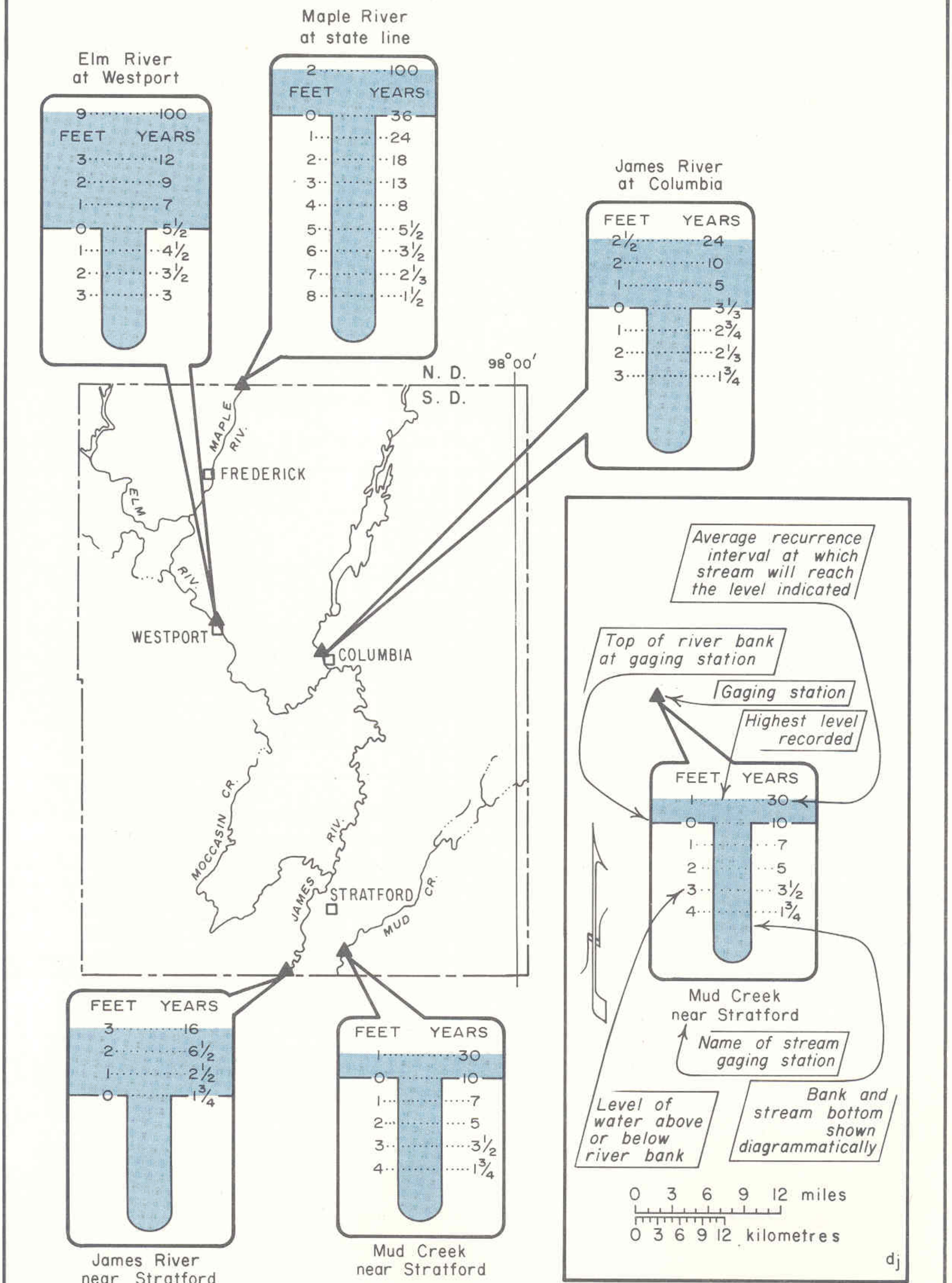

Figure 10. Planned use of river flood plains should take into account the magnitude and frequency of floods.

Maps of flood-prone areas along the James, Elm, and Maple Rivers have been prepared by the U.S. Geological Survey and are available from its Huron office. The flood-prone areas are shown on topographic maps at a scale of about 2½ in to the mile (6.6 cm to the kilometre). These maps show areas subject to flooding by a flood that has a 1 in 100 chance on the average of occurring in any year.

Reservoirs

Surface water may be stored on the land surface in both natural and man-made reservoirs. Most storage of surface water today (1973) in Brown County is in man-made reservoirs. There are no natural lakes in the County and many of the small natural ponds, sloughs, and swamps have been drained to increase the area of cropland. The largest reduction of natural storage was effected by draining the swamp that formerly occupied much of the Lake Dakota plain.

The principal reservoirs are on the James and Elm Rivers and Foot Creek (fig. 3). The James River is dammed 3 mi (5 km) north of Columbia to form the Columbia Road Reservoir and 1 mi (1.6 km) northwest of Houghton to form Mud Lake Reservoir. The two reservoirs cover an area of about 11,000 acres (4,452 ha) and contain from 7,000 acre-ft (8.6 million m^3) of water in January to 30,000 acre-ft (37 million m^3) in May and average 12,000 acre-ft (15 million m^3). Both of these reservoirs are used to regulate water levels in the Sand Lake Migratory Waterfowl Refuge to promote waterfowl production and survival. Elm Lake reservoir, on the Elm River in the northwestern corner of the County, has an area of 1,203 acres (487 ha) and a storage capacity of about 15,190 acre-ft (18.7 million m^3). Willow Creek Lake reservoir, 10 mi (16 km) southeast of Elm Lake reservoir, has an area of about 640 acres (259 ha) and a storage capacity of about 4,100 acre-ft (5.1 million m^3). The Elm Lake and Willow Creek Lake reservoirs are used to supply water to Aberdeen. Richmond Lake reservoir, about 6 mi (9.6 km) northeast of Aberdeen, has an area of 829 acres (335 ha) and a storage capacity of 7,700 acre-ft (9.5 million m^3).

There are about 1,922 stock ponds and dugouts in Brown County (Soil Conservation Service, Huron, South Dakota, oral communication, April 1974). The ponds and dugouts collectively occupy an area of about 120 acres (49 ha) and have a total storage capacity of about 700 acre-ft (863,100 m^3). These ponds generally are individually owned and are used primarily for watering stock.

Chemical Quality

The dissolved-solids concentration of water from streams in Brown County generally varies inversely with the volume of streamflow. During periods of high flow, such as floods, the dissolved-solids concentration of the water may be less than 300 mg/l (milligrams per litre), but during periods of low flow it may be more than 2,000 mg/l.

Plots of specific conductance and discharge at the Columbia gaging station on the James River are shown in figure 11. Specific conductance is low each spring during high flow, then gradually rises as the flow decreases, until about August when the conductance peaks. About October, when discharge is very low, a sharp rise in conductance occurs.

Specific conductance in Elm and Richmond Lakes ranges from 500 to 1,100 micromhos per centimetre at 25°C. Four measurements taken from 1961 to 1964 on Moccasin Creek show a range from 1,600 micromhos during periods of high flow to 2,200 micromhos during periods of low flow.

Chemical analyses of water from some streams and lakes in Brown County are published annually by the U.S. Geological Survey in the series, "Water Resources Data for South Dakota, Pt. 2, Water Quality,"

Hardness of water in the Elm River varies inversely with water discharge. Figure 12 illustrates the relationship of hardness, as measured at the Aberdeen Water Plant, to discharge as measured at the gaging station. During floods the hardness of water may be less than 200 mg/l, but during periods of low flow, when ground-water discharge is the main source of water, hardness may exceed 400 mg/l.

The predominant chemical constituents in water from the James and Elm Rivers are sodium and bicarbonate ions; minor constituents are calcium, magnesium, and sulfate ions. In the Maple River the predominant constituents are sodium and sulfate ions; minor constituents are calcium and bicarbonate ions.

Ground Water, Quantity and Quality

Aquifers in the Glacial Drift

Glacial drift includes all rock material transported by glacier ice even though subsequently affected by wind or water (Thwaites, 1961, p. 30). It can be divided into till, the unstratified and unsorted drift deposited by ice without subsequent movement by wind or water; and stratified drift, most of which has been reworked and deposited by wind or water. Outwash is material deposited by meltwater that flowed on or away from the glacier. Loess is material deposited by wind.

In Brown County, till is composed of a heterogeneous mixture of clay, silt, and sand that

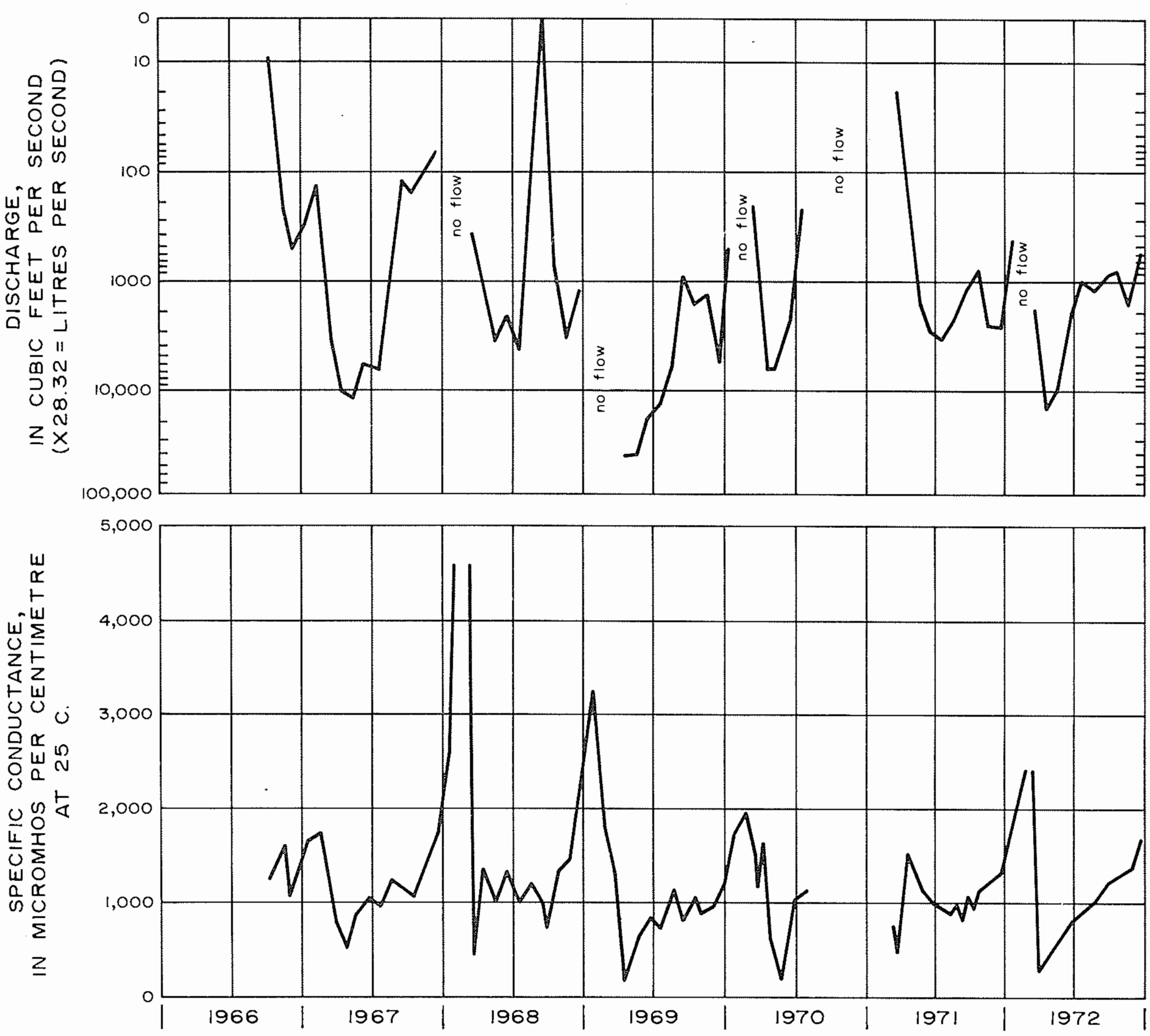

Figure 11. Specific conductance of water from the James River at Columbia rises as discharge decreases.

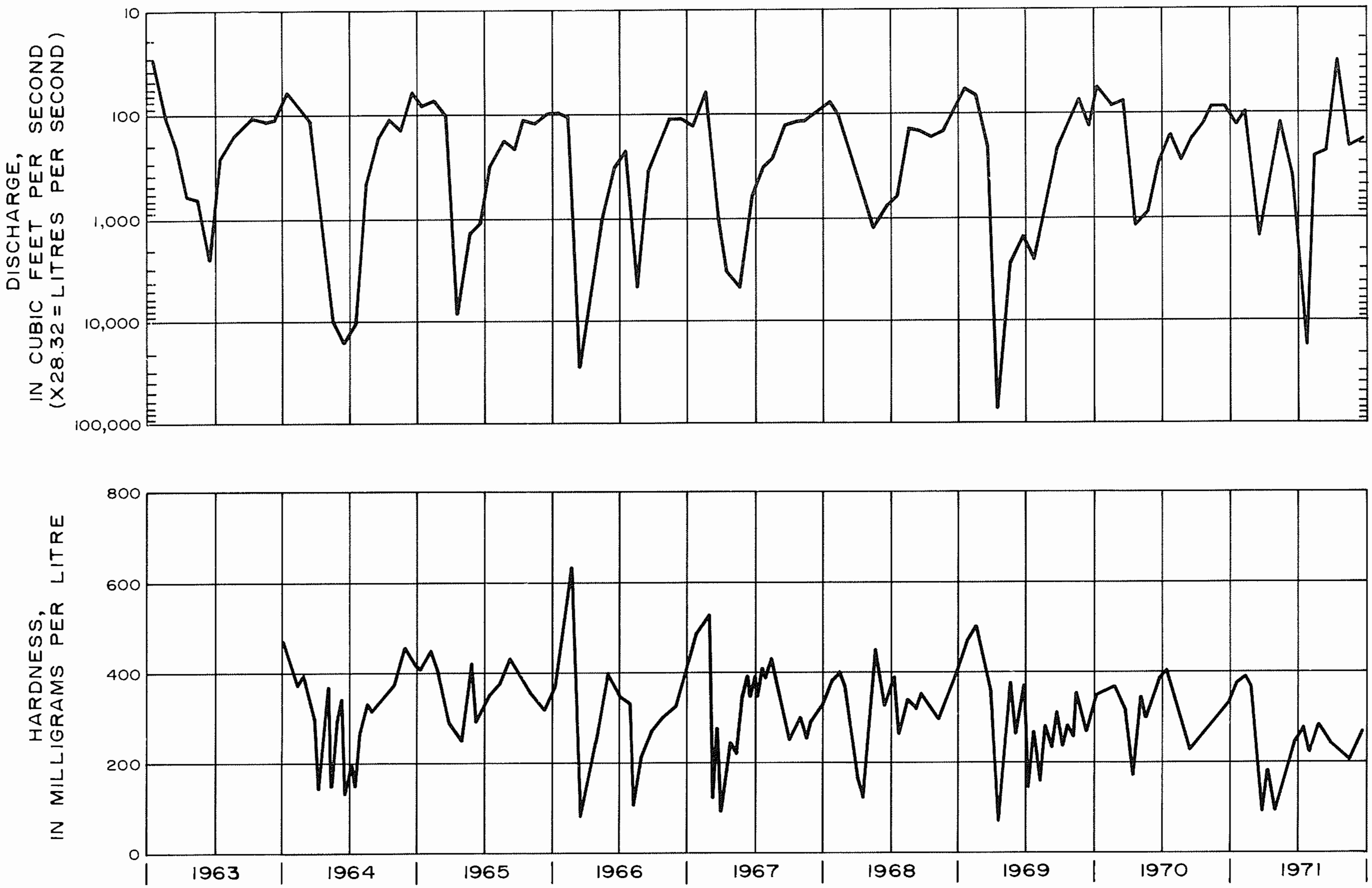

Figure 12. Hardness of water from the Elm River at Westport increases as discharge decreases.

contains lesser amounts of rock fragments ranging in size from gravel to huge boulders. Because of its large clay content, the till has low permeability and, in general, is a poor source of water. However, till locally contains small sand lenses that may yield as much as 5 gal/min (0.3 l/s).

Outwash consisting of sorted gravel, sand, and silt constitutes the most permeable deposits in Brown County. Thus, in discussing aquifers above the bedrock surface, this report will primarily be concerned with determining the areal extent, thickness, and water-bearing properties of outwash deposits.

A complex system of aquifers in glacial deposits underlies much of the James valley. 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. In Brown County the James aquifer complex has been divided into three aquifers for purposes of describing their hydrologic characteristics.

Three major aquifers in outwash or alluvium are here named the Deep James, Middle James, and Elm aquifers. In Marshall County, the Deep and Middle James aquifers merge to become a single aquifer, which was named the James aquifer (Koch, 1975). The topographic and stratigraphic relations of these aquifers, and of some other water-bearing deposits of lesser extent, are shown in the cross-sections of figure 13. The thickness of the water-saturated sand and gravel are shown in figure 14.

The salinity hazard and sodium hazard of water are shown in figure 15. The interpretation of these hazards for irrigation use is given in the appendix.

Deep James Aquifer

The Deep James aquifer (fig. 16), a buried, interconnected system of ancient river channels, underlies about 250 mi^2 (648 km^2) in Brown County. The aquifer is outwash and alluvium consisting of sand and gravel. Water in the aquifer occurs under artesian pressure and moves northward under a low gradient; water levels range from 5 to 32 ft (2 to 10 m) below land surface. Wells yielding 500 gal/min (32 l/s) or more can be constructed where more than 40 ft (12 m) of medium sand to gravel occur.

Thickness and areal distribution of sand and gravel in the aquifer are shown in figure 16. Additional information and the stratigraphic setting of the Deep James aquifer are shown in figure 13. The greatest known thickness of sand and gravel is 160 ft (49 m), found at test hole 125N62W18CCDC.

The Deep James aquifer contains about 1 million acre-ft (1.2 billion m^3) of water in storage. Water in storage was estimated by using an average saturated thickness of 30 ft (9 m) and an estimated porosity of 20 percent.

The Deep James aquifer occurs between 950 and 1,175 ft (290 and 358 m) above sea level, which is about 125 to 390 ft (38 to 119 m) below land surface. The deepest part of the aquifer is in the westernmost channel (see fig. 16). In T. 121 N., R. 65 W. the Deep James is at a depth of about 340 ft (104 m) and is separated from an overlying aquifer by thick deposits of till and lake silt. In T. 124 N., R. 63 W. the Deep James aquifer is found from 140 to 250 ft (43 to 76 m) below land surface. Farther north, in T. 126 N., R. 63 W., the aquifer is about 200 to 290 ft (61 to 88 m) below land surface. Here the aquifer consists of two sand and gravel zones separated by as much as 42 ft (13 m) of gravelly clay.

The eastern channels in the southern and northern parts of the County are shallower than the westernmost channel and contain only the upper sands and gravels of the Deep James aquifer. The aquifer is at depths of 125 to 200 ft (38 to 61 m) below land surface. In many places the eastern channels of the aquifer are hydraulically connected with overlying aquifers; they also contain cleaner sand and gravel and fewer clay stringers than the western part of the aquifer.

Recharge to the aquifer is by percolation through overlying lake silt, outwash, and till, and as subsurface inflow from Spink and Marshall Counties. Most recharge to the Deep James aquifer is from overlying aquifers where they are hydraulically connected (fig. 16). Additional water moves from a recharge area in Marshall County west into Brown County in T. 126 N. toward a discharge area. Water-quality data also suggest the possible westward movement of water from Marshall County in that the aquifer water in Marshall County has a much lower dissolved-mineral concentration than water in the aquifer in Brown County.

Water-level fluctuations in most aquifers in Brown County can usually be separated into seasonal and long term. Seasonal fluctuations of water levels are caused by differences in recharge or discharge throughout the year. Water levels rise in the spring and early summer when recharge from percolation of snowmelt and spring rains is greater than discharge by subsurface outflow. Conversely, water levels decline from mid-summer to mid-winter when discharge is greater than recharge.

Long-term fluctuations in water levels reflect cumulative differences in recharge and discharge during a period greater than 1 year. Water levels

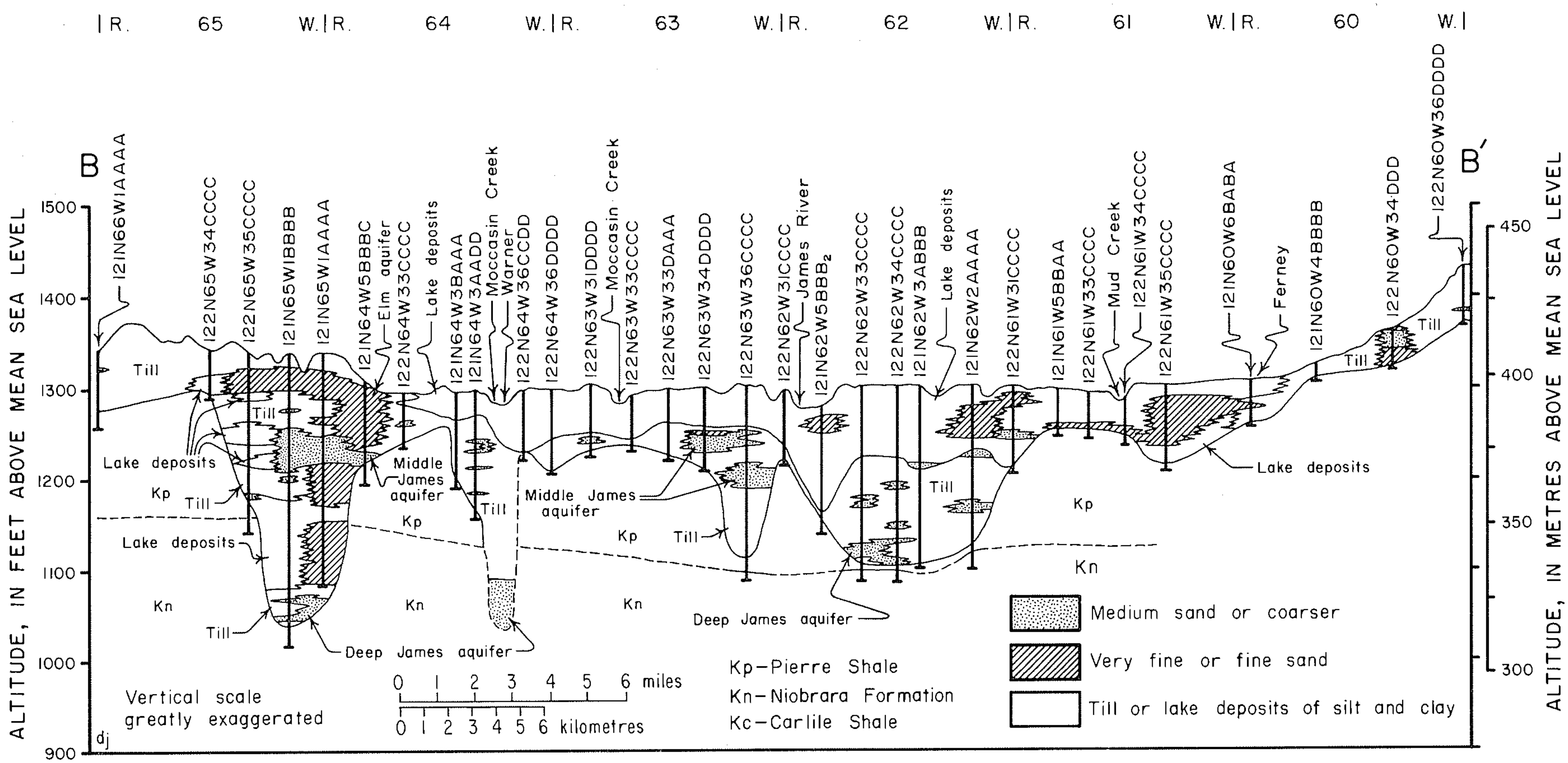

Figure 13 (B–B′). Lithologic sections A–A′ to G–G′ showing where major aquifers occur.

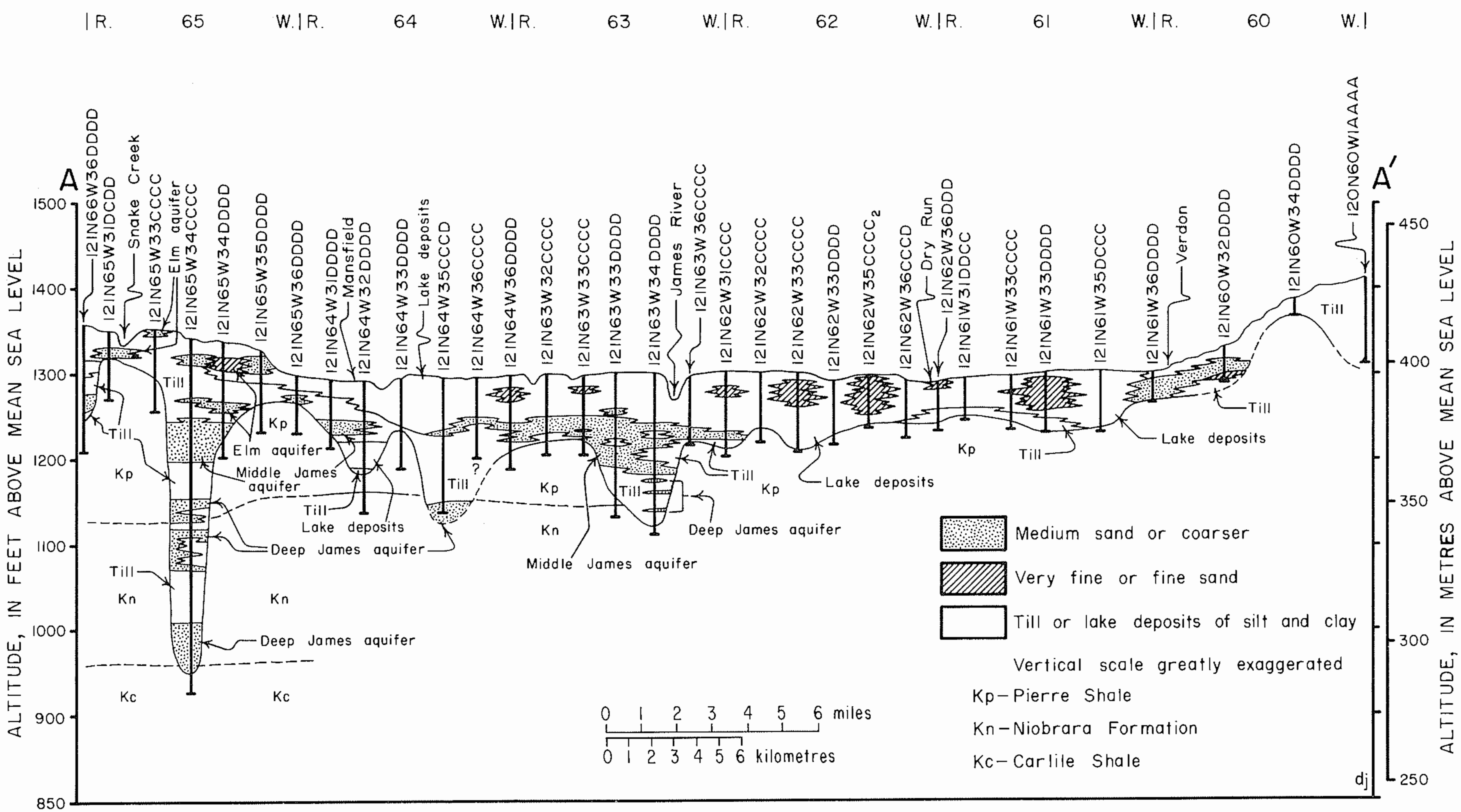

Figure 13 (A-A′). Lithologic sections A-A′ to G-G′ showing where major aquifers occur.

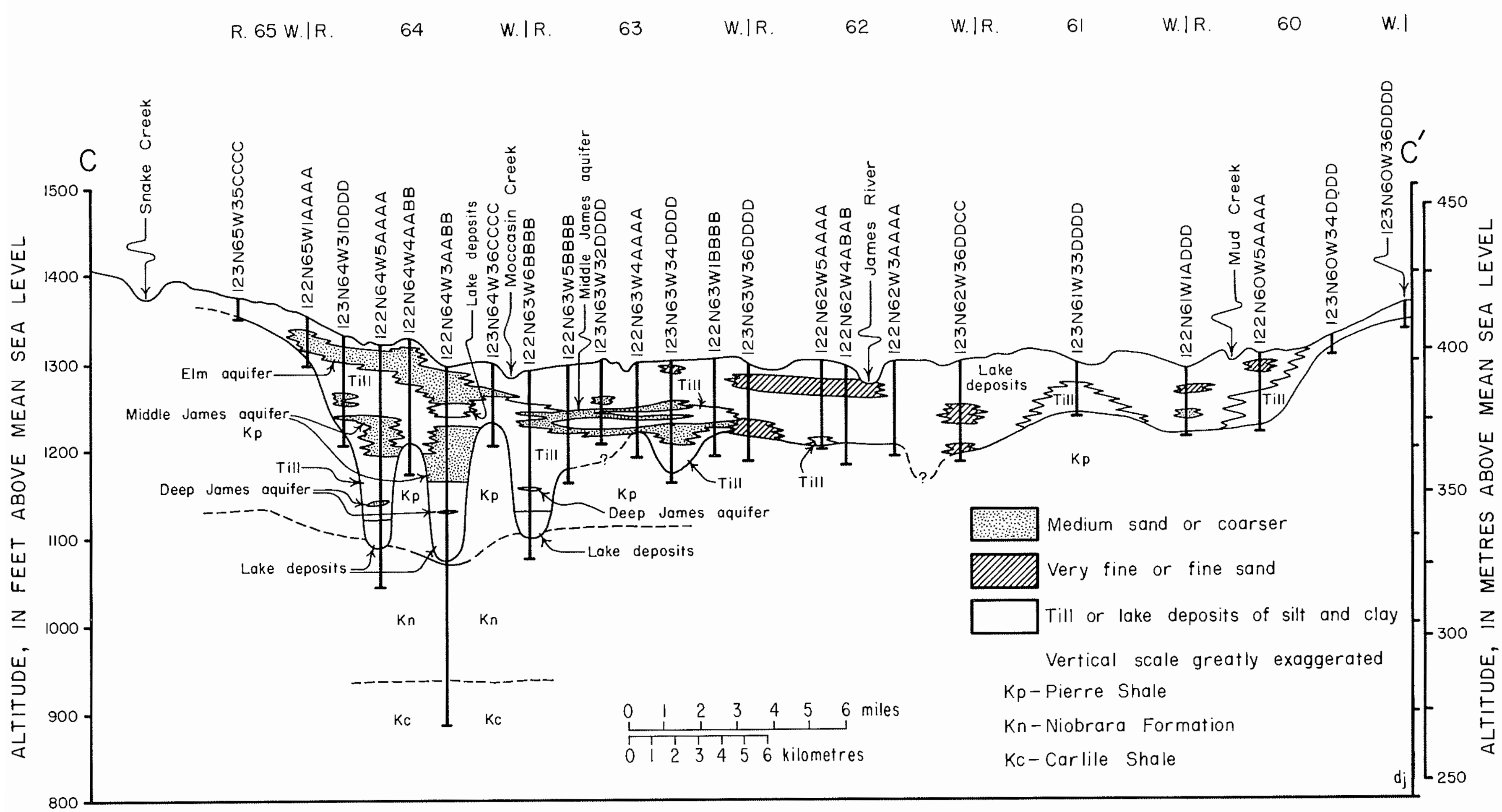

Figure 13 (C-C′) Lithologic sections A-A′ to G-G′ showing where major aquifers occur.

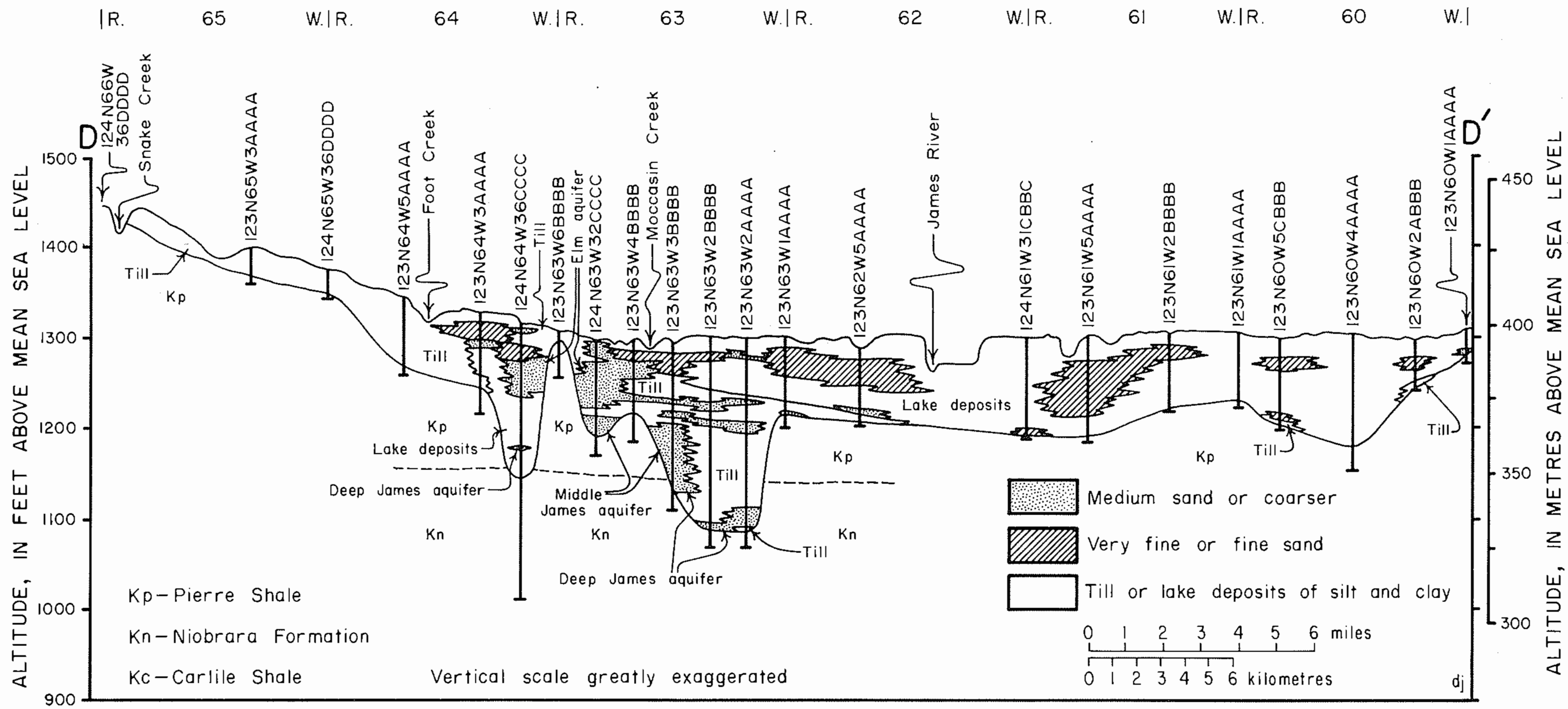

Figure 13(D–D′) Lithologic sections A–A′ to G–G′ showing where major aquifers occur.

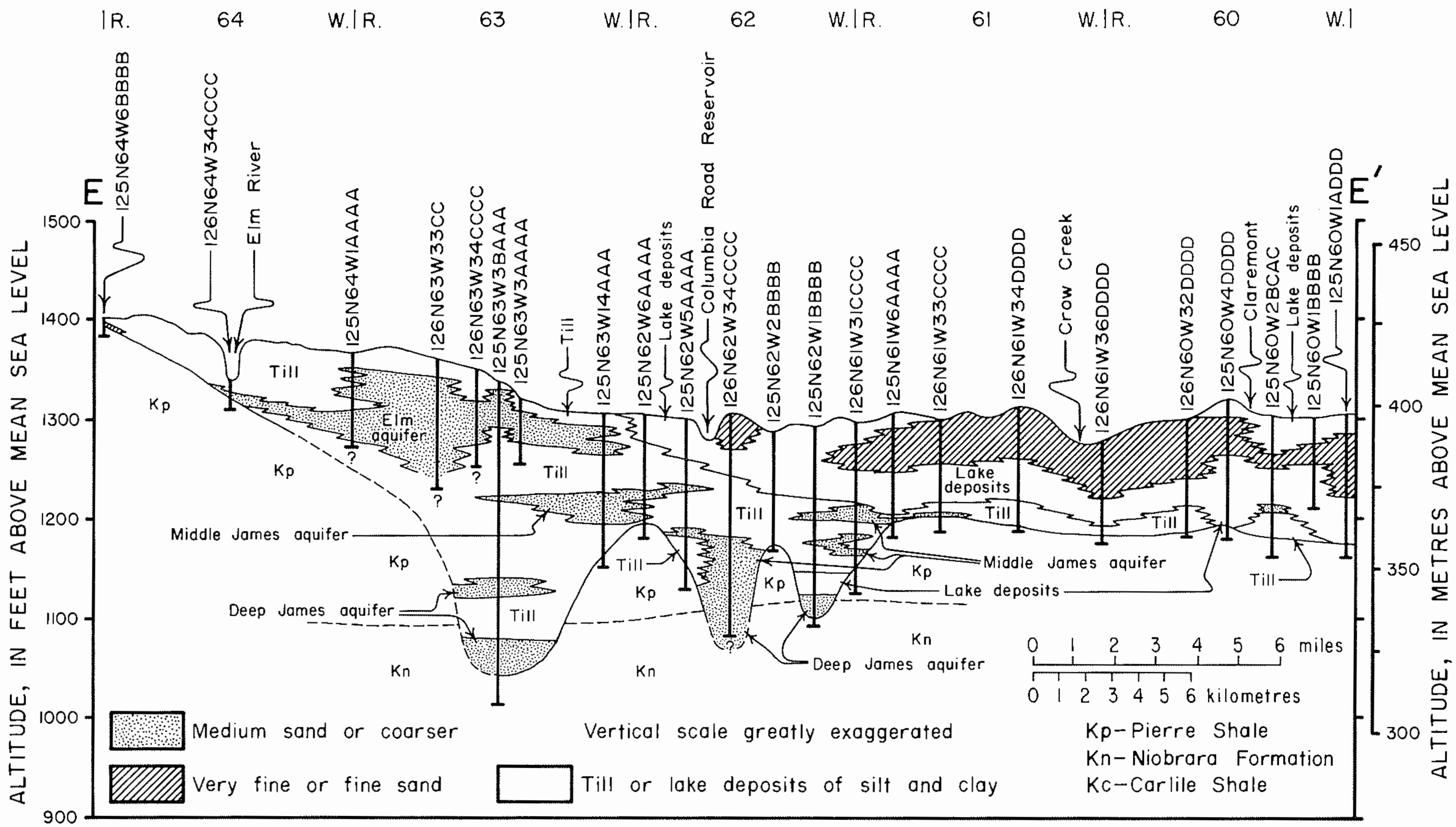

Figure 13(E-E′) Lithologic sections A-A′ to G-G′ showing where major aquifers occur.

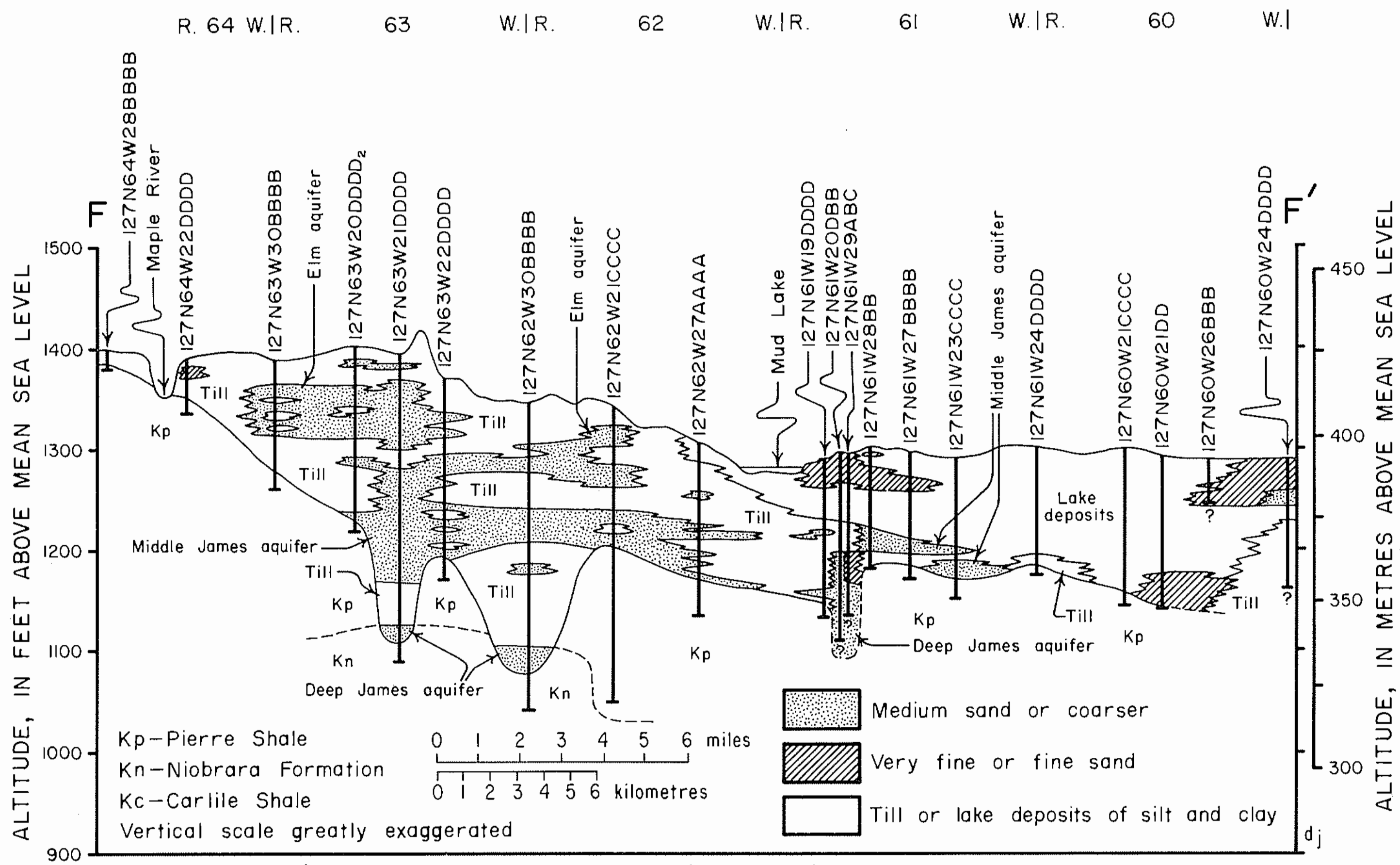

Figure 13(F–F′) Lithologic sections A–A′ to G–G′ showing where major aquifers occur.

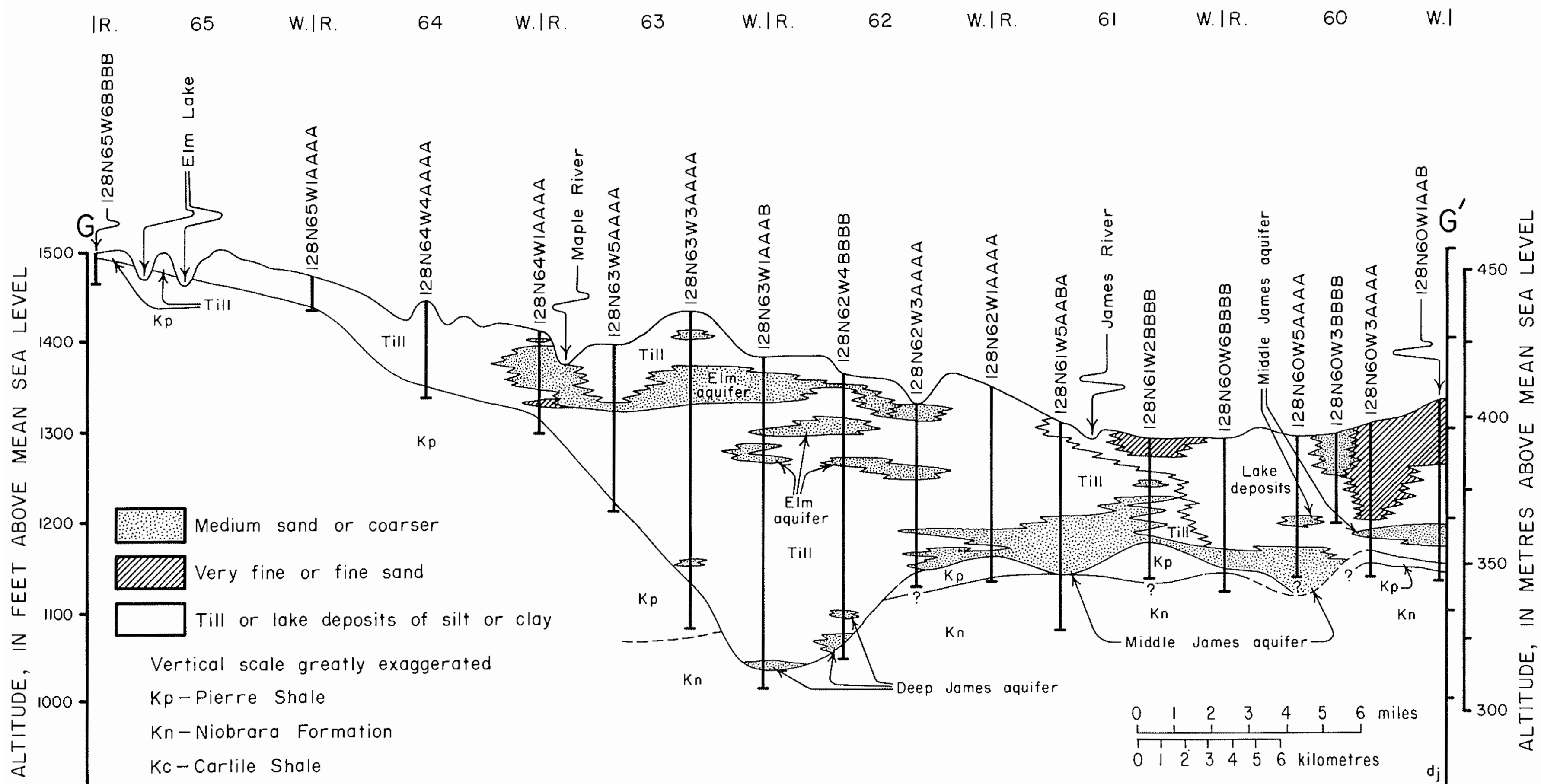

Figure 13 (G–G′). Lithologic sections A–A′ to G–G′ showing where major aquifers occur.

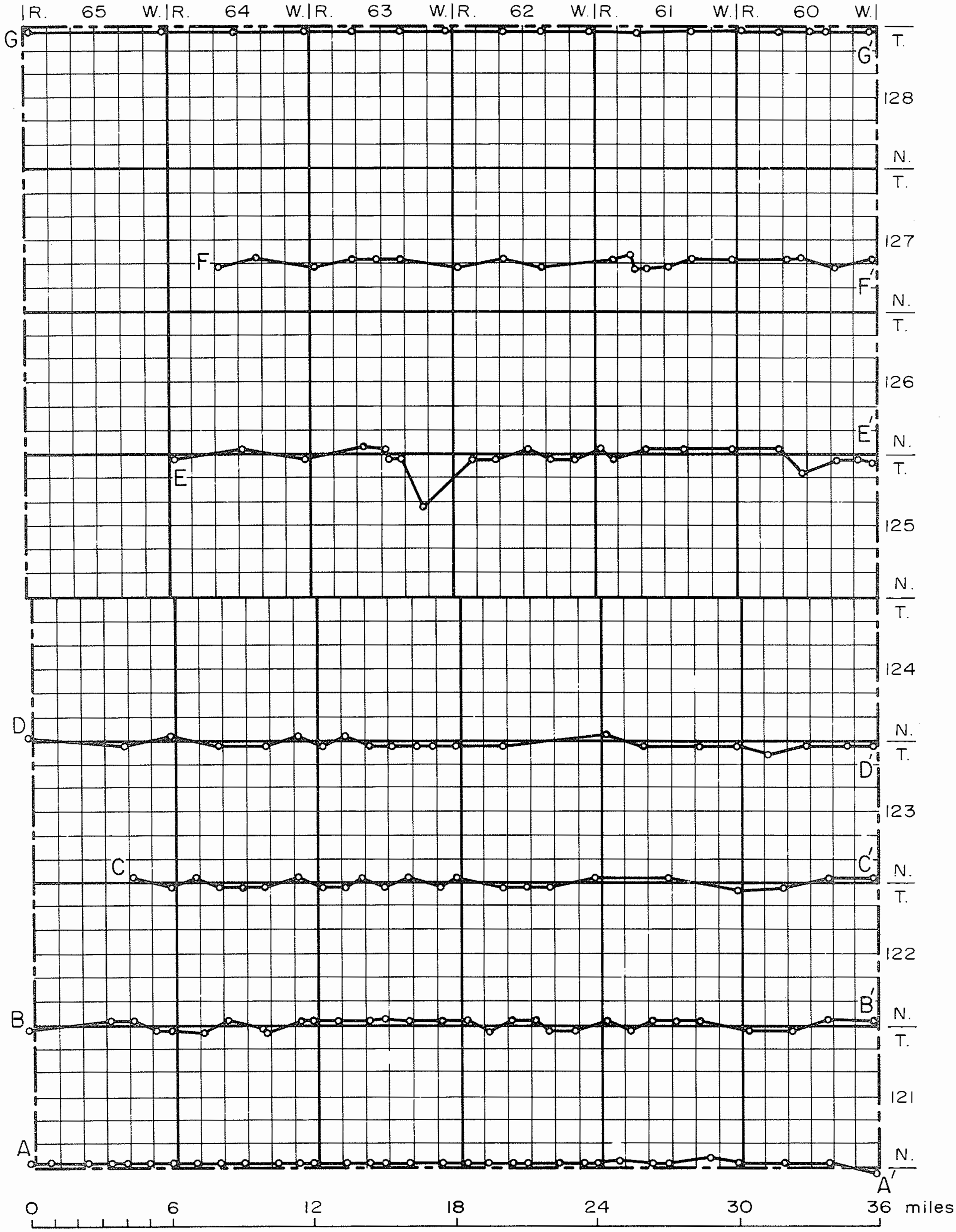

Figure 13(I). Index map of Brown County showing location of lithologic sections A-A′ to G-G′.

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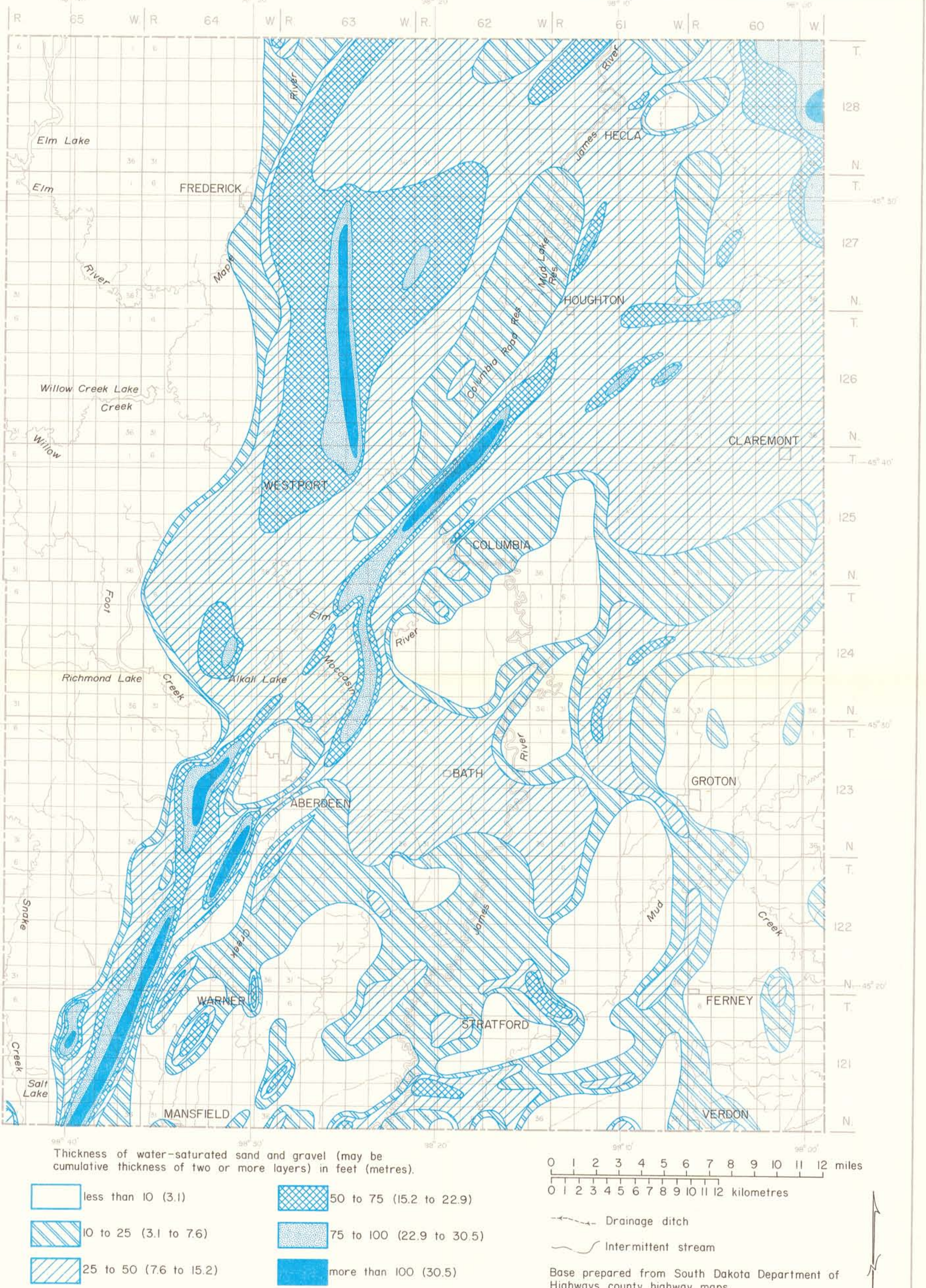


Figure 14. Map showing thickness of water-saturated sand and gravel in deposits above the bedrock surface.

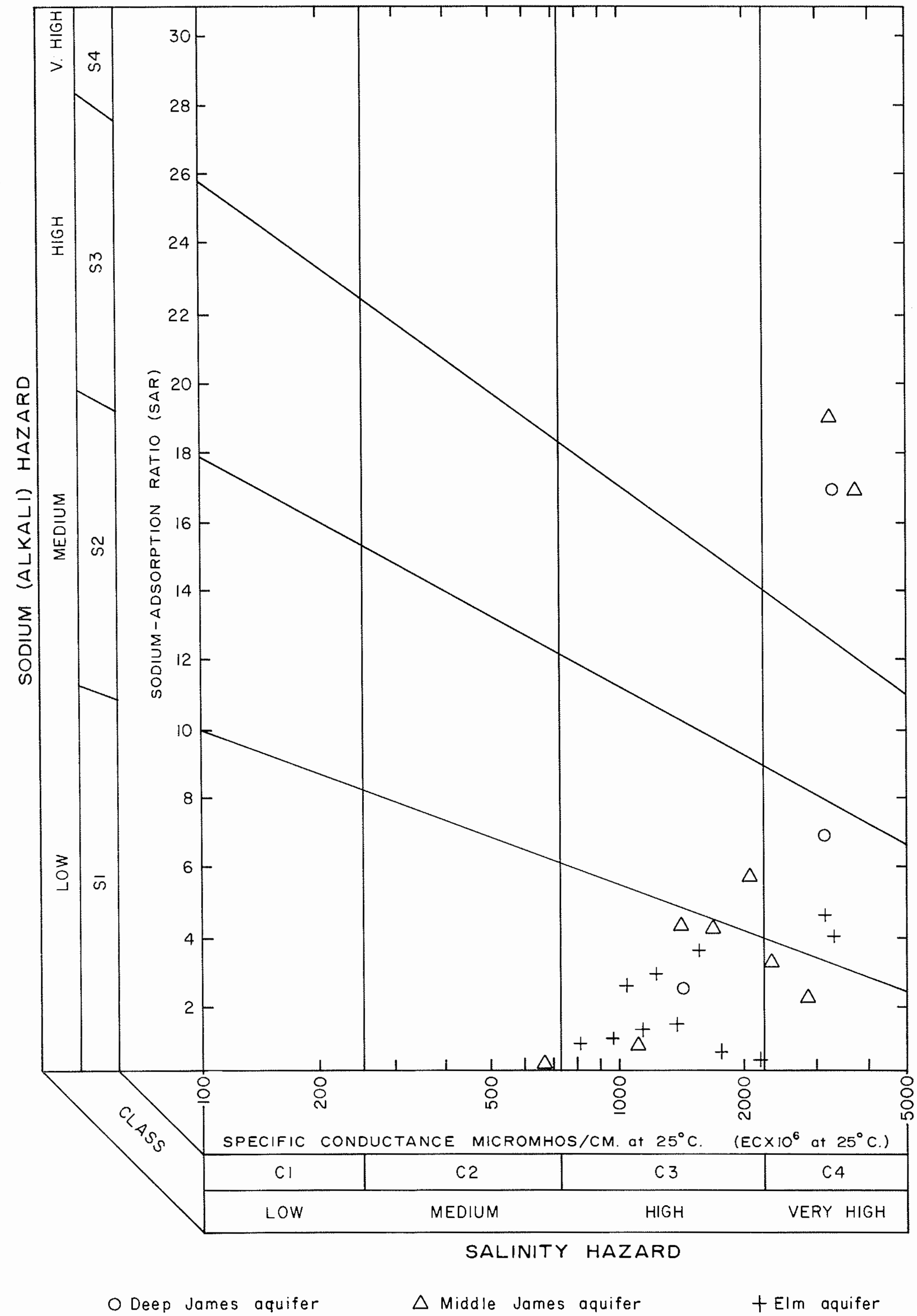


Figure 15. Diagram of classification of ground water for irrigation use.

TABLE 1. Chemical analyses of water from the Deep James aquifer

(results in milligrams per litre except as indicated)

	121N65W34CCCC (5 miles west of Mansfield)	121N64W2ADAB (at Warner)	125N62W21CCCC (at Columbia)
Calcium (Ca)	150	150	54
Magnesium (Mg)	30	35	18
Sodium (Na)	130	410	580
Potassium (K)	14	19	14
Bicarbonate (HCO_3)	366	246	213
Sulfate (SO_4)	280	460	7.8
Chloride (Cl)	170	390	970
Fluoride (F)	.2	----------	.3
Specific conductance (micromhos per cm at 25°C)	1,530	3,100	3,400
Hardness as $CaCO_3$	500	520	210

generally rise in years of above-normal precipitation and drop in years of below-normal precipitation.

There appears to be no relationship of water-level change in the Deep James aquifer to seasonal or long-term changes in precipitation. Most of the time the water level in observation well 121N65W1AAAA3 has remained about 30 ft (9 m) below land surface showing very little change over the 11-year period of record (fig. 17).

Natural discharge from the Deep James aquifer is by subsurface outflow into North Dakota and locally by upward leakage into the till.

The chemical quality of water in the Deep James aquifer may vary greatly throughout the area, not only in salinity, but also in the proportions of the major constituents listed in table 1.

The wide variation in the chemical composition of dissolved mineral matter within fairly short distances in the Deep James aquifer may be caused by several factors, such as differences in the chemical constituents in recharge water, a very low rate of water movement, and the lenticular nature of the sand and gravel layers.

Water recharging the aquifer may have different proportions of chemical constituents than water already in the aquifer. In Brown County, the predominant source of recharge is from snowmelt and precipitation. Recharge is from a large flat area that was swampy prior to draining and development for agricultural use. Over thousands of years, the swampy flat lake plain lost much of the surface and shallow ground water by evapotranspiration. The water that remained became high in salts. Each spring snowmelt and precipitation would flush the salts downward. The heavier saline water would percolate to the deeper aquifers displacing the lighter fresher water in the aquifers.

The very low rate of lateral movement of water in the drift aquifers, and the lack of discharge to streams, means that the major mode of discharge in

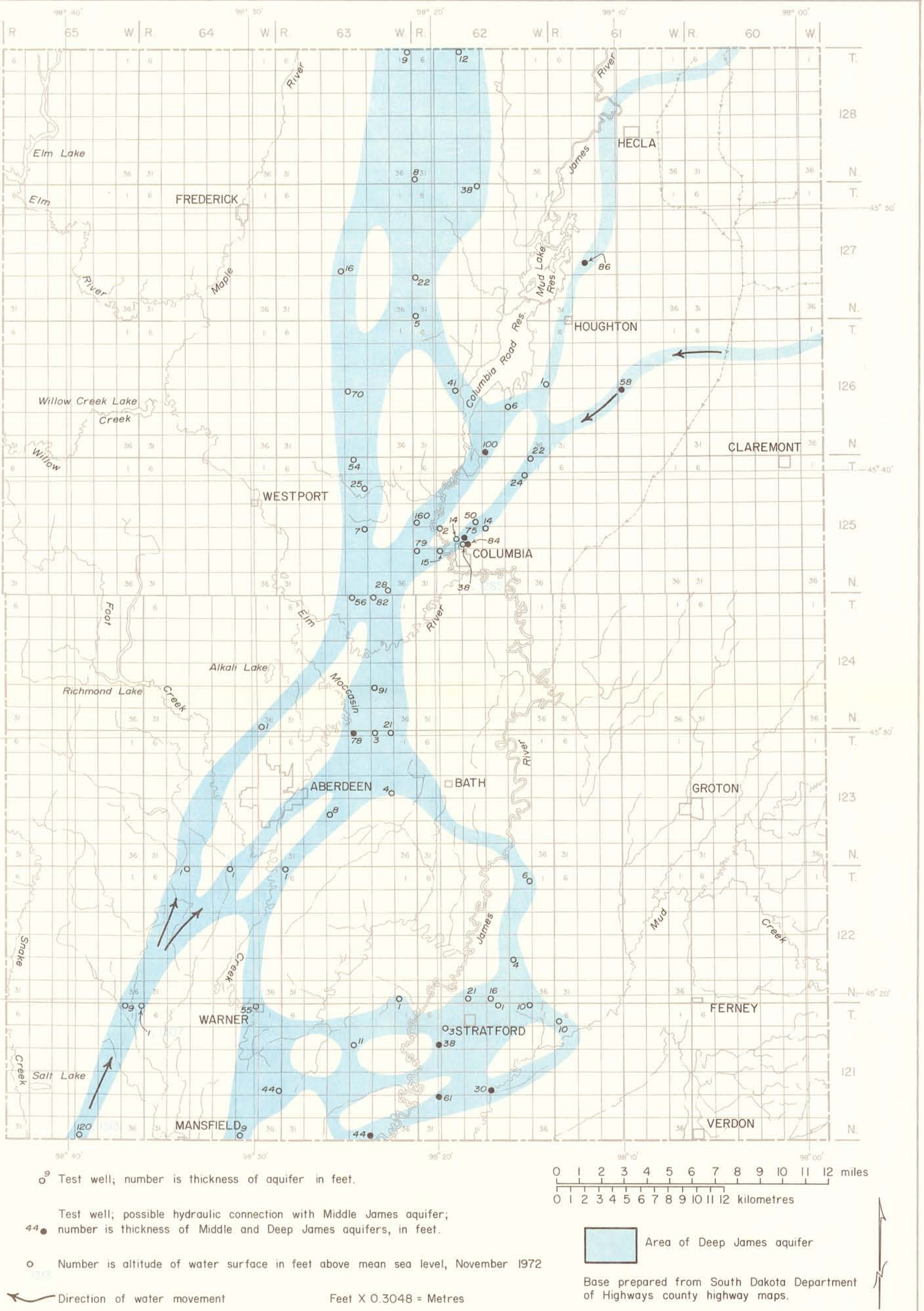


Figure 16. Map showing location and thickness of the Deep James aquifer.

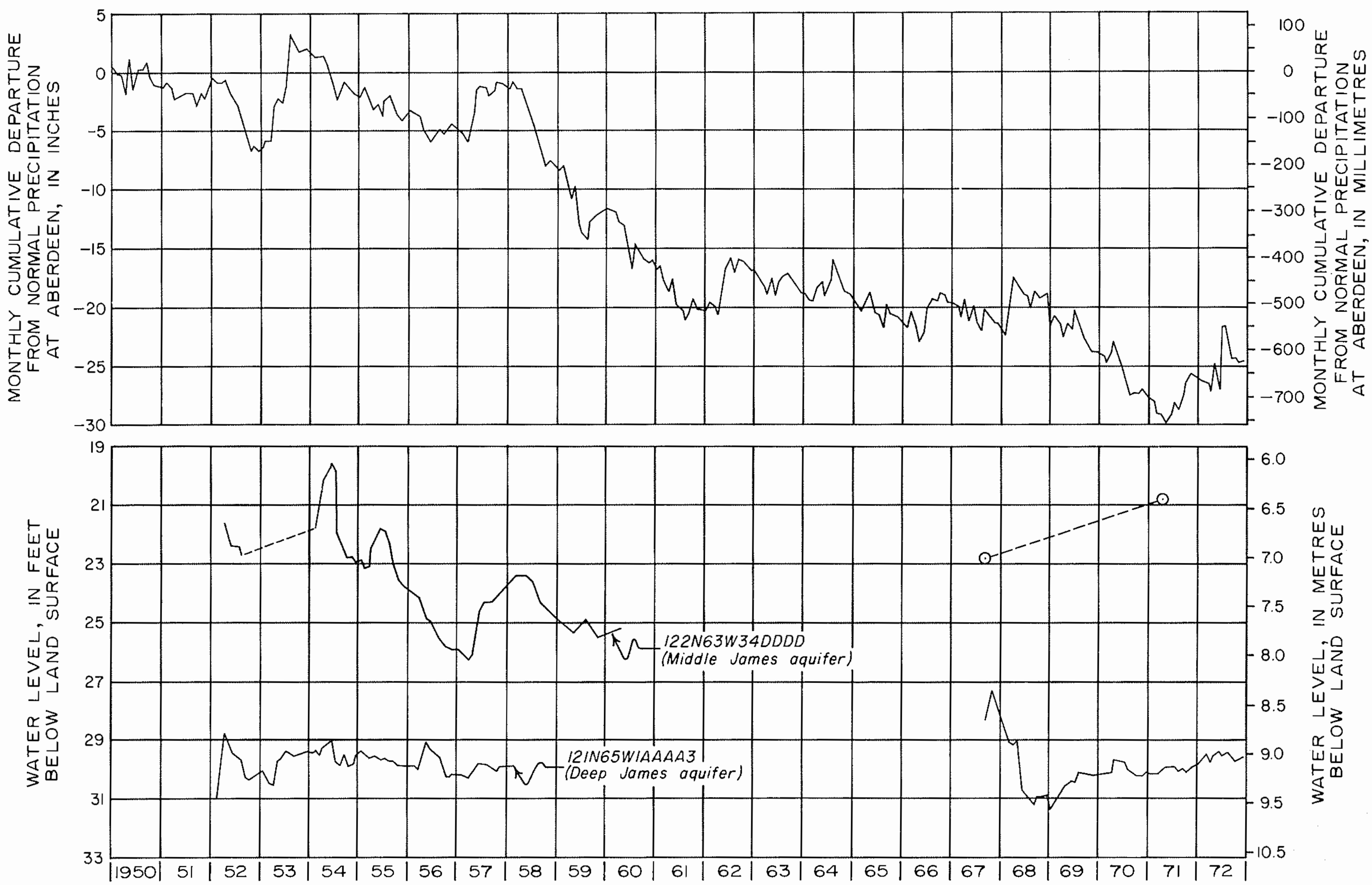


Figure 17. Water levels in wells in the Deep and Middle James aquifers remained about the same in 1971 as they were 19 years earlier even though precipitation totaled 25 inches below normal from 1950 to 1972.

the shallow aquifers is by evapotranspiration. Residence time may be long enough for vertical circulation to have developed due to density differences in waters of different salinities. In addition to evaporation from swamps and ponds where the water table is above land surface, an appreciable volume of water may be discharged in the vapor phase where the water table is below land surface.

Water in the Deep James aquifer may be mixing with water from the Niobrara Formation. Several test holes indicate that the Niobrara Formation is permeable and several wells obtain water from the Niobrara Formation. Water from the Niobrara Formation in wells 121N64W32DDDD and 128N61W17BAAA is high in sodium and chloride and low in sulfate, which is similar to the quality of water from the Deep James aquifer in well 125N62W21CCCC.

The lenticular nature of the sand and gravel layers in the Deep James aquifer could result in differences in water quality. For example, where water in a sand and gravel layer is mixing with water from the Niobrara Formation, the water quality could be considerably different from the quality of water in a sand and gravel layer that has a very poor hydraulic connection with water in the Niobrara Formation.

Middle James Aquifer

The Middle James aquifer underlies about 530 mi^2 (1,373 km^2) of Brown County. Water in the aquifer is under artesian conditions, and moves, in general, from west to east. Water levels range from above land surface to 32 ft (10 m) below land surface. Yields of 500 gal/min (32 l/s) or more can be expected from properly constructed wells where medium-grained sand to gravel is 40 ft (12 m) or more thick. The Middle James contains about 1.4 million acre-ft (1.7 billion m^3) of water in storage. Water in storage was estimated by using an average saturated thickness of 20 ft (6 m) and an estimated porosity of 20 percent.

Thickness and areal distribution of sand and gravel in the Middle James aquifer are shown in figure 18. Additional information and the stratigraphic setting of the aquifer are shown in figure 13. Thickness ranges from 1 to 105 ft (0.3 to 32 m). The deposits of sand and gravel are lenticular and contain many clay layers.

The Middle James aquifer occurs between 1,150 to 1,250 ft (351 to 381 m) above sea level. In the lowland areas this is about 40 to 150 ft (12 to 46 m) below land surface. At higher land-surface altitudes, as in R. 63 W. in the northern part of the County, the aquifer is as much as 250 ft (76 m) below land surface. In some areas the aquifer is in the upper part of the Deep James channels and overlies the bedrock surface adjacent to these channels. In the lowland of the northern part of the County, the Middle James is about 100 to 150 ft (30 to 46 m) below land surface. In the southern part of the County, the aquifer is about 50 to 100 ft (15 to 30 m) below land surface.

Recharge to the Middle James aquifer is from percolation of snowmelt and precipitation through overlying lake silt, outwash, and till. Probably the largest recharge is from the Elm aquifer where it is in contact with the Middle James aquifer (fig. 18).

Water levels in the Middle James aquifer rise in the spring and early summer, when recharge from precipitation and snowmelt is greater than discharge. Conversely, water levels decline from mid-summer to mid-winter when discharge is greater than recharge.

Long-term fluctuations of water level in the Middle James aquifer correlate with long-term precipitation trends as shown on graphs of departures from normal precipitation. For example, figure 17 shows that the water level in well 122N63W34DDDD declined 6 ft (2 m) between June 1954 and March 1957 then rose 3 ft (1 m) by May 1958, fluctuations that correlate with a general decline from normal precipitation and subsequent above normal precipitation.

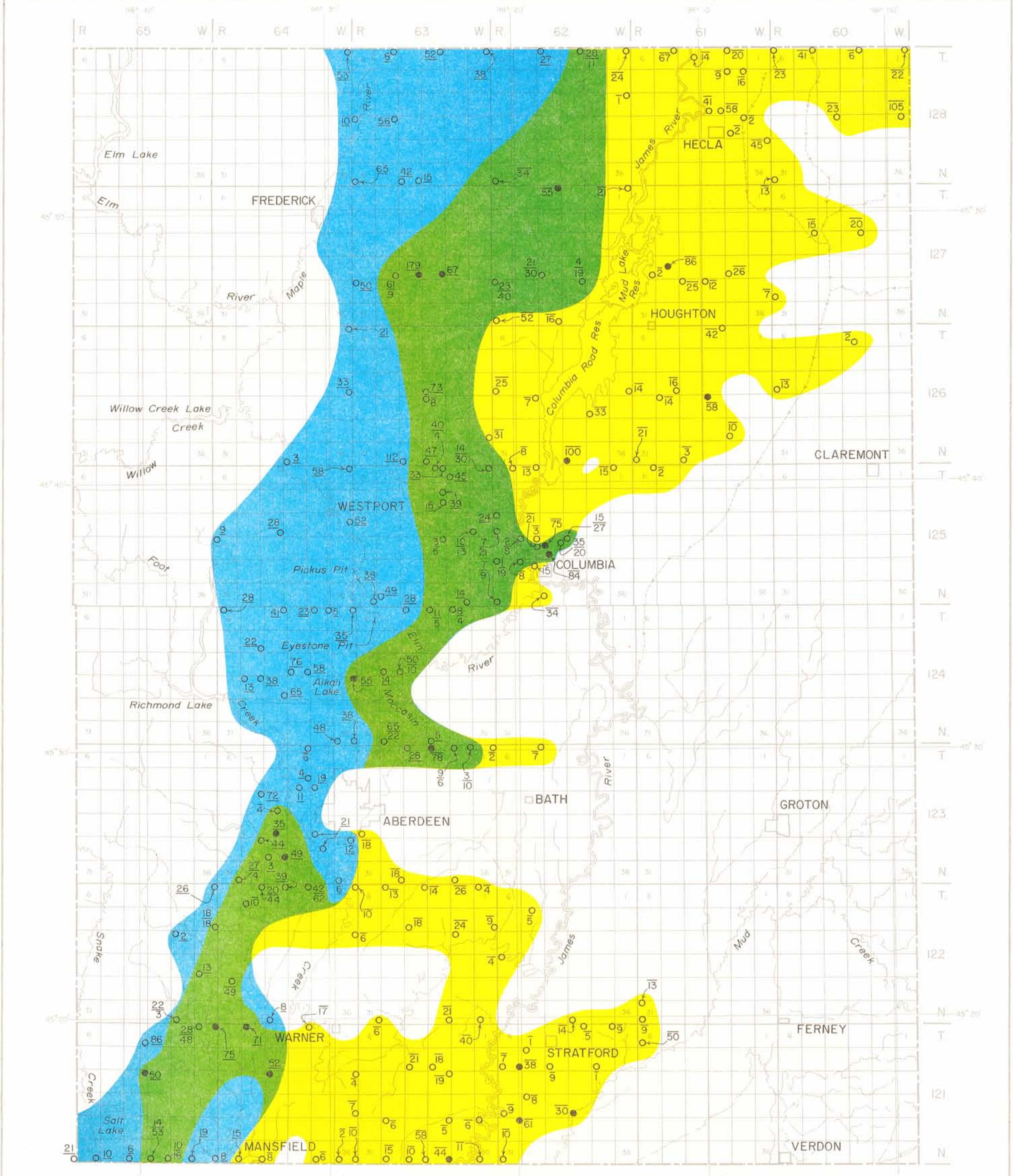
Natural discharge from the aquifer is by percolation into the Deep James aquifer and by eastward flow into the Lake Dakota sediments and into till.

The predominant chemical constituents of water from the Middle James aquifer are sodium and chloride ions in some areas but mixtures of calcium, magnesium, bicarbonate, and sulfate ions are the dominant ions in others. The wide differences in the proportions of major ions from one location to another make it difficult to predict water quality, or even the predominant ions, in water from an area where no data are available. The range and average of selected chemical constituents are given in table 2.

The wide variation in the chemical composition of water within short distances in the Middle James aquifer may be caused by the following factors:

1) The slow drainage of surface water results in evaporation, which increases the salinity of the water that percolates to the Middle James aquifer;

2) Highly mineralized water from flowing wells from bedrock aquifers percolates to the Middle James aquifer. Flowing wells from bedrock aquifers have discharged billions of gallons of highly mineralized water onto the land surface in Brown County during the last 70 years;



Elm aquifer

Area where Elm aquifer overlies Middle James aquifer

Middle James aquifer

0 1 2 3 4 5 6 7 8 9 10 11 12 miles

0 1 2 3 4 5 6 7 8 9 10 11 12 kilometres

Feet X 0.3048 = metres

Intermittent stream

28/48 ○ Test well; upper number is thickness of Elm aquifer, in feet. Lower number is thickness of Middle James aquifer, in feet.

179/55 ● Test well, possible hydraulic connection with two aquifers. Upper number is thickness of Elm and Middle James aquifers, in feet. Lower number is thickness of Middle and Deep James aquifers, in feet.

Base prepared from South Dakota Department of Highways county highway maps

Figure 18. Map showing areal extent and thickness of the Middle James and Elm aquifers.

TABLE 2. **Summary of chemical analyses of water from the Middle James aquifer**
(results in milligrams per litre except as indicated)

Constituent or Property	No. of analyses	Average[1]	Range
Calcium (Ca)	17	135	24-400
Magnesium (Mg)	17	47	12-163
Sodium (Na)	15	340	8.8-700
Potassium (K)	12	12	5.9-18
Bicarbonate (HCO_3)	16	526	300-1,040
Sulfate (SO_4)	18	370	80-1,300
Chloride (Cl)	18	283	12-1,200
Fluoride (F)	13	.38	.1-.8
Nitrate (NO_3)	20	.9	0-8.8
Iron (Fe) in ug/l	21	300	20-20,000
Manganese (Mn) in ug/l	3	200	200-1,500
Hardness as $CaCO_3$	16	542	180-1,500
Specific conductance (micromhos per cm at 25°C)	13	2,155	679-3,000
Percent sodium	25	51	4-93
Sodium-adsorption ratio (SAR)	16	4.3	.2-38
pH (units)	23	7.5	7.1-8.0

[1] Values shown for iron, manganese, sodium-adsorption ratio, and pH are median values.

3) Effect of Elm aquifer recharge; and,

4) Lenticular nature of the Middle James aquifer.

The water in the Middle James aquifer, in general, has a high to very high salinity hazard and a low sodium hazard (fig. 15).

Before construction of any major facility to develop a water supply from the Middle James aquifer, a chemical analysis should be made of water at the selected location to determine the quality and suitability of the water for the intended use. The range in quality, as shown in table 2, indicates that in some areas the water is excellent for many uses, but in other areas the water is of such poor quality as to have very limited potential for use.

Elm Aquifer

The Elm aquifer (fig. 18) underlies about 390 mi^2 (1,010 km^2) in Brown County and extends from north to south across the west-central part of the County where it overlies the western part of the Middle James aquifer. Well depths range from 15 to 100 ft (5 to 30 m). Water is under water-table conditions in some places and under artesian conditions in others. Water levels range from 4 to 50 ft (1 to 15 m) below land surface. The Elm aquifer contains about 1.2 million acre-ft (1.5 billion m^3) of water in storage. Water in storage was estimated by using an average saturated thickness of 25 ft (8 m) and an estimated porosity of 20 percent.

Thickness and extent of the aquifer are shown in figures 13 and 18. Aquifer thickness ranges from 2 to 112 ft (1 to 34 m). The western part of the aquifer is divided into upper and lower units separated by as much as 30 ft (9 m) of till. In general, the deposits of sand and gravel that make up the aquifer are less lenticular and contain fewer clay layers than deposits in other glacial aquifers in Brown County.

The Elm aquifer occurs between 1,225 and 1,400 ft (373 to 427 m) above sea level, which is about 15 to 150 ft (5 to 46 m) below land surface. The aquifer is deepest below land surface in topographically high areas. It slopes to the east at about the same gradient as the topographic surface, about 15 ft/mi (2.8 m/km).

The general direction of water movement in the aquifer is from northwest to southeast, at a gradient of about 10 ft/mi (1.9 m/km). The general configuration of the water surface and the direction of water movement are shown in figure 19.

Recharge to the Elm aquifer is by percolation of precipitation, snowmelt, and surface water through overlying outwash, lake sediments, and till. Recharge takes place rapidly in level areas where permeable sediments overlie the aquifer but slowly where till overlies the aquifer.

Water-level fluctuations, such as those shown in figure 20 are caused by seasonal changes in recharge where the Elm aquifer underlies the lake sediments. Water levels rise 1 to 10 ft (0.3 to 3 m) from about March to June and decline from July to March. As measured in observation wells, the rise and fall of the water table in any one well have been almost the same each year for the 18 years of record.

In the western part of the Elm aquifer, where the water is under artesian conditions, changes of water level generally correspond to long-term departures from normal precipitation. For example, water levels rose in response to above-normal precipitation between April and August 1953, but fell from August 1953 to April 1958 because of below-normal precipitation (fig. 21). Apparent exceptions to this occurred in 1969 when the water level rose and then retained its higher level through 1970 and 1971. The rise in 1969, however, was due to the coincidence of an unusually heavy snowpack and an earlier than normal soil thaw, thus permitting more recharge than normal.

Natural discharge is into Elm River and Foot Creek, to the atmosphere by evapotranspiration, by recharge into the Middle James aquifer, and by eastward flow into lacustrine deposits underlying the Lake Dakota plain. Discharge to the lacustrine deposits from the Elm aquifer is, on an annual average, about equal to discharge from the lacustrine deposits as is indicated by the water levels dropping to about the same low year after year.

Wells that have a productive capacity of 500 gal/min (32 l/s) or more can be constructed where at least 40 ft (12 m) of medium sand is found (fig. 18). For coarser material a lesser thickness is needed. For example, about 400 gal/min (25 l/s) was pumped from a deposit of coarse sand and gravel only 21 ft (6 m) thick at well 124N63W8BACC. At the end of the aquifer test made at this site maximum drawdown was 7.9 ft (2.4 m) in the pumped well and 1.1 and 0.8 ft (0.3 and 0.2 m) in observation wells that were 100 and 300 ft (30 and 91 m) respectively from the pumped well (Black and Veatch, 1956, p. 51).

Pumpage from the 164 wells known to tap the Elm aquifer is used mostly for domestic and stock needs. The aquifer does supply water for irrigation, however, though not from a well, but from a gravel pit that penetrates the aquifer.

Pumpage of water from gravel pits has been a major method of withdrawing water from the Elm aquifer in the past. During drought, in 1939 and 1940, the city of Aberdeen pumped about 422 million gallons (1.6 million m^3) of water from the Pickus Pit (Black and Veatch, 1956, p. 9) at the rate of about 1,200 gal/min (76 l/s), and also pumped about 100 million gallons (0.4 million m^3) from the Eyestone Pit.

The large areal extent of the Elm aquifer, the ease with which it has supported rapid rates of removal during past emergencies, and its estimated storage capacity of 1.2 million acre-ft (1.5 billion m^3) of water, indicate a much larger potential as a widespread major source of supply than had been realized in the past.

The predominant chemical constituents in water from the Elm aquifer vary with location and may be calcium or sodium, and sulfate or bicarbonate. The chemical quality of water varies from one location to another almost as much as it does in the Middle James aquifer and for the same reasons. The water generally has a high salinity hazard and a low sodium hazard (fig. 15). The ranges and averages of selected chemical constituents are given in table 3.

Water in the western part of the Elm aquifer commonly is lower in dissolved solids where the aquifer is at or close to land surface. Water in the aquifer below the Elm River flood plain contains the lowest dissolved solids, about 250 mg/l.

Lake Dakota Plain Deposits

The Lake Dakota plain (see fig. 3) covers about 940 mi^2 (2,435 km^2) of eastern Brown County.

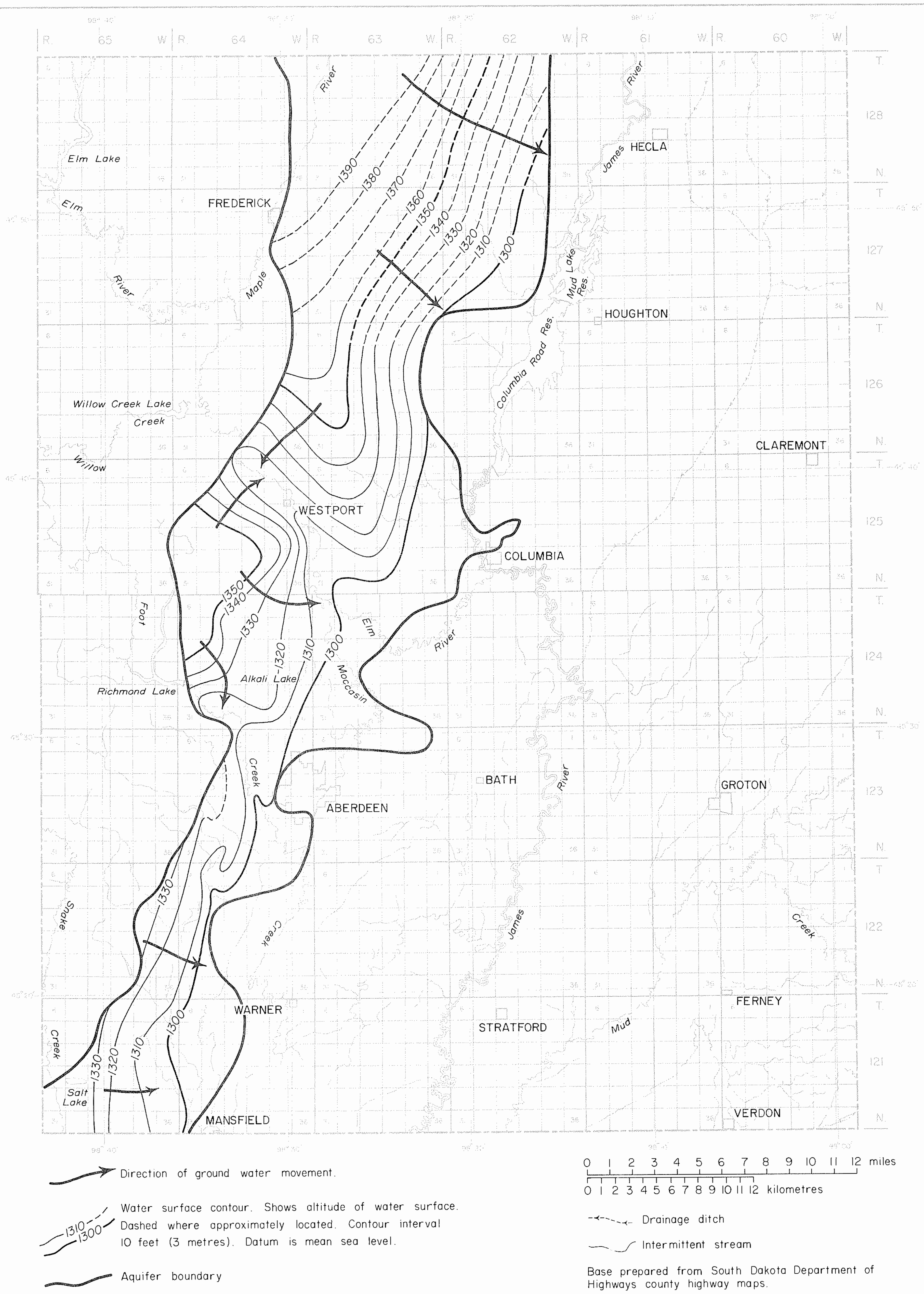


Figure 19. Map showing approximate altitude of the water surface and direction of ground-water movement in the Elm aquifer, 1968 to 1970.

TABLE 3. Summary of chemical analyses of water from the Elm aquifer

(results in milligrams per litre except as indicated)

Constituent or Property	No. of analyses	Average[1]	Range
Calcium (Ca)	14	189	65-620
Magnesium (Mg)	14	94	16-390
Sodium (Na)	11	226	27-1,200
Potassium (K)	7	14	5-26
Bicarbonate (HCO_3)	61	461	107-1,000
Sulfate (SO_4)	65	612	4-4,000
Chloride (Cl)	66	173	8-790
Fluoride (F)	14	.4	.0-.9
Nitrate (NO_3)	17	10	.0-60
Iron (Fe) in ug/l	13	200	10-4,900
Manganese (Mn) in ug/l	3	300	200-600
Hardness as $CaCO_3$	62	862	78-3,300
Specific conductance (micromhos per cm at 25°C)	57	2,017	246-5,900
Percent sodium (percent)	15	30	6-57
Sodium-adsoprtion ratio (SAR)	16	1.8	.4-11
pH (units)	59	7.4	6.5-7.9

[1] Values shown for iron, manganese, sodium-adsorption ratio, and pH are median values.

Deposits of silt, fine sand, and clay, which average about 75 ft (23 m) in thickness, were laid down by glacial meltwaters on the bed of ancient Lake Dakota. Wells completed in these deposits may yield 1 to 5 gal/min (0.06 to 0.3 l/s) but well failure is common due to clogging of the screen by very fine sand, silt, and clay. Such material commonly passes through the well screen and enters the water system, not only clogging the well but also abrading and seriously damaging pumps and other equipment.

The Lake Dakota plain is nearly flat and the water table in much of the area is at or very close to the land surface. Fluctuations in a shallow water table may cause problems of waterlogging, flooding, or drying up of marshes. Therefore it is important to know the depth of the water table and the magnitude of the water table fluctuation.

Water-Table Fluctuations

Koopman (1957) made a detailed study of water-table fluctuations in the Sand Lake area located in the northeastern part of the County. He concluded that lateral movement of the ground water is exceedingly slow and that most ground-water discharge is by evapotranspiration.

Water in the lake plain deposits is under water-table conditions. Depth to water ranges from land surface to about 27 ft (8 m) below land surface. Much of the Lake Dakota plain was a swamp as recently as the early 1900's because the flat land surface and poorly developed natural drainage impede runoff. Today, man-made ditches have drained most of the swampy area, though the water table remains close to the land surface.

The altitude of the water table and direction of ground-water movement on April 15, 1971, are shown in figure 22; hydrographs of selected observation wells also are shown. Ground-water movement, in general, is toward topographic depressions made by natural streams and by drainage ditches. The depth to water varies with local topography and also varies, of course, with short and long-term variations in recharge and discharge.

As might be expected, the water table rises in spring and early summer because of recharge by snowmelt, spring rainfall, and floodwaters of streams entering the area. The water table declines the rest of the year due to evapotranspiration and drainage through the extensive network of ditches.

In the spring and early summer discharge is usually less than in summer and fall even if recharge is the same both times of the year. This is due to increased discharge by evapotranspiration in summer and fall.

The range in water-level fluctuations varies considerably across the lake plain. Such fluctuations have been from less than 3 ft (1 m) in well 121N61W31DDCC to as much as 17 ft (5 m) in well 121N61W5BBAA during the 17-year period of record, as is shown in figure 22. East of the James River the water-table fluctuation was less than 6 ft (2 m) in half of the wells. West of the James River the fluctuation was more than 9 ft (3 m) in half of the wells. The area west of the James River probably has larger fluctuations in water level because that is where the lake plain deposits receive recharge from the Elm aquifer. East of the James River the water table receives recharge only by local snowmelt, precipitation, and floodwater inflow.

Aquifers in the Bedrock

As many as eight major bedrock aquifers underlie parts of Brown County; at present, however, only the uppermost three are used as sources of water (table 4). These three aquifers are the Dakota, Fall River, and Sundance Formations (fig. 23). Deeper aquifers such as the Minnelusa, Red River, and Deadwood Formations underlie the northwestern part of the County. The Madison Group may be present in the southwestern part of the County. Limestone and sandstone of Devonian age may be present in the western part of the County. The Dakota Formation underlies Brown County and the Fall River Formation underlies all but the extreme eastern part of the County. The Sundance, however, is absent in the southeastern half of the County.

The source of recharge to the bedrock aquifers in South Dakota is an unresolved problem. Some geologists and hydrologists believe that the ultimate sources of recharge are the Black Hills and the Rocky Mountains. Many investigators believe that the Dakota aquifer is receiving most of its recharge by leakage from underlying aquifers in central South Dakota. Other investigators favor other locations for recharge from above or from below.

In Brown County the bedrock aquifers are recharged by subsurface inflow mostly from the west and locally from the east. Some individual bedrock aquifers are recharged by upward leakage from underlying aquifers that contain water under greater pressure.

Prior to development as sources of water, the bedrock aquifers contained water under artesian pressure exceeding 250 lb/in^2 (18 kg/cm^2) at land surface. Development of these aquifers during the last 90 years has caused a large and rapid drop in the pressure. This decline is graphically illustrated for the Dakota Formation in figure 24. One of the first artesian wells in South Dakota was drilled at Aberdeen in 1882, but, apparently no measurements of artesian pressure were made until about 1900. By 1900 three high-pressure artesian horizons had been tapped, two in the Dakota and one in the Fall River Formation. Wells tapping the Dakota Formation had pressures of 40 to 177 lb/in^2 (3 to 12 kg/cm^2). Between 1900 and 1923, the artesian head in the Dakota had decreased by about 340 ft (104 m) in the Aberdeen area. From 1923 to 1970, the decline in head was an additional 50 ft (15 m), an average of about 1 ft (0.3 m) per year.

Together with the decline in artesian pressure there has been a decrease in well yields by natural flow. About the year 1900, artesian-well yields reportedly ranged from 300 to 1,060 gal/min (19 to 67 l/s). In 1909, Todd (1909, p. 10) reported yields of about 25 gal/min (2 l/s) from 1¼-in (32-cm) diameter wells and 200 to 300 gal/min (13 to 19 l/s) from 3-in (7.6-cm) diameter wells. By the 1950's most wells flowed less than 5 gal/min (0.3 l/s) (Hopkins and Petri, 1963); the average flow was 2.8 gal/min (0.2 l/s). Also, in parts of the County, artesian pressure, particularly in the Dakota Formation, had dropped sufficiently so that wells ceased to flow. In 1973 the average well flow was about 3 gal/min (0.2 l/s).

The large decline in artesian pressure, the attendant drop in well yield, and the decrease of the area within which flowing wells can be obtained, have aroused much concern in eastern South Dakota. Part of the response to that concern has been the establishment of a statewide network of observation wells to monitor changes of artesian pressure in the major bedrock aquifers. In Brown County the program of artesian-pressure measurement began in 1960. The artesian-pressure decline has leveled off in some areas in recent years. Indeed, the decline of

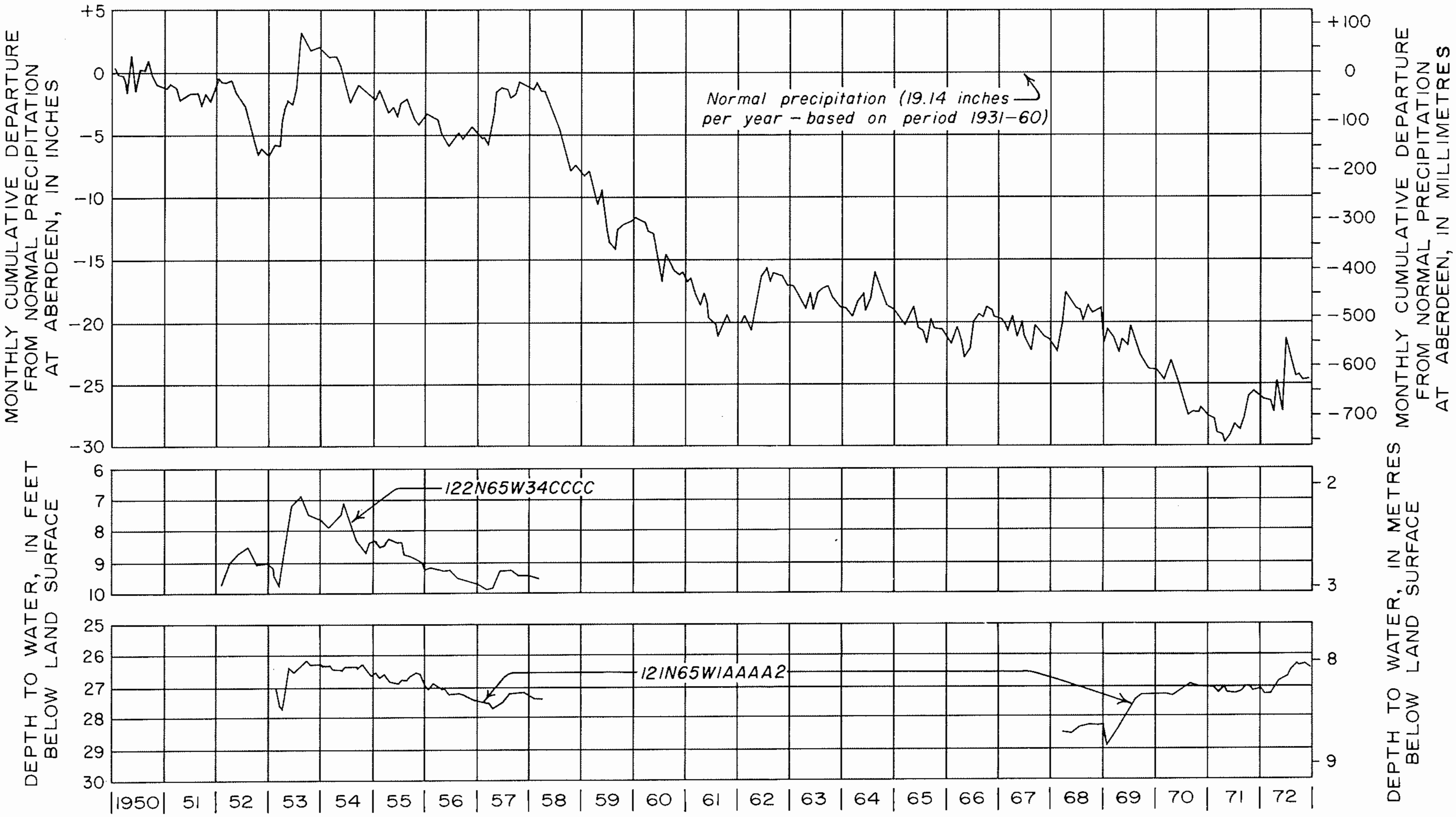


Figure 21. Although precipitation between 1950 and 1972 totaled more than 25 inches below normal, the water level in the western part of the Elm aquifer remained about the same in 1972 as it was 20 years earlier.

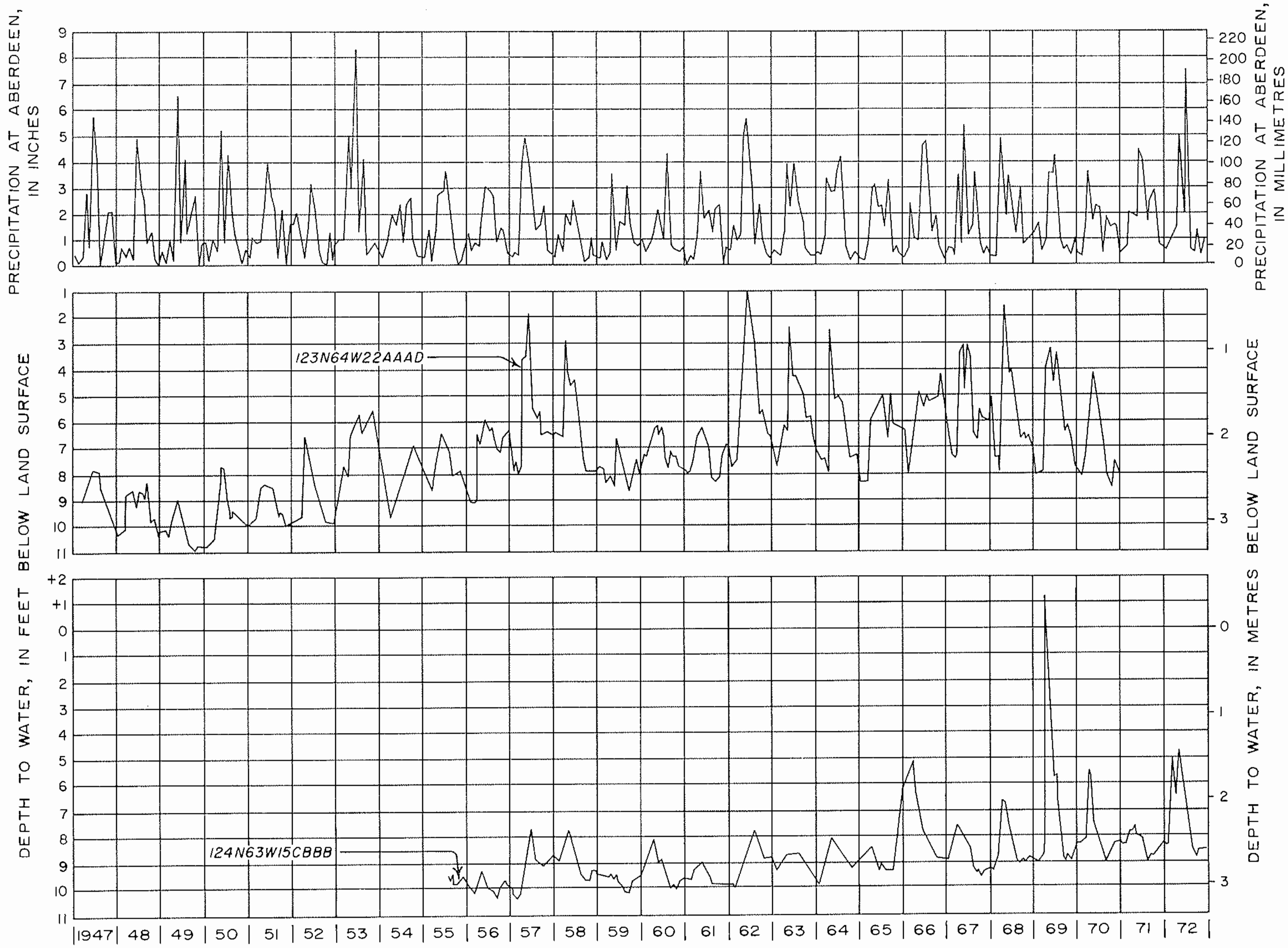
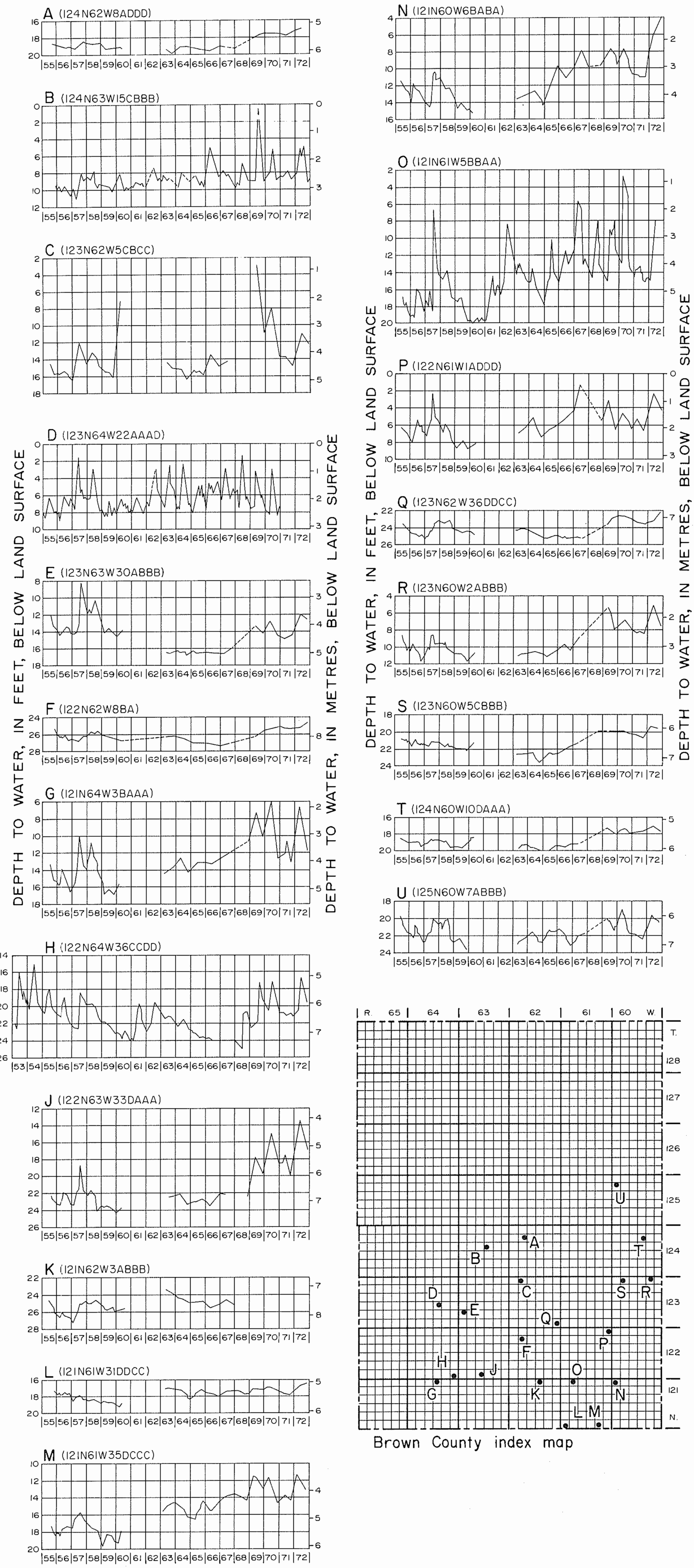
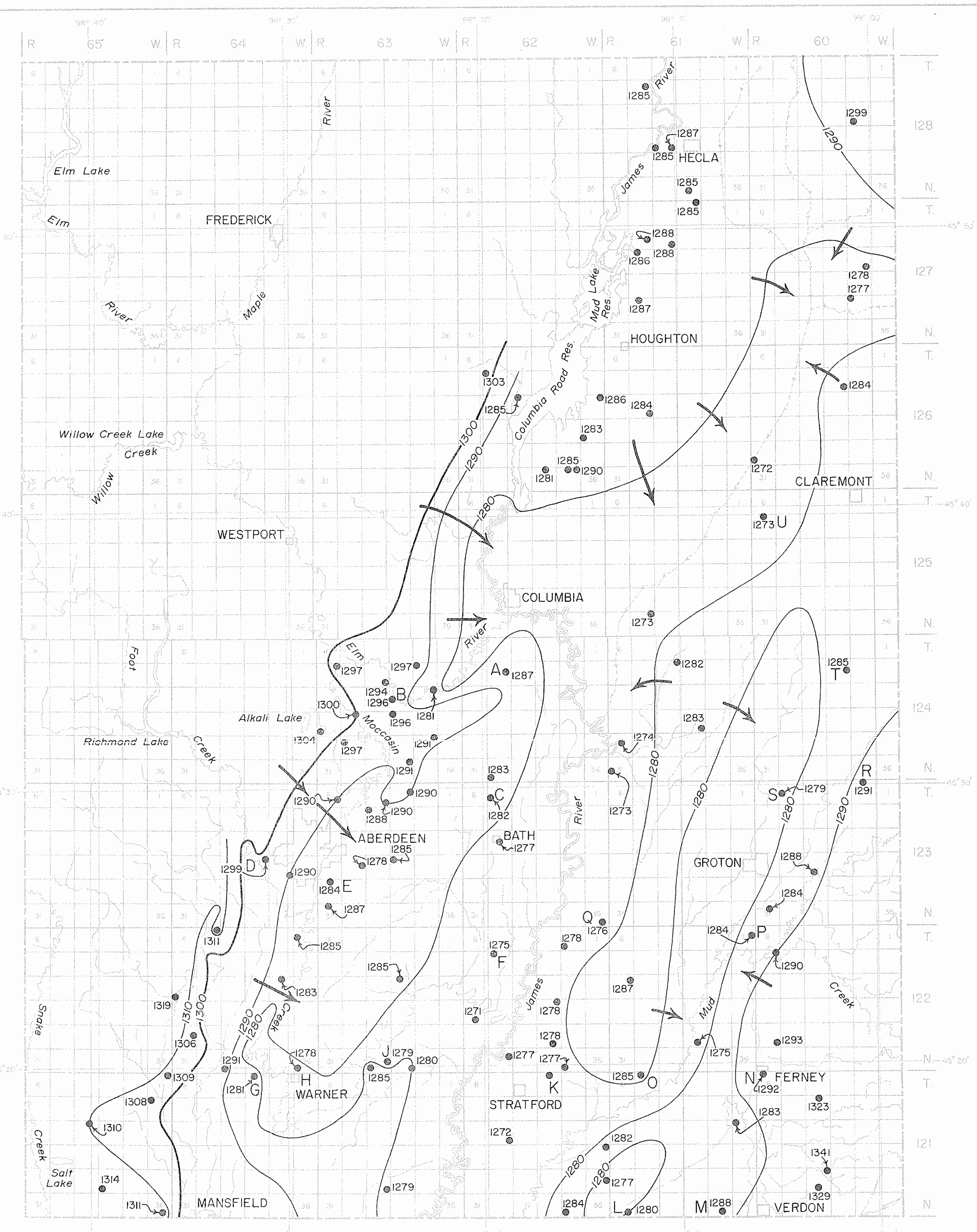


Figure 20. Comparison of water level in the Elm aquifer with precipitation shows that water level varies in direct response to snowmelt, rainfall, or drought with only a short time lag.



DEPTH TO WATER, IN FEET, BELOW LAND SURFACE
DEPTH TO WATER, IN METRES, BELOW LAND SURFACE
A (124N62W8ADDD)
B (124N63W15CBBB)
C (123N62W5CBCC)
D (123N64W22AAAD)
E (123N63W30ABBB)
F (122N62W8BA)
G (121N64W3BAAA)
H (122N64W36CCDD)
J (122N63W33DAAA)
K (121N62W3ABBB)
L (121N61W31DDCC)
M (121N61W35DCCC)
N (121N60W6BABA)
O (121N61W5BBAA)
P (122N61W1ADDD)
Q (123N62W36DDCC)
R (123N60W2ABBB)
S (123N60W5CBBB)
T (124N60W10DAAA)
U (125N60W7ABBB)
Brown County index map



1275 •F Well location; number is altitude of water surface, in feet above mean sea level, April, 1971. A capital letter refers to a hydrograph on the back of this map. Feet X 0.3048 = metres.

1310 1300 Water surface contour. Shows altitude of water table. Contour interval 10 feet (3 metres). Datum is mean sea level.

Direction of water movement.

0 1 2 3 4 5 6 7 8 9 10 11 12 miles

0 1 2 3 4 5 6 7 8 9 10 11 12 kilometres

Drainage ditch

Intermittent stream

Base prepared from South Dakota Department of Highways county highway maps.

Figure 22. Map showing altitude of the water table and water levels in selected wells in the Lake Dakota plain deposits.

See back of figure for additional information

Age		Unit	Lithology	Max. thickness (feet)	Water-bearing characteristics
QUATERNARY	HOLO.	Alluvium	*Sand, silt, and clay.*	10	*Permeable. Yields small amounts of water to wells.*
	PLEISTOCENE	Lake sediments	*Clay, silt, and fine sand; stratified.*	125	*Locally wells may yield 1 to 5 gallons/minute.*
		Outwash	*Sand and gravel, well sorted and stratified.*	119	*Forms major aquifers. Wells may yield 25 to 2,000 gallons/minute.*
		Till	*Clay mixed with variable proportions of silt, sand and gravel. Locally may contain sand lenses.*	225	*Acts as a confining layer over deeper outwash deposits Locally wells may yield 1 to 5 gallons/minute.*
CRETACEOUS		Pierre Shale	*Shale.*	318	*Relatively impermeable and is usually a barrier to the movement of water. Locally wells may yield 1 to 5 gallons/minute of poor-quality water.*
		Niobrara Fm.	*Marl and chalk, shaly.*	172	*Low permeability. Not known to yield water to wells in Brown County.*
		Carlile Shale	*Shale, locally may contain some sand lenses.*	275	*Relatively impermeable and is usually a barrier to the movement of water. Not known to yield water to wells in Brown Co.*
		Greenhorn Limestone	*Limestone interbedded with limey shale.*	70	*Low permeability. In some areas may yield small amounts of muddy, very saline water.*
		Graneros Shale	*Shale interbedded with silt and very fine sand.*	290	*Relatively impermeable and is usually a barrier to the movement of water. Locally, sand lenses may yield muddy water at sufficient pressure to flow at land surface.*
		Dakota Fm.	*Fine to very fine-grained sandstone that contains shale lenses.*	330	*Permeable. Wells yield water under sufficient pressure to flow at land surface. Recharged by Fall River aquifer and subsurface inflow from adjacent counties.*
		Skull Creek Shale	*Shale.*	65	*Relatively impermeable but does permit water in the Fall River to move up to the Dakota. Does not yield water to wells.*
		Fall Riv. Fm.	*Sandstone that contains shale lenses.*	150	*Permeable. Wells yield water under pressures higher than do wells tapping the Dakota. Recharged by the Sundance aquifer and subsurface inflow from counties to the west.*
JURASSIC		Sundance Fm.	*Sandstone; also siltstone and shale.*	80	*Permeable. Wells yield water under pressures higher than do wells tapping the Fall River. Recharged by underlying aquifers and by subsurface inflow from counties to the west.*
PERMIAN & PENN.		Minnelusa Fm.	*Shale and limestone.*	?	*Probably permeable. No wells are known to obtain water from these formations. Probably underlie only the western part of the county. Potential for development is unknown.*
MISSIS-SIPPIAN		Madison (?) Group	*Limestone and dolomite.*	?	
DEVONIAN (?)		Devonian (?) rocks undif.	*Sandstone, limestone, dolomite, and shale.*	?	*Probably permeable. No wells are known to obtain water from these formations. Probably underlie only the western part of the county. Potential for development is unknown.*
ORDOVICIAN		Red Riv. Fm.	*Limestone.*	?	
		Winnipeg Fm.	*Shale and sandstone.*	?	
CAMBRIAN		Deadwood Fm.	*Sandstone, limestone, dolomite, and shale.*	?	
PRE-CAMBRIAN		Precambrian rocks undif.	*Igneous and metamorphic rock.*	?	*Nearly impermeable. Not considered to be an aquifer. Locally might be possible to obtain water from fractures.*

Table 4.--Principal rock units and their water-bearing characteristics in Brown County.

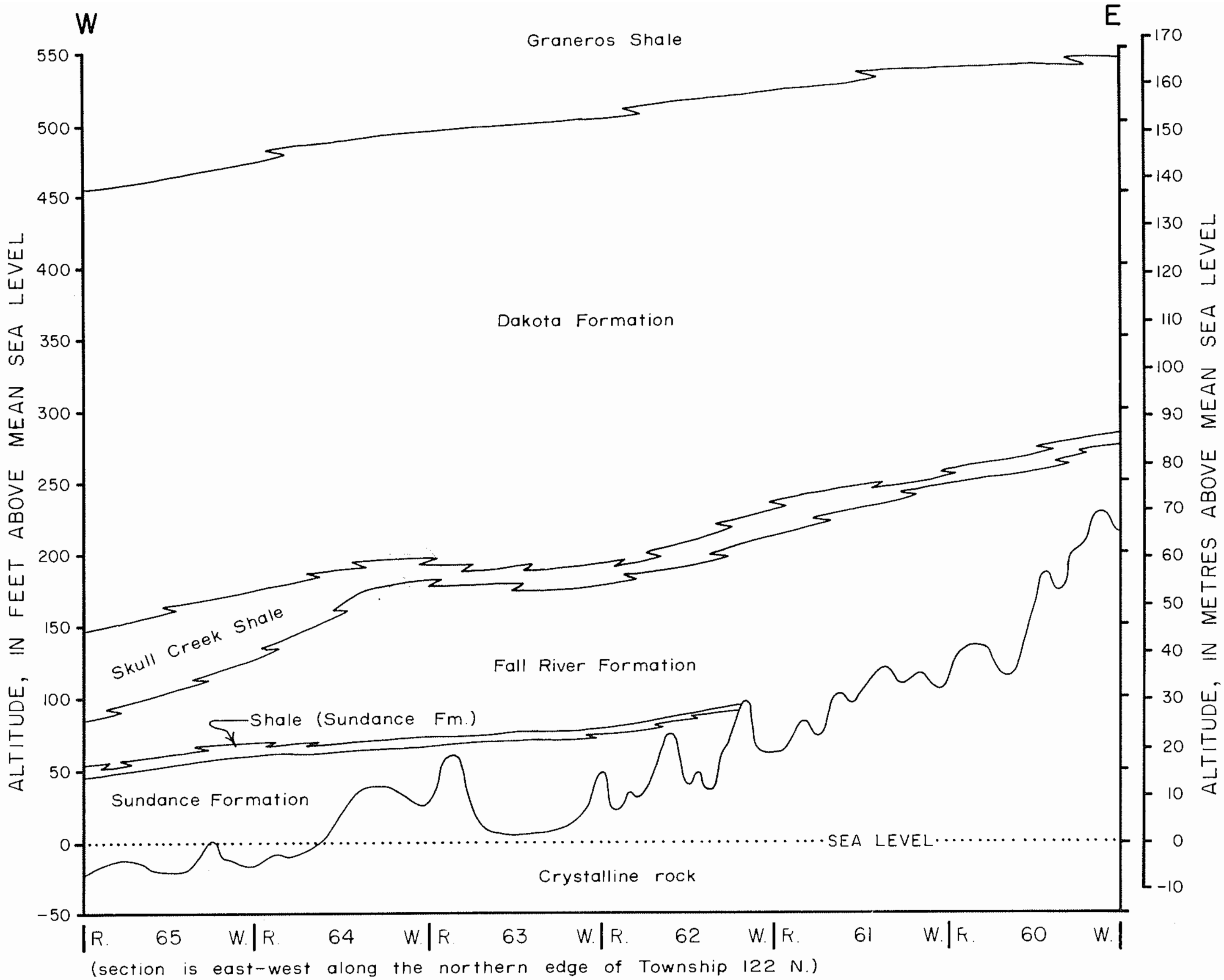


Figure 23. Generalized geologic section showing major bedrock aquifers.

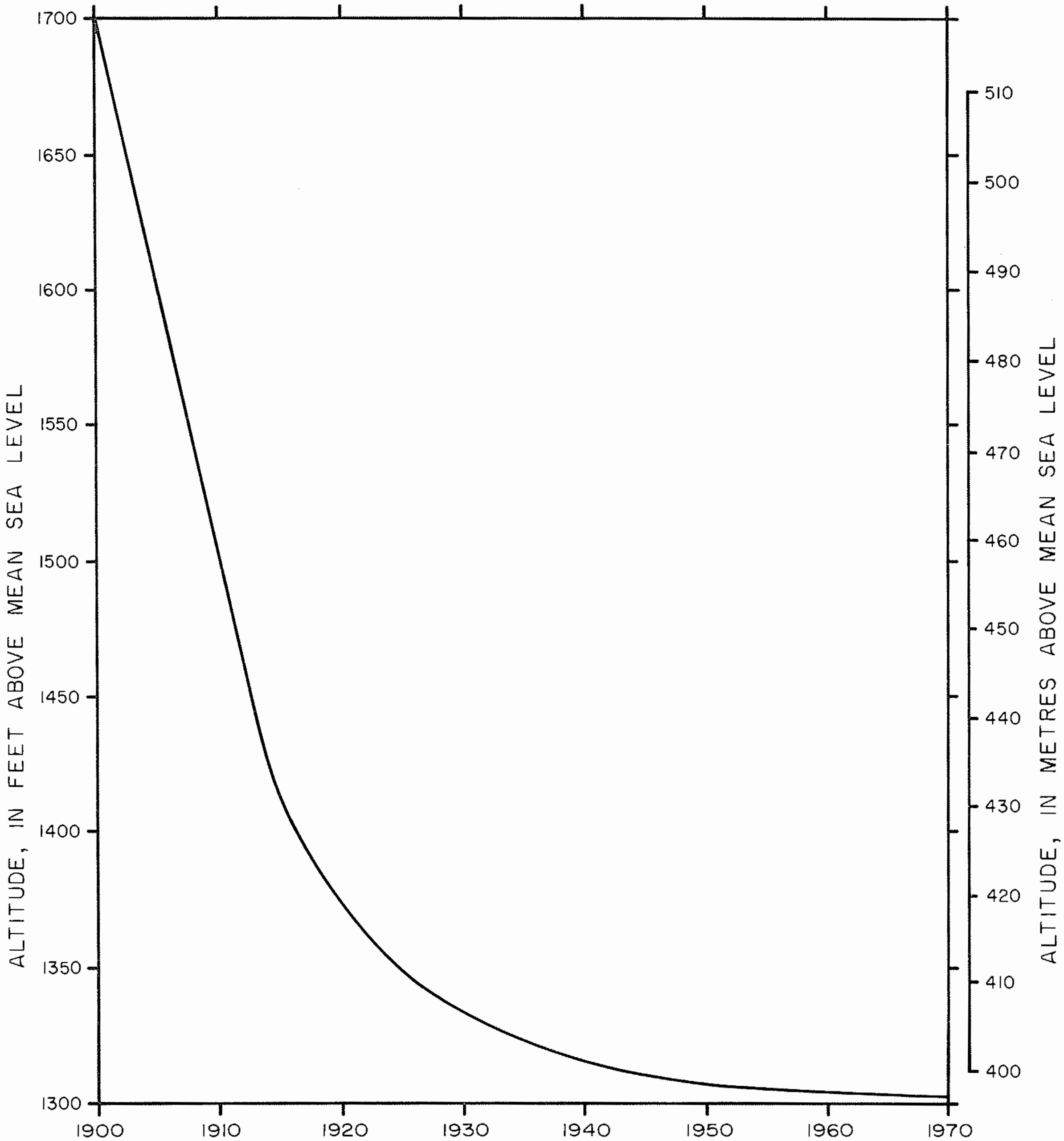


Figure 24. The artesian head declined more than 390 feet in the Dakota aquifer in the Aberdeen area from 1900 to 1950.

artesian pressure in these areas may be ending and a period of stable artesian pressure might ensue. The available artesian-pressure measurements are shown graphically in figure 25.

Any additional development or increase in the rate of withdrawal from the bedrock aquifers will result in an additional decline in artesian pressure unless it is balanced by a compensating decrease in waste (unused flow). In 1970, more than 57 percent of the water supplied by these aquifers was unused and wasted (see "water use" section). A substantial reduction in such waste now (1973) could result in an increase in artesian pressure.

The large decrease in artesian head in the Dakota aquifer has caused a considerable decrease in artesian head in the Fall River and Sundance aquifers (fig. 26). Prior to development of the bedrock aquifers in Brown County the artesian heads in the Dakota and Fall River aquifers probably were the same; possibly that in the Fall River was slightly higher. Because the two aquifers had similar water pressures, very little movement of water took place between them. After development of the Dakota began, its pressure decreased, thus producing a large pressure difference between the two. This pressure differential has caused upward movement of water from the Fall River to the Dakota and a consequent decrease in artesian pressure in the Fall River. The hydraulic connection between the Dakota and Fall River aquifers is mostly east of R. 64 W. (fig. 26), where the artesian head in the Fall River shows its sharpest decline. West of R. 63 W., if the artesian head in the Fall River aquifer decreases in the years ahead, the artesian head in the Sundance should show a decline as a result of upward leakage from the Sundance to the Fall River.

Determination of the hydrology of the bedrock aquifers is difficult. Not only is the natural system complex, but the data collected may be misleading. For example, a pressure measurement may be in error for a reason not normally detectable by the hydrologist--water may be leaking through a ruptured seal or hole in a well casing. These may be common occurrences in older wells and in wells tapping high pressure aquifers. An instance of peculiar results is noted in the hydrograph for well 126N65W14ADD, which is shown in figure 27. The artesian head in this well declined about 28 ft (9 m) between 1960 and 1966, then dropped 40 ft (12 m) in 1 year, and then rose by almost 100 ft (30 m) the following year. This peculiar steep decline and rise occurred a second time. Had only the two lowest measurements been recorded after 1966, one could conclude that the artesian head was declining at the rate of 6 ft (2 m) a year during the last 10 years. However, with the two high water-level readings there appears to be virtually no appreciable change in artesian head in the last 10 years. What may have happened is that the slotted well casing was clogged by fine sediment closing off the high pressure zones but on two occasions the slots may have been flushed of this sediment, thus allowing the full pressure of the aquifer to be measured. A second possible explanation is that the casing has ruptured and is releasing the pressure; occasionally shale slumps around the break and reseals the casing, thus allowing the full pressure to be measured.

Sundance Aquifer

The Sundance aquifer underlies the Fall River aquifer and is separated from it by a thin layer of shale (see fig. 23). Several wells tap the Sundance in Brown County at depths ranging from 1,150 to 1,450 ft (351 to 422 m). However, the casing in most of the wells has been slotted in both the Sundance and the Fall River. The artesian pressure in the Sundance aquifer in Brown County ranges from 120 to 150 lb/in^2 (8 to 11 kg/cm^2) at land surface.

Recharge to the Sundance aquifer is by subsurface inflow from the west and possibly by upward leakage from deeper aquifers.

Discharge from the Sundance aquifer is primarily by upward leakage to the Fall River aquifer and within wells where the casing has been slotted adjacent to several aquifers, from higher pressure Sundance aquifer to lower pressure Fall River and Dakota aquifers.

Fall River Aquifer

The Fall River aquifer, locally called the "third flow," underlies the Dakota aquifer and is separated from it by the Skull Creek Shale (see fig. 23). Water quality and pressure in the Fall River are notably different from those of the Dakota. Measured at land surface, the artesian head of the Fall River is about 260 ft (79 m) greater than the artesian head of the Dakota aquifer in the western third of the County and in the northern part of the County in Rs. 62 and 63 W., but only about 40 ft (12 m) greater than that of the Dakota in the eastern two-thirds of the County (fig. 26). The artesian pressure in the Fall River aquifer ranges from about 24 to 120 lb/in^2 (2 to 8 kg/cm^2).

Depths to the Fall River aquifer range from 1,000 to 1,100 ft (305 to 335 m) below land surface in the southeastern half of the County and from 1,100 to 1,200 ft (335 to 366 m) in the northwestern half.

Recharge to the Fall River aquifer in Brown County is by subsurface inflow from the west and by upward leakage from the Sundance aquifer.

Discharge from the Fall River aquifer is by upward leakage to the Dakota aquifer. Most of the upward

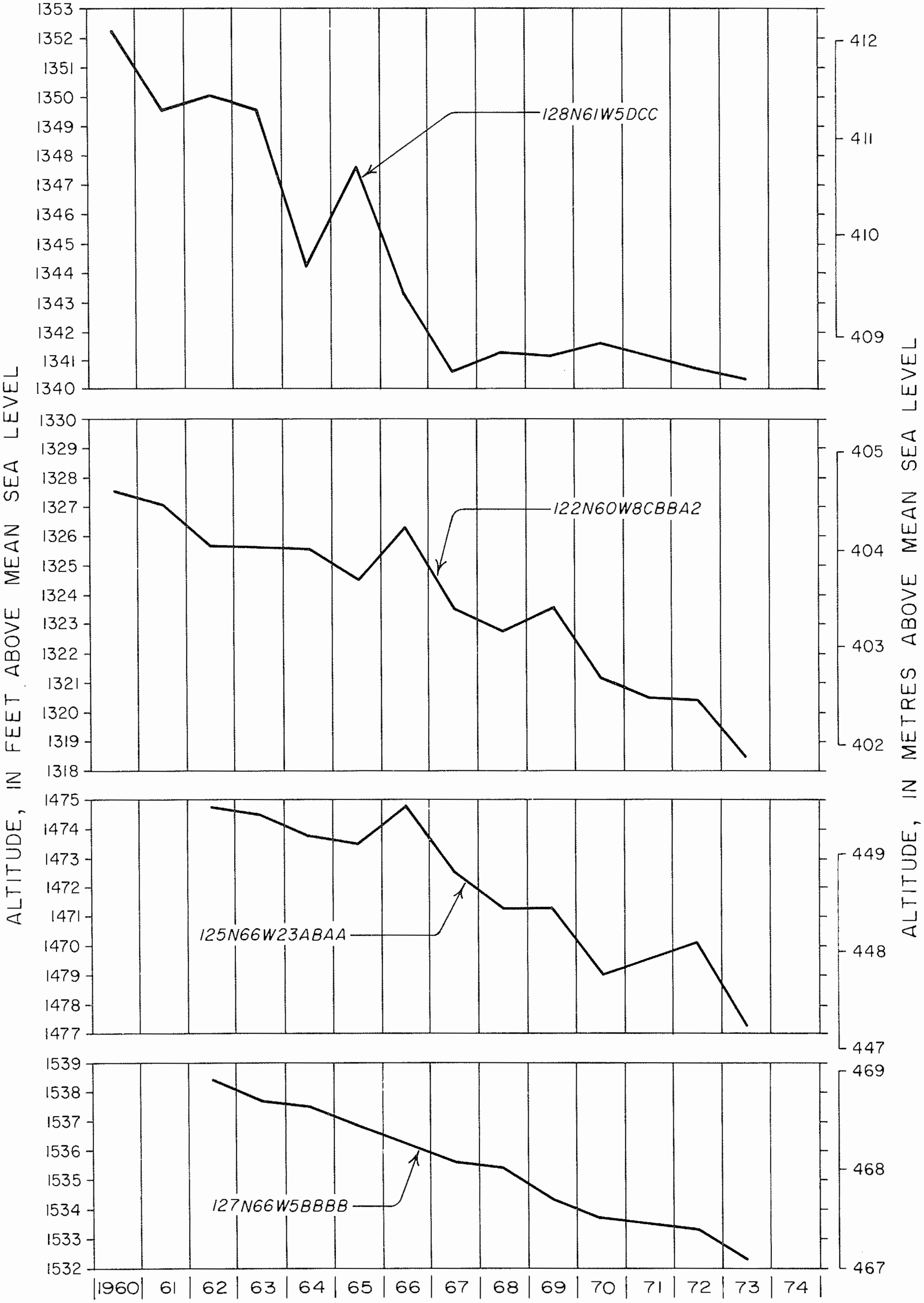


Figure 25. Artesian head in the Dakota aquifer has declined about 2 feet per year from 1960 to 1973.

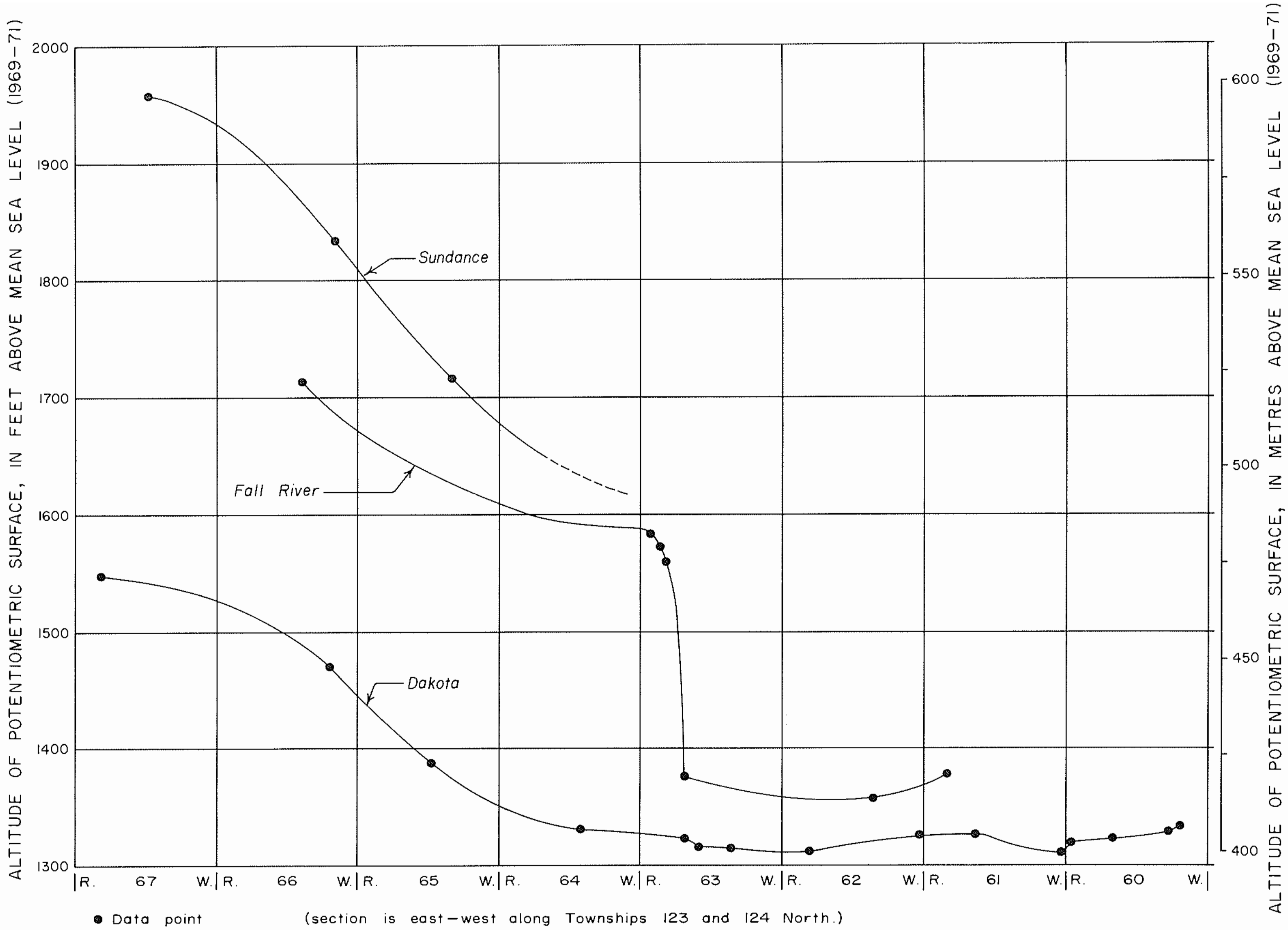


Figure 26. A large decrease in artesian head in the Fall River aquifer occurs east of R. 64 W. where the Fall River and the Dakota aquifers are in good hydraulic connection.

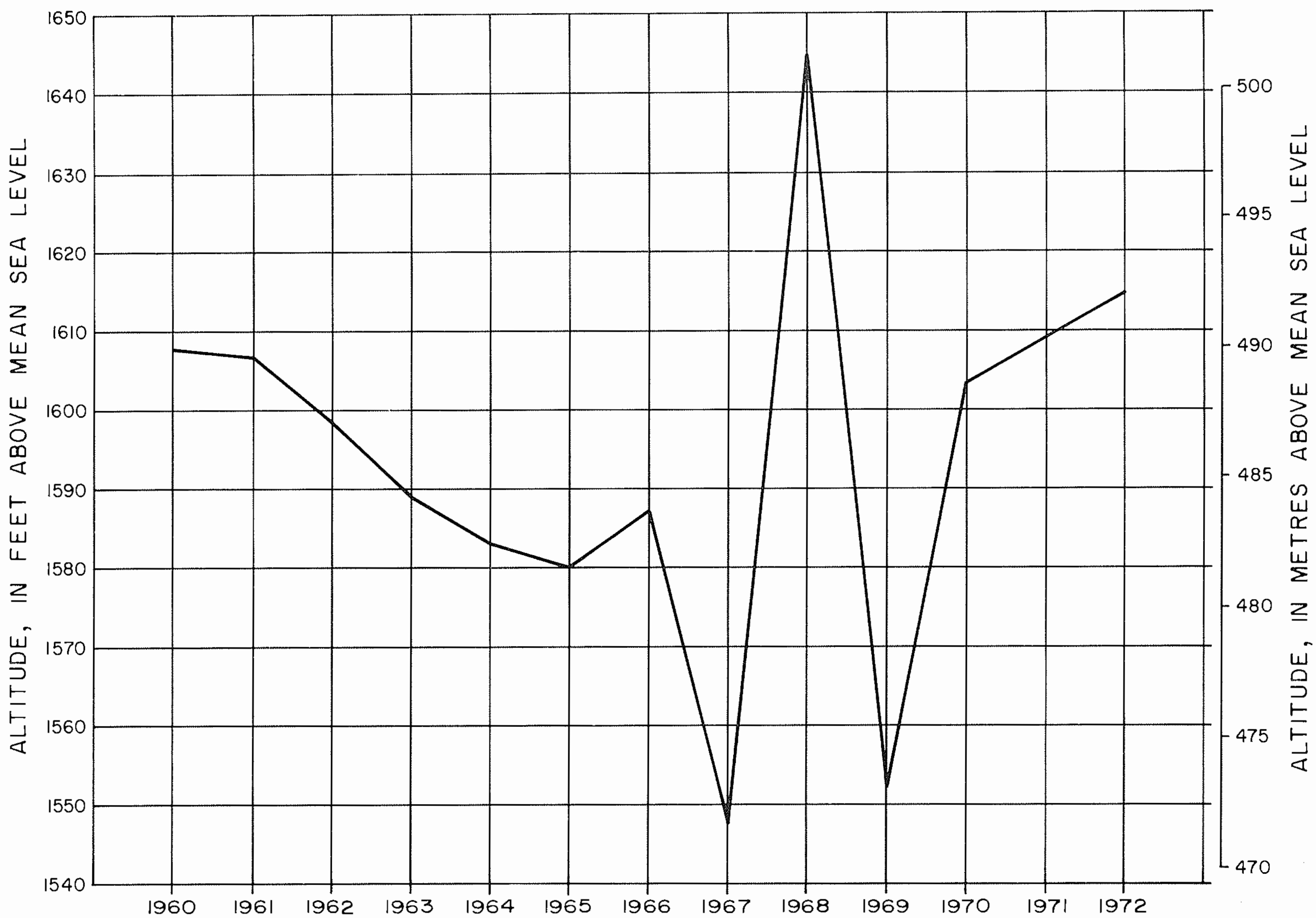


Figure 27. Hydrograph showing artesian head in well I26N65WI4ADD in the Fall River aquifer.

leakage takes place east of a line that nearly divides the County in half from northeast to southwest. East of this line the Skull Creek Shale may thin and become permeable or may be missing altogether in some areas.

Dakota Aquifer

The Dakota aquifer has, in the past, been divided by drillers and water users into an upper sandstone, locally called the "first flow," and a lower sandstone, locally called the "second flow." Extensive development of the Dakota has resulted in mixing water from the two sandstone units to such an extent that, in most areas, the artesian pressure and water quality are the same in both. Depth to the Dakota aquifer ranges from 850 to 1,000 ft (259 to 305 m) below land surface in the southeastern half of the County and from 900 to 1,100 ft (274 to 335 m) in the northwestern half. The artesian pressure generally is less than 20 lb/in^2 (1 kg/cm^2) at land surface in wells tapping the aquifer. Wells in topographically low areas of Brown County flowed in 1973. Many wells obtain water from both the Dakota and Fall River aquifers, which results in mixed water quality and in a water pressure more nearly that of the aquifer that has the lower pressure.

In Brown County the Dakota aquifer is recharged by subsurface inflow, mostly from the west, locally from the east, and by upward leakage from the Fall River aquifer. The potentiometric surface of the Dakota aquifer slopes about 8 ft/mi (1.5 m/km) to the southeast in western Brown County (fig. 28). In the Lake Dakota plain area the potentiometric surface flattens, varying only about 25 ft (8 m) across the area.

Chemical Quality

The chemical constituents of water from the Dakota, Fall River, and Sundance are the result of the mixing of water from two or more aquifers in much of Brown County. Water movement is, in general, from west to east across the County and from lower aquifers to higher aquifers. Because the chemical constituents of water change where mixing occurs these aquifers are best described beginning with the Sundance aquifer. Chemical analyses of water from the Sundance, Fall River, and Dakota aquifers are given in table 5.

The predominant chemical constituents in water from the Sundance aquifer are calcium, sodium, and sulfate. The water contains about 50 mg/l of chloride, 3 mg/l of fluoride, and about 900 mg/l of hardness as $CaCO_3$.

Very few wells in Brown County tap only the Sundance; most wells tapping the Sundance are also perforated in the Fall River aquifer. However, chemical analyses were made of water from wells 123N65W22AAD and 123N66W25BCAB (located less than 1 mi or 1.6 km west of the County line), which are know to tap only the Sundance.

Where water from the Sundance and Fall River aquifers has mixed, the major constituents are sodium, calcium, and sulfate. The only apparent difference between water from the Sundance and mixed water from the Sundance and Fall River is that the mixed water contains less calcium and magnesium, the hardness is less by 100 to 200 mg/l, and the proportion of sodium exceeds that of calcium (table 5).

Unmixed water from the Fall River aquifer can be classified as a sodium sulfate type. Calcium is a minor cation and hardness is less than mixed water by about 200 mg/l.

Water from the Fall River has recharged the Dakota aquifer in the southeastern part of the County to such an extent that there is little or no unmixed water in the Dakota. The major constituents in mixed Fall River-Dakota water are sodium and sulfate (table 5). Bicarbonate, chloride, fluoride, and specific conductance are much higher in this mixed water than in Fall River water; hardness is low, less than 60 mg/l.

Unmixed water of the Dakota aquifer is found mostly in the northwestern part of the County; the major constituents are sodium and chloride. Bicarbonate, chloride, and specific conductance are much greater--almost double that of the mixed Dakota water, but sulfate is lower by about half.

Chloride concentration of water in the Dakota aquifer ranges from more than 1,000 mg/l in parts of northwestern Brown County to less than 250 mg/l in the southeastern part of the County, as is shown in figure 29. Several apparently anomalous chloride analyses were noted within the zones shown in figure 29, particularly in the 250-500 and 500-800 mg/l zones, where the chloride concentration of water from some wells was higher than the limits for the zone. The anomalous chloride concentrations are due to the fact that in some areas the sand lenses in the Dakota are poorly connected and the Dakota water has not mixed with Fall River water. Water from wells finished in the uppermost poorly connected sands in the Dakota has a higher chloride concentration than has water from wells finished in the lowermost sands of the Dakota. When wells are finished in upper sands that contain unmixed (sodium chloride type) Dakota water, the artesian pressure usually is higher than that found in other wells that tap the Dakota. Conversely water from some wells was lower in chloride concentration than the limits

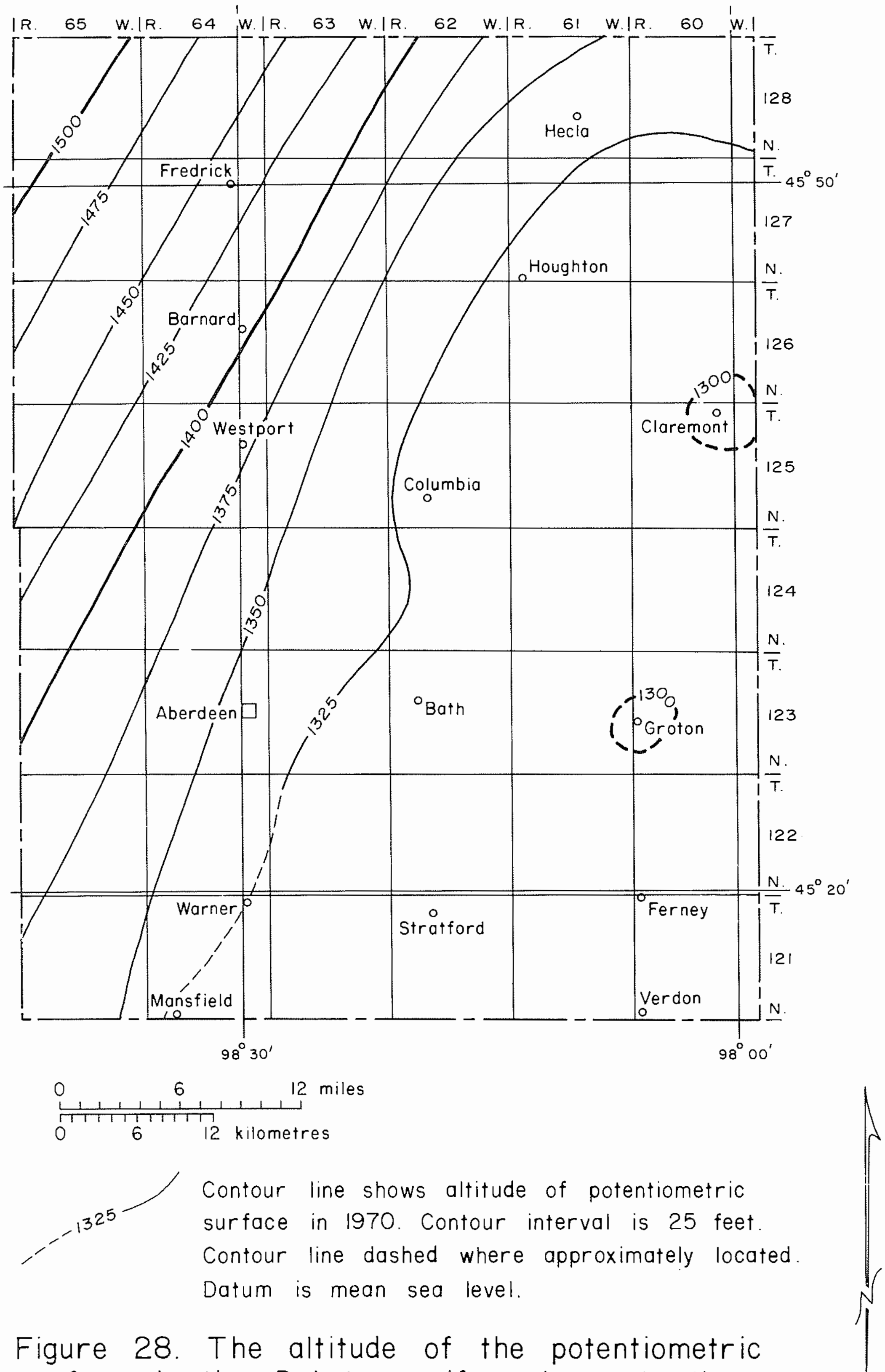


Figure 28. The altitude of the potentiometric surface in the Dakota aquifer slopes to the southeast in western Brown County.

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TABLE 5. Chemical analyses of water from the Sundance, Fall River, and Dakota aquifers

(results in milligrams per litre except as indicated)

Location	Well Depth (feet)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Hardness as $CaCO_3$	Specific Conductance (micromhos per cm at 25° C)
Wells tapping the Sundance aquifer											
123N65W22AAD	1,343	280	58	260	30	146	1,200	48	-----	940	3,100
123N66W25BCAB	1,396	250	69	240	32	180	1,200	57	2.7	910	2,470
Wells tapping the Sundance and Fall River aquifers											
122N61W18ADDD	1,147	255 [1]	-------	400	-------	168	1,200	81	1.6	580	2,750
122N62W15CBB	1,224	313 [1]	-------	370	-------	128	1,200	71	1.4	630	2,680
123N61W31CBBB	1,148	170	45	400	26	171	1,200	80	1.8	600	2,730
123N63W30DAA	1,161	200	54	320	28	195	1,200	64	1.7	710	2,610
123N64W12BDBB	1,242	200	56	330	25	181	1,200	66	1.7	720	2,610
123N64W20BAA	1,260	210	60	320	29	184	1,200	60	2.0	770	2,600
123N64W21BACC	1,260	220	65	300	32	180	1,300	60	1.7	820	2,580
Wells tapping the Fall River aquifer											
121N61W12BBBA	1,145	110	28	470	18	160	1,200	86	3.0	390	2,790
122N64W2DAA	1,180	---------	-------	600	-------	150	---------	---------	-----	150	2,600
122N64W26BBBC	1,140	37 [1]	-------	610	-------	138	1,200	78	1.2	110	2,880
123N62W30DDD2	1,161	140 [1]	-------	560	-------	159	1,200	98	1.8	350	3,000
124N63W30BBC	1,206	119 [1]	-------	580	-------	185	1,200	82	1.4	260	2,990
124N65W25DCD	1,285	79	23	590	-------	144	1,200	67	2.8	290	---------
125N63W15CBCC	1,250	15	3.5	680	7.7	191	1,200	80	1.6	52	3,040
126N65W14ADD	1,376	150	42	410	33	193	1,200	66	1.9	550	2,760
122N62W23DADD	1,148	160	43	420	27	167	1,300	84	1.3	580	2,770

Wells tapping the Dakota aquifer where water from the Fall River has recharged the Dakota and mixed with Dakota water											
121N60W2ABC	1,072	---------	-------	740	-------	328	1,100	190	4.4	37	3,320
121N61W7BBBA	1,215	---------	-------	730	-------	219	1,200	160	2.4	70	3,360
121N61W28BAB	800	4	2	840	8	390	950	350	3.7	20	3,500
121N62W22ADDD2	1,210	8.7	2.4	760	8.7	377	1,000	280	5.3	32	3,520
121N62W24ADDD	1,177	---------	-------	810	-------	449	920	330	4.4	27	3,590
122N60W8CBBA2	1,050	30	3.6	750	10	371	1,000	190	4.3	90	3,360
122N60W31CDBA (1938)	1,100	12	1	------	-------	316	1,100	200	4.0	35	---------
122N60W31CDBA (1963)	1,100	1	3	750	10	315	1,100	160	3.8	42	---------
122N61W25ADD	800	8	8.5	650	11	378	1,200	230	-----	----	3,350
122N62W2DAAD	961	30	7.4	670	13	308	950	280	4.6	105	3,250
122N63W35BACB	1,140	19	4.6	800	9.5	375	1,000	380	4.3	67	3,710
123N60W25DCCC	988	8.5	2.9	740	9.7	339	1,100	170	3.0	33	3,300
123N61W33BBBD	900	14	3.3	660	10	233	1,100	170	2.7	48	3,060
123N62W35DDDD	940	19	5.5	760	12	463	860	380	4.9	71	3,530
124N61W9ACC	1,093	---------	-------	810	-------	336	1,000	300	6.0	45	3,640
124N62W17DDDD2	1,170	---------	-------	800	-------	237	1,300	210	4.8	88	3,580
125N60W2BADC	905	18	2.9	880	-------	300	1,200	320	5.5	58	4,000
125N60W2BCAA	939	14	4	820	18	278	1,300	290	4.8	53	---------
126N60W15DA2	975	---------	-------	880	-------	264	1,200	380	5.2	68	3,990
127N62W4DAA	1,260	23	4.2	740	9.2	225	1,300	110	3.1	75	3,280
128N61W5DCCC	1,000	41	4.3	800	11	439	760	450	4.6	120	3,660
128N61W22DCB	1,000	23	2	810	13	356	1,100	280	4.8	67	---------
128N62W23CCDC	1,172	31	5.9	710	12	223	1,300	120	1.9	100	3,280
Wells tapping the Dakota aquifer where little or no water from the Fall River aquifer has recharged and mixed with Dakota water											
121N63W1ABC	1,149	9.5	2.3	900	8.7	482	760	600	3.0	33	4,030
121N63W18DCC	915	5.0	2.1	790	6.4	544	720	390	3.0	21	3,520
121N64W28ABAB	975	7.5	2.5	700	7.6	419	680	390	3.4	29	3,230
121N64W32DCCD	1,200	12	2.4	680	8.3	260	620	460	1.8	40	3,170
121N64W32DCCD3	1,145	14	3.0	------	-------	273	610	480	2.2	48	---------
121N65W28CDD	1,250	28	7.3	850	4	293	800	600	-----	100	3,600
123N62W21ABBA	1,110	8.6	3.2	840	9.3	579	770	470	6.0	35	3,870

Table 5 -- continued.

Location	Well Depth (feet)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Hardness as $CaCO_3$	Specific Conductance (micromhos per cm at 25° C)
123N65W5ADD	1,100	40	17	760	20	414	400	800	-----	170	4,250
123N65W10CAD2	1,206	55	18	600	22	274	520	570	2.3	210	3,170
125N61W5CC	903	---------	-------	860	-------	616	580	560	6	33	3,850
125N62W20DA	1,096	7.5	1.8	760	7.9	454	540	520	3.2	26	3,450
125N64W9CDA	1,107	---------	-------	780	-------	392	560	610	2.4	57	3,610
126N61W6AAB	930	25	4	870	11	532	580	640	5	84	---------
126N62W22DCC	948	8.5	3.2	900	9.9	629	440	740	3.0	34	4,060
127N60W14BAA	974	15	4.5	900	13	614	580	700	3.6	55	4,070
127N60W15AAD	935	---------	-------	930	-------	536	750	640	6.0	58	4,210
127N60W27CCDB	900	13	5.8	840	12	417	770	370	-----	----	3,400
127N61W32DCD	1,050	---------	-------	810	-------	471	540	620	5.6	100	3,740
127N62W34ACD	943	12	3.1	890	12	538	600	620	6.1	43	3,860
127N63W6ADD	1,163	18	6.6	990	17	572	400	980	2.8	72	4,600
127N64W5DAD	1,143	---------	-------	1,000	-------	593	220	1,100	3.2	44	4,780
127N65W36ADD	1,200	40	12	790	20	------	320	890	-----	100	4,550
128N60W23CDC	895	18	4.8	860	13	592	690	600	5.6	65	4,030
128N61W5DCCC	1,000	12	5.6	900	11	582	610	700	4.3	53	4,050
128N62W25AADA	900	12	4.9	870	11	530	650	610	5.3	50	3,940
128N62W34CBB	1,101	---------	-------	890	-------	550	670	610	3.2	46	4,020
128N64W10AAAD	1,178	---------	-------	1,000	-------	400	280	1,100	3.2	74	4,700
128N65W35BADD	1,265	25	9.4	920	21	523	250	980	2.4	101	4,320

[1] Number represents amount for calcium and magnesium calculated by taking the difference between the total cations and anions.

for the zone, particularly in the 250-500 zone in T. 124 N., R. 62 W.

The proportions of various chemical constituents of water from the Dakota have been changing as water from deeper aquifers recharges the Dakota and mixes with the "original" Dakota water. Water collected in 1938 and in 1963 from well 122N60W31CDBA (see table 5) shows notable changes in the concentrations and proportions of major dissolved constituents, particularly in chloride which decreased from 200 to 160 mg/l.

Temperature

The temperature of water ranges from 11°C in the Dakota aquifer to 25°C in the Sundance aquifer. Water temperatures from 12 wells in the Sundance ranged from 20° to 25°C, from 30 wells in the Fall River ranged from 15° to 23°C, and from more than 80 wells in the Dakota ranged from 11° to 19°C. In general the temperatures in the three aquifers increase from east to west.

Water from flowing wells in the Dakota showed noticeable differences in temperature because of differences in volume of discharge (Adolphson, LeRoux, 1968). Water from wells with little flow has opportunity to cool. The greater the rate of flow, the more likely is the water temperature to reflect the temperature of water in the aquifer.

WATER USE

Surface water in Brown County is used for recreation, irrigation, habitat for wildlife, and municipal water supply.

Richmond Lake, Elm Lake, the reservoirs on the James River, and the various rivers and creeks provide people with the opportunity to enjoy many types of water-related recreation.

Table 6 shows the water use by aquifer and total surface supply. The city of Aberdeen draws its water supply from the Elm River. The city uses slightly over half of all the water used in the County.

The Dakota aquifer yielded about 35 percent of the water used in 1970. The amount used for domestic and stock and for five towns was about 588 million gallons (2.2 billion l), but about 1,052 million gallons (4 billion l) was discharged, mostly by flowing wells. Thus, about 464 million gallons (1.8 billion l) of water in 1970 was withdrawn from the Dakota and wasted, unused. This waste amounted to about 880 gal/min (55 l/s).

One town (Hecla) obtains its water supply from the Middle James aquifer. Small withdrawals for irrigation are made from the Middle James and Elm aquifers.

Water use in Brown County is estimated to have been 1.3 billion gallons (4.9 billion l) in 1950, 1.4 billion gallons (5.3 billion l) in 1960, and 1.7 billion gallons (6.4 billion l) in 1970.

SUMMARY

Most streamflow and any floods in Brown County occur in spring and early summer from snowmelt and precipitation. Except for the Elm River, most streams commonly have no flow in the late summer, fall, and winter. The James River between Columbia and Stratford loses water at an average rate of 3,000 acre-ft (3.7 million m^3) per year by evaporation. During major flooding from 1950 to 1970 five periods of major stream loss occurred, ranging from 16,000 to 40,000 acre-ft (19.7 to 49.3 million m^3).

The Deep James aquifer, an interconnected system of buried channels, underlies about 250 mi^2 (648 km^2) in the County. The channel sands and gravels are composed mainly of glacial outwash and interglacial or proglacial alluvium. Water in the aquifer is under artesian pressure; water levels range from 5 to 32 ft (2 to 10 m) below land surface. The aquifer occurs between 125 and 390 ft (38 and 119 m) below land surface.

Recharge to the aquifer is by infiltration of precipitation through overlying lake silts, outwash, and till, and by subsurface inflow from Spink and Marshall Counties. Water in the aquifer moves, in general, from south to north.

The Middle James aquifer, comprised of interconnected deposits of outwash, underlies about 530 mi^2 (1,373 km^2) in Brown County. Water in the aquifer is under artesian pressure and moves, in general, from west to east; water levels range from above land surface to 32 ft (10 m) below land surface. The aquifer occurs between 40 and 250 ft (12 and 76 m) below land surface.

Recharge to the Middle James aquifer is by infiltration and percolation of snowmelt and precipitation through overlying lake silts, outwash, and till.

Discharge is by percolation into the Deep James aquifer and by eastward flow into lake silts and till.

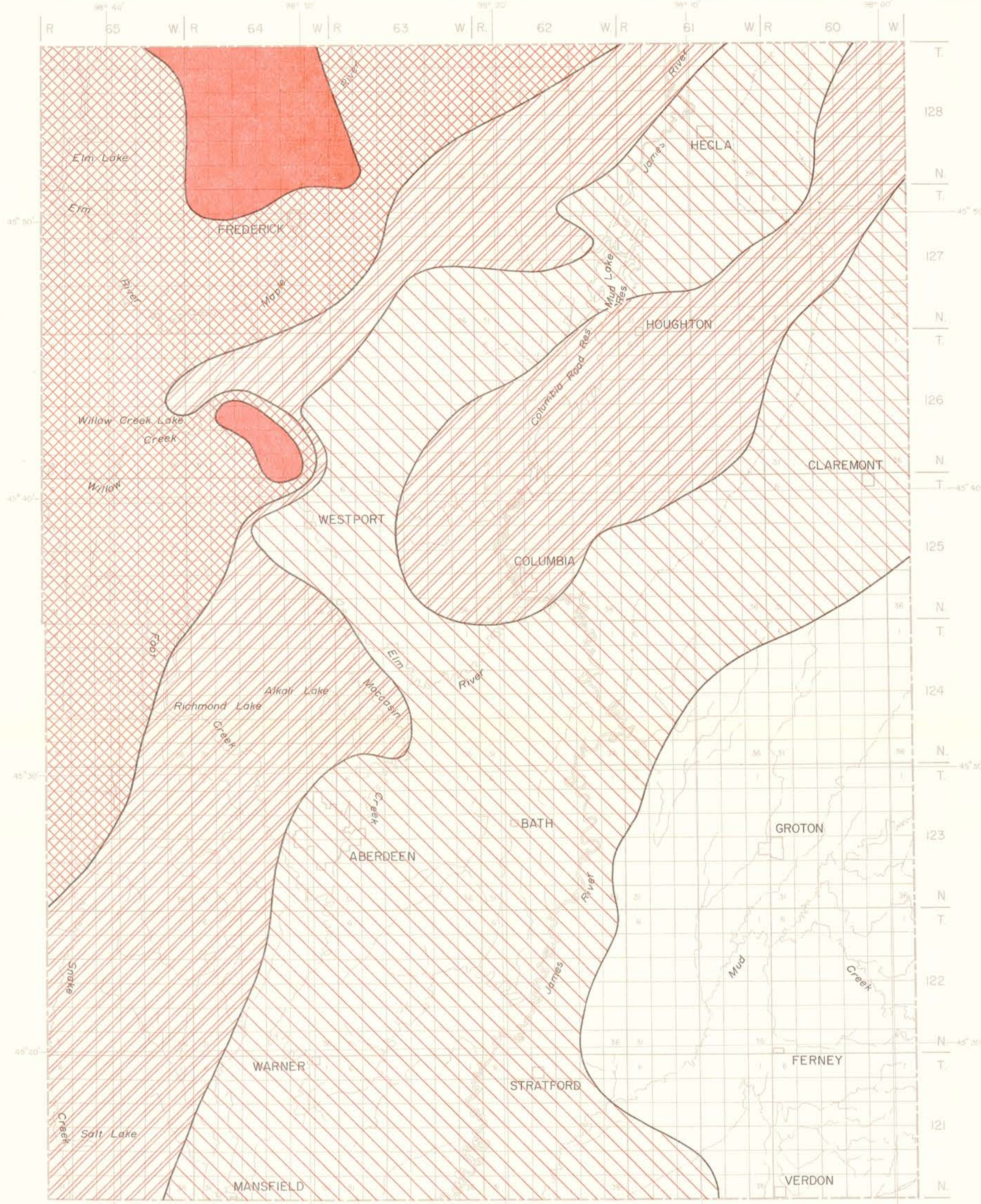
The quality of water in the Deep James and Middle James aquifers varies so greatly from place to place that a general description of the water quality is not possible. In some areas the water is suitable for irrigation but in others it is unsuitable because of a high salt content.

TABLE 6. Water use in Brown County for 1970

Source	Area underlain by aquifer in the county: Square miles	Area underlain by aquifer in the county: Percent of total	Number of private wells	Number of city wells	Amount withdrawn (million gallons)	Estimated actual use (million gallons)	Percent of total use
Deep James aquifer	250	15	4	0	2	2	.1
Middle James aquifer	530	31	49	3	48	48	3
Elm aquifer	390	23	164	0	144	144	8
Dakota aquifer	1,683	100	about 640	9	1,052[1]	588	35
Fall River aquifer	1,470	87	16[2]	1	252[1]	14	.8
Sundance aquifer	864	51	3	0	95[1]	2.6	.1
Surface water	---------	------	--------	----	898	898	53
Total			about 876	13	2,491	1,697	100

[1] Much of the flow is wasted and not put to beneficial use, thus dissipating a valuable resource. About 44 percent of the flow of the Dakota, 94 percent of the Fall River, and 97 percent of the Sundance, totalling over half, 57 percent of the amount withdrawn from bedrock aquifers was wasted.

[2] Wells that are open to the Fall River and Dakota aquifers are included in the Dakota aquifer count because the pressure and flow are similar to the Dakota aquifer.



greater than 1000

800 to 1000

500 to 800

250 to 500

0 to 250

Numbers are milligrams per litre

0 1 2 3 4 5 6 7 8 9 10 11 12 miles

0 1 2 3 4 5 6 7 8 9 10 11 12 kilometres

Drainage ditch

Intermittent stream

Base prepared from South Dakota Department of Highways county highway maps

Figure 29. Map showing chloride content of water from the Dakota aquifer.

The Elm aquifer underlies 390 mi^2 (1,010 km^2) in the County. The aquifer extends from north to south across the west central part of the County and overlies the western part of the Middle James aquifer. Well depths range from 15 to 100 ft (5 to 30 m). Water in the aquifer is under water-table conditions in some places and under artesian conditions in others. Water levels range from 4 to 50 ft (1 to 15 m) below land surface.

Recharge to the Elm aquifer is by infiltration and percolation of precipitation, snowmelt, and surface water through overlying lake silts and till.

Natural discharge is by evapotranspiration, percolation into the Middle James aquifer, and eastward flow into lacustrine silt deposits.

Major cations and anions in water from the Elm aquifer are calcium, sodium, sulfate, and bicarbonate. The water has a high salinity hazard and a low sodium hazard. The best quality water in the aquifer is found in the Elm River floodplain, where the dissolved-solids concentration is as low as 250 mg/l.

Yields of 500 gal/min (32 l/s) or more can be expected from properly constructed wells in any of the aquifers above the bedrock at locations where 40 ft (12 m) or more of medium (or coarser) sand is found.

In the Lake Dakota plain area the water table ranges from land surface to 27 ft (8 m) below land surface.

The major bedrock aquifers in Brown County are in the Dakota, Fall River, and Sundance Formations. Water from the Sundance aquifer recharges the Fall River aquifer, which in turn, recharges the Dakota aquifer.

Wells in the Dakota and Fall River aquifers range in depth from 850 to 1,200 ft (259 to 366 m). Wells in the Sundance aquifer range in depth from 1,150 to 1,450 ft (351 to 442 m).

The artesian head in the Dakota aquifer near Aberdeen declined about 390 ft (119 m) from 1900 to 1970. Some water-level measurements indicate that the decline of artesian head has been slowing or has ceased recently.

The predominant chemical constituents in water from the Sundance aquifer are calcium, sodium, and sulfate. The water contains about 50 mg/l of chloride, less than 3 mg/l of fluoride, and about 900 mg/l of hardness. Major constituents of Fall River water are sodium and sulfate. Hardness is about 550 mg/l.

The predominant constituents of water from the Dakota aquifer are sodium, chloride, and sulfate. Hardness is less than 60 mg/l. Where water from the Dakota has not mixed with water from deeper aquifers, bicarbonate, chloride, and specific conductance are almost double and sulfate is lower by about half than where the water has mixed with recharge from the Fall River. Water from bedrock aquifers is not suitable for irrigation.

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APPENDIX

Water used for irrigation should not have a detrimental affect on the productivity of the soil. The main water properties that effect soil productivity are the total dissolved solids and the relative proportion of sodium to calcium and magnesium. Relatively small amounts of boron or other constituents can be toxic to certain plants.

The amount of dissolved solids in irrigation water and the soil properties determine the accumulation of salts in the soil. Salinity hazard is the tendency of water to cause an increase of salts in the soil. The specific conductance of the water is used to calculate the salinity hazard.

The relative proportion of sodium to calcium and magnesium in irrigation water can affect soil structure. Calcium and magnesium flocculate the soil, giving it looseness, providing for penetration of air and water, and good tillage properties. Sodium tends to deflocculate soil which produces packing, thus preventing or reducing the movement of air and water. The effect on soil of high concentrations of sodium in irrigation is called the sodium hazard which is determined by the SAR (sodium-adsorption ratio).

The salinity hazard and sodium hazard (U.S. Salinity Laboratory Staff, 1954) of water are shown in figure 15 which is interpreted as follows:

Salinity Hazard

Low-salinity water (C1) can be used for irrigation of most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium-salinity water (C2) can be used for irrigation if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown, usually without special practices for salinity control.

High-salinity water (C3) cannot be used for irrigation on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

Sodium Hazard

The classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants, however, may suffer injury as a result of sodium accumulation in plant tissues even when exchangeable sodium values are lower than those causing deterioration of the physical condition of the soil.

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees may accumulate injurious concentrations of sodium.

Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse textured or organic soils with good permeability.

High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management--good drainage, high leaching, and organic matter additions. Soils containing gypsum might not develop harmful levels of exchangeable sodium from such water. Chemical improvements may be required for replacement of exchangeable sodium, except that improvements may not be feasible with waters of very high salinity.

Very high sodium water (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gpysum or other additives may make the use of such water feasible.