THE HYDROLOGIC SYSTEM OF THE LOWER JAMES RIVER, NORTH DAKOTA

By Paul K. Christensen,
North Dakota State Water Commission,

and

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Prepared by the North Dakota State Water Commission
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Water-Resources Investigation 2, Part II
North Dakota State Water Commission
Vernon Fahy, State Engineer

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For those readers who may prefer to use metric (International System) units rather than inch-pound units, the conversion factors for the terms used in this report are given below.

Multiply inch-pound unit	By	To obtain metric unit
Acre	0.4047	hectare
	0.004047	square kilometer
Acre-foot (acre-ft)	1,233	cubic meter
Cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	28.32	liter per second
Foot (ft)	0.3048	meter
Foot per day (ft/d)	0.3048	meter per day
Foot squared per day (ft^2/d)	0.0929	meter squared per day
Foot per mile (ft/mi)	0.1894	meter per kilometer
Gallon per minute (gal/min)	0.06308	liter per second
Inch (in.)	25.40	millimeter
Mile (mi)	1.609	kilometer
Square mile (mi^2)	2.590	square kilometer

To convert degrees Fahrenheit (°F) to degrees Celsius (°C) use the following formula: °C = (°F-32)x5/9.

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

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ABSTRACT

Withdrawals of water from the lower James River and from aquifers near the river have increased more than 300 percent since 1973. To provide a basis for water-resource management this study was undertaken to better define the hydrologic system of the lower James River.

The lower James River study area extends from Jamestown to the North Dakota-South Dakota State line and consists of 1,080 square miles in the lower part of the James River basin. The lower James River generally is a perennial stream, although periods of no flow may occur. Contributing drainage area of the river is about 1,170 square miles at Jamestown and 2,180 square miles at the State line. Average annual runoff is about 0.7 inch; average annual discharge at LaMoure is about 66,300 acre-feet. The slope of the channel is about 1.3 feet per mile from Jamestown to Grand Rapids, 0.28 foot per mile from Grand Rapids to the LaMoure-Dickey county line, and 0.09 foot per mile from the county line to the State line.

Flow in the lower James River is regulated by Jamestown Dam on the James River and Pipestem Dam on Pipestem Creek. Outflow from the two reservoirs and direct surface runoff account for most of the annual discharge of the lower James River.

The total reported simultaneous pumping rate from the James River has increased from 21.1 cubic feet per second in 1973 to 44.5 cubic feet per second in 1983. Flow-duration curves for the James River at LaMoure indicate that a discharge of 50 cubic feet per second was equaled or exceeded 52 percent of the time in May, 54 percent of the time in June, 40 percent of the time in July, 24 percent of the time in August, and 28 percent of the time in September. Since 1976, periods of no flow in the James River have been reported by irrigators downstream from LaMoure. In 1983, approximately 80 percent of the withdrawals from the James River occurred between LaMoure and the State line.

During the summer irrigation period, flows in the river are maintained by reservoir releases, releases from bank and channel storages, and outflow from aquifers to the river. Reservoir releases provide periodic high flows that contribute to temporary bank and channel storage. Water released from these storages can support low flows for as much as 2 weeks. During extended low-flow periods, nearly all flow in the lower James River is derived from leakage at Jamestown and Pipestem Dams and by discharge from the Grand Rapids aquifer.

Aquifer outflow to the river accounts for about 18 percent of the 1983 total reported simultaneous pumping rate. The major aquifers in the lower

James River study area consist of sand and gravel in glacial-drift deposits of Pleistocene age. Five aquifers that directly underlie or abut the lower James River in the study area interact with the river.

The Grand Rapids aquifer of the Spiritwood aquifer system extends from the Stutsman-LaMoure county line to Grand Rapids. The aquifer ranges from 1.5 to 6 miles in width, has an area of about 60 square miles, and an average saturated thickness of about 90 feet. The Grand Rapids aquifer discharges about 4 to 6 cubic feet per second of water to the James River during long-term low-flow periods. Transmissivity and hydraulic conductivity values estimated from stream hydrographs and values derived from aquifer tests indicate that the Grand Rapids aquifer apparently controls the recession of low flows in the lower James River.

The west unit of the Oakes aquifer extends from near Oakes to the North Dakota-South Dakota State line. The unit ranges from 0.5 to 5 miles in width and has an area of about 29 square miles. Because of low hydraulic conductivities, predominance of local flow systems, and intervening silt, clay, or till in the unit, the quantity of water contributed to the lower James River during low-flow periods probably is insignificant.

The Jamestown aquifer is located in the valleys of the James River, Pipestem Creek, and Seven Mile Coulee near the city of Jamestown. The aquifer ranges from 0.25 to 1.5 miles in width, has an area of about 9 square miles, and an average saturated thickness of about 30 feet. Large withdrawals of water (2,833 acre-feet in 1983) from the Jamestown aquifer probably are counteracted by induced seepage from the James River and by discharge from the Midway aquifer. These withdrawals probably have substantially reduced annual outflow from the aquifer to the lower James River.

The Ypsilanti aquifer underlies the James River valley from north of the city of Ypsilanti to near the Stutsman-LaMoure county line. The aquifer ranges from 0.3 to 0.8 mile in width, has an area of about 8 square miles, and an average saturated thickness of about 18 feet. Because of the small extent of the Ypsilanti aquifer, the quantity of water contributed by the aquifer to the river during low-flow periods probably is very small.

The LaMoure aquifer extends from the junction of the James River and Bone Hill Creek downstream to near Oakes. The aquifer ranges from 0.5 to 2.5 miles in width, has an area of about 45 square miles, and an average saturated thickness of about 40 feet. An overall long-term decline in water levels has occurred in part of the central unit of the LaMoure aquifer. Irrigation withdrawals locally may induce seepage from the James River, and large withdrawals (3,427 acre-feet in 1983) probably have reduced the annual outflow from the central unit of the LaMoure aquifer to the river. The quantity of water contributed by the central unit of the LaMoure aquifer to the James River during low-flow periods probably is less than 1 cubic foot per second.

INTRODUCTION

The development of ground-water and surface-water resources along the lower James River in North Dakota (downstream of Jamestown Dam to the North Dakota State line) has increased significantly in the 1970's and early 1980's. Nearly all of the additional development was for irrigation.

Previous investigators, including Armstrong (1980), have noted a ground-water and surface-water interaction between glacial-drift and alluvial aquifers and the lower James River. Irrigation and other developments along the lower James River withdraw water from both the ground-water and surface-water systems. To provide a basis for water-resource management, a comprehensive geohydrologic investigation was needed to better define the hydrologic system. The hydrologic system can be divided into three parts; ground water, surface water, and the interaction between them. When there is significant interaction between ground water and surface water, the system is difficult to describe. In this report, the terms aquifer-stream interaction or ground-water and surface-water interaction describe the exchange of water between an aquifer and a stream where the aquifer directly underlies or abuts the stream.

The study of the hydrologic system began in October 1981 as a cooperative investigation by the North Dakota State Water Commission and the U.S. Geological Survey. The field investigation was completed in February 1984. The results of the study will be published in two reports: the ground-water and surface-water data collected during the study (Wald and Christensen, 1986), and this report, which is a description and analysis of the ground-water system, surface-water system, and the interaction between them.

Purpose and Scope

This report describes the results of a study designed to: (1) Obtain additional geologic and hydrologic data to further define the hydrologic system and (2) define the hydrologic system to provide a basis for water-resources management. The definition of the hydrologic system includes the description of the geologic setting, hydrologic system, water withdrawals, and ground-water and surface-water interaction. Emphasis is given to those aquifers that interact with the lower James River.

A drilling program and four seepage evaluations were conducted to obtain data for this investigation. The drilling program included drilling test holes and constructing observation wells. Stage-level measuring sites also were constructed along the James River. Water-level and stage-level measurements were made and water samples were collected for chemical analysis.

Location

The James River basin north of the North Dakota-South Dakota State line has an area of about 5,550 mi^2 in south-central and central North Dakota. This study is limited to the lower part of the basin that extends from Jamestown to the North Dakota State line. The study area includes 1,080 mi^2 in parts of southeastern Stutsman County, central LaMoure County, and eastern Dickey County (fig. 1).

Location-Numbering System

The location-numbering system used in this report (fig. 2) is based on the Federal system of rectangular surveys of public lands. The first numeral denotes the township, the second denotes the range, and the third denotes the section in which the well or test hole is located. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract); thus, well 132-061-15DAA would be located in the NE1/4NE1/4SE1/4 sec. 15, T. 132 N., R. 61 W. Consecutive terminal numbers are added if more than one well or test hole is recorded within a 10-acre tract.

Previous Investigations

Numerous investigators have studied the ground-water and surface-water resources of the basin. The relationship between the ground-water and surface-water systems in the lower James River basin, however, has not been studied in detail.

Paulson (1962) investigated the ground-water resources at a Federal wildlife research center in the James River valley near Jamestown. As part of the county ground-water studies series of the North Dakota State Water Commission, Huxel and Petri (1963) collected ground-water data for Stutsman County. Huxel and Petri (1965) also described the ground-water resources of Stutsman County. A report that contains ground-water data for Dickey and LaMoure Counties was prepared by Armstrong and Luttrell (1978). Armstrong (1980) described the ground-water resources of these two counties. Two reports in the county ground-water studies series--one by Winters (1963) for Stutsman County and the other by Bluemle (1979) for Dickey and LaMoure Counties--describe the geology of the area along the lower James River.

The U.S. Army Corps of Engineers, War Department (1935), reported on water supply and sewage disposal in the James and Sheyenne River basins. The North Dakota State Planning Board (1939) reported on the James River drainage basin in North Dakota. Both reports describe the hydrologic characteristics of the surface-water system of the James River basin. The U.S. Bureau of Reclamation prepared several unpublished reports on the hydraulic characteristics of the James River for the Garrison diversion project. One of these administrative reports describes the hydrology of the basin and the effects of Jamestown Dam (U.S. Bureau of Reclamation, 1951). The Missouri Basin Interagency Committee (1967) published a report on the streamflow characteristics of the eastern Dakota tributaries to the Missouri River. The Missouri River Basin Commission (1977, 1980a, 1980b, 1980c, 1980d, and 1980e) has published numerous reports on agriculture, flooding, physical characteristics, and water resources of the James River basin.

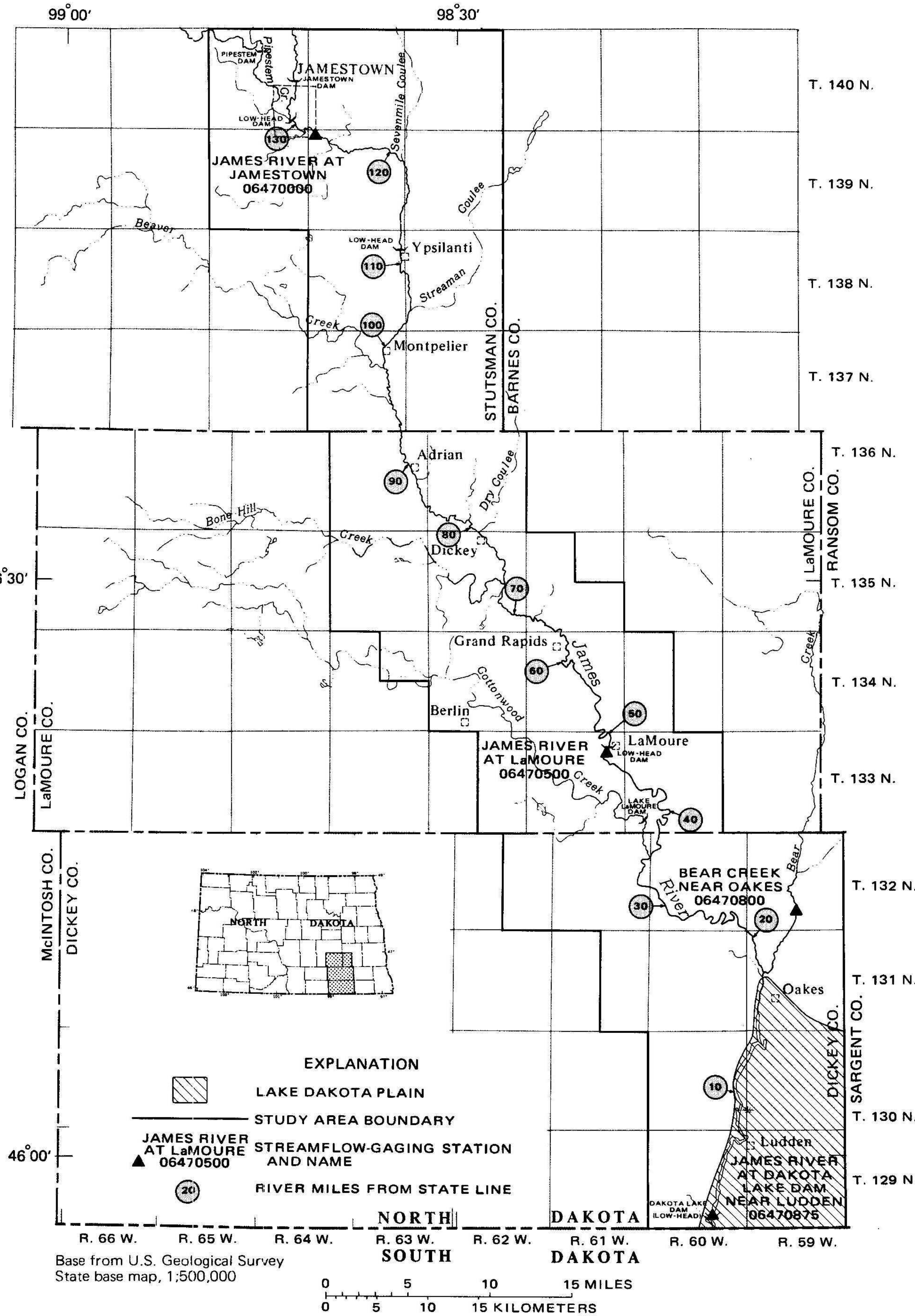


Figure 1.—Study area.

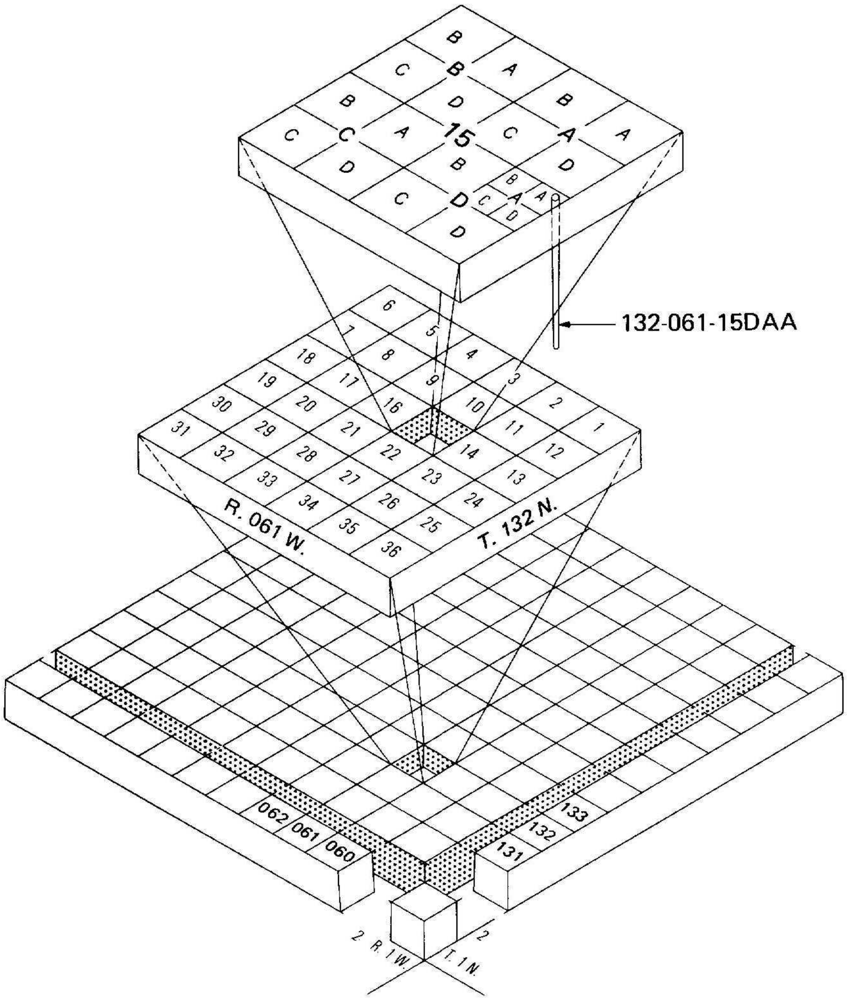


Figure 2.—System of numbering wells and test holes.

Acknowledgments

Recognition is due the following North Dakota State Water Commission employees--Royce L. Cline for providing climatologic data in graphical form and Allen E. Comeskey for logging of test holes. Robert L. Houghton, U.S. Geological Survey, provided assistance in the interpretation of water-quality data. Appreciation is expressed to the well drillers who furnished well logs and to the farmers and ranchers who allowed access to their lands and provided information on wells and pumping periods. Richard Behrens and Marjorie Lakin, U.S. Army Corps of Engineers, Omaha, Nebr., and Robert Martin, local Jamestown Reservoir manager, assisted in controlling reservoir releases during the seepage runs.

Physiography, Climate, and Vegetation

The study area lies in the young glaciated plain of the Central Lowland province of Fenneman (1946). The glaciated plain is characterized by low topographic relief except where streams have incised the plain. Drainage is in a late youthful stage and is only partly developed. The James River originates near Fessenden, N.Dak., at an altitude of about 2,000 ft above sea level. The river flows eastward and then southward in a valley of varying width into South Dakota. Altitudes in the study area range from about 1,500 ft west of Jamestown to about 1,290 ft at the North Dakota-South Dakota State line.

The climate of the study area is subhumid. Climatological normals for temperature, precipitation, and total annual evaporation are given in table 1. Temperature and precipitation data are given for Jamestown, which is located near the northern end of the study area, and Oakes, which is located near the southern end. About 70 percent of the precipitation generally falls from April through August; however, the amount of summer precipitation is extremely variable. Snowfall averages slightly over 30 in/yr. Total snowfall of more than 100 in. in one winter has been recorded infrequently. High winds often cause drifting of snow (Missouri River Basin Commission, 1980d, p. 5), which can localize available moisture from spring snowmelt.

Most of the vegetation in the basin consists of cultivated crops. Major crops are corn, oats, alfalfa, sorghum, barley, wheat, sunflowers, and soybeans. Some land is used for range and pasture or to produce hay. Small areas of woodlands occur as native woods along the flood plain of the James River and as shelterbelts and windbreaks (Missouri River Basin Commission, 1980a, p. 24).

GEOLOGIC SETTING

The Niobrara and Pierre Formations[1] of Cretaceous age underlie the glacial drift of Quaternary age. Glacial drift covers most of the study

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

Table 1.--Climatological data for selected sites in or near the study area

January	February	March	April	May	June	July	August	September	October	November	December	Annual
					Temperature normals, in degrees Fahrenheit							
					Jamestown Federal Aeronautics Administration airport[1]							
5.4	12.6	24.3	41.4	54.3	64.2	69.9	68.2	56.9	45.6	27.7	13.7	40.4
					Oakes[1]							
5.3	12.3	24.8	42	55.3	65	70.7	69.1	57.8	46.1	28.6	14.1	40.9
					Precipitation normals, in inches							
					Jamestown Federal Aeronautics Administration airport[1]							
0.60	0.58	0.79	1.52	2.32	3.59	3.02	2.12	1.61	0.94	0.52	0.51	18.12
					Oakes[1]							
.60	.62	.93	2.23	2.68	3.53	2.37	2.45	1.94	1.12	.69	.58	19.74
					Percent of total annual evaporation							
					Basin[2]							Total evaporation, in inches
--	--	--	9.6	13.3	14.5	16.9	15.9	11	7.2	--	--	[3]37-39

[1]Based on records for the 30-year period 1951-80 (U.S. Department of Commerce, 1982a).

[2]Based on records for the period 1956-70 at Redfield, South Dakota (U.S. Department of Commerce, 1982b). During the irrigation period May through October, 79 percent of the evaporation occurs, and during the period November through April, 21 percent of the evaporation occurs.

[3]Data taken from a national map that includes the James River study area and shows a range of values from 37 inches in the northern part of the area to 39 inches in the southern part of the area (U.S. Department of Commerce, 1982b).

area; however, major alluvial deposits occur on the flood plain of the James River.

Deposits of Cretaceous Age

The Cretaceous Niobrara and Pierre Formations are composed of marine shales. The Niobrara Formation underlies the glacial drift in much of the southern half of the area and the Pierre Formation underlies the glacial drift in the northern half and extreme southern part of the area. The Niobrara Formation, which is the older of the two units, is not exposed. Small outcrops of the Pierre Formation occur in Stutsman County along the James River valley north of Jamestown and along parts of the valleys of Pipestem and Beaver Creeks.

The Niobrara Formation consists of light- to medium-gray calcareous shale with white limey inclusions (Bluemle and others, 1980). The upper part of the unit weathers to tan, yellow, or gold colors and the lower part to grayish hues.

The Pierre Formation consists of light- to dark-gray fissile shale that generally is noncalcareous (Bluemle and others, 1980). Bentonitic and montmorillonitic beds and concretions occur in the formation.

Deposits of Quaternary Age

Deposits of Pleistocene Age

Glacial drift comprises all the materials deposited by glacial ice and by flowing and ponded water associated with the ice. Collectively, the drift is referred to as the Coleharbor Group (Bluemle, 1979, p. 12). Thicknesses generally range from about 100 to 300 ft. The Coleharbor Group consists of three main textural facies: (1) Till, (2) sand and gravel, and (3) silt and clay.

The till facies is composed of a clay- and silt-sized matrix with sand, pebbles, cobbles, and boulders. Till was deposited by the glacial ice. Oxidized till facies is yellowish brown to brownish gray in color, and unoxidized till facies is light to dark olive gray in color. Near the land surface, the till facies may be weakly jointed. Till is the most commonly distributed of the three facies in the area.

The sand and gravel facies (glaciofluvial) is characterized by gravel, sand, silt, and clay deposits. The facies was deposited by melt-water rivers and by running water that resulted from precipitation that fell during and immediately following glaciation (Bluemle, 1979, p. 20). Parts of this facies are buried beneath the till facies, silt and clay facies, or Holocene deposits.

The silt and clay facies (glaciolacustrine) consists of materials deposited by water in lakes and includes laminated clay, silt, and fine sand. The facies is widely exposed near the city of Oakes and locally is buried in the rest of the study area.

Deposits of Holocene Age

Sand, silt, and clay deposits accumulated during Holocene time. These deposits, called the Oahe Formation, are divided into three facies by Bluemle (1979): (1) The clay facies; (2) the sand and silt facies; and (3) the bouldery, gravelly clay facies.

The clay facies was deposited in sloughs and ponds. Clay is the dominant lithology, but silt is common.

The sand and silt facies is composed of alluvial and eolian deposits. Alluvial deposits occur on the flood plain of the James River valley and along some of the tributaries. Generally, the younger alluvial deposits are finer grained than the older glaciofluvial deposits. Sand commonly occurs near the base of the alluvial deposits, and clay and silt commonly occur at or near the flood-plain surface. The alluvial deposits generally have a thickness of less than 35 ft. The generally light- to dark-gray sand and dark-brown silt and clay are obscurely bedded and commonly contain organic material. Eolian deposits in the form of sand dunes and loess have been deposited south of Oakes, east of the James River. Smaller eolian deposits also occur in the study area.

The bouldery, gravelly clay facies consists of colluvial materials deposited by slopewash, slumping, sliding, and earth creep. This facies occurs along the fronts of the walls of the James River valley. The facies consists of a wide range of grain sizes and is poorly sorted.

Geomorphology

The landscape in the James River area was formed by glaciation during Wisconsinan time and was modified by subsequent erosion. The James River flows through a large melt-water trench that dissects the glaciated plain. In the southern part of the study area, the James River valley broadens and coalesces with the lake plain of glacial Lake Dakota (fig. 1). The lake plain is covered by a sheet of loess, sand dunes, and alluvium.

The James River valley is steep sided and nearly flat bottomed. The width of the valley ranges from about 0.5 mi from rim to rim near Montpelier to about 3 mi near LaMoure. The flood plain correspondingly ranges from about 0.25 to 2 mi in width. From rim to flood plain, valley depth ranges from about 150 ft near Dickey to about 40 ft where the valley coalesces with the Lake Dakota plain. Terraces occur in the valleys of the James River, Pipestem Creek, Seven Mile Coulee (Sevenmile Coulee), Beaver Creek, Bone Hill Creek, and Cottonwood Creek. One to three terraces are recognizable in the James River valley. Oxbows, meander scars, and levees characterize the flood plain of the James River.

HYDROLOGIC SYSTEM

Ground-Water System

The shales of the Niobrara and Pierre Formations locally may yield small quantities of water to wells but are considered to be an insignificant aquifer in the study area. Where fractured, shale in the Pierre Formation, the Pierre aquifer, may yield as much as 50 gal/min.

Glacial-drift deposits yield the largest quantities of water to wells (yields may exceed 1,000 gal/min) and, thus, are the major aquifers located along the lower James River. These glacial-drift aquifers are composed largely of sand and gravel interbedded with silt and clay. The aquifers occur in buried valleys, in buried outwash plains, in melt-water channels, in deltaic and lacustrine environments, and in isolated pockets of sand and gravel surrounded by clay or glacial till. The glacial-drift aquifers along the lower James River are the Spiritwood aquifer system, Homer aquifer, Montpelier aquifer, Adrian aquifer, Dickey aquifer, Ellendale aquifer, Guelph aquifer, Oakes aquifer, and James River aquifer system.

Locally, alluvial sand deposits beneath the flood plain of the James River and its tributaries are contiguous with underlying glacial-drift aquifers and hydrologically are part of the underlying glacial-drift aquifers. In other areas, the alluvial sand deposits form local minor aquifers separated from the glacial-drift aquifers.

The locations of the aquifers are shown in figures 3 and 4. Two figures are used to avoid the problem of showing superposition of one aquifer on another. Aquifers and aquifer systems that may significantly interact with the James River are discussed in the following sections in more detail than those that do not.

For convenience of discussion, identification, and future reference, aquifer names generally are continued from previous investigations. Newly recognized aquifers are named after local geographic features or are distinguished by the directional adjectives north, south, or west. Prominent zones of low hydraulic conductivity in an aquifer allow the division of the aquifer into separate units. These units also are distinguished by the adjectives north, south, east, west, or central. For detailed location designations used in the remainder of this report, refer to plate 1 (in pocket) and figures 3 and 4.

Only pertinent information is given in each individual aquifer description. For example, the description of the composition of the glacial-drift aquifers is presented in the introductory paragraphs to the subsection called ground-water system. This description is not repeated in each aquifer discussion in the remainder of the report. When glacial drift is referred to as underlying or overlying an aquifer or when glacial drift is referred to as an intervening unit between an aquifer and a stream, the glacial drift is composed mostly of glacial till but does include some glaciofluvial and glaciolacustrine deposits interspersed in the glacial till.

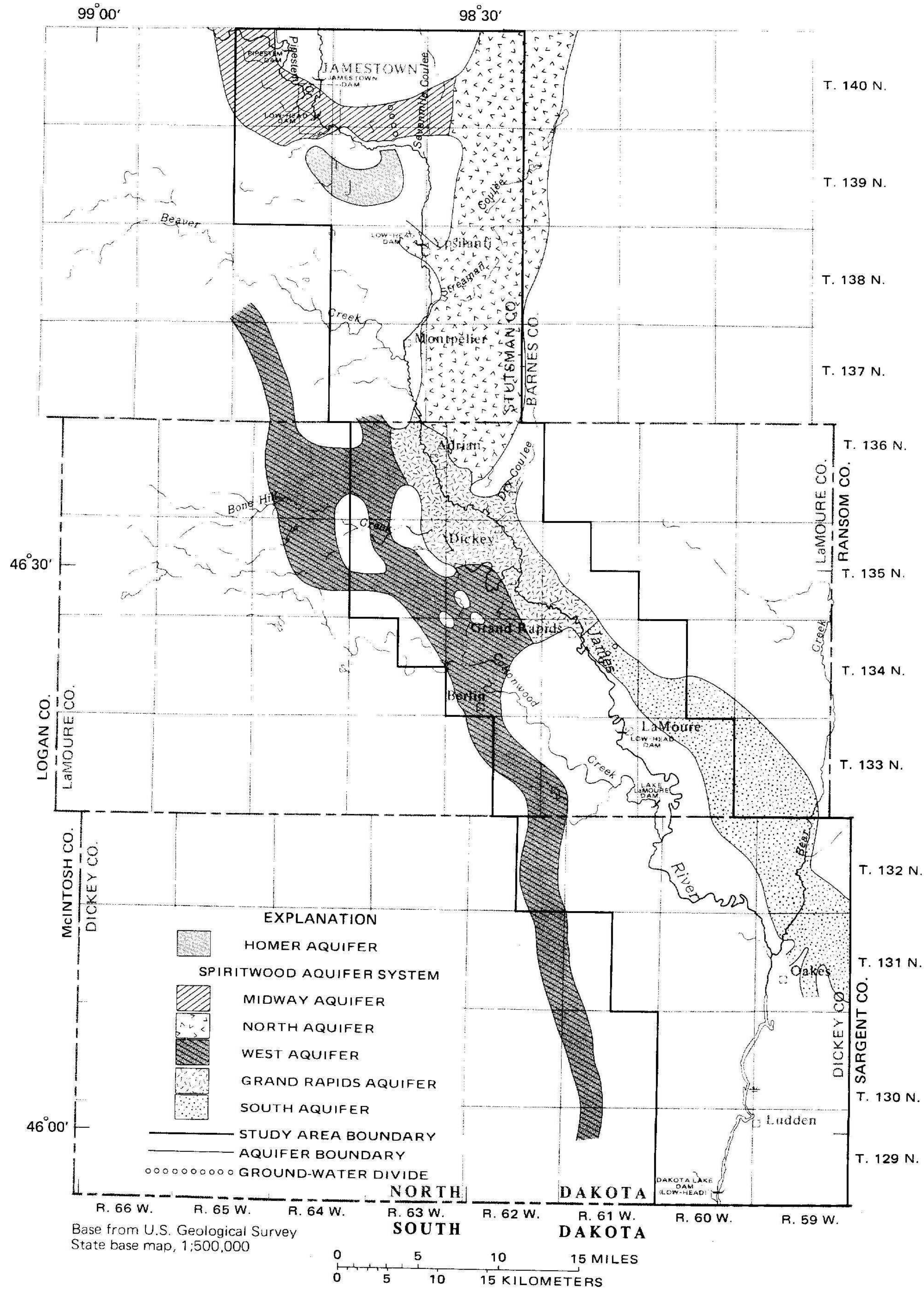


Figure 3.—The Homer aquifer and Spiritwood aquifer system.

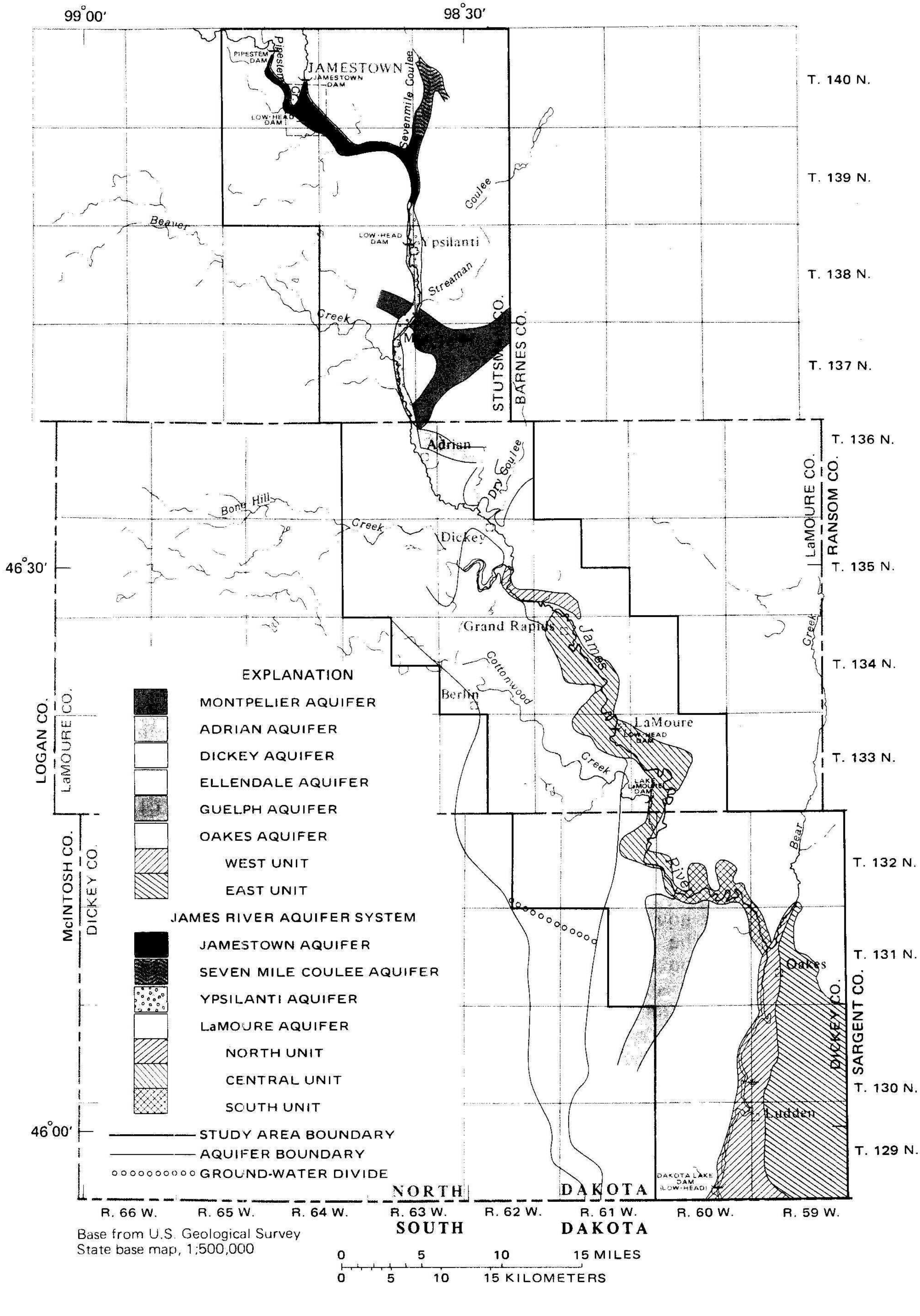


Figure 4.—Glacial-drift aquifers including the James River aquifer system.

Pierre Aquifer

The Pierre aquifer underlies the glacial drift in the study area north and west of LaMoure and near Ludden (Armstrong, 1980). The aquifer porosity occurs, in part, as fractures in dark-gray fissile shale in the upper part of the Pierre Formation. The fractures generally are larger and more common in the upper 10 to 50 ft of the shale (Armstrong, 1980, p. 24-25). Locally, in areas of thin glacial drift, the fracture system apparently is better developed. The potentiometric surface of the aquifer reflects surface topography. Recharge to the aquifer mainly is from vertical leakage from the overlying glacial drift. Discharge from the aquifer is by leakage into overlying glacial drift and glacial-drift aquifers and by seepage into the James River, Pipestem Creek, Seven Mile Coulee, and Beaver Creek. Generally yields from wells are less than 5 gal/min, but locally, in the areas of thin glacial drift, yields of as much as 50 gal/min may be obtained (Armstrong, 1980, p. 25). Armstrong (1980, p. 25) reported that dissolved-solids concentrations ranged from 1,400 to 8,630 mg/L and had a mean of 3,500 mg/L in six samples obtained from the Pierre aquifer. Sodium was the major cation and either chloride or bicarbonate was the major anion.

Spiritwood Aquifer System

The Spiritwood aquifer system, named by Huxel (1961), is the largest glacial-drift aquifer system in the study area (fig. 3 and pl. 1). The aquifer system ranges from about 1 to 9 mi in width, has an area of about 425 mi^2, and occurs in a buried drainage system consisting of several channels. The Niobrara Formation or Pierre Formation generally underlies the aquifer system; but locally, glacial drift underlies the aquifer system. Glacial drift generally overlies the aquifer system. Boulders and cobbles commonly occur at the base of the aquifer system. Clay and silt deposits interbedded in the aquifer system deposits (sand and gravel) are extensive locally. The saturated thickness of the aquifer system is quite variable and ranges from 0 to about 275 ft.

Water in the aquifer system generally is confined, but locally is unconfined near the James River in the vicinity of the cities of Adrian and Dickey. The potentiometric surface gently slopes towards discharge areas, but locally steepens in zones of lower transmissivity and near discharge areas. Zones of lower transmissivity commonly occur in the aquifer system and are due to thinning of the aquifer system deposits or to decreasing hydraulic conductivity values (less than 1 ft/d) of the aquifer system deposits.

Recharge to the aquifer system mainly is from precipitation and snowmelt that percolates through overlying glacial drift. Additional recharge to the aquifer system is derived from leakage from adjacent glacial drift and from the underlying Pierre aquifer.

Six aquifer tests have been made on the Spiritwood aquifer system (table 2). Results of the tests indicate that transmissivity values in

Table 2.--Results of aquifer tests on the Spiritwood aquifer system

Location of production well	Number of observation wells used in test	Test duration (hours)	Pumping rate (gallons per minute)	Analytic method	Transmissivity (feet squared per day)	Storage coefficient	Mean hydraulic conductivity (feet per day)	Remarks
131-059-11AAC[1]	16	102	1,360-1,490	Two-dimensional finite-difference ground-water model (Trescott and others, 1976).	9,000-20,000	0.00024	500	Zones of low transmissivity, aquifer boundaries, and leakage from adjacent sediments were detected. Barrier transmissivity ranges from 10 to 250 feet squared per day.
131-059-16CCC[1]	1	46	2,339	Analytic simulation using the equation of Theis (1935).	18,000	.0002	420	Zones of low transmissivity, aquifer boundaries, and leakage from adjacent sediments were detected.
131-059-22BDA[1]	4	100	870	Time drawdown and distance drawdown (Wenzel, 1942; Cooper and Jacob, 1946).	25,000	.0002	600	Zones of low transmissivity, aquifer boundaries, and leakage from adjacent sediments were detected.
132-059-21CBD[1]	11	100	1,043	Distance drawdown (Cooper and Jacob, 1946).	37,700	.0002	420	Zones of low transmissivity, aquifer boundaries, and leakage from adjacent sediments were detected.
135-061-30BDD[2]	2	25	1,300	Time drawdown (Wenzel, 1942; Cooper and Jacob, 1946).	9,000	.0004	120(?)	Results are inconclusive due to very close zones of low transmissivity, aquifer boundaries, and leakage from adjacent sediments.
140-062-22CAB4[3]	4	75	500	Distance drawdown and time drawdown (Wenzel, 1942; Cooper and Jacob, 1946).	15,000	.0004	250	Zones of low transmissivity and aquifer boundaries were detected.

[1]R.B. Shaver, 1984.
[2]J.C. Reiten, North Dakota State Water Commission, written communication, 1981.
[3]R.W. Schmid, North Dakota State Water Commission, written communication, 1975.

the aquifer system range from 9,000 to 37,700 ft^2/d and storage coefficients range from 0.0002 to 0.0004. Pumping rates during the aquifer tests ranged from 500 to 2,339 gal/min. Irrigation and industrial wells currently (1983) yield 250 to 2,400 gal/min from the aquifer system.

The Spiritwood aquifer system is divided into five aquifers in this report: (1) Midway aquifer, (2) North aquifer, (3) West aquifer, (4) Grand Rapids aquifer, and (5) South aquifer.

Midway aquifer

The Midway aquifer, named by Huxel and Petri (1965), extends from Pipestem Lake to Seven Mile Coulee (fig. 3 and pl. 1). The aquifer has a width of 1 to 4 mi, an area of about 50 mi^2, and occurs in a buried valley. The Midway aquifer lies beneath parts of the Jamestown aquifer (fig. 5) and Seven Mile Coulee aquifer (fig. 6). The Midway aquifer generally is contiguous with the Jamestown aquifer, but only locally is contiguous with the Seven Mile Coulee aquifer. Glacial drift generally separates the Midway aquifer and the Seven Mile Coulee aquifer. The aquifer deposits mostly consist of interbedded fine to medium sand, silt, clay, and some till; however, coarse sand and gravel make up about one-third of the aquifer deposits. The saturated thickness of the aquifer ranges from 0 to about 190 ft, and the average saturated thickness is about 120 ft.

Water in the aquifer generally is confined, but locally it is unconfined near the James River valley. A ground-water divide occurs between Jamestown and Seven Mile Coulee (fig. 3). Water levels range from near or above land surface in the stream channel of Seven Mile Coulee to about 110 ft below land surface beneath the glaciated plain.

In addition to that derived from precipitation and snowmelt, recharge to the aquifer is from leakage from the North aquifer of the Spiritwood aquifer system east of Seven Mile Coulee and from seepage from Pipestem Lake. Discharge from the aquifer is by pumpage and by ground-water movement into the Jamestown and Seven Mile Coulee aquifers. Irrigation wells completed in the aquifer yield 250 to 550 gal/min. Water-quality characteristics for the Midway aquifer are shown in table 3.

North aquifer

The North aquifer of the Spiritwood aquifer system is located east of the James River in the northeastern part of the study area (fig. 3), and does not interact with the James River. Part of the North aquifer lies beneath the Ypsilanti aquifer at Ypsilanti and is separated from the Ypsilanti aquifer by about 10 to 30 ft of glacial drift. Water levels in wells penetrating the North aquifer at Ypsilanti are about 5 to 15 ft above the water levels in the Ypsilanti aquifer. Discharge from the north aquifer is by pumpage and by ground-water movement into the Midway aquifer, the Grand Rapids aquifer, and the Ypsilanti aquifer. The North aquifer also discharges by seepage through intervening glacial drift into Streaman Coulee and through small springs and seeps located at the base of the James River valley wall in 138-062-31B and in 137-063-25D (pl. 1).

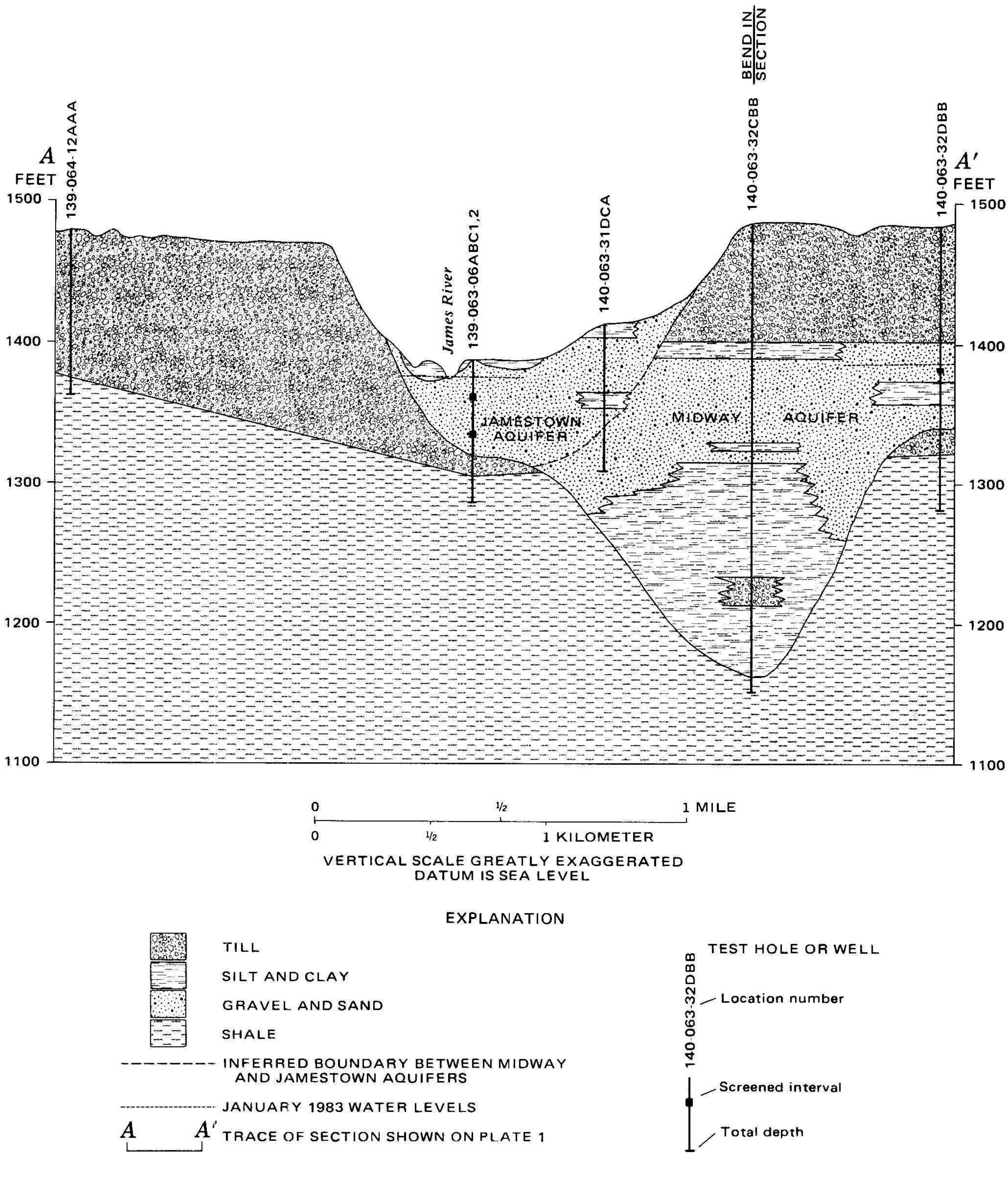


Figure 5.—Hydrogeologic section A-A' of the Midway and Jamestown aquifers near Jamestown.

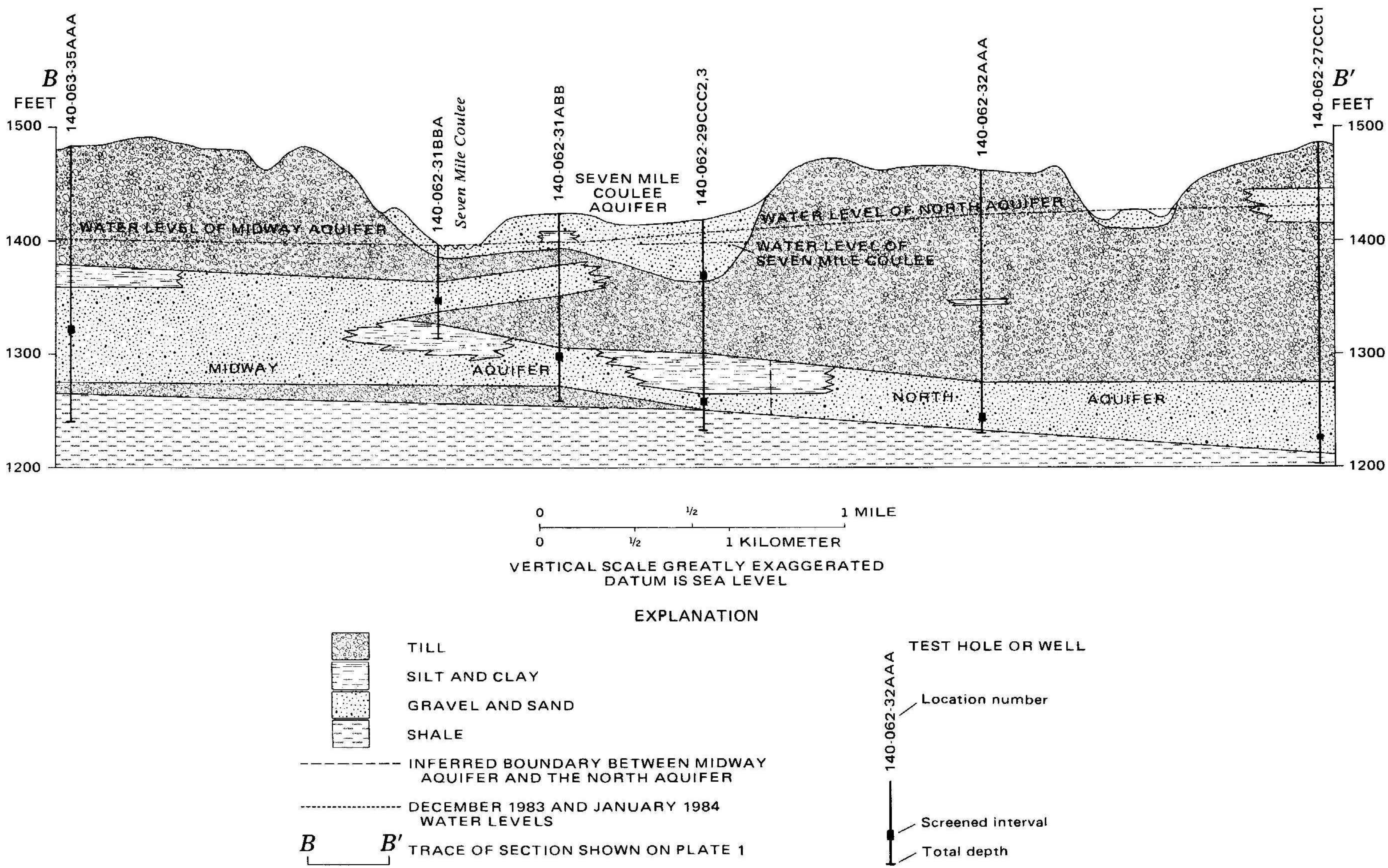


Figure 6.—Hydrogeologic section B-B′ of the Midway aquifer, North aquifer of the Spiritwood aquifer system, and Seven Mile Coulee aquifer at Seven Mile Coulee.

Table 3.--Water-quality characteristics of selected aquifers and aquifer systems

Aquifer or aquifer system	Dissolved solids[1] (milligrams per liter)	Major anions and cations
Midway	Values: 625, 732, 937 Number of samples: 3	The major anion is bicarbonate. None of the three major cations (calcium, magnesium, and sodium) dominate.
Spiritwood aquifer system (Grand Rapids aquifer)	Range: 348 to 2,170 Mean: 984 Number of samples: 31	The major anion is bicarbonate. The major cation is sodium.
Ellendale	Range: 475 to 1,560 Mean: 1,131 Number of samples: 11	The major anion is sulfate. The major cations are calcium and sodium.
Guelph	Range: 710 to 1,440 Mean: 951 Number of samples: 5	The major anion is sulfate. The major cation is calcium.
Oakes (west unit)	Values: 351, 457, 794 Number of samples: 3	The major anion is bicarbonate. The major cation is calcium.
Jamestown	Range: 491 to 1,190 Mean: 858 Number of samples: 5	The major anion is bicarbonate. The major cations are calcium and magnesium.
Seven Mile Coulee	Values: 626, 913 Number of samples: 2	Insufficient data.
Ypsilanti	Range: 534 to 852 Mean: 705 Number of samples: 5	The major anion is bicarbonate. None of the three major cations dominate.
LaMoure	Range: 236 to 1,720 Mean: 625 Number of samples: 78	The major anion is bicarbonate. The major cations are calcium and sodium.

[1]The dissolved-solids concentration is calculated from the weight of residue at 180 °C from a known quantity of water.

West aquifer

The West aquifer of the Spiritwood aquifer system is located west of the James River in LaMoure County (fig. 3), and does not interact with the James River. The West aquifer includes the previously named Sydney (Huxel and Petri, 1965) and Nortonville (Armstrong, 1980) aquifers. Discharge from the West aquifer is by pumpage, by ground-water movement into the Grand Rapids aquifer, and by seepage into Bone Hill and Cottonwood Creeks.

Grand Rapids aquifer

The Grand Rapids aquifer of the Spiritwood aquifer system is here named after the city of Grand Rapids. The aquifer extends from the Stutsman-LaMoure county line to Grand Rapids (fig. 3). The Grand Rapids aquifer ranges from about 1.5 to 6 mi in width and has an area of about 60 mi^2.

The deposits of the Grand Rapids aquifer often are contiguous with the younger deposits of the Ypsilanti aquifer in the James River valley in the river reach from the Stutsman-LaMoure county line downstream to near Dickey. In this reach, glacial drift locally separates the deposits of the Grand Rapids aquifer from the deposits of the Ypsilanti aquifer, but the intervening glacial drift generally is less than 20 ft thick. The deposits of the Ypsilanti aquifer in this reach are treated as part of the Grand Rapids aquifer. Silt and clay of glaciofluvial, glaciolacustrine, or alluvial origin generally overlies the aquifer deposits in the flood plain of the James River in this reach (figs. 7 and 8). The silt and clay ranges from 0 to about 26 ft in thickness and averages about 15 ft.

The LaMoure aquifer lies above the Grand Rapids aquifer (fig. 9) in the river reach from the junction of the James River and Bone Hill Creek downstream to Grand Rapids. The thickness of the glacial drift separating the Grand Rapids aquifer from the LaMoure aquifer in this reach ranges from about 30 to 60 ft, but locally it is thinner in parts of 135-062-23.

The aquifer deposits that comprise the Grand Rapids aquifer from the Stutsman-LaMoure county line to near Dickey consist of three contiguous geohydrologic units deposited in sequence: (1) Spiritwood aquifer system deposits; (2) Ypsilanti aquifer deposits; and, locally, (3) alluvial sand deposits. The percentage of gravel and sand that composes the Grand Rapids aquifer at test-hole sites ranges from 0 to 100 percent and averages about 76 percent. The saturated thickness of the aquifer ranges from 0 to about 166 ft and averages about 90 ft.

The potentiometric surface of the Grand Rapids aquifer in December 1983 sloped towards the James River (fig. 10). Beneath the glaciated plain, water levels are about 100 to 170 ft below land surface. From the Stutsman-LaMoure county line to Dickey, the water levels in the aquifer are about 7 to 12 ft below land surface in the flood plain of the James River. From Dickey to Grand Rapids, water levels range from about 5 ft below land surface to about 15 ft above land surface in the flood plain of

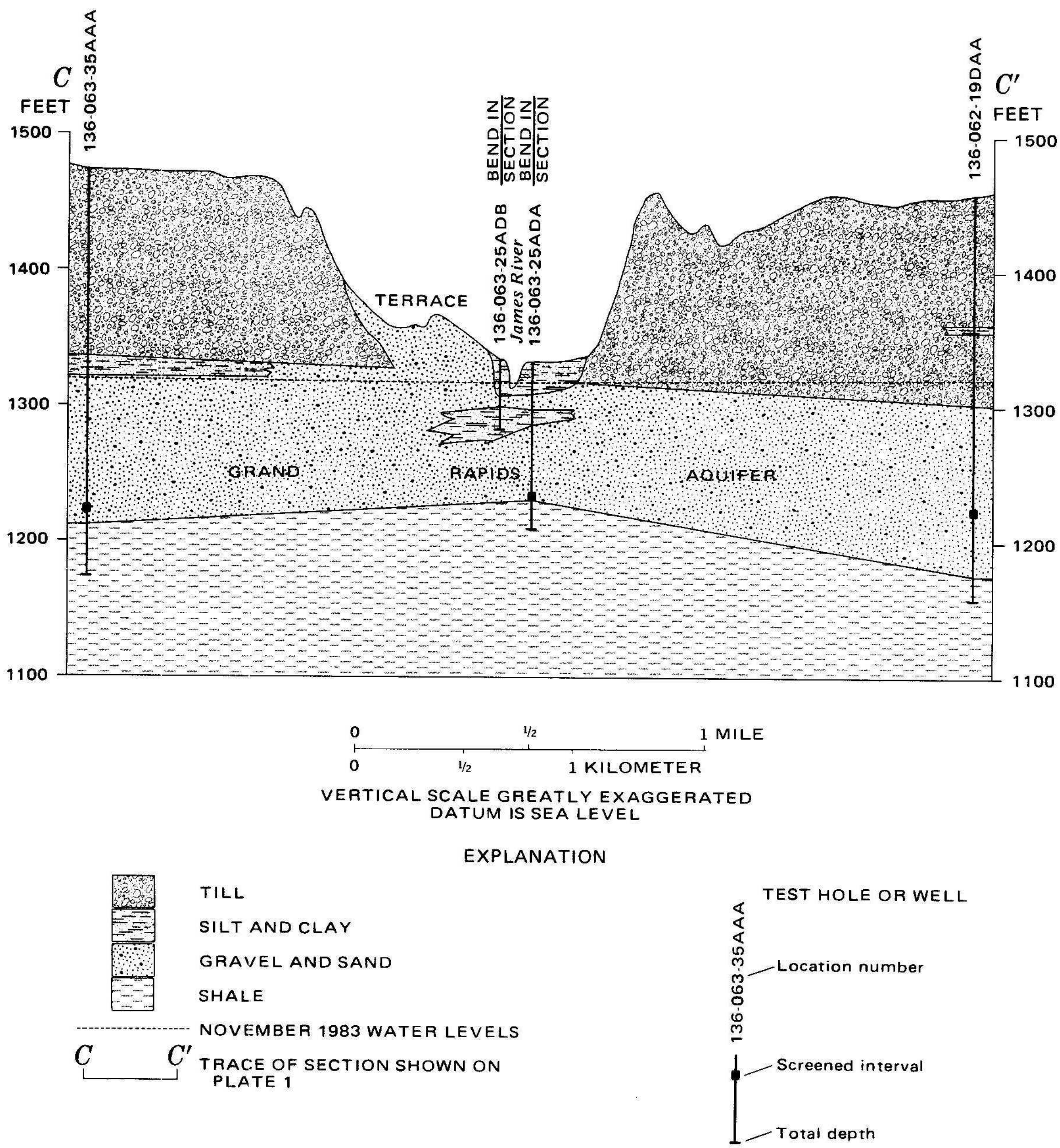


Figure 7.—Hydrogeologic section C-C′ of the Grand Rapids aquifer of the Spiritwood aquifer system below Adrian.

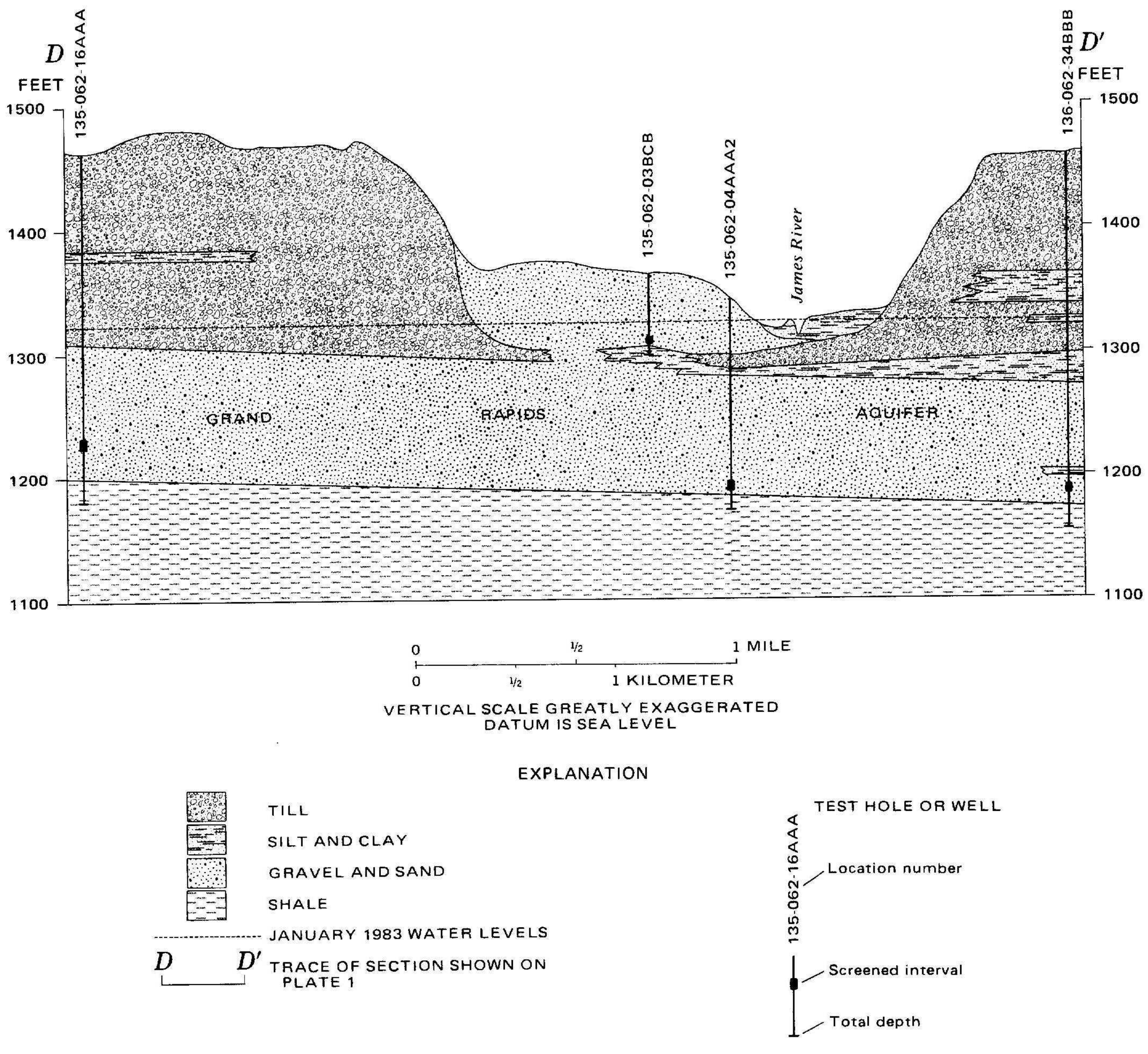


Figure 8.—Hydrogeologic section D-D′ of the Grand Rapids aquifer of the Spiritwood aquifer system at Dickey.

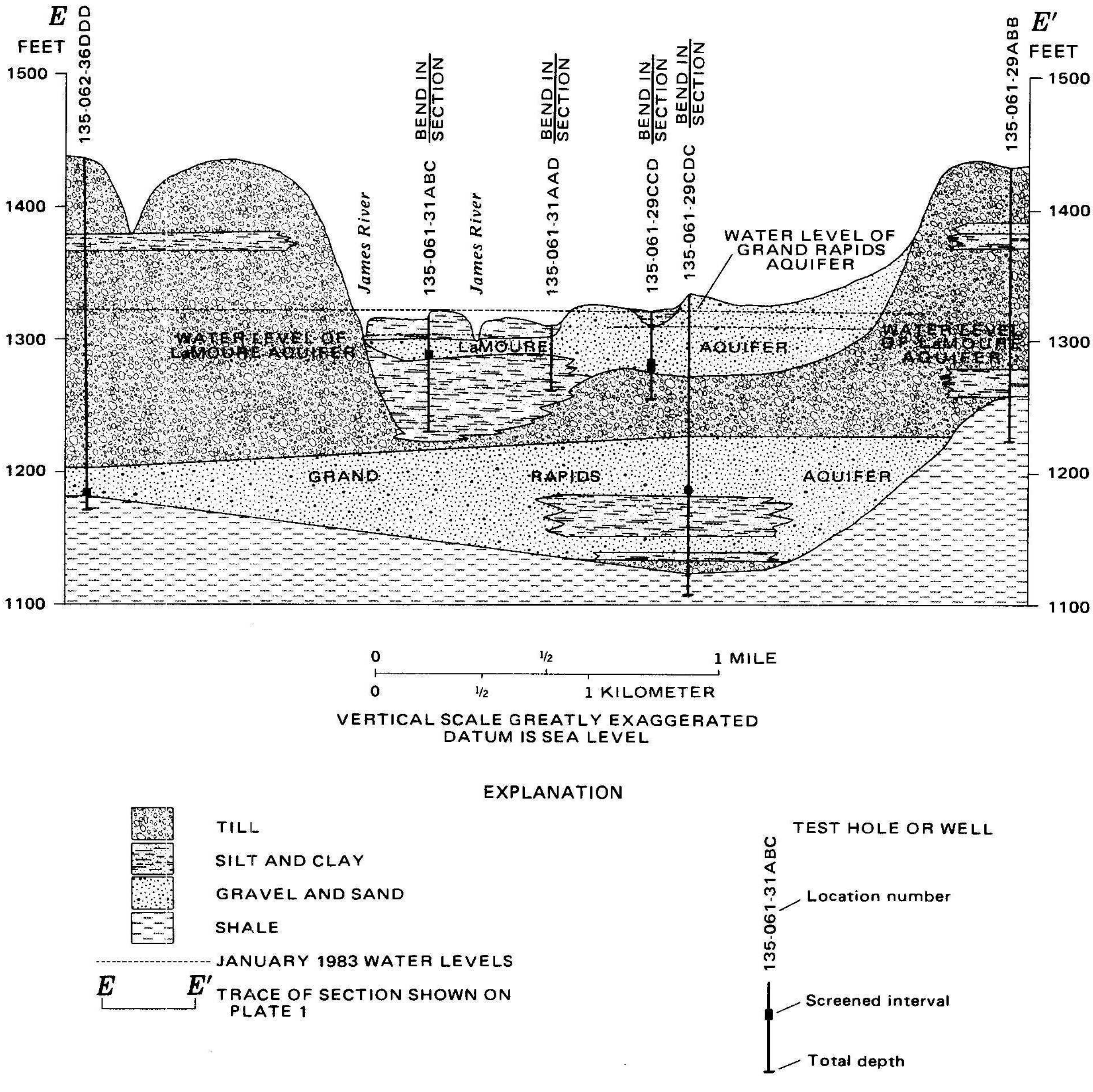
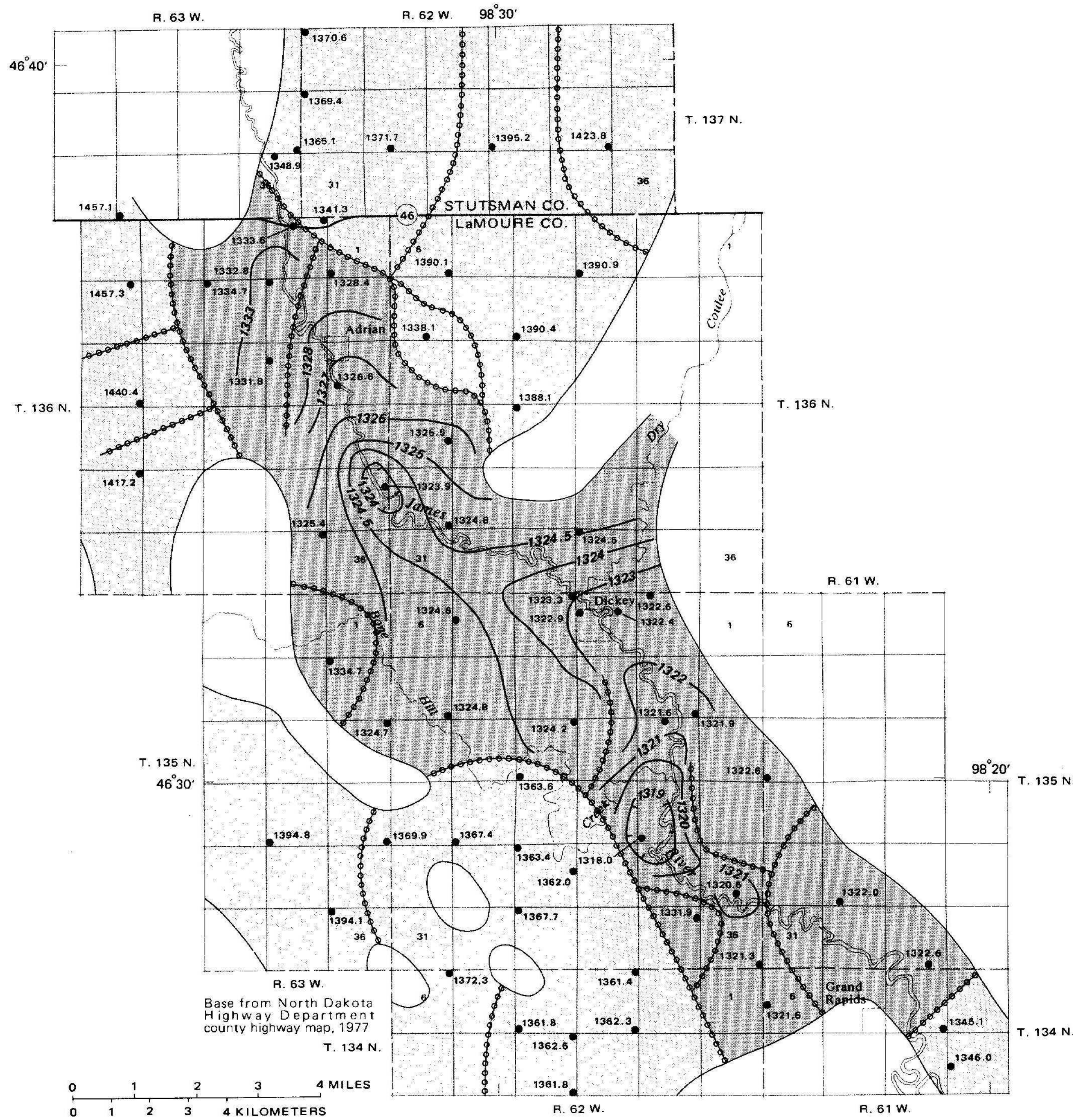


Figure 9.—Hydrogeologic section E-E' of the Grand Rapids aquifer of the Spiritwood aquifer system and LaMoure aquifer above Grand Rapids.



EXPLANATION

SPIRITWOOD AQUIFER SYSTEM

GRAND RAPIDS AQUIFER

OTHER AQUIFERS

AQUIFER BOUNDARY

1320 / 1319 POTENTIOMETRIC CONTOUR—Shows altitude at which water level would have stood in tightly cased wells, December 1983. Contour interval 0.5 and 1 foot. Hachures indicate depression contours. Datum is sea level

TRANSMISSIVITY BOUNDARY

1361.8 OBSERVATION WELL—Number is altitude of potentiometric surface, in feet. Datum is sea level

Figure 10.—Potentiometric surface of the Grand Rapids aquifer of the Spiritwood aquifer system, December 1983.

the James River. Water levels beneath terraces are about 15 to 50 ft below land surface. Water levels in the Grand Rapids aquifer often are about 10 to 20 ft higher than water levels in the LaMoure aquifer (fig. 9).

In addition to that derived from precipitation and snowmelt, recharge to the Grand Rapids aquifer is from ground-water movement from the other aquifers of the Spiritwood aquifer system, discharge from the Ypsilanti aquifer, and locally high flows in the James River (bank storage). Recharge from infiltration to the Grand Rapids aquifer probably is greater beneath terraces in the James River valley from the Stutsman-LaMoure county line to Dickey than beneath the glaciated plain because the terraces are composed mostly of permeable sand and gravel. Discharge from the Grand Rapids aquifer is by pumpage, by leakage through intervening glacial drift into the LaMoure aquifer, by leakage into the James River, and by evapotranspiration in the flood plain of the James River. The aquifer also may discharge into Bone Hill Creek near the mouth of the creek at the James River. Numerous springs and seeps occur along the James River from the Stutsman-LaMoure county line downstream to Dickey.

An aquifer test was performed in the Grand Rapids aquifer (135-061-30BDD in table 2). Additional information on the hydraulic characteristics of the aquifer is provided by two irrigation wells completed in the aquifer that yield water at a rate of 800 to 1,300 gal/min.

For most aquifers and aquifer systems, the available data are insufficient for the estimation of a water budget. However, there are sufficient data to estimate a budget for the Grand Rapids aquifer. On the basis of work by Shaver (1984), the North Dakota State Water Commission has estimated that the net recharge-evapotranspiration balance for the South aquifer of the Spiritwood aquifer system near Oakes is about 0.5 in/yr. Based on an area of 60 mi^2 for the Grand Rapids aquifer, about 1,600 acre-ft of water per year enters the aquifer. If the Grand Rapids aquifer discharges 5 ft^3/s to the James River, the aquifer discharges about 3,600 acre-ft/yr through seepage to the river. In 1983, an additional 200 acre-ft was withdrawn by pumping, resulting in a total outflow from the Grand Rapids aquifer of about 3,800 acre-ft/yr. Therefore, about 2,200 acre-ft/yr of water enters the aquifer from adjacent aquifers of the Spiritwood aquifer system.

Water-quality characteristics of the Grand Rapids aquifer are shown in table 3. Water-quality data from three sets of adjacent observation wells located on the floor of the James River valley indicate a decrease of about 20 percent in concentrations of dissolved solids, sodium, and chloride from the base of the aquifer upwards. The decrease suggests that a shallow flow system overlies a deeper flow system in the James River valley.

South aquifer

The South aquifer of the Spiritwood aquifer system is located east of the James River in the southeastern part of the study area (fig. 3), and does not interact with the James River. The South aquifer probably lies beneath the LaMoure aquifer in parts of 134-061. The South aquifer and the LaMoure aquifer are separated by glacial drift. The water levels in the South aquifer are about 30 to 50 ft above the water levels in the LaMoure aquifer. The South aquifer also lies beneath part of the Oakes aquifer. Locally, near Oakes, the deposits of the South aquifer and the Oakes aquifer are contiguous, but generally the aquifers are separated by variable thicknesses of till, silt, and clay. Discharge from the South aquifer primarily is by pumpage and by ground-water movement downgradient into Sargent County. The South aquifer also discharges by leakage into the Oakes and LaMoure aquifers and by seepage through overlying glacial till and or silt and clay into Bear Creek.

Homer Aquifer

The Homer aquifer, named by Huxel and Petri (1965), is located south and southeast of Jamestown (fig. 3). The aquifer is about 2 to 4 mi wide, has an area of about 14 mi^2, and occurs in a buried valley. The Pierre Formation and glacial drift underlie the aquifer, and glacial drift overlies the aquifer. The Homer aquifer deposits probably are contiguous with the deposits of the Jamestown aquifer in 139-063-10, where the base of the Homer aquifer is about 5 to 10 ft beneath the floor of the James River valley. The saturated thickness of the aquifer ranges from 0 to 72 ft and averages about 45 ft. Water in the aquifer generally occurs under confined conditions, but locally it is unconfined near the James River valley. Recharge to the aquifer is derived from precipitation and snowmelt that percolates to the aquifer through overlying glacial drift. Discharge from the aquifer is by ground-water movement into the Jamestown aquifer.

A water sample from observation well 139-064-24AAA had a dissolved-solids concentration of 753 mg/L. The major anion was bicarbonate, and the major cation was calcium.

Montpelier Aquifer

The Montpelier aquifer is here named after the nearby community of Montpelier and is located in the southwestern part of Stutsman County (fig. 4). The aquifer ranges from 1 to 2.5 mi in width, is known to have an area of about 23 mi^2, and occurs in a buried valley. Glacial drift generally underlies and overlies the aquifer. The North aquifer of the Spiritwood aquifer system generally lies beneath the Montpelier aquifer and is separated from the Montpelier aquifer by a variable thickness of glacial drift. The deposits of the Montpelier aquifer, however, locally are contiguous with the deposits of the North aquifer in parts of 137-062-01 and 137-062-02 and near the Stutsman-LaMoure county line. The deposits of the Montpelier aquifer are dissected by the James River valley north of Montpelier (fig. 11) where the base of the aquifer is about 25 to 50 ft above the valley floor. Saturated thickness ranges from 0 to about 75 ft and averages about 42 ft. Water in the aquifer generally is confined, but locally it is unconfined near the James River valley.

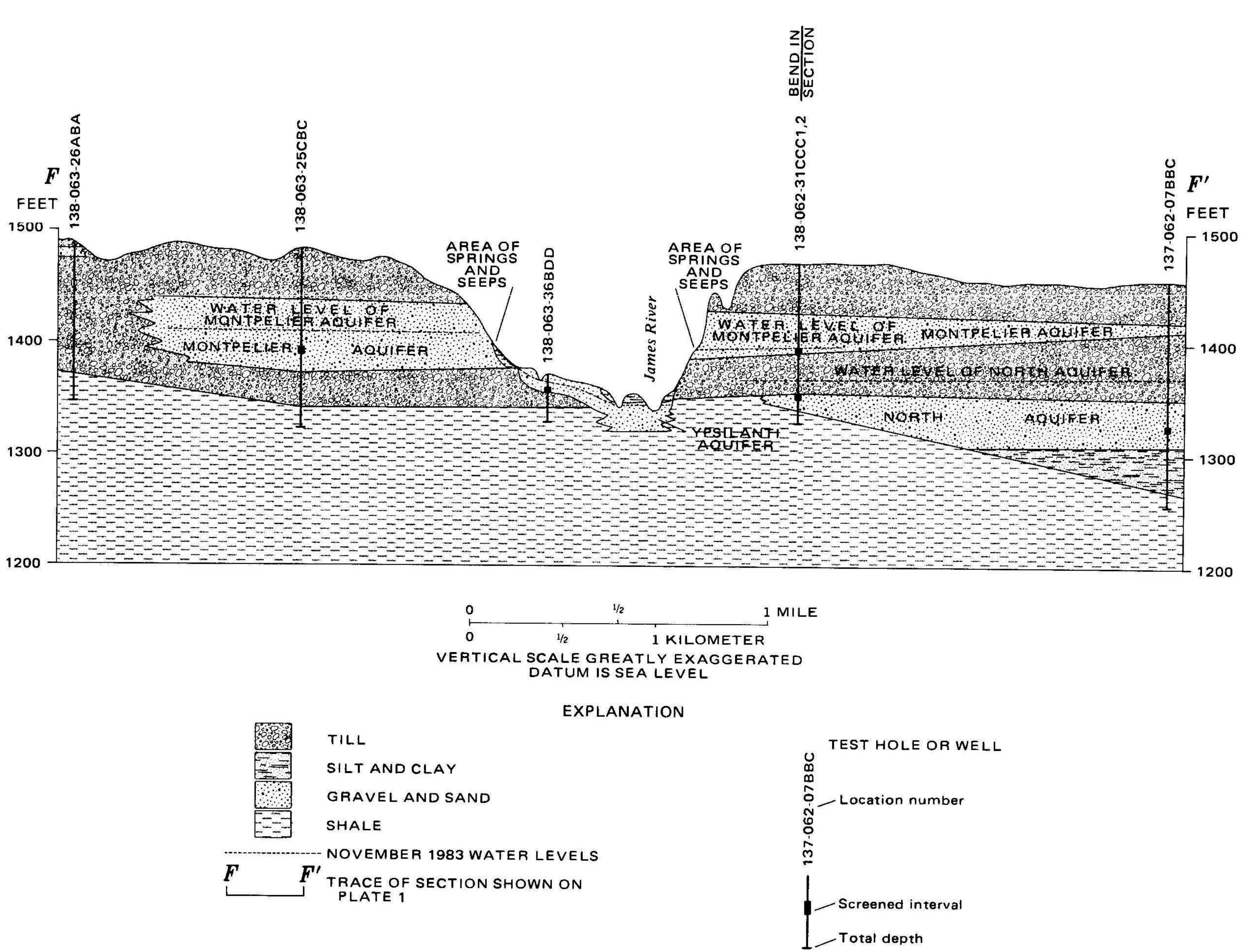


Figure 11.—Hydrogeologic section F-F′ of the North aquifer of the Spiritwood aquifer system, Montpelier aquifer, and Ypsilanti aquifer above Montpelier.

Recharge to the aquifer is derived from precipitation and snowmelt that percolates to the aquifer through overlying glacial drift. Discharge from the aquifer is through seeps and small springs along the valley walls of the James River about 2 mi north of Montpelier and by leakage into the North aquifer. The springs and seeps occur in an area of about 0.5 mi^2 on both sides of the James River valley (fig. 11). A water sample from observation well 138-063-25CBC had a dissolved-solids concentration of 688 mg/L. The major anion was bicarbonate, and the major cation was calcium.

Adrian Aquifer

The Adrian aquifer is here named after the community of Adrian and is located north and east of Adrian (fig. 4). The aquifer is about 1 mi wide, has an area of about 4 mi^2, and occurs in a buried valley. The aquifer is underlain and overlain by glacial drift. The Spiritwood aquifer system lies beneath the Adrian aquifer and is separated from the aquifer by glacial drift. The James River valley is incised through the Adrian aquifer. The base of the aquifer lies about 70 ft above the valley floor of the James River. The thickness of the aquifer deposits at two test sites is 42 and 74 ft. Water in the aquifer is unconfined. Recharge to the aquifer is derived from precipitation and snowmelt that percolates to the aquifer through overlying glacial drift. Discharge from the aquifer is through springs and seeps on the valley wall north of Adrian and by leakage through intervening glacial drift into the Spiritwood aquifer system.

Dickey Aquifer

The Dickey aquifer is here named after the city of Dickey and is located north of the city (fig. 4) beneath the glaciated plain. The aquifer ranges from about 1 to 3 mi in width, has an area of about 8 mi^2, and occurs in a buried valley. Glacial drift overlies and underlies the aquifer. The aquifer locally lies above parts of the Spiritwood aquifer system and is separated from the aquifer system by glacial drift. The Dickey aquifer deposits probably are contemporaneous with the Ellendale aquifer deposits. The James River and Dry Coulee valleys are incised through the Dickey aquifer deposits. The base of the aquifer is about 45 to 50 ft above the valley floor of the James River. Saturated thickness of the aquifer ranges from 0 to 30 ft and averages about 23 ft. Water in the aquifer generally is confined, but locally it is unconfined near the James River and Dry Coulee valleys.

Recharge to the aquifer is derived from precipitation and snowmelt that percolates to the aquifer through overlying glacial drift. Discharge from the aquifer is: (1) By leakage through intervening glacial drift into the Spiritwood aquifer system, (2) through small springs and seeps on the valley walls of the James River, and (3) through small springs and seeps in Dry Coulee.

Ellendale Aquifer

The Ellendale aquifer, named by Naplin (1973), is located west of the James River and extends from Bone Hill Creek to the South Dakota border (fig. 4). The aquifer ranges from 1 to 10 mi in width, has an area of about 150 mi^2, and occurs in a buried valley or on a buried outwash plain. Glacial drift generally underlies and overlies the aquifer deposits. The aquifer lies above parts of the Spiritwood aquifer system and generally is separated from the aquifer system by a variable thickness of glacial drift. The Ellendale aquifer locally is contiguous with the West aquifer and Grand Rapids aquifer of the Spiritwood aquifer system near Bone Hill Creek. The James River valley is incised through the eastern edge of the Ellendale aquifer from Dickey to LaMoure (fig. 12). The base of the aquifer along this reach of the river is about 30 to 50 ft above the valley floor and is higher than the water levels in the nearby LaMoure aquifer. Bone Hill Creek is incised through the aquifer deposits in 135-062. The saturated thickness of the Ellendale aquifer ranges from 0 to about 71 ft and averages about 23 ft. The saturated thickness increases in the Cottonwood Creek area and south of Cottonwood Creek.

Water in the aquifer generally is confined, but locally it is unconfined near the James River valley. A ground-water divide occurs south of Cottonwood Creek (fig. 4). The water levels in the aquifer near the James River valley are about 50 to 70 ft above the water levels in the LaMoure aquifer (fig. 12).

Recharge to the Ellendale aquifer is derived from precipitation and snowmelt that percolates to the aquifer through intervening glacial drift. Discharge from the aquifer is: (1) By pumpage; (2) by leakage into the Spiritwood aquifer system; (3) by flow into the LaMoure aquifer (fig. 12); (4) by seepage into Cottonwood Creek in 133-061-17, 133-061-20, 133-061-21, 133-061-22, and 133-061-24; (5) by seepage into Bone Hill Creek; and (6) by small springs and seeps along the wall of the James River valley in 133-061-13 and 133-061-14.

Water-quality characteristics of the Ellendale aquifer are shown in table 3. Flow from the Ellendale aquifer into the LaMoure aquifer affects the water quality of the LaMoure aquifer west of the James River.

Guelph Aquifer

The Guelph aquifer, named by Armstrong (1980), is located south of the James River in Dickey County (fig. 4). The aquifer ranges from 2 to 4 mi in width and has an area of about 16 mi^2. The aquifer occurs in a buried valley and is dissected by the James River valley. The base of the aquifer is about 10 to 40 ft above the valley floor. Glacial drift underlies and overlies the aquifer deposits. The aquifer deposits consist of sand and gravel interbedded with silt and clay or glacial till. The aggregate saturated thickness of the aquifer ranges from 24 to 53 ft, and averages about 35 ft (Armstrong, 1980, p. 38).

Water in the aquifer generally is confined, but locally it is unconfined near the James River valley. Recharge to the aquifer is derived primarily from precipitation and snowmelt that percolates to the aquifer through overlying glacial drift. Discharge from the aquifer is by pumpage and by several small springs and seeps on the valley wall of the James

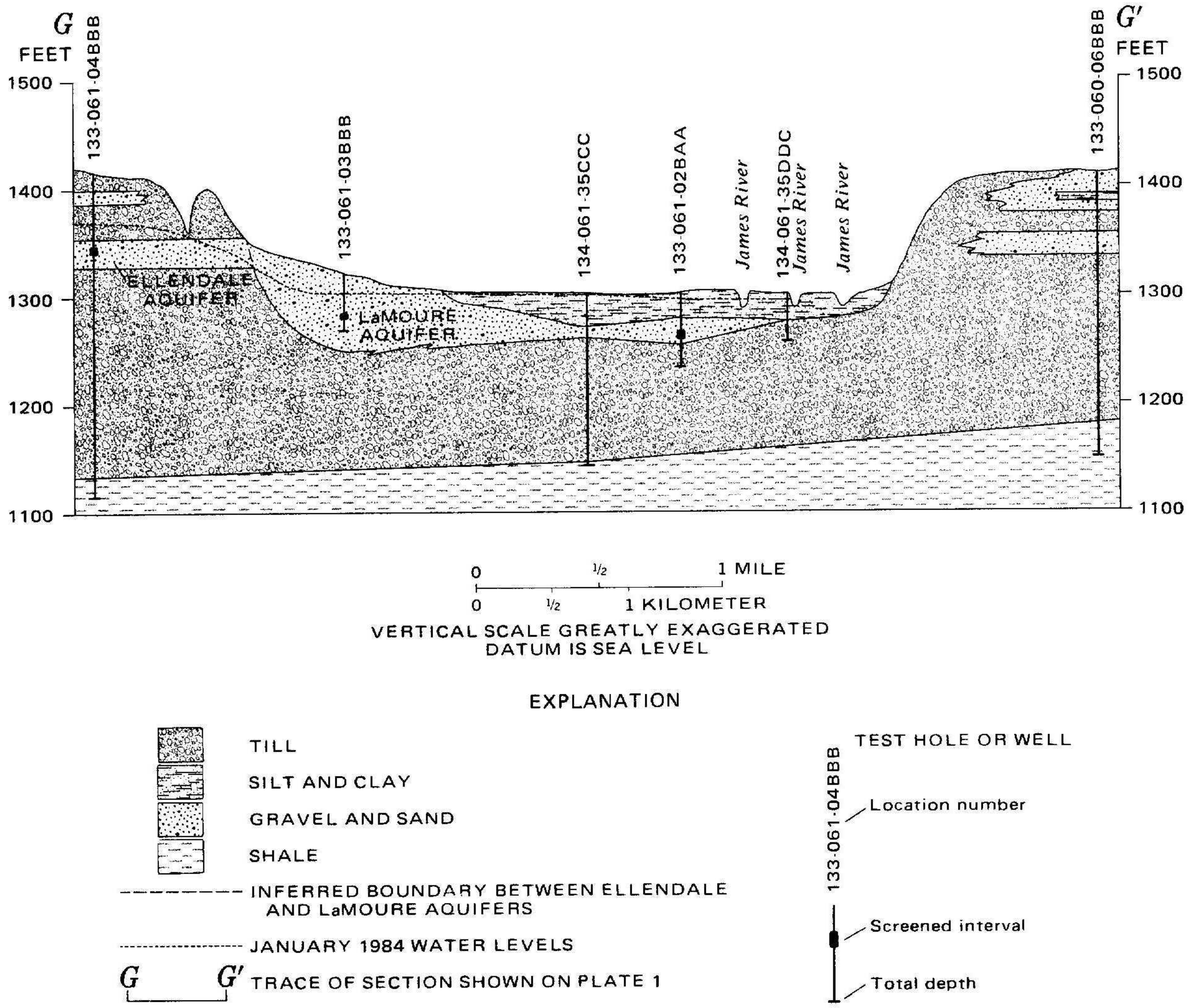


Figure 12.—Hydrogeologic section G-G′ of the Ellendale and LaMoure aquifers above LaMoure.

River in 132-060-32, 132-060-33, and 132-060-34. Water-quality characteristics of the Guelph aquifer are shown in table 3.

Oakes Aquifer

The Oakes aquifer, named by Armstrong (1980), is located beneath the Lake Dakota plain east of the James River in the southern part of the study area (fig. 4). The aquifer ranges from about 1 to 8 mi in width, has an area of about 122 mi^2, and is underlain by glacial drift. The Oakes aquifer generally is exposed at the surface; however, glacial drift overlies the northernmost part of the aquifer, and alluvial deposits, composed mostly of silt and clay, overlie the aquifer deposits in the flood plain of the James River. The Oakes aquifer is contiguous with the south unit of the LaMoure aquifer. The aquifer is comprised of sand and gravel deposited in melt-water channels and in deltaic and glaciolacustrine environments. Driller's logs and test-hole data indicate that the aggregate saturated thickness of sand and gravel in the aquifer ranges from about 2 to 99 ft and averages about 30 ft (Armstrong, 1980, p. 39).

Water in the Oakes aquifer generally is unconfined, but locally it is confined. Due to the low relief and hummocky topography of the Lake Dakota plain, the aquifer contains numerous local flow systems controlled by local depressions. A prominent zone of lower transmissivity divides the aquifer into two units--the west unit and the east unit. Water-level altitudes in the west unit are about 5 to 15 ft lower than those in the east unit.

Recharge to the Oakes aquifer is derived mainly from precipitation and snowmelt that percolates to the aquifer. Other sources of recharge are ground-water movement from the South aquifer of the Spiritwood aquifer system and from the south unit of the LaMoure aquifer.

West unit of the Oakes aquifer

The west unit of the Oakes aquifer underlies the James River and the lower reach of Bear Creek (fig. 4). The west unit ranges from 0.5 to 5 mi in width and has an area of about 29 mi^2. The deposits of the west unit generally are much finer grained than those of the east unit and consist mostly of fine sand interbedded with silt and clay. Water in the west unit generally is confined by a variable thickness of silt and clay. In addition to rainfall and snowmelt, sources of recharge to the west unit are the return flow of irrigation water pumped from the James River and high flows in the James River. Discharge from the west unit mainly is by evapotranspiration in local depressions. Some discharge may occur as general leakage to the James River during low-flow periods. Water-quality characteristics are shown in table 3.

East unit of the Oakes aquifer

The east unit of the Oakes aquifer is located east of the James River and Bear Creek (fig. 4). Discharge from the aquifer mainly is by pumpage and by evapotranspiration. Irrigation wells yield 50 to about 1,600 gal/min. The wide yield range is due to variation in the saturated thickness and hydraulic conductivity of the aquifer deposits.

James River Aquifer System

The James River aquifer system is located in the James River valley from the northern end of the study area to near Oakes (fig. 4) and in the valleys of Pipestem Creek and Seven Mile Coulee. The aquifer system ranges from 0.25 to 2.5 mi in width, has an area of about 66 mi^2, and occurs in a drainage system incised into the glacial drift. The aquifer system generally is exposed at the surface except beneath the flood plains of the James River, Pipestem Creek, and Seven Mile Coulee, where the aquifer system generally is overlain by silt and clay deposits of glaciofluvial, glaciolacustrine, or alluvial origin. The thickness of the silt and clay deposits is variable.

The aquifer system consists of glaciofluvial sand and gravel deposits and of overlying alluvial sand deposits beneath the flood plains of the James River, Pipestem Creek, and Seven Mile Coulee. The alluvial sand deposits only locally are contiguous with the older glaciofluvial deposits of the aquifer system from Dickey downstream to near Oakes. The saturated thickness of the aquifer system ranges from 0 to about 120 ft.

Water in the aquifer system generally is unconfined, but locally it is confined beneath the flood plains of the James River and Pipestem Creek. The potentiometric surface of the aquifer system slopes toward streams, steepening locally in zones of low transmissivity.

Recharge to the aquifer system is derived mainly from precipitation and snowmelt that percolates into the aquifer system. Another source of recharge is leakage from adjacent glacial drift. Discharge from the aquifer system is: (1) By seepage into streams, (2) by evapotranspiration in the flood plains of streams and in the topographically low areas of terraces where the water table is close to the surface, and (3) through springs and seeps. Irrigation and municipal wells yield about 250 to 1,350 gal/min. The aquifer system, in this report, is divided into the Jamestown aquifer, Seven Mile Coulee aquifer, Ypsilanti aquifer, and LaMoure aquifer.

Jamestown aquifer

The Jamestown aquifer, named by Huxel and Petri (1965), is located in the valleys of the James River, Pipestem Creek, and Seven Mile Coulee in the northern part of the study area (fig. 4). The aquifer ranges in width from 0.25 to 1.5 mi and has an area of about 9 mi^2. The aquifer is underlain by the Pierre Formation or glacial drift. The silt and clay deposits overlying the Jamestown aquifer in the flood plain of the James River range from 0 to about 20 ft in thickness and average about 10 ft. A large difference in water levels of the Jamestown aquifer and the Seven Mile Coulee aquifer is caused by a zone of lower transmissivity in 139-062-06. This zone is characterized by a thinning of the aquifer deposits. Near this zone, the water levels in the Jamestown aquifer are about 20 ft lower than those in Seven Mile Coulee aquifer. The Jamestown aquifer apparently pinches out or is contiguous with the Ypsilanti aquifer in 139-063-25.

The saturated thickness of the aquifer ranges from 0 to about 78 ft and averages about 30 ft. The saturated thickness of the aquifer is greatest near Jamestown and thins and narrows downstream in the James River valley. The depth to water ranges from about 2 ft below land surface locally in the flood plain of the James River to about 40 ft beneath terraces.

In addition to rainfall and snowmelt, sources of recharge to the Jamestown aquifer are: (1) Ground-water movement from the Pierre, Midway, Homer, and Seven Mile Coulee aquifers; (2) return flow of water pumped from the James River and from irrigation and municipal wells; and (3) high flows in the James River and Pipestem Creek. Discharge from the Jamestown aquifer primarily is through pumpage. Water-quality characteristics are shown in table 3.

Seven Mile Coulee aquifer

The Seven Mile Coulee aquifer, named by Huxel and Petri (1965), is located in Seven Mile Coulee northward from 139-062-06 (fig. 4). The aquifer ranges from 0.5 to 1 mi in width and has an area of about 4 mi^2. The aquifer is underlain by the Pierre Formation or glacial drift. The silt and clay deposits overlying the aquifer in the flood plain of Seven Mile Coulee generally are less than 5 ft thick.

The saturated thickness of the Seven Mile Coulee aquifer is quite variable and ranges from 0 to about 70 ft. The saturated thickness of the aquifer is least near the stream channel in Seven Mile Coulee in 140-062-30 and 140-062-31. Water levels range from near land surface in the narrow flood plain of Seven Mile Coulee to about 25 ft or more below land surface beneath terraces.

In addition to rainfall and snowmelt, recharge sources to the Seven Mile Coulee aquifer are leakage from the bedrock Pierre aquifer and the Midway aquifer and possibly from return flow of irrigation water pumped from wells. Discharge from the Seven Mile Coulee aquifer primarily is by pumpage and by evapotranspiration. Discharge also occurs by ground-water movement to the Jamestown aquifer, through leakage into the stream channel in Seven Mile Coulee, and through small seeps and springs located in 139-062-06B. Water-quality characteristics of the Seven Mile Coulee aquifer are shown in table 3.

Ypsilanti aquifer

The Ypsilanti aquifer is here named after the town of Ypsilanti and is located in the James River valley from 139-063-25 downstream to near the Stutsman-LaMoure county line (fig. 4). The aquifer ranges from 0.3 to 0.8 mi in width, but generally is 0.5 mi or less in width. The aquifer has an area of about 8 mi^2. The aquifer generally is underlain by the Pierre Formation but locally is underlain by glacial drift at Ypsilanti, in

138-063-36B, and near the Stutsman-LaMoure county line. The silt and clay overlying the Ypsilanti aquifer in the flood plain of the James River ranges from 0 to about 22 ft in thickness and averages about 10 ft.

In the reach from the Stutsman-LaMoure county line downstream to near Dickey, deposits that are contemporaneous with deposits of the Ypsilanti aquifer generally are contiguous with the deposits of the underlying Grand Rapids aquifer of the Spiritwood aquifer system (fig. 8). In this reach, these deposits are considered as part of the Grand Rapids aquifer. Deposits contemporaneous with deposits of the Ypsilanti aquifer are absent or unsaturated from near Dickey downstream to the junction of the James River and Bone Hill Creek.

The saturated thickness of the Ypsilanti aquifer ranges from 0 to about 45 ft and averages about 18 ft. The saturated thickness of the aquifer is greatest at Ypsilanti and least beneath a terrace at Montpelier. Water levels beneath the flood plain of the James River range from about 4 to 15 ft below land surface. Water levels beneath terraces may be 30 ft or more below land surface.

In addition to rainfall and snowmelt, sources of recharge to the Ypsilanti aquifer are: (1) Discharge from the bedrock Pierre aquifer, (2) flow from the Montpelier aquifer, (3) leakage from the North aquifer of the Spiritwood aquifer system, and (4) high flows in the James River. Discharge from the Ypsilanti aquifer is through ground-water movement to the Grand Rapids aquifer of the Spiritwood aquifer system, evapotranspiration, and leakage into the James River. A large spring, often flowing at more than 20 gal/min, issues from the Ypsilanti aquifer in 138-063-36DB. Water-quality characteristics of the Ypsilanti aquifer are shown in table 3.

LaMoure aquifer

The LaMoure aquifer, named by Armstrong (1980), is located in the James River valley from the junction of the James River and Bone Hill Creek downstream to near Oakes (fig. 4). The aquifer ranges from 0.5 to 2.5 mi in width and has an area of about 45 mi^2. The aquifer generally is underlain by glacial drift but locally is underlain by the Niobrara Formation in Dickey County. The thickness of the silt and clay deposits overlying the aquifer beneath the flood plain of the James River ranges from 0 to about 104 ft and averages about 32 ft. The thickness of the overlying silt and clay deposits generally increases in a downstream direction (figs. 13 and 14).

The LaMoure aquifer is composed mostly of glaciofluvial sand and gravel deposits. Alluvial sand deposits that overlie the glaciofluvial sand and gravel deposits are discontinuous and in many cases are separated from the glaciofluvial sand and gravel deposits by silt and clay. In Dickey County, the proportion of fine- to medium-grained sand in the aquifer deposits is significantly larger than the proportion of coarse sand and gravel. Coarser deposits occur towards the base of the aquifer, and boulders and cobbles are common at the base of the aquifer. The

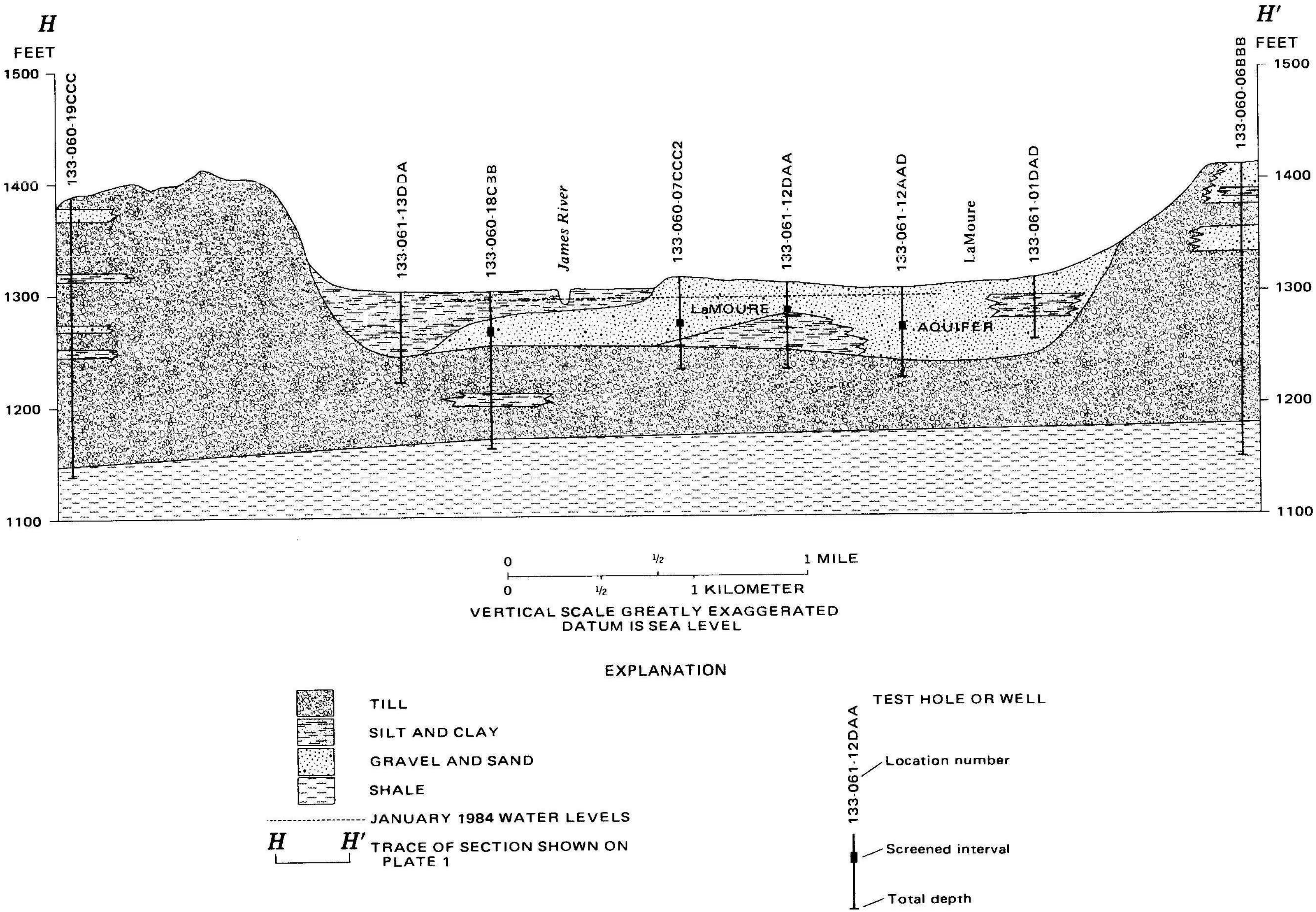


Figure 13.—Hydrogeologic section H-H' of the LaMoure aquifer at LaMoure.

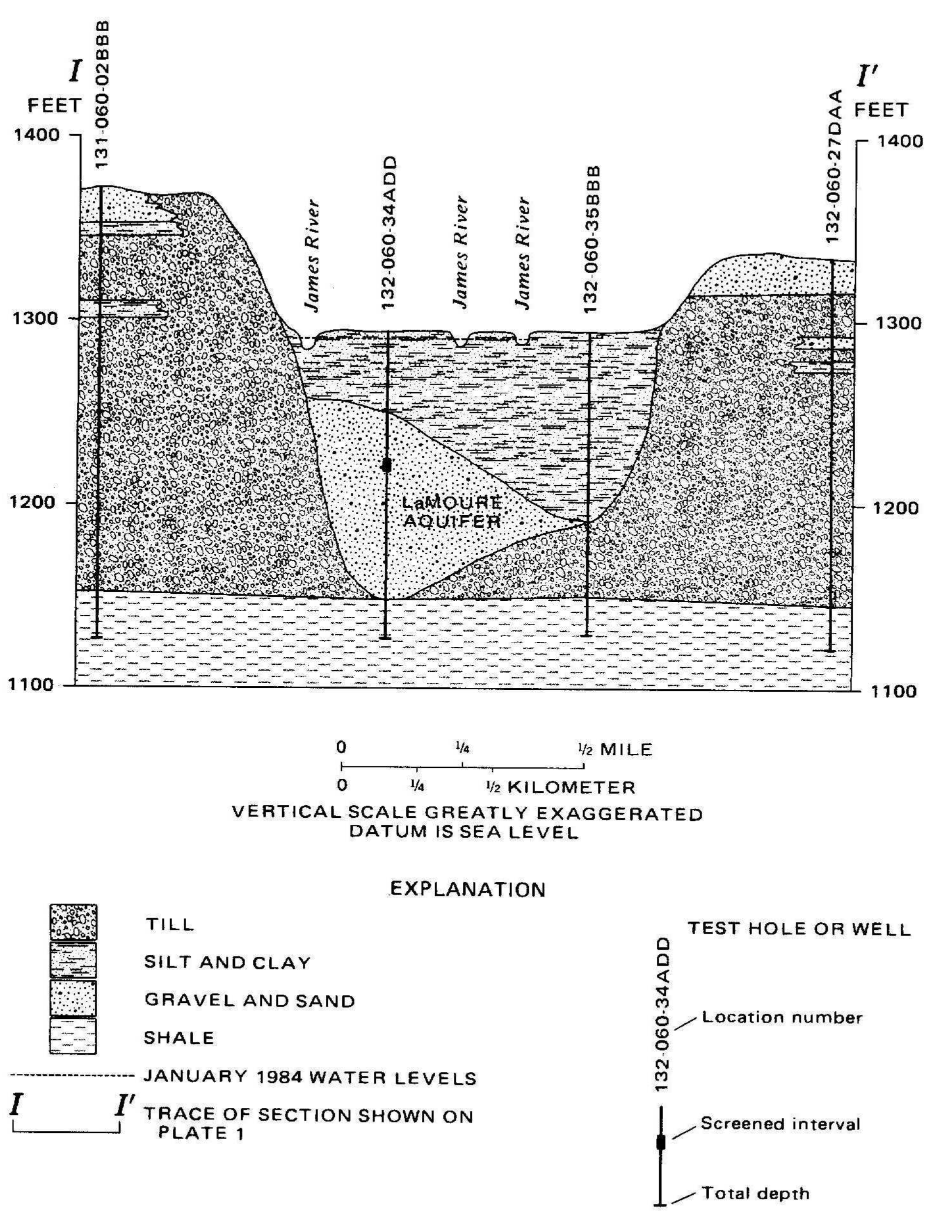


Figure 14.—Hydrogeologic section I-I′ of the LaMoure aquifer above Oakes.

saturated thickness of the LaMoure aquifer ranges from 0 to about 120 ft and averages about 40 ft. The saturated thickness generally is greatest beneath terraces and locally beneath the flood plain in Dickey County. An anomalous saturated thickness of 155 ft occurs at test hole 132-060-23ADD where the aquifer is contiguous with an underlying undifferentiated glacial-drift aquifer.

Water levels beneath terraces range from about 10 to 50 ft below land surface. Water levels beneath the flood plain of the James River range from 2 to 10 ft below land surface in LaMoure County and from about 5 ft below land surface to about 3 ft above land surface in Dickey County.

Water-quality characteristics of the LaMoure aquifer are shown in table 3. Adjacent observation wells 133-060-21CAA1 and 133-060-21CAA2 are located about 50 ft from the James River. The screens are separated by a vertical distance of 24 ft. Water-quality data from the two wells indicate a decrease in dissolved-solids concentration, sodium, sulfate, and chloride from the base of the aquifer upwards.

In this report, the LaMoure aquifer is divided into three units; the north unit, the central unit, and the south unit. The reason for the division is threefold: (1) For convenience of reference, (2) because of a change in lithology of the deposits that comprise the aquifer, and (3) because of a ground-water divide in the aquifer.

North unit of the LaMoure aquifer.--The north unit of the LaMoure aquifer is located along the James River north of Grand Rapids (fig. 4). The north unit ranges from 0.25 to 1 mi in width and has an area of about 4 mi^2. The north unit is separated from the central unit of the LaMoure aquifer by silt and clay. In addition to rainfall and snowmelt, sources of recharge to the north unit are: (1) Leakage from the Grand Rapids aquifer of the Spiritwood aquifer system, (2) possible return flow of water pumped from irrigation wells, and (3) high flows in the James River. Discharge from the north unit primarily is through pumpage. The north unit also discharges by leakage into the James River in 135-062-25 and 135-062-26.

Central unit of the LaMoure aquifer.--The central unit is located along the James River in Dickey and LaMoure Counties (fig. 4). The central unit ranges from about 0.5 to 2.5 mi in width and has an area of about 30 mi^2. The central unit is separated from the south unit by a ground-water divide. The potentiometric surface of the central unit (fig. 15) slopes towards the James River, steepening locally in zones of low transmissivity. In addition to rainfall and snowmelt, sources of recharge to the central unit are: (1) Flow from the Ellendale aquifer and leakage from the South aquifer of the Spiritwood aquifer system, (2) return flow of water pumped from the James River and from irrigation wells, and (3) high flows in the James River. Discharge from the central unit primarily is through pumpage, although the unit also discharges by leakage into the James River and through springs and seeps in 134-061-05A.

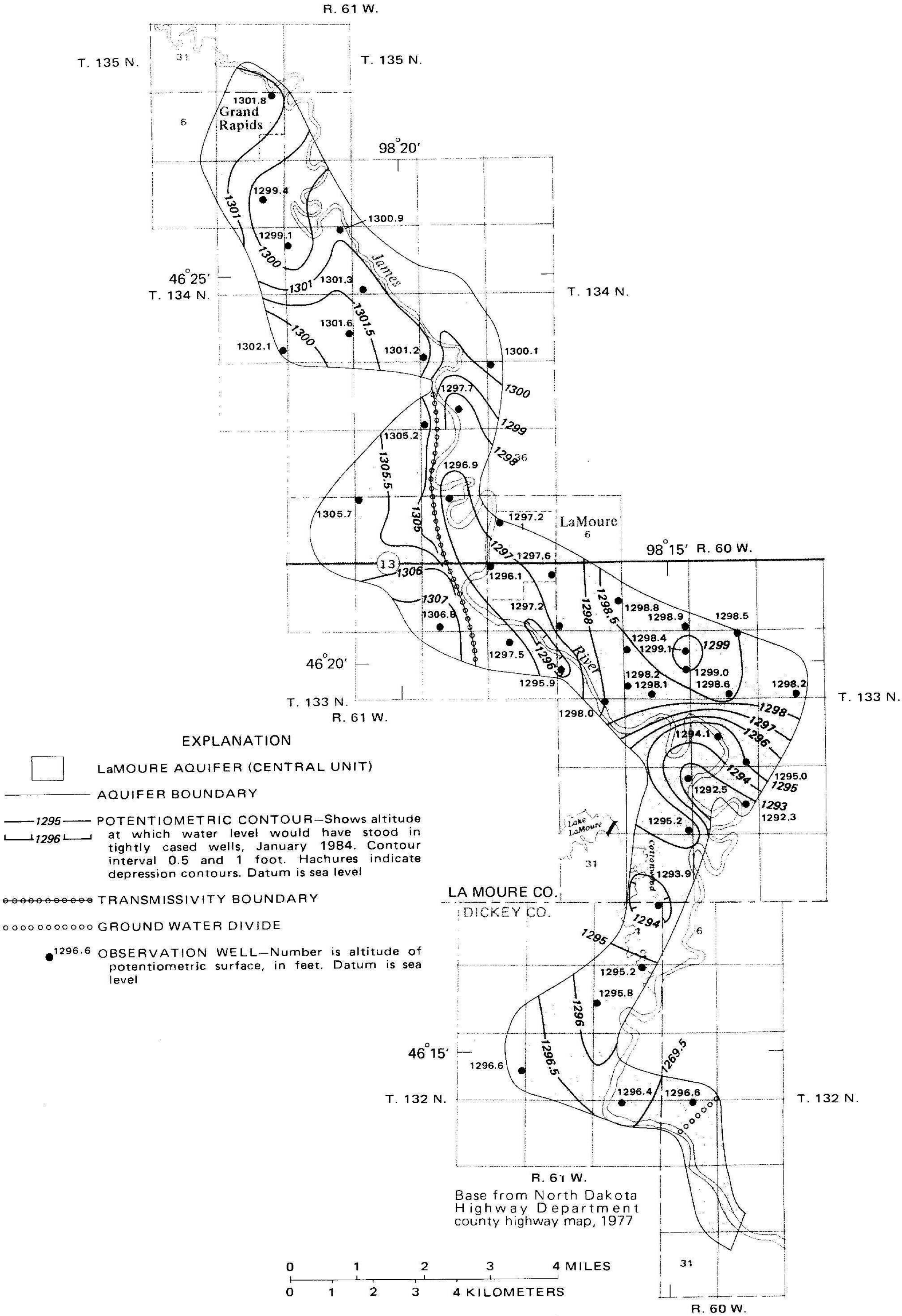


Figure 15.—Potentiometric surface of the central unit of the LaMoure aquifer, January 1984.

An aquifer test was conducted on the central unit of the LaMoure aquifer using irrigation well 133-060-15CAC and six observation wells (R. B. Shaver, North Dakota State Water Commission, written commun., 1976). The irrigation well was pumped for 64.8 hours at an average rate of 924 gal/min. Time-drawdown methods, described by Lohman (1972, p. 34-40), indicated a transmissivity of 101,000 ft^2/d, a mean horizontal hydraulic conductivity of 1,100 ft/d, and a vertical hydraulic conductivity of 241 ft/d. The determined specific yield of 0.10 probably is low because a power failure terminated the test before the effects of delayed yield from storage could be determined.

South unit of the LaMoure aquifer.--The south unit of the LaMoure aquifer is located along the James River in Dickey County (fig. 4). The south unit ranges from 0.5 to 2.5 mi in width and has an area of about 11 mi^2. In addition to rainfall and snowmelt, sources of recharge to the south unit are leakage from the South aquifer of the Spiritwood aquifer system and return flow of water pumped from irrigation wells. Discharge from the south unit of the LaMoure aquifer is primarily by pumpage. The south unit also discharges by ground-water movement to the Oakes aquifer and by seepage through overlying silt and clay into the James River.

Undifferentiated Glacial-Drift Aquifers

Undifferentiated glacial-drift aquifers interspersed with the glacial drift consist of sand and gravel. The aquifers have not been traced beyond the well or test hole where they were encountered. Valleys and coulees in the study area are local discharge areas for these aquifers.

Surface-Water System

The James River originates in Wells County in central North Dakota and follows an easterly and southerly course to the North Dakota-South Dakota State line. The main stem is about 152 mi in length from the basin divide to Jamestown Dam, the upstream end of the present study area (fig. 1). The drainage area at the dam is about 1,760 mi^2. Pipestem Creek, the largest tributary of the James River in North Dakota, joins the river downstream of Jamestown Dam. The creek has a drainage area of about 1,040 mi^2. Pipestem Dam, about 7 mi upstream of the mouth, controls most of the flow in the creek. The combined drainage area of the most upstream gaging station in the study area, James River at Jamestown, is about 2,820 mi^2, of which about 1,650 mi^2 probably is noncontributing. Within the study area, from Jamestown Dam to the North Dakota-South Dakota State line, the James River is about 135 mi long. The drainage area at the State line is about 5,480 mi^2, of which about 3,300 mi^2 probably is noncontributing.

Hydrologic Characteristics

The surface topography of the upper James River basin in North Dakota generally is an undulating plain. Numerous small prairie potholes or glacial depressions characterize the western part of the basin. Shjeflo (1968) and Eisenlohr and others (1972) studied prairie potholes in the central region of North Dakota (Missouri Coteau). Runoff rates in the headwaters of the James River basin are difficult to evaluate because much of the potential drainage area usually does not contribute to streamflow in the basin (Shjeflo, 1968, p. B1).

In the study area, the James River meanders in a shallow valley and flows at a relatively steep slope (about 1.3 ft/mi) from Jamestown to Grand Rapids. Further downstream, the slope of the river decreases significantly (0.1 to 0.3 ft/mi) and the stream flows through a series of long, shallow manmade and natural storages. The James River from just below Oakes to the North Dakota-South Dakota State line flows through the Lake Dakota plain. Within this reach, the river probably loses a significant amount of water to evaporation and transpiration because it is a relatively wide, shallow stream characterized by slow velocities and bordered by a large amount of vegetation.

The James River upstream from Jamestown Reservoir (pl. 1) is an intermittent stream. Downstream from Jamestown and Pipestem Dams, the James River in North Dakota generally is perennial, although periods of no flow can occur. Drainage areas and annual runoff for gaging stations on the James River in the study area are listed in table 4. Because of the many depressional storage areas in the basin, the contributing drainage areas are difficult to determine; therefore, the values given are only approximate. The contributing drainage area is about 1,170 mi^2 at Jamestown and 2,180 mi^2 at the State line. The average annual runoff from the contributing area is 0.7 in., and the areal distribution of runoff is relatively constant within the study area.

In addition to Pipestem Creek, which is a tributary to the James River just upstream of Jamestown, principal tributaries to the James River in the study reach are Seven Mile Coulee, Beaver Creek, Bone Hill Creek, Cottonwood Creek, and Bear Creek (fig. 1). Base flow in all the tributaries is insignificant when compared to base flow in the James River. Only Pipestem Creek, Seven Mile Coulee, Beaver Creek, Bear Creek, and an unnamed tributary fed by a large number of springs 2 mi north of Montpelier have continuous base flow. The combined base flow of these tributaries, excluding Pipestem Creek, is less than 1 ft^3/s. The Lake LaMoure Dam, located on Cottonwood Creek just above the junction of Cottonwood Creek and the James River (fig. 1), controls flow in Cottonwood Creek.

Jamestown Reservoir on the James River and Pipestem Lake on Pipestem Creek provide flood-control protection for the entire study reach (Missouri River Basin Commission, 1980c, p. 7). Flows have been regulated below Jamestown Reservoir (usable storage capacity of 229,470 acre-ft) since 1953. Flows on Pipestem Creek have been regulated below Pipestem Lake (capacity of 147,000 acre-ft) since 1973. Four small reservoirs with low-head dams, located at Jamestown, Ypsilanti, LaMoure, and south of Ludden (fig. 1), create long, shallow storage areas.

The distribution of high flows in the James River is governed largely by climate (especially snowfall, snow distribution, and snowmelt processes), antecedent soil-moisture conditions, physiography, plant cover, and reservoir regulation within the basin. The distribution of low

Table 4.--Drainage area and runoff at gaging stations on the James River in the study area

Location	James River at Jamestown, North Dakota (06470000)[1]	James River at LaMoure, North Dakota (06470500)[1]	James River at Dakota Lake Dam (near State line) (06470875)[1]
Drainage area (square miles)	2,820	4,390	5,480
Noncontributing area (square miles)	1,650	2,600	3,300
Contributing area (square miles)	1,170	1,790	2,180
Average annual runoff (acre-feet)	42,310	66,300	([2])
Average annual runoff from contributing area (inches)	.7	.7	([2])
Period of record used to compute average (water years)	1929-34, 1938-39, 1944-81	1951-81	1982
Length of period (years)	46	31	1

[1]See figure 1 for location of streamflow-gaging station.
[2]Recently installed gage; only preliminary data available.

flows is governed by the geology of the basin and by reservoir regulation. Runoff in the basin occurs as the result of snowmelt, rainfall, or a combination of the two. A large percentage of the annual runoff occurs in the spring because of: (1) The large volume of water available over the entire basin as a result of winter snow accumulation, (2) the spring rains, and (3) the reduced infiltration capacity of frozen soil. Jamestown and Pipestem reservoirs provide significant control of natural flows originating within the basin upstream from the study area.

Examination of hydrographs for water years 1954-81 (the period since the construction of Jamestown Dam) indicates that, with the exception of some winter periods, daily flows of the James River in the study area are extremely variable due to runoff events and reservoir releases. Flow-duration curves (Searcy, 1959), based on a long-term flow record, provide a means of determining the distribution of expected flows. Flow-duration curves for the growing season (May through September) have been developed for the James River at Jamestown and at LaMoure for the period 1954-81 (figs. 16 and 17). Flow-duration curves were developed for Bear Creek for the period 1977-81 (fig. 18). The curves indicate differences in flow characteristics of the two basins. The curves for Bear Creek are based on a much shorter period of record, but the primary reason for the difference in slope is that the flows in Bear Creek are not regulated. The curves for Bear Creek are steeper than those for the James River and indicate highly variable streamflows that respond more quickly to precipitation events than streamflows in the James River.

Flow-duration hydrographs for the James River at Jamestown and at LaMoure for 1954-82 are shown in figures 19 and 20. Flow-duration hydrographs show the percent of time the indicated discharge is equaled or exceeded. The hydrographs are developed in the same manner as the flow-duration curves except that the analysis is done separately for each individual day of the year. The hydrographs show the discharges that are exceeded for each probability on any one day, but do not show the probability of maintaining a flow for periods of longer than 1 day. The zero percent exceedance probability hydrograph shows the largest discharge that has occurred on each day of the year for the 29-year period. The 100 percent exceedance probability hydrograph shows the smallest discharge that has occurred on each day of the year for the 29-year period.

Examples of the interpretation of flow-duration hydrographs for determining flows occurring during the year are as follow. From figure 19, discharges on April 15 can be expected to exceed 15 ft^3/s 80 percent of the time. However, discharges on August 15 can be expected to exceed only 3 ft^3/s 80 percent of the time. Discharges in August have never been smaller than 1 ft^3/s, and discharges in January have never been larger than 45 ft^3/s. Application of the flow-duration hydrographs is similar to application of the flow duration except that the flow-duration curves represent flows analyzed for all days in the month instead of for individual days. Each day on the flow-duration hydrograph is determined by the value for that day for each year of record. Therefore, each day shown on the hydrographs is based on only 28 days of data.

The relatively smooth compression of the flow-duration hydrographs for December through January indicates a uniformly regulated low-flow period. The flow-duration hydrographs for the remaining months indicate a larger variation in flows due to snowmelt, rain, and reservoir releases.

Hydraulic Characteristics

The slope of the James River in the study area changes from relatively steep (about 1.3 ft/mi from Jamestown to Grand Rapids), to relatively flat (about 0.28 ft/mi from Grand Rapids to the LaMoure-Dickey county line), to very flat (about 0.09 ft/mi from the county line to the North Dakota-South

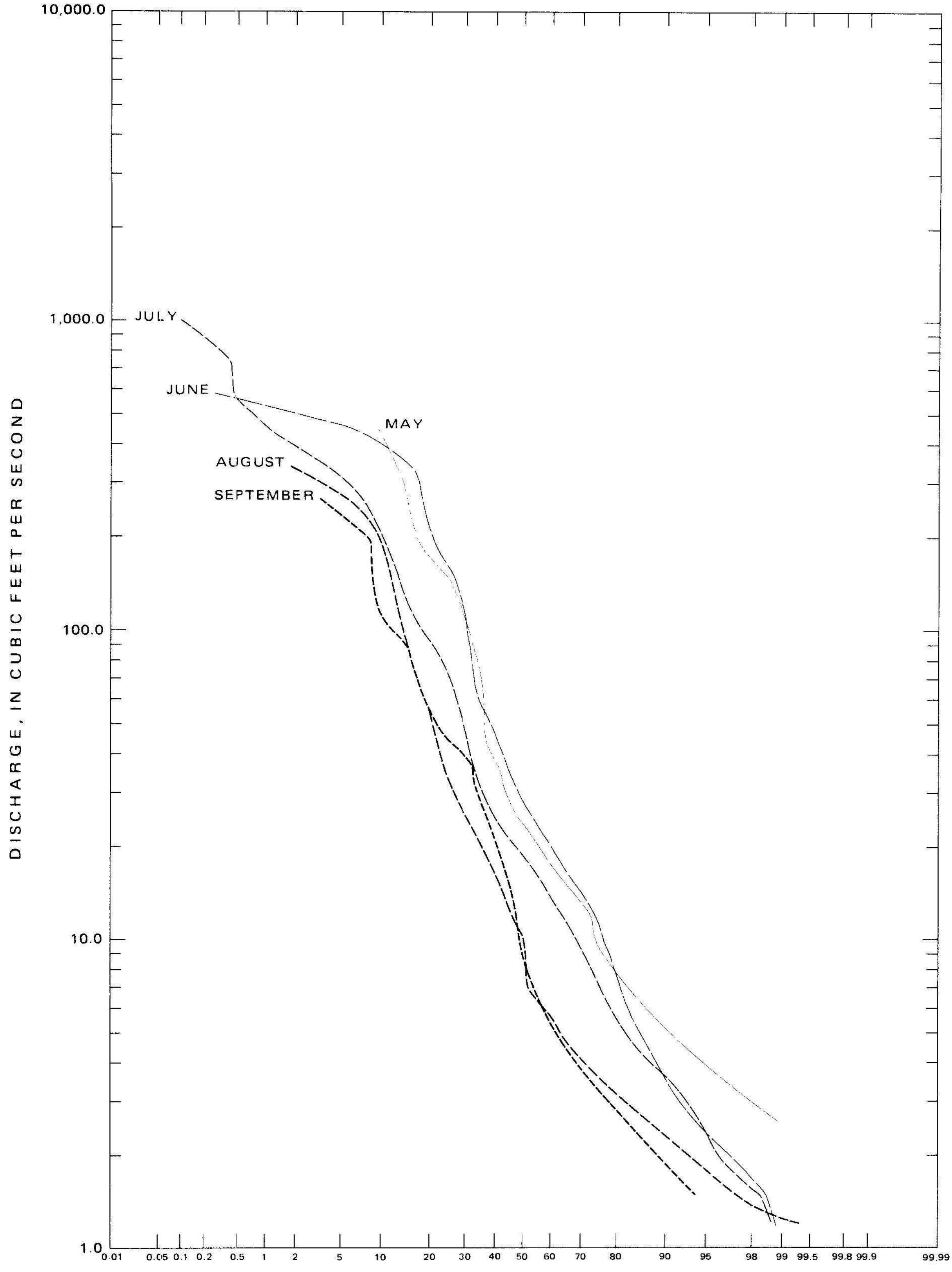


Figure 16.—Flow-duration curves for the James River at Jamestown for May, June, July, August, and September 1954-81.

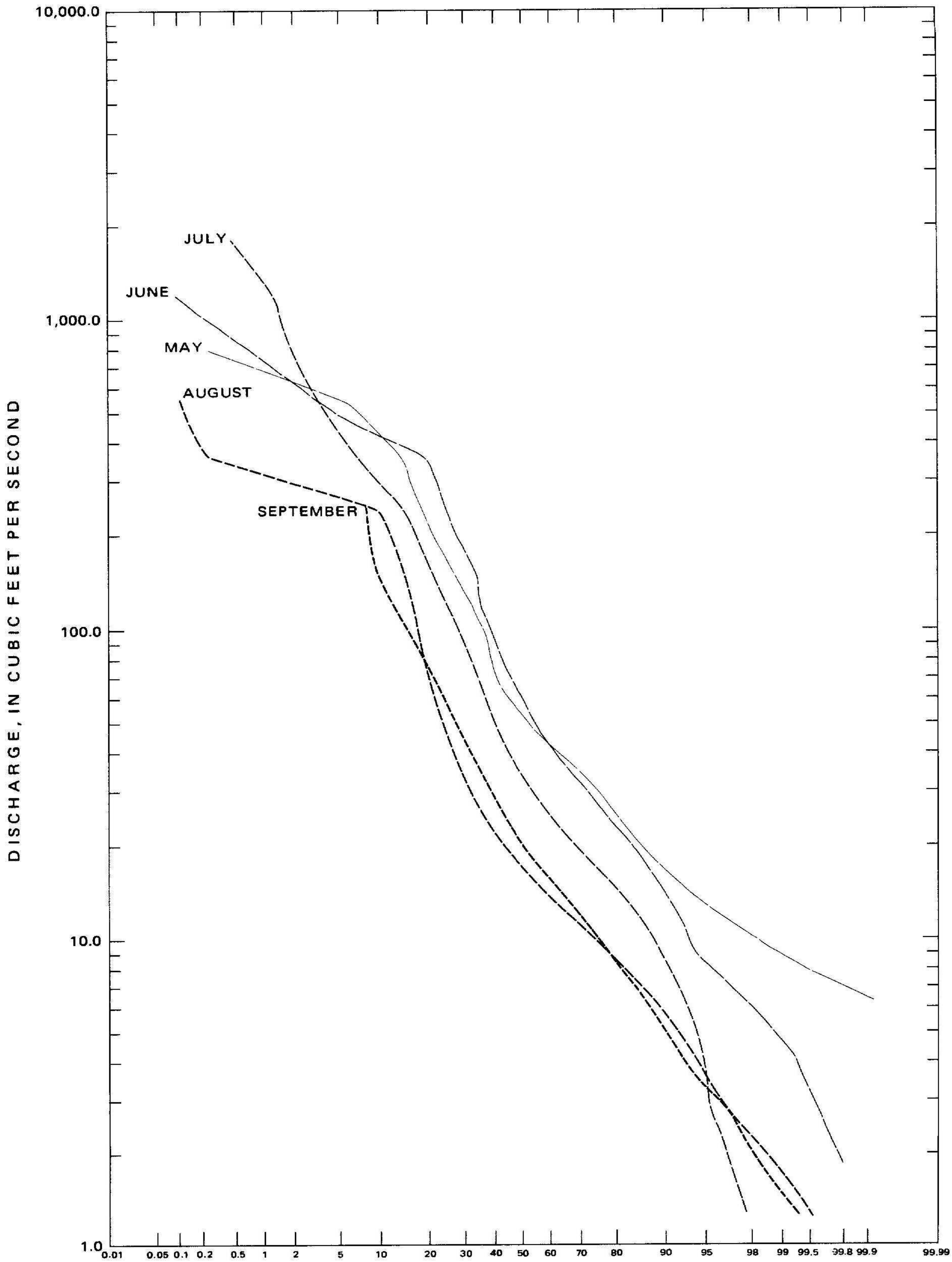


Figure 17.—Flow-duration curves for the James River at LaMoure for May, June, July, August, and September 1954-81.

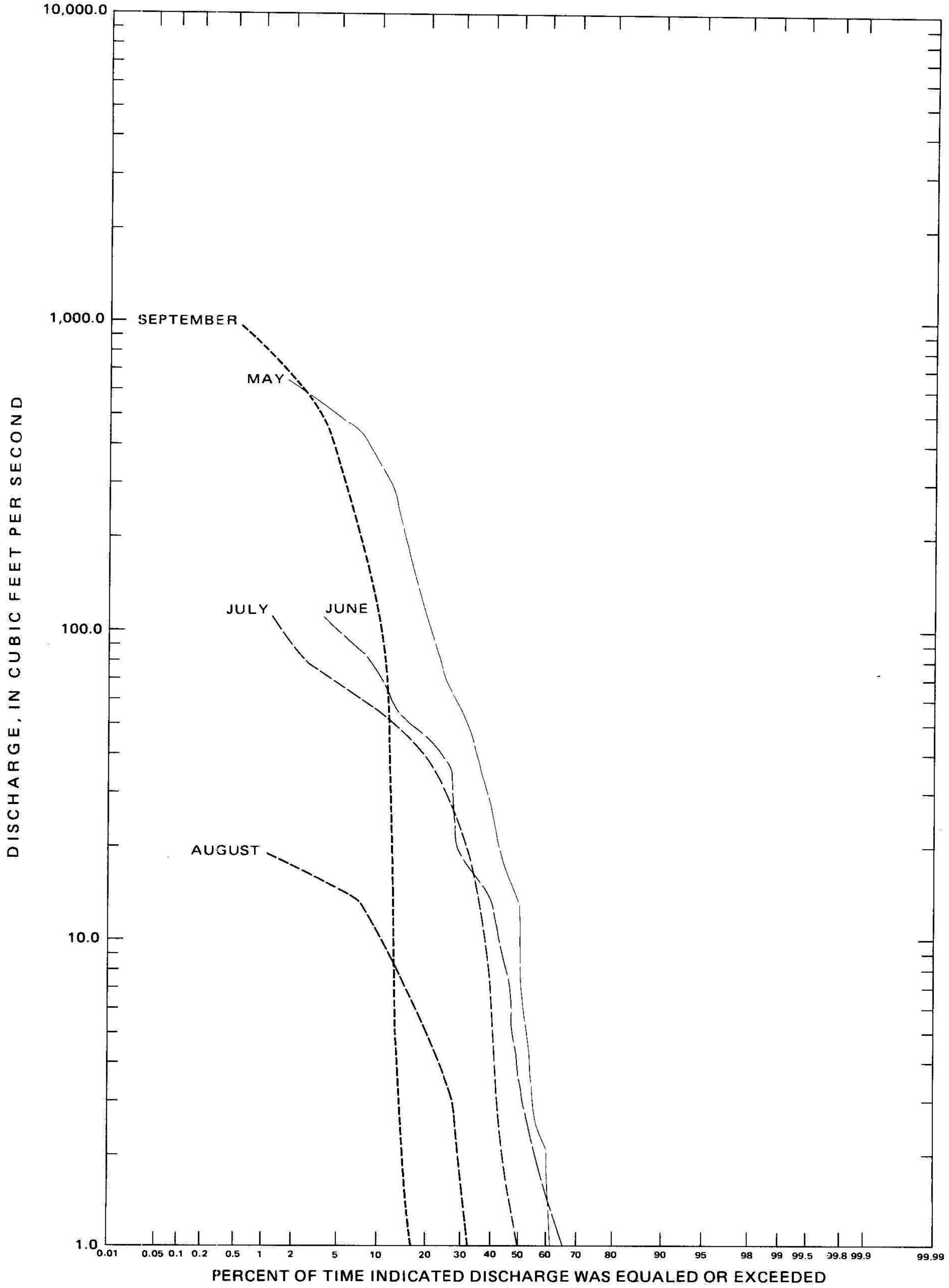


Figure 18.—Flow-duration curves for Bear Creek near Oakes for May, June, July, August, and September 1977-81.

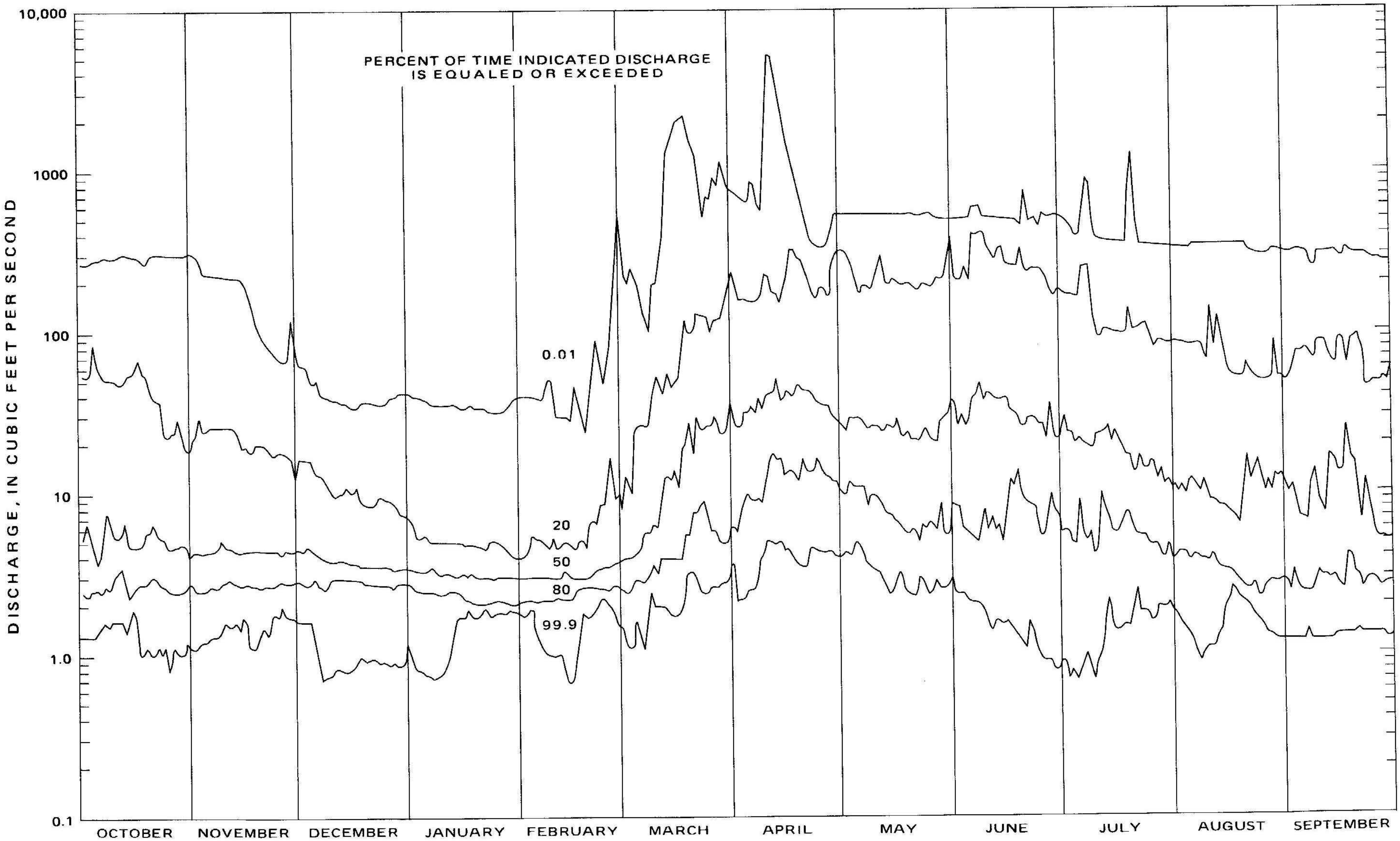


Figure 19.—Flow-duration hydrographs for the James River at Jamestown, 1954-82.

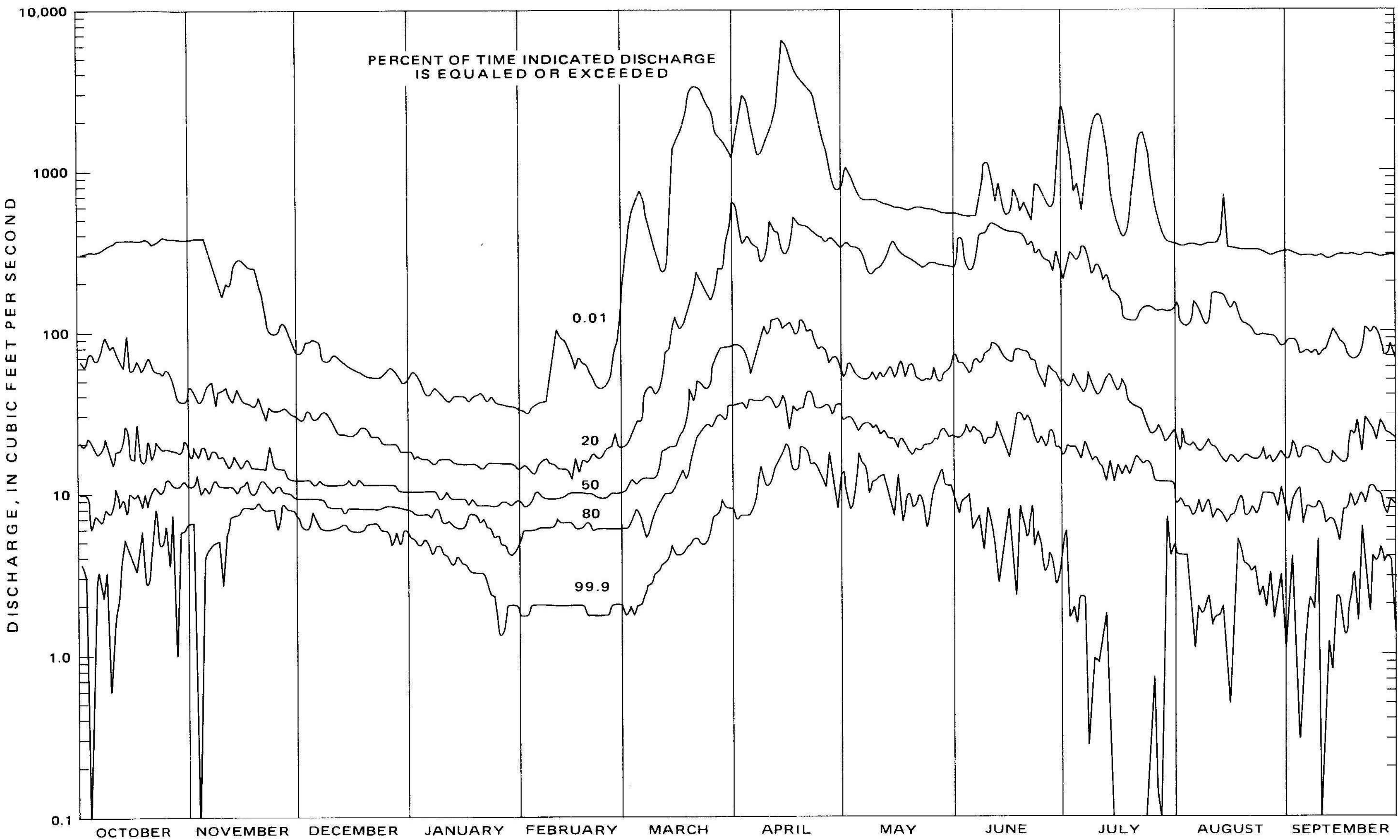


Figure 20.—Flow-duration hydrographs for the James River at LaMoure, 1954-82.

Dakota State line). The James River low-water surface profile as determined from bridge tape-downs and topographic maps is shown in figure 21.

The U.S. Bureau of Reclamation has developed detailed water-surface profiles of the James River from Jamestown to Oakes based on standard step-backwater analyses (Norman A. Roth, U.S. Bureau of Reclamation, written commun., 1971). The analyses provide an estimate of the rating curves at many points along the study reach and show that the stream-channel capacities are about 500 ft^3/s in the upper part of the study area and about 1,800 ft^3/s in the lower part.

According to a study by the U.S. Bureau of Reclamation (Norman A. Roth and Jerrold Gregg, U.S. Bureau of Reclamation, written commun., 1978) and an analysis of kinematic-wave celerities based on rating curves, an increase in discharge superimposed on a relatively steady flow at Jamestown will arrive at LaMoure, a distance of 79.6 river miles, in about 3 days. The period, however, will vary somewhat depending on the rate of increase and range of discharges involved.

Analysis of flows in the James River is particularly difficult because of some of the hydraulic characteristics of the stream channel. The upper reaches of the river in the study area have a relatively steep slope, but the reaches downstream from Grand Rapids have a nearly flat slope characterized by slow velocities, a poorly defined stage-discharge relationship, and a wide, exposed channel that is especially subject to strong wind effects.

Steady flow through a river reach greatly simplifies an analysis of gains and losses along the stream. However, steady flows on the lower James River are difficult to obtain because of highly variable releases from the upstream reservoirs. When releases from the reservoirs are held steady, a long period of time is required to reach a steady-flow condition because of the slow velocities and numerous storage areas.

The residence time (time it would take for a given volume of water to move through the reservoir given the cross-sectional area and velocity) in the storage areas can be substantial during low flows. For example, the residence time in the small reservoir behind the dam at LaMoure was estimated, based on cross-section data from the U.S. Bureau of Reclamation, to be about 20 to 40 days at an inflow rate of 10 ft^3/s. When a steady-flow condition finally is reached, the flows still can be altered locally by strong wind effects. The wind can even change the direction of flow for short periods of time. At the small Dakota Lake Dam near Ludden, wind has been observed to have caused discharge to change from about 20 to 0 ft^3/s in less than 2 hours. Steady-flow conditions are reached most often during the winter when flows are under ice.

Water Quality

Water-quality characteristics of the James River are shown in table 5. Water-quality data are available for the James River at Jamestown from 1957 to 1983, at LaMoure from 1956 to 1984, and at the North Dakota-South

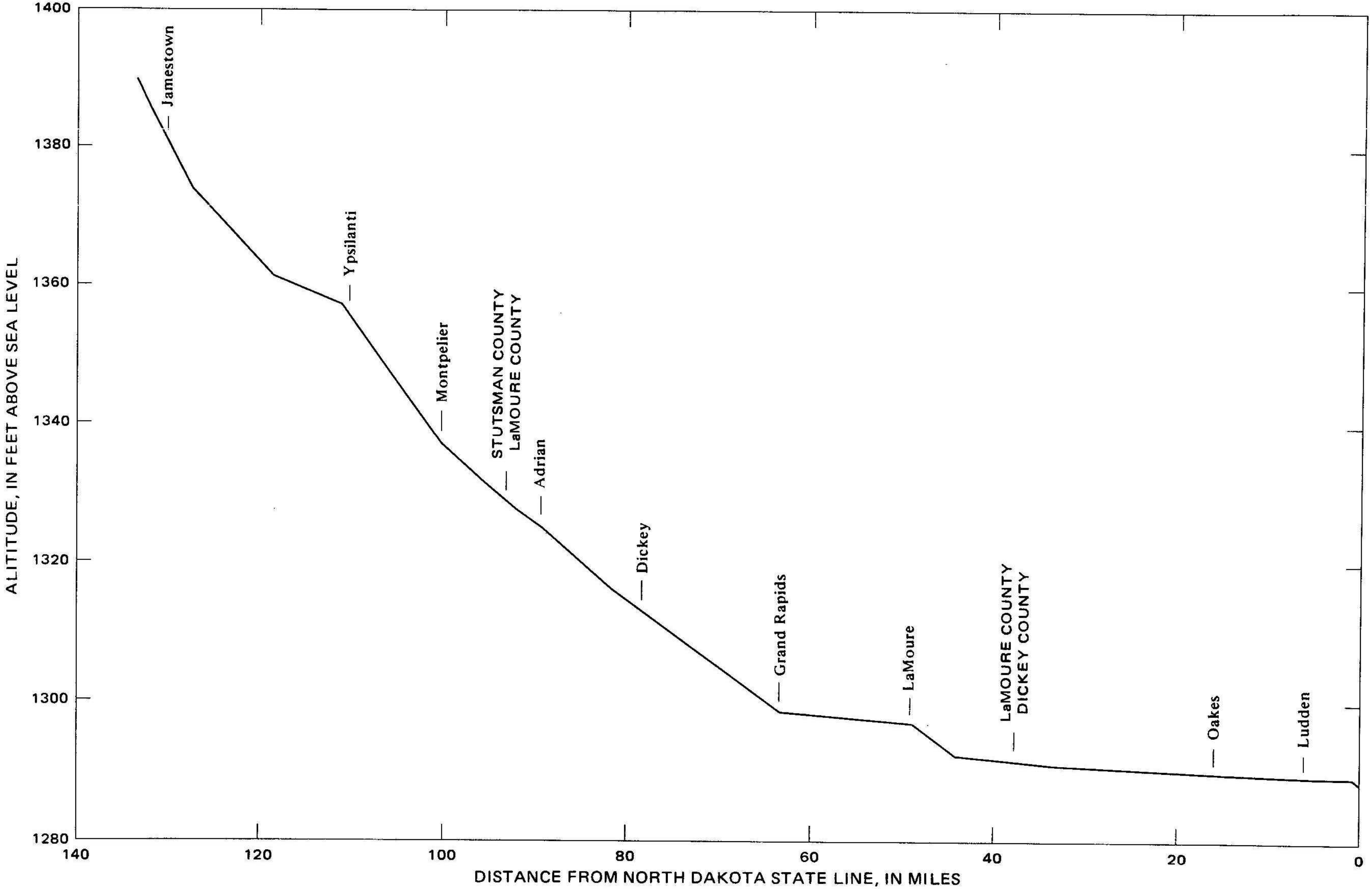


Figure 21.—Low-water surface profile of the James River.

Table 5.--Water-quality characteristics of the James River

Gaging station[2]	Dissolved solids[1] (milligrams per liter)	Major anions and cations
James River at Jamestown (06470000)	Range: 82 to 1,050 Mean: 544 Number of samples: 73	The major anion is bicarbonate. The major cations are sodium and calcium.
James River at LaMoure (06470500)	Range: 141 to 1,200 Mean: 574 Number of samples: 177	The major anion is bicarbonate. The major cations are sodium and calcium.
James River at Dakota Lake Dam (near State line) (06470875)	Range: 177 to 2,960 Mean: 689 Number of samples: 74	The major anions are bicarbonate and sulfate. The major cations are sodium and calcium.

[1]The dissolved-solids concentration is calculated from the weight of residue at 180 °C from a known quantity of water.

[2]Samples collected at streamflow-gaging sites. See figure 1 for location.

Dakota State line from 1974 to 1981. The dissolved-solids concentrations of the river water are largest during low-flow conditions. The water chemistry is controlled largely by releases from the Jamestown Reservoir and Pipestem Lake, but it still can vary seasonally.

Water samples for chemical analyses were collected from the James River at 11 sites during low flow on February 7, 8, and 9, 1983. For the reach of the James River from Jamestown to the North Dakota-South Dakota State line, the chemical constituents of the river water varied little. Dissolved-solids concentrations ranged from 771 to 945 mg/L and averaged 881 mg/L. The major anion was bicarbonate. The major cations were sodium and calcium.

WATER WITHDRAWALS

Large quantities of water are withdrawn from aquifers near the James River (7,749 acre-ft/yr in 1983) and from the James River (2,032 acre-ft/yr in 1983) for irrigation and municipal use. The quantity of water withdrawn from the aquifers is more than three times that withdrawn from streams. The quantity withdrawn was determined from available power-usage records, pumpage rates, and water-use records submitted by the appropriators. Withdrawals vary from year to year and month to month according to agricultural and municipal needs. Municipal withdrawals occur year-round with peak withdrawals in the summer. Irrigation withdrawals are limited to late spring, summer, and early fall, and peak withdrawals occur in July and August. A small percentage of water withdrawn for irrigation returns to the aquifers through infiltration and returns to the river by overland flow, interflow, and ground-water flow.

Ground Water

The most extensively developed aquifers or aquifer units are the North aquifer of the Spiritwood aquifer system, the South aquifer of the Spiritwood aquifer system, the east unit of the Oakes aquifer, the Jamestown aquifer, and the LaMoure aquifer. The word developed refers to the magnitude of water withdrawals for irrigation and municipal use. Other, less extensively, developed aquifers or aquifer units are the Midway aquifer, the West aquifer of the Spiritwood aquifer system, the Grand Rapids aquifer of the Spiritwood aquifer system, the Ellendale aquifer, the Guelph aquifer, and the Seven Mile Coulee aquifer. The following aquifers or aquifer units are the least extensively developed: Pierre, Homer, Montpelier, Adrian, Dickey, west unit of the Oakes, and Ypsilanti. Water for domestic and stock use is withdrawn from all aquifers, but the quantity of water withdrawn for this use is considered insignificant. Water withdrawals from the following aquifers or aquifer units were not considered in detail because the aquifers do not have a significant connection to the James River: North aquifer of the Spiritwood aquifer system, West aquifer of the Spiritwood aquifer system, South aquifer of the Spiritwood aquifer system, Ellendale aquifer, Guelph aquifer, and east unit of the Oakes aquifer. The water withdrawals from these aquifers or aquifer units are not considered pertinent to this study because: (1) The withdrawals are located a long distance from the James River, (2) zones of low transmissivity or sufficient thicknesses of intervening glacial drift separate these aquifers or aquifer units from the James River, or (3) the volume of withdrawals is small.

Allocations for the withdrawal of ground water have been granted since 1960. Allocated withdrawal of water from the Midway aquifer, Grand Rapids aquifer, Jamestown aquifer, Seven Mile Coulee aquifer, and LaMoure aquifer has increased significantly since 1973 (table 6), particularly from 1973 to 1978. Reported withdrawals in 1983 were 34 percent of the allocated withdrawals.

The city of Jamestown has used the Jamestown aquifer as a public-water supply since 1909, and the city of LaMoure has used the central unit of the LaMoure aquifer for several decades. The city of Jamestown pumped 2,542 acre-ft of water from the Jamestown aquifer in 1983. The city's annual withdrawal has increased steadily since 1965 when 1,148 acre-ft was withdrawn. The city's withdrawal in 1983 is about 33 percent of total water withdrawn from the selected aquifers shown in table 6. The North Dakota State Hospital withdrew 150 acre-ft of water from the Jamestown aquifer in 1982. In 1983, the State Hospital began obtaining water from the city of Jamestown. Industrial withdrawals in the Jamestown area are unavailable. The city of LaMoure reported the withdrawal of 38 acre-ft of water from the central unit of the LaMoure aquifer in 1981 and 122 acre-ft in 1983. A new municipal water system was installed in 1983.

Table 6.--Allocated and reported withdrawals of water from selected aquifers or aquifer systems in 1973, 1978, and 1983

Aquifer or aquifer system[2]	Allocated withdrawal of water[1] (acre-feet per year)			Reported withdrawal of water (acre-feet per year)			Reported withdrawal, as a percentage of allocated withdrawal		
	1973	1978	1983	1973	1978	1983	1973	1978	1983
Midway	0	706	810	0	152	234	--	22	29
Spiritwood (Grand Rapids aquifer)	1,040	2,703	2,703	0	129	213	0	5	8
Jamestown	8,505	8,620	8,620	2,164	2,213	2,833	25	26	33
Seven Mile Coulee	0	1,060	1,060	0	140	220	--	13	21
LaMoure (north unit)	203	1,172	1,172	135	331	429	67	28	37
LaMoure (central unit)	0	5,795	7,728	38	2,002	3,427	([3])	35	44
LaMoure (south unit)	0	735	735	0	241	393	--	33	53
Totals	9,748	20,791	22,828	2,337	5,208	7,749	24	25	34

[1]Cancelled allocations were not included.
[2]See figures 3 and 4 for aquifer location.
[3]Withdrawal occurred with no allocation.

Water from the Midway aquifer, Grand Rapids aquifer, and Seven Mile Coulee aquifer is used solely for irrigation. Water from the LaMoure aquifer is used predominantly for irrigation. In 1983, about 10 percent of the withdrawals from the Jamestown aquifer was used for irrigation.

Surface Water

The withdrawal of water from the James River is variably distributed along the river from Jamestown to the State line. Water also is withdrawn from Bear Creek at a point about 1 mi upstream from its confluence with the James River.

Allocation of water from the James River for irrigation began in 1938. However, no allocations have been granted since 1976. A summary of allocated withdrawals is given in table 7. No significant development has occurred between Jamestown Dam and the Jamestown gaging station, and 70 percent of the withdrawals allocated through 1976 were located between the LaMoure gaging station and the North Dakota-South Dakota State line. Withdrawals from the James River increased substantially between 1968 and 1983 (table 7).

In 1983, the total reported pumpage rate from the James River was 44.5 ft^3/s (table 8, excluding Bear Creek). Duration curves for the James River at Jamestown show that, during the peak irrigation period, a flow of

Table 7.--Allocated and reported withdrawals of water from the James River and Bear Creek in 1968, 1973, 1978, and 1983

River reach[2]	Allocated withdrawal of water[1] (acre-feet per year)				Reported withdrawal of water (acre-feet per year)				Reported withdrawal, as a percentage of allocated withdrawal			
	1968	1973	1978	1983	1968	1973	1978	1983	1968	1973	1978	1983
Jamestown Dam to Jamestown gaging station	4	4	4	4	1	0.2	0	0	25	5	0	0
Jamestown gaging station to the junction with Beaver Creek	337	337	503	503	47	84	29	61	14	25	6	12
Junction with Beaver Creek to LaMoure gaging station	60	515	664	604	30	131	280	302	50	25	42	50
LaMoure gaging station to junction with Bear Creek	153	214	575	495	33	75	249	286	22	35	43	58
Junction with Bear Creek to North Dakota-South Dakota State line	232	757	2,163	2,163	163	185	897	1,351	70	24	41	62
Bear Creek	110	110	110	30	80	85	46	32	73	77	42	107
Totals	896	1,937	4,019	3,799	354	560	1,501	2,032	40	29	37	53

[1]Currently cancelled allocations are not included if not used from 1968 to 1983. Some allocations have been used but are now cancelled.

[2]See figure 1 for location of streamflow-gaging sites.

Table 8.--Allocated and reported pumpage rates of water from the James River and Bear Creek in 1968, 1973, 1978, and 1983

River reach[2]	Allocated pumpage rate[1] (cubic feet per second)				Reported pumpage rate (cubic feet per second)				Reported pumpage rate, as a percentage of allocated pumpage rate			
	1968	1973	1978	1983	1968	1973	1978	1983	1968	1973	1978	1983
Jamestown Dam to Jamestown gaging station	0.3	0.3	0.3	0.3	0.03	0.03	0	0	10	10	0	0
Jamestown gaging station to junction with Beaver Creek	2.9	2.9	5.6	5.6	1.6	1.6	1.6	1.6	55	55	29	29
Junction with Beaver Creek to LaMoure gaging station	1.0	6.4	8.0	7.0	1.0	2.2	2.4	3.6	100	34	30	51
LaMoure gaging station to junction with Bear Creek	1.9	6.4	12.2	11.2	2.8	10.6	12.4	12.4	147	166	102	111
Junction with Bear Creek to North Dakota-South Dakota State line	3.3	8.0	25.2	25.2	4.9	6.7	25.6	26.9	148	84	102	107
Bear Creek	2.2	2.2	2.2	.2	2.6	2.6	.6	.6	118	118	27	300
Totals	11.6	26.2	53.5	49.5	12.9	23.7	42.6	45.1	111	90	80	91

[1]Currently cancelled allocations are not included if not used from 1968 to 1983. Some allocations have been used but are now cancelled.

[2]See figure 1 for location of streamflow-gaging sites.

50 ft^3/s is equaled or exceeded 29 percent of the time in July and 20 percent of the time in August (fig. 16). Duration curves for the James River at LaMoure show a flow of 50 ft^3/s is exceeded or equaled 40 percent of the time in July and 24 percent of the time in August (fig. 17). Since 1976, periods of insufficient quantities of water in the James River have been observed by appropriators in the Oakes area. However, storages in the river, periodic releases from Jamestown Reservoir and Pipestem Lake, bank-storage discharge, and aquifer outflow to the river generally provide sufficient quantities of water. The reported pumpage rate (table 8) is attained only if all appropriators pump their maximum rate simultaneously.

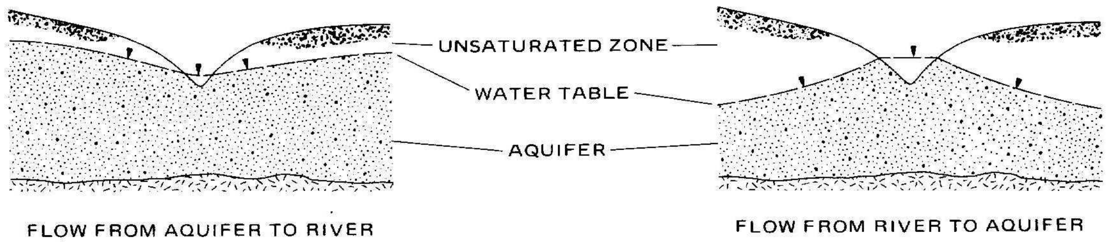
GROUND-WATER AND SURFACE-WATER RELATIONSHIPS

The ground-water and surface-water relationships are described in four parts: (1) Aquifer-stream interaction, (2) seepage analysis, (3) aquifer parameters from stream hydrographs, and (4) water quality. The aquifer-stream interaction was defined using test-hole data, measured water levels of aquifers, and measured stage levels of the James River. The seepage analysis shows the results of the seepage evaluations. Stream hydrographs were used to determine aquifer parameters. Available water-quality analyses for aquifers and the James River provided information to determine the nature of the chemical relationship between water in the aquifers or aquifer systems and in the James River.

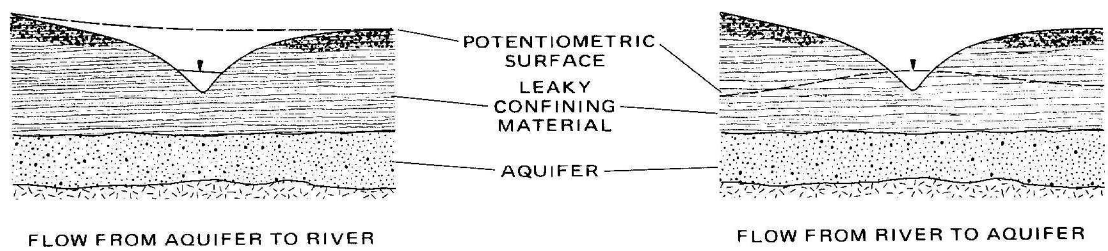
Aquifer-Stream Interaction

Four basic configurations of aquifer-stream interaction that may occur in the study area are shown in figure 22. Generally the James River only partly penetrates the unconfined parts of the aquifers beneath the flood plain of the river; however, in rare cases, the river may completely penetrate the unconfined parts of the aquifers where the aquifer deposits are thin and the base of the aquifer is near the land surface of the flood plain of the river. The description of aquifer-stream hydrology is divided into five areas for discussion: (1) Area of the Jamestown aquifer, (2) area of the Ypsilanti aquifer, (3) area of the Grand Rapids aquifer, (4) area of the LaMoure aquifer, and (5) area of the Oakes aquifer.

In the James River basin, ground-water-level declines in observation wells are due to: (1) Frost accumulation, (2) evapotranspiration, (3) pumpage, and (4) movement of ground water towards discharge areas. Ground-water-level rises are due to: (1) Frost melt; (2) infiltration of surface water, including precipitation and snowmelt; (3) ground water moving into the cone of depression created by pumpage; and (4) ground-water movement from recharge areas. The extent of frost accumulation and frost melt depends on soil temperature, the soil-moisture content and water-holding capacity of the soil profile, and depth to water table (Willis and others, 1964, and Benz and others, 1968). In the valleys of the James River and its tributaries, where water levels are within 9 ft of land surface, frost accumulation and frost melt can occur (Willis and others, 1964.) The infiltration of surface water to the aquifer is controlled by soil-moisture content, evapotranspiration, hydraulic head, hydraulic conductivity, and the presence or absence of the frost zone.



A. River reaches where aquifer is unconfined.



B. River reaches where aquifer is confined.

Figure 22.—Four possible configurations of aquifer-stream interaction along the James River.

Frost accumulation and evapotranspiration seasonally reduce the quantity of ground water discharged into the James River.

Stage-measurement sites on the James River were established on bridges crossing the James River. The three gaging stations within the study area also were used for stage measurements. Surveyed altitudes accurate to within 0.1 ft are available for the stage-measurement sites and observation wells used in the study. Stages and water levels used in this study were collected from October 1982 to January 1984. Stages measured during the winter were to an open water surface.

Area of the Jamestown Aquifer

Water levels in the Jamestown aquifer and stage of the James River are shown in figure 23. Observation well 139-063-08ACC is completed in the aquifer and located about 2,500 ft south of the James River (pl. 1). The well is screened from 64 to 69 ft below land surface. The hydrographs of the observation well and stage measuring site 139-063-06DAA seem to indicate that large fluctuations in river stage may affect the aquifer water levels at the distance of 2,500 ft. The ground-water-level fluctuations shown in figure 23 follow the annual pattern observed in wells in the Jamestown aquifer but rise and fall with greater amplitudes where the aquifer is closer to the river. Smaller stage fluctuations probably would only affect ground-water levels nearer the river. Precipitation in June and July maintained the ground-water levels during the 2-month period. River stage commonly does not fluctuate in direct response to precipitation because of the regulation of flows in the James River by Jamestown and Pipestem Dams.

Pumping from the aquifer near the river affects the aquifer-stream relationship. Observation wells 139-063-06ABC1, screened from 50 to 55 ft below land surface, and 139-063-06ABC2, screened from 22 to 27 ft below land surface, are completed in the Jamestown aquifer and are located 50 ft east of the gaging station at Jamestown. Well 139-063-06ABC3 is located 150 ft east of the gaging station at Jamestown. No water levels are available for this well. This well supplied water to the State Hospital at Jamestown until October 1983. The hydrographs of the two observation wells and river stage at the gaging station are shown in figure 24.

The city of Jamestown withdraws large quantities of water from the aquifer in 140-064-36 through four municipal wells that are located from about 100 to 1,800 ft from the river. Withdrawals by the four municipal wells probably induce seepage from the James River into the Jamestown aquifer. Two irrigation wells in 139-063-08A also may induce seepage from the James River. The effects that large ground-water withdrawals (2,833 acre-ft in 1983) would have on the small Jamestown aquifer probably are counteracted by both seepage from the James River and discharge from the Midway aquifer into the Jamestown aquifer. In turn, the potential outflow from the Midway and Jamestown aquifers to the James River probably has decreased substantially.

Geologic, water-level, and stage data indicate that the Jamestown aquifer interacts with the James River (pl. 1, fig. 25, and table 9). The

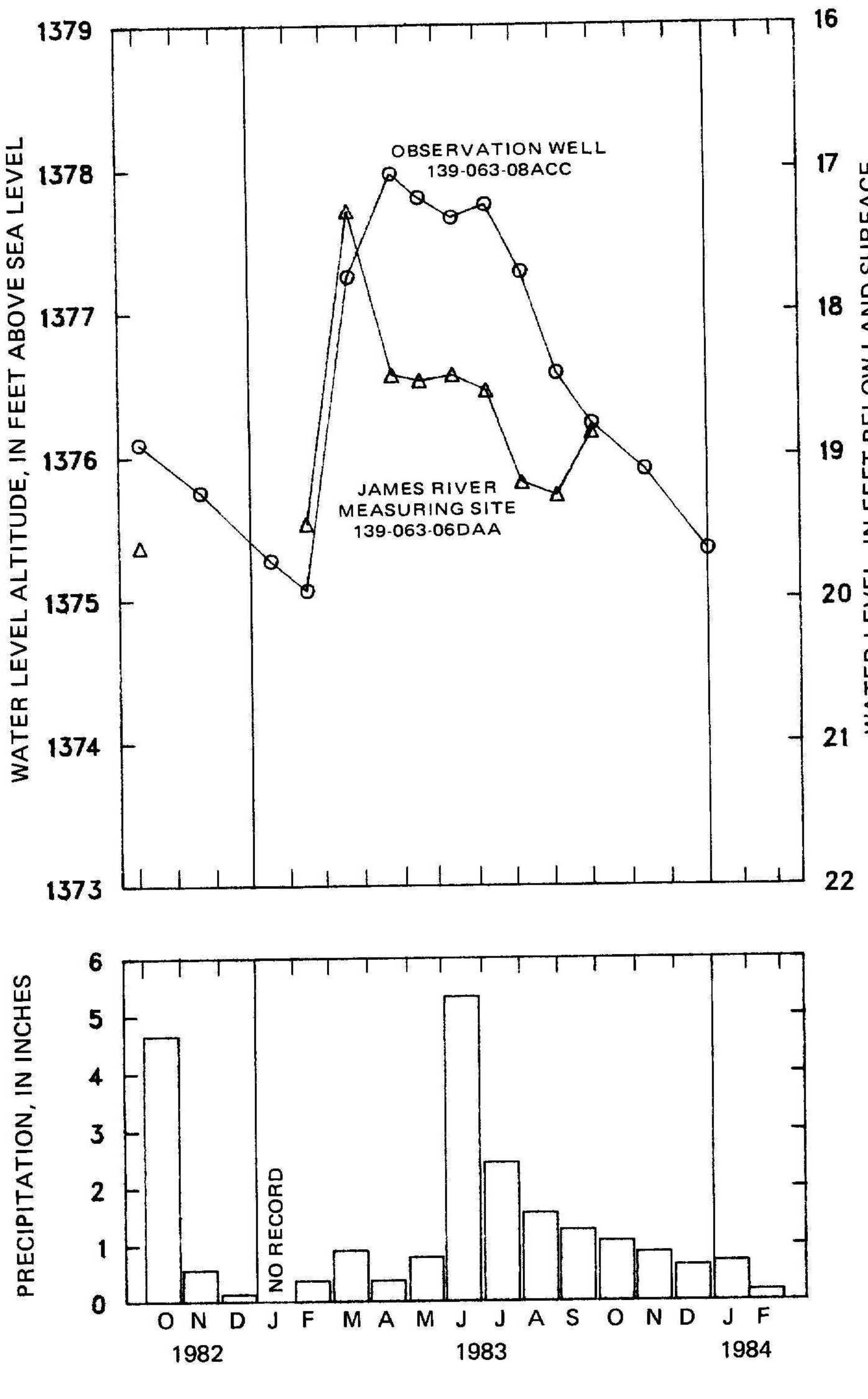


Figure 23.—Water levels in the Jamestown aquifer below Jamestown, and river stage and precipitation at Jamestown, 1982-84.

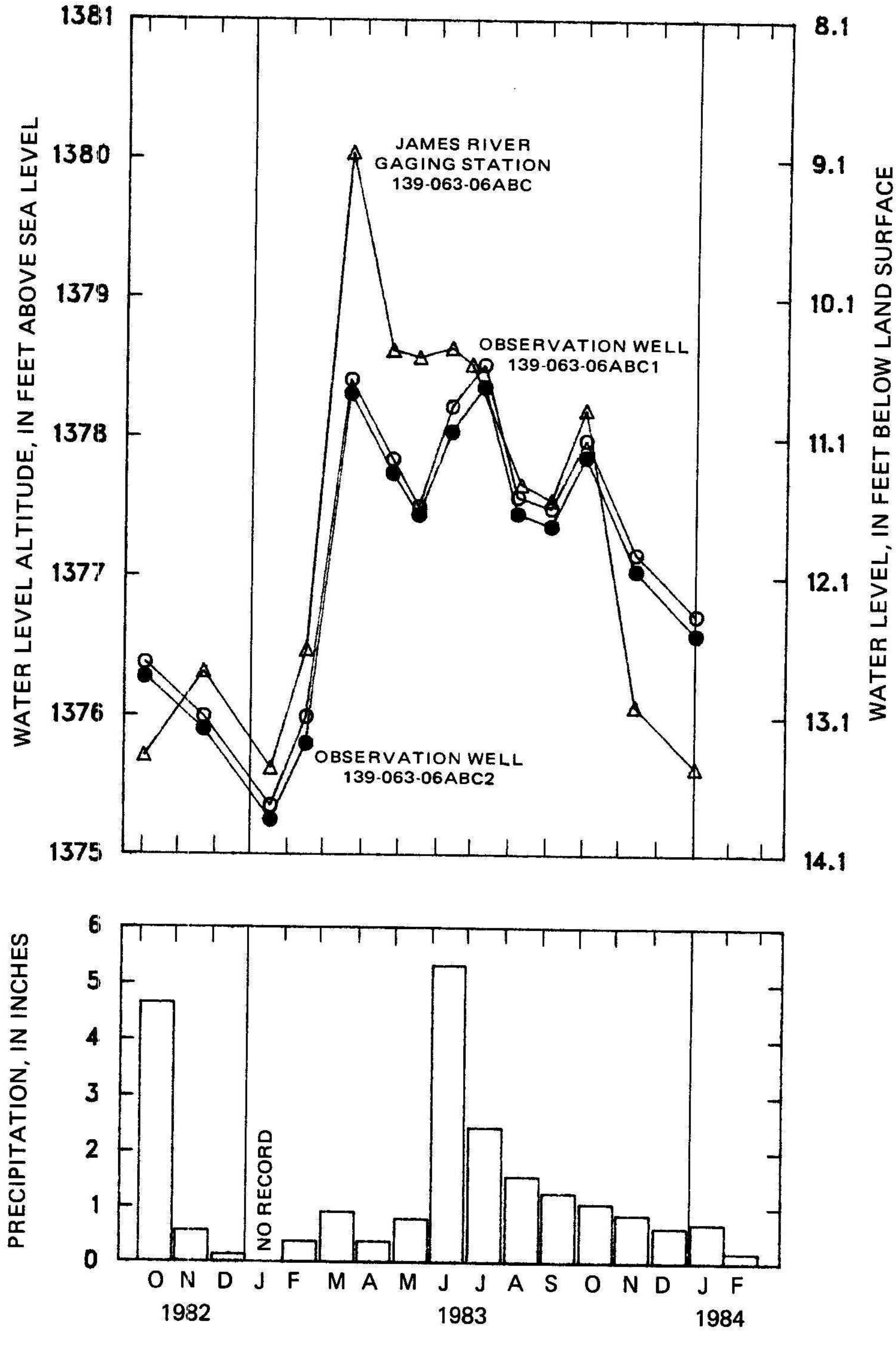


Figure 24.—Water levels in the Jamestown aquifer, and river stage and precipitation at Jamestown, 1982-84.

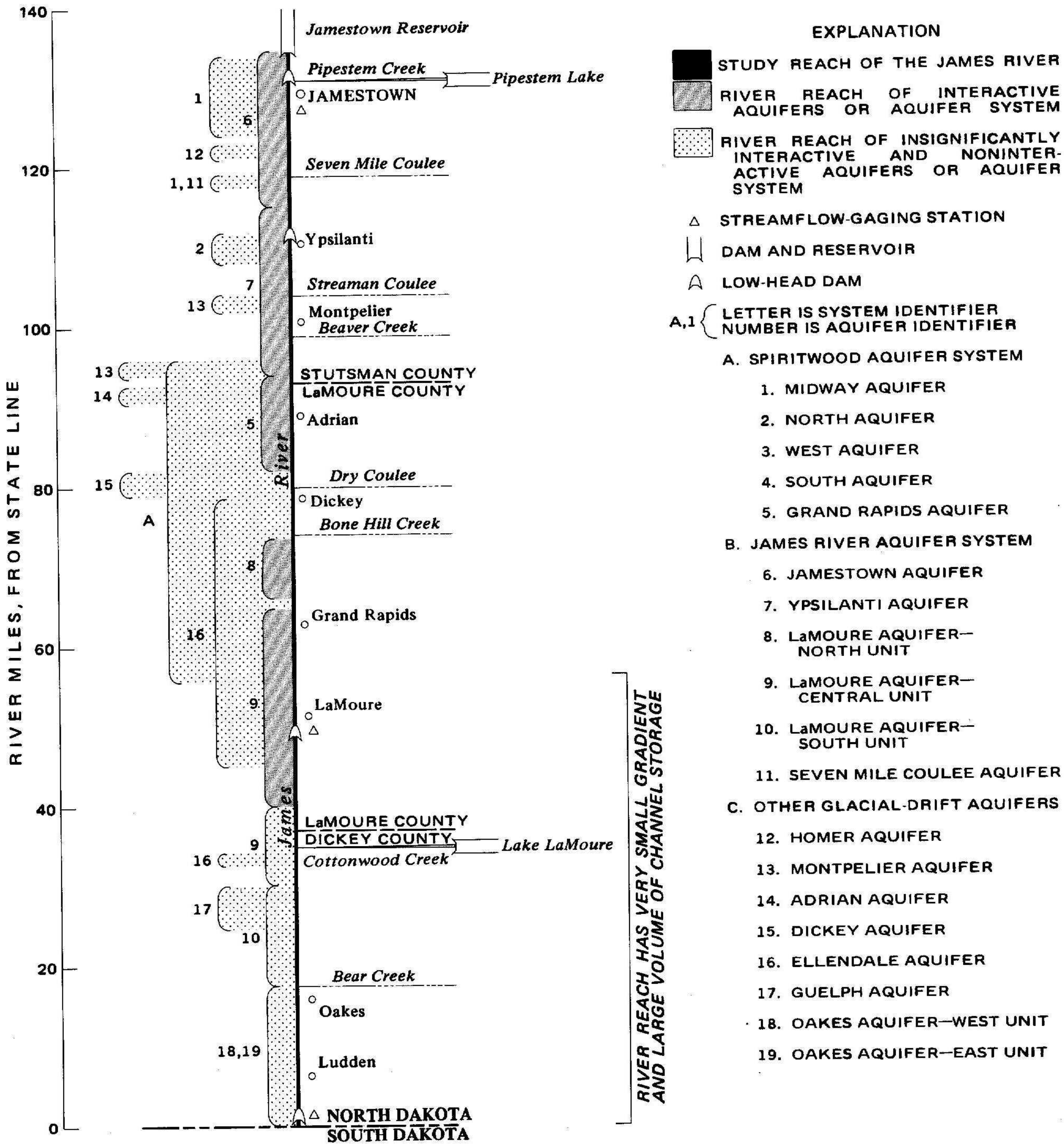


Figure 25.—Aquifers and aquifer systems, tributaries, reservoirs, and landmarks in the lower James River hydrologic system.

Table 9.--Aquifer relationships with the James River

Aquifer or aquifer system	Contribution to the low flow of the James River	Length of river reach over aquifer or aquifer system (river miles)	Approximate areal extent of aquifer or aquifer system (square miles)
Pierre	Contributes through intervening glacial-drift aquifers; quantity unknown, probably negligible.	--	--
Midway	Contributes through the Jamestown and Seven Mile Coulee aquifers; quantity unknown.	--	50
Spiritwood (North, West, and South aquifers)	Contributes through the Midway aquifer, Grand Rapids aquifer, Ypsilanti aquifer, and LaMoure aquifer; quantity unknown.	--	365
Spiritwood (Grand Rapids aquifer)	During long-term low-flow periods contributes 4-6 cubic feet per second to streamflow.	35	60
Homer	Contributes through the Jamestown aquifer; quantity unknown.	--	14
Montpelier	Contributes through the Ypsilanti aquifer and the Spiritwood aquifer system; quantity unknown, probably negligible. Base of the aquifer above the floor of the James River valley.	--	23
Adrian	Quantity unknown, probably negligible. Base of the aquifer above the floor of the James River valley.	--	4
Dickey	Quantity unknown, probably negligible. Base of the aquifer above the floor of the James River valley.	--	8
Ellendale	Contributes through the LaMoure aquifer; quantity unknown. Base of the aquifer above the floor of the James River valley.	--	150
Guelph	Quantity unknown, probably negligible. Base of the aquifer above the floor of the James River valley.	--	16
Oakes (west unit)	Quantity unknown, probably negligible.	17	29
Oakes (east unit)	Quantity unknown, probably negligible.	--	93
Jamestown	Quantity unknown; James River probably loses water to the aquifer in the Jamestown area.	20	9
Seven Mile Coulee	Contributes through the Jamestown aquifer and Seven Mile Coulee; about 0.2 cubic feet per second through Seven Mile Coulee.	--	4
Ypsilanti	Quantity unknown, probably negligible.	21	8
LaMoure (north unit)	Contributes less than 1 cubic foot per second.	5	4
LaMoure (central unit)	Contributes less than 1 cubic foot per second.	35	30
LaMoure (south unit)	Contributes less than 1 cubic foot per second.	13	11
Undifferentiated glacial-drift aquifers	Quantity negligible.	--	--

interaction between the aquifer and the river may be insignificant locally because of zones of low transmissivity between the aquifer and river. The zones indicate the presence of intervening silt and clay.

The Pierre aquifer and the Midway, Homer, and Seven Mile Coulee aquifers do not interact with the river; they do, however, discharge into the Jamestown aquifer (table 9).

Seven Mile Coulee is a perennial stream from 139-062-06 downstream to its junction with the James River. Base flow in Seven Mile Coulee is maintained through seepage from the Midway, Jamestown, and Seven Mile Coulee aquifers. Irrigation pumpage from the Seven Mile Coulee aquifer and from the Midway aquifer near Seven Mile Coulee temporarily lowers the water levels in the two aquifers about 1 to 2 ft and about 4 to 6 ft, respectively, and probably decreases ground-water outflow into Seven Mile Coulee in late summer.

Area of the Ypsilanti Aquifer

The hydrographs of observation well 137-063-11ABD in the Ypsilanti aquifer and stage measuring site 137-063-11ABC are shown in figure 26. The observation well is located 500 ft east of the James River and is screened from 32 to 37 ft below land surface. Only the large changes in the river stage appear to affect ground-water levels at the observation well. Smaller stage fluctuations would only affect ground-water levels near the river. The hydrograph indicates the response in ground-water levels to precipitation and possibly to river stage in the river reach underlain by the Ypsilanti aquifer. Water levels in two observation wells completed in the Ypsilanti aquifer next to a meander scar are related to the stage fluctuations of the ponds in the scar and indicate a local interaction.

Ice and subsurface frost accumulation may cause flows from springs and seeps to decrease or cease in the winter, as shown by discharge data collected from a spring at 138-063-36DB that issues from the Ypsilanti aquifer. The spring flowed at about 0.5 ft^3/s in November 1981 and November 1982, but the flow had decreased to less than 0.01 ft^3/s in February 1983 and February 1984. A considerable thickness of ice was present in February 1983 and February 1984.

Geologic, water-level, and stage data indicate that the Ypsilanti aquifer interacts with the James River (pl. 1, fig. 25, and table 9). The interaction between aquifer and river may be insignificant locally due to zones of low transmissivity between the aquifer and river. The zones indicate the presence of intervening silt and clay.

Most of the discharge from the Ypsilanti aquifer into the James River probably occurs where: (1) The North aquifer of the Spiritwood aquifer system lies beneath the James River valley at Ypsilanti and provides leakage to the Ypsilanti aquifer, and (2) water from the Montpelier aquifer leaks into the Ypsilanti aquifer. The North aquifer of the Spiritwood aquifer system does not interact with the river because it is separated from the river by semipervious glacial drift. Pumpage at

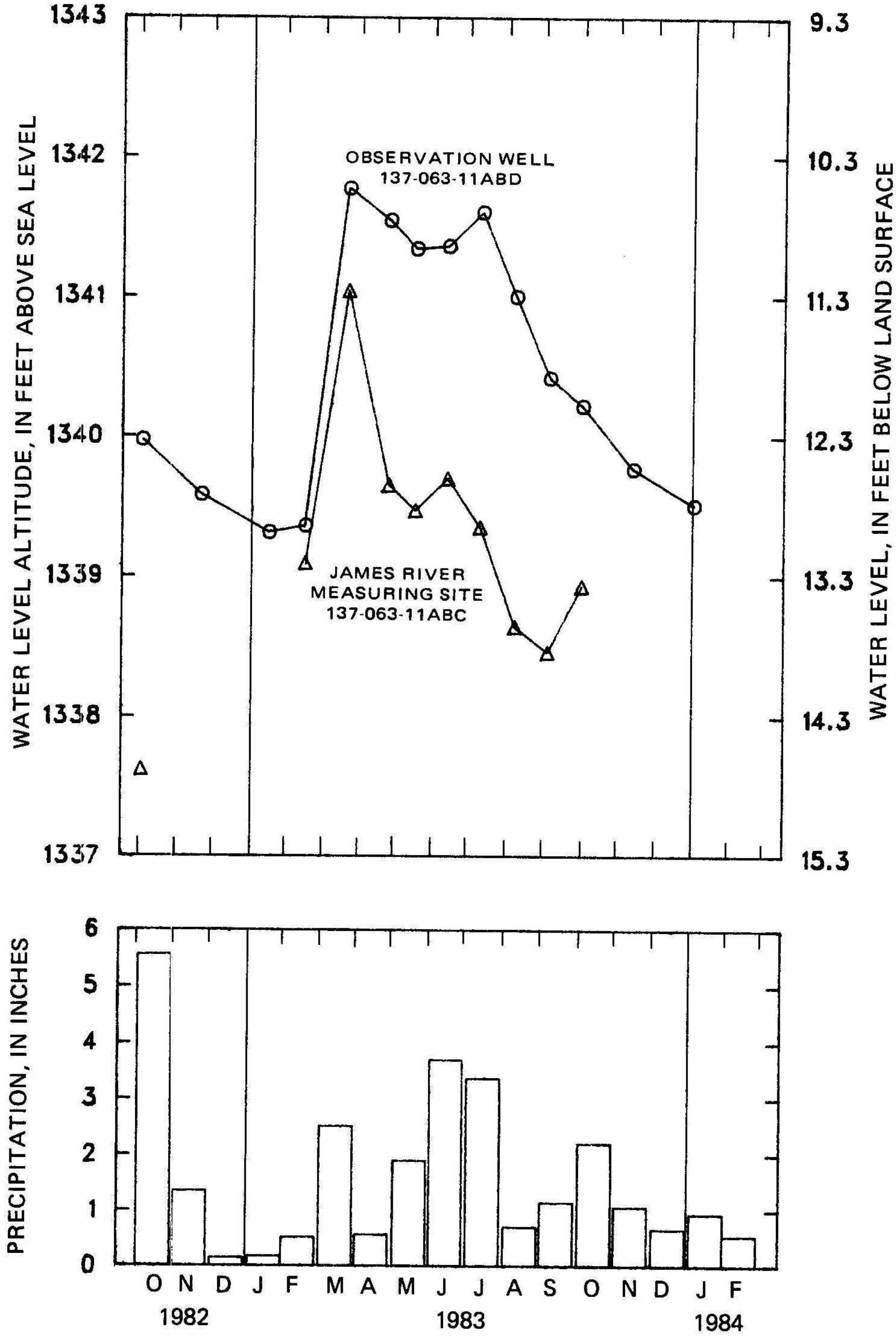


Figure 26.—Water levels in the Ypsilanti aquifer, and river stage and precipitation at Montpelier, 1982-84.

irrigation well 138-062-31DBB in the North aquifer during late summer 1983 lowered the water levels sufficiently to cause a small spring in 138-062-31BA to cease flowing. Large drawdowns were observed in nearby observation wells in the North aquifer. The Montpelier aquifer does not interact with the river because the base of the aquifer lies 25 to 50 ft above the valley floor and therefore is not in hydraulic connection with the river.

Streaman Coulee is only a minor discharge area for the North aquifer of the Spiritwood aquifer system. The coulee generally is separated from the North aquifer by 75 to 200 ft of intervening glacial drift. Near the junction of Streaman Coulee and the James River, the intervening glacial drift is about 25 ft thick.

Base flow in Beaver Creek is 0.0 to less than 0.1 ft^3/s. It is possible that the small base flow in Beaver Creek is maintained by seepage from the Pierre aquifer and minor undifferentiated glacial-drift aquifers.

Area of the Grand Rapids Aquifer

The hydrographs of observation wells 136-063-02BAD1 and 136-063-02BAD2 and stage measuring site 136-063-02BAB are shown in figure 27. The two adjacent observation wells are located 150 ft east of the James River. Observation well 136-063-02BAD1 is screened from 28 to 33 ft below land surface, and observation well 136-063-02BAD2 is screened from 75 to 80 ft below land surface. The river stage is about 2 to 4 ft below ground-water levels and probably indicates that the river at that location is a discharge area for the aquifer. Springs occur along the banks of the river near the observation wells. The hydrographs indicate that: (1) Ground water in the Grand Rapids aquifer of the Spiritwood aquifer system near the river moves upwards, and (2) river-stage fluctuations are reflected more significantly in ground-water levels that are nearer to the land surface.

Hydrographs of observation wells 136-062-30DDD1 and 136-062-30DDD2 (both completed in the Grand Rapids aquifer) and stage measuring site 136-062-31AAD are shown in figure 28. Observation well 136-062-30DDD1 is screened from 121 to 126 ft below land surface, and observation well 136-062-30DDD2 is screened from 35 to 40 ft below land surface. The wells are located 1,400 ft from the river. The water-level fluctuations in the wells represent the general fluctuation pattern of water levels in observation wells in the Grand Rapids aquifer in areas where no pumpage occurs, and where the fluctuations in river stage generally are not reflected in ground-water levels. The ground-water-level fluctuations thus suggest that the observation wells are at a distance where the river-stage levels have little or no effect on ground-water levels, or that there is a zone of lower transmissivity between the observation wells and the river. The ground-water-level fluctuations also indicate that there is little or no vertical gradient most of the time.

The hydrographs of observation wells 136-063-13CBD1 and 136-063-13CBD2 and stage measuring site 136-063-13CBD are shown in figure 29. The two observation wells are located 150 ft west of the stage measuring site.

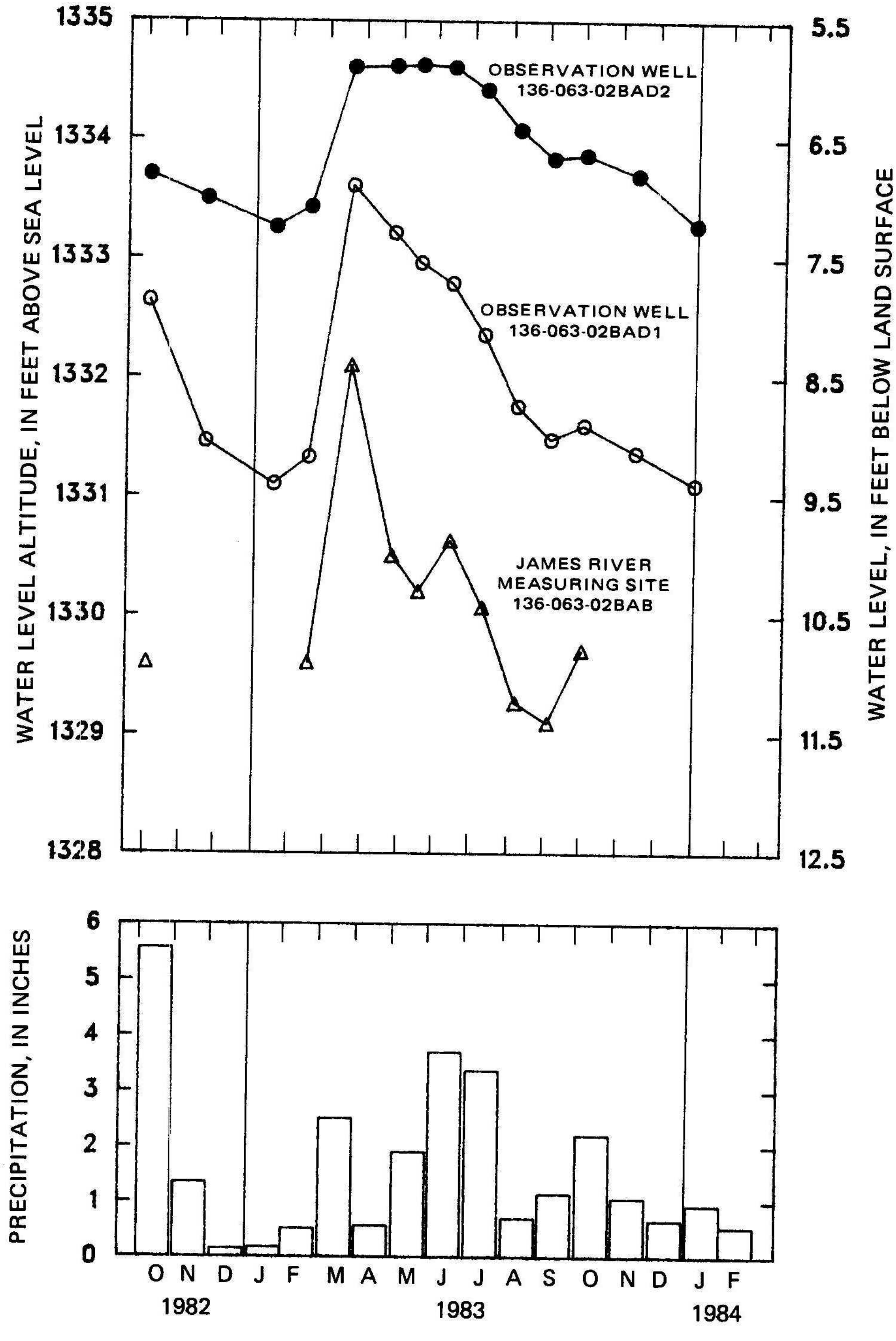


Figure 27.—Water levels in the Grand Rapids aquifer of the Spiritwood aquifer system, river stage above Adrian, and precipitation at Montpelier, 1982-84.

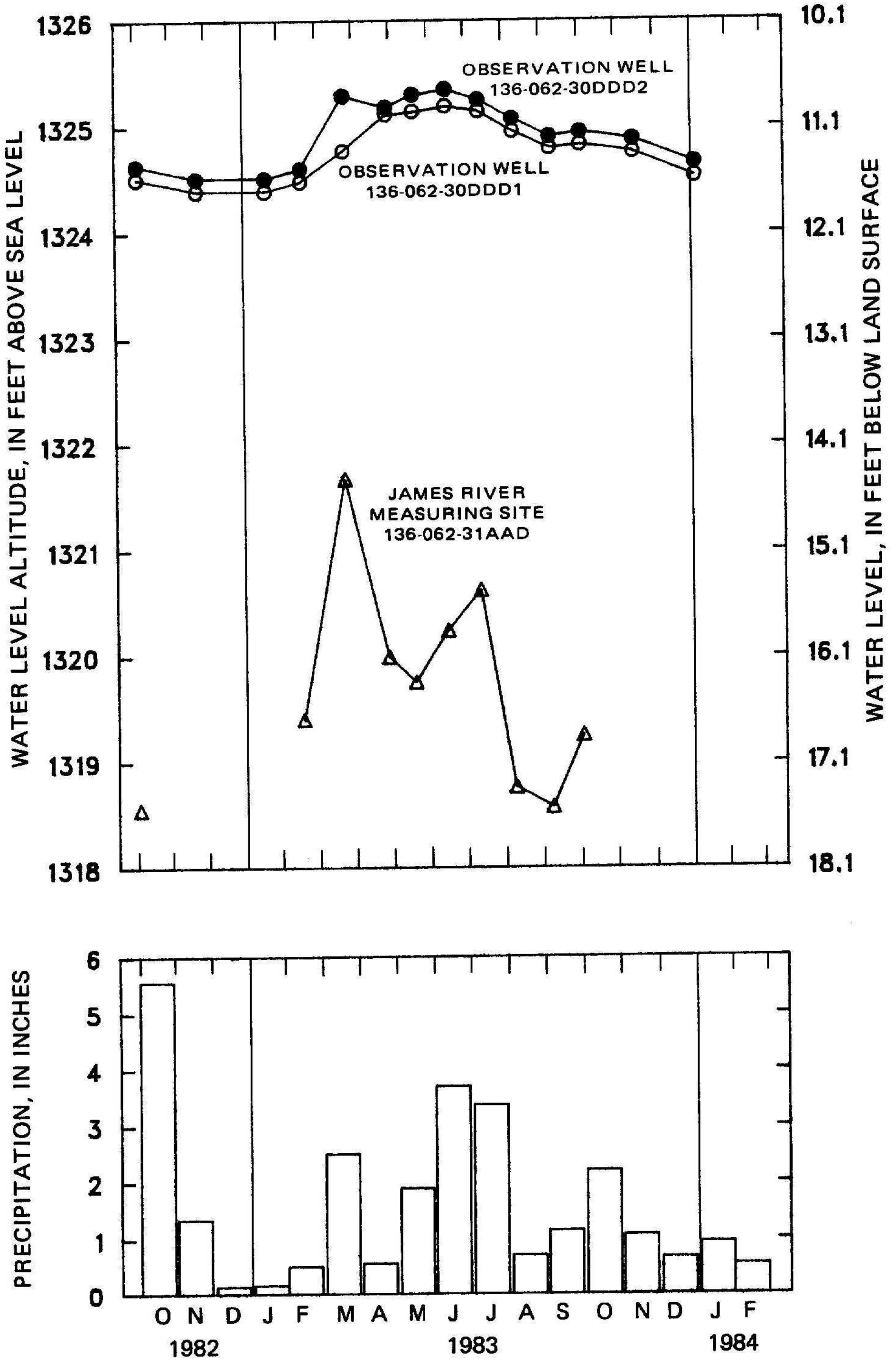


Figure 28.—Water levels in the Grand Rapids aquifer of the Spiritwood aquifer system, river stage above Dickey, and precipitation at Montpelier, 1982-84.

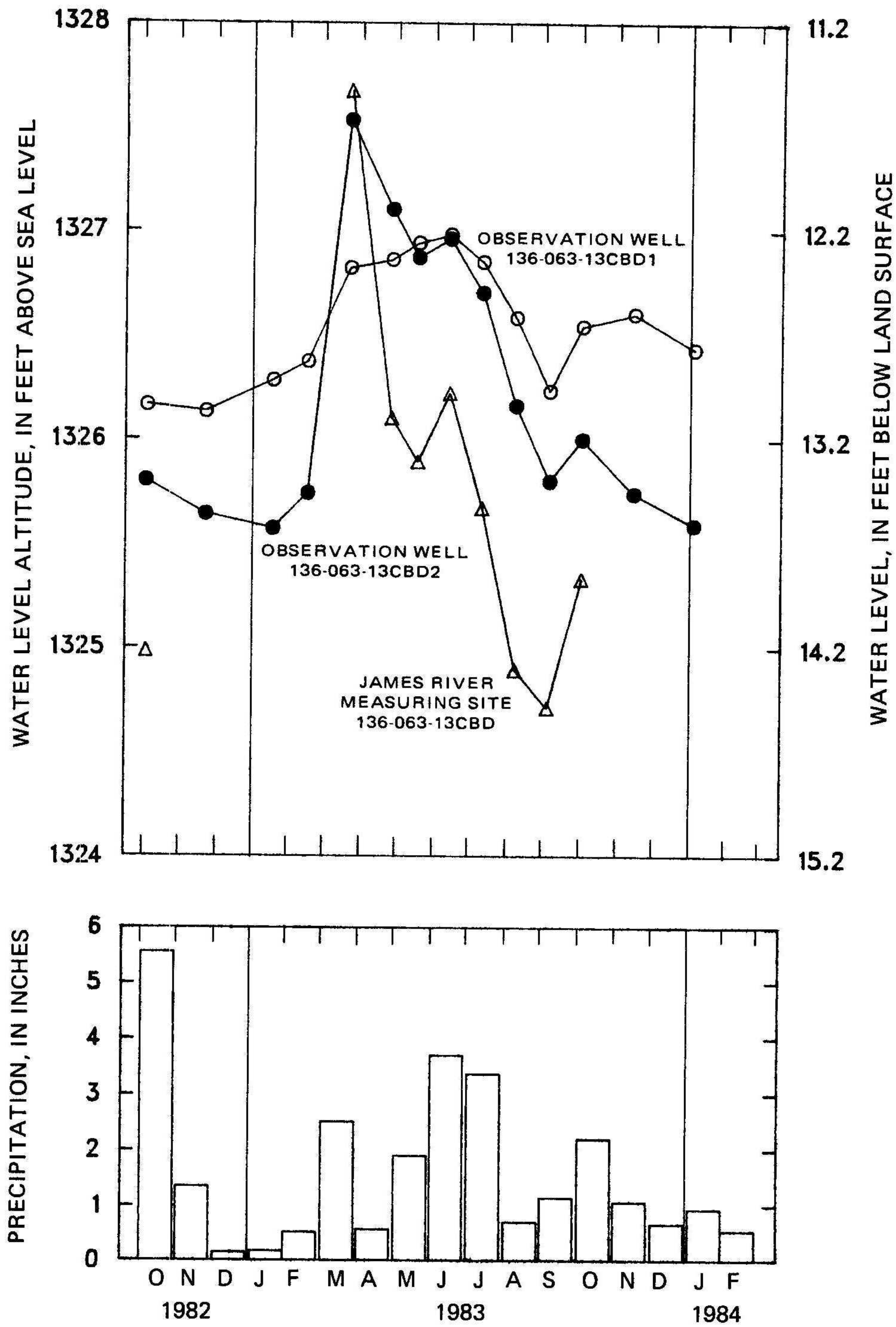


Figure 29.—Water levels in the Grand Rapids aquifer of the Spiritwood aquifer system, river stage below Adrian, and precipitation at Montpelier, 1982-84.

Observation well 136-063-13CBD1 is screened from 98 to 103 ft below land surface, and observation well 136-063-13CBD2 is screened from 33 to 38 ft below land surface. A 24-ft thick layer of sandy silt occurs between the screens. Irrigation well 136-063-14DDA is completed in the Grand Rapids aquifer and is located 1,400 ft southwest of the stage measuring site. The irrigation well also is screened in two places and was pumped during the summer of 1983. The hydrographs indicate that: (1) The effects of pumpage at the irrigation well are not discernible in the observation wells, (2) upward movement of ground water generally occurs in the aquifer, and (3) the water levels in observation well 136-063-13CBD2 (the shallow well) closely reflect the fluctuation in river stage. An exception to upward movement of ground water occurs during high flows in the James River or during major recharge events.

Numerous springs and seeps occur along the banks of the James River from the Stutsman-LaMoure county line downstream to Dickey. The springs mark the most significant discharge area for the Grand Rapids aquifer. Ground-water-level and river-stage data indicate that the stage levels of the James River during high flows are above the water levels of the Grand Rapids aquifer near the river in the reach from Adrian downstream to 136-062-32. In this reach, the largest amount of water is exchanged between the Grand Rapids aquifer and the river. The interaction may be insignificant locally due to zones of low transmissivity between river and aquifer. The zones of low transmissivity are due to intervening silt, clay, or till.

The potentiometric-surface map of the Grand Rapids aquifer (fig. 10) probably indicates significant potential for discharge from the aquifer to the James River in 135-062-23. The differential between river stage and the water levels in the Grand Rapids aquifer near the river increases downstream from about 4 ft in 136-062-32 to 35 ft or more near Grand Rapids. The increasing differential is due to the increasing thickness of silt, clay, and till separating the aquifer from the river (figs. 8 and 9). The amount of water exchanged in the aquifer-stream interaction decreases correspondingly.

Irrigation well 135-061-30BDD, located about 3,200 ft from the James River, withdraws water from the Grand Rapids aquifer. Seasonal drawdowns in the aquifer near the well were about 20 ft in 1983. The withdrawals have little or no effect on flows in the James River due to the thick confining units separating the aquifer from the river in this area (fig. 9).

The Adrian and Dickey aquifers do not interact with the James River because the bases of the two aquifers lie about 45 to 70 ft above the floor of the James River valley. No flow has been observed in Bone Hill Creek and Dry Creek during possible base-flow periods. Seepage from other glacial-drift aquifers, however, maintains pools of water in the Bone Hill Creek channel during the summer.

Area of the LaMoure Aquifer

The north unit of the LaMoure aquifer discharges to the James River in 135-062-25 and 135-062-26 (pl. 1). The north unit is separated from the

James River by silt and clay in 134-061-04, parts of 135-061-31, 135-061-32, and 135-061-33. The north unit of the LaMoure aquifer interacts with the James River but, because of its small size, the quantity of water interchanged is very small (table 9).

The hydrographs of observation well 134-061-05AAB, completed in the central unit of the LaMoure aquifer, and of stage measuring site 134-061-04BBB are shown in figure 30. The observation well is screened from 43 to 48 ft below land surface and is located 50 ft west of the James River. The river-stage fluctuations are not reflected in the ground-water-level fluctuations in the observation well, possibly because of a very limited connection with the river. Springs and seeps occur near the river in 134-061-05A. The water-level fluctuations in observation well 134-061-05AAB probably represent the natural fluctuation pattern of water levels in the LaMoure aquifer in areas where the ground-water levels are not affected by river-stage fluctuations or the effects of irrigation withdrawals. Locally, irrigation withdrawals in the central unit have distorted the natural fluctuation pattern of ground-water levels.

The low-head dam located west of LaMoure at 133-061-12BBB affects water levels in the central unit of the LaMoure aquifer upstream of the dam. Hydrographs of observation well 133-061-02BAA and stage measuring site 134-061-35DCD are shown in figure 31. The observation well is screened from 38 to 43 ft below land surface and is 75 ft from the James River. The hydrographs indicate that water levels in the LaMoure aquifer at the well location reflect changes in river-stage fluctuations above the low-head dam and indicate an area of where it is possible to interchange a large amount of water between the aquifer and the river.

The hydrographs of observation wells 133-061-01BCD1 and 133-061-12BBB, both completed in the central unit of the LaMoure aquifer, and of stage at the gaging station at 133-061-11AAA are shown in figure 32. Both observation wells are screened from 23 to 28 ft below land surface and are about 3,300 ft apart. Well 133-061-01BCD1 is located 400 ft east of the James River, and well 133-061-12BBB is located 50 ft east of the James River at the gaging station. The gaging station is located just above the low-head dam. At well 133-061-01BCD1, the aquifer generally discharges to the river. The water levels of observation well 133-061-12BBB and the stage measured at the gaging station show that near the dam, the river discharges to the aquifer.

An abrupt water-level decline occurred in wells 133-061-01BCD1 and 133-061-12BBB in October and November 1983 (fig. 32). The drop also occurred in several other observation wells downstream from the low-head dam. The water levels in these observation wells appeared to fall in response to the lower stage levels downstream of the low-head dam, and perhaps in a delayed response to evapotranspiration and to irrigation withdrawals earlier in the year. The lower stage was caused by a significant decrease in water releases from the two large reservoirs upstream. The water-level rise in January 1984 could have been caused by water-level recovery after the irrigation season.

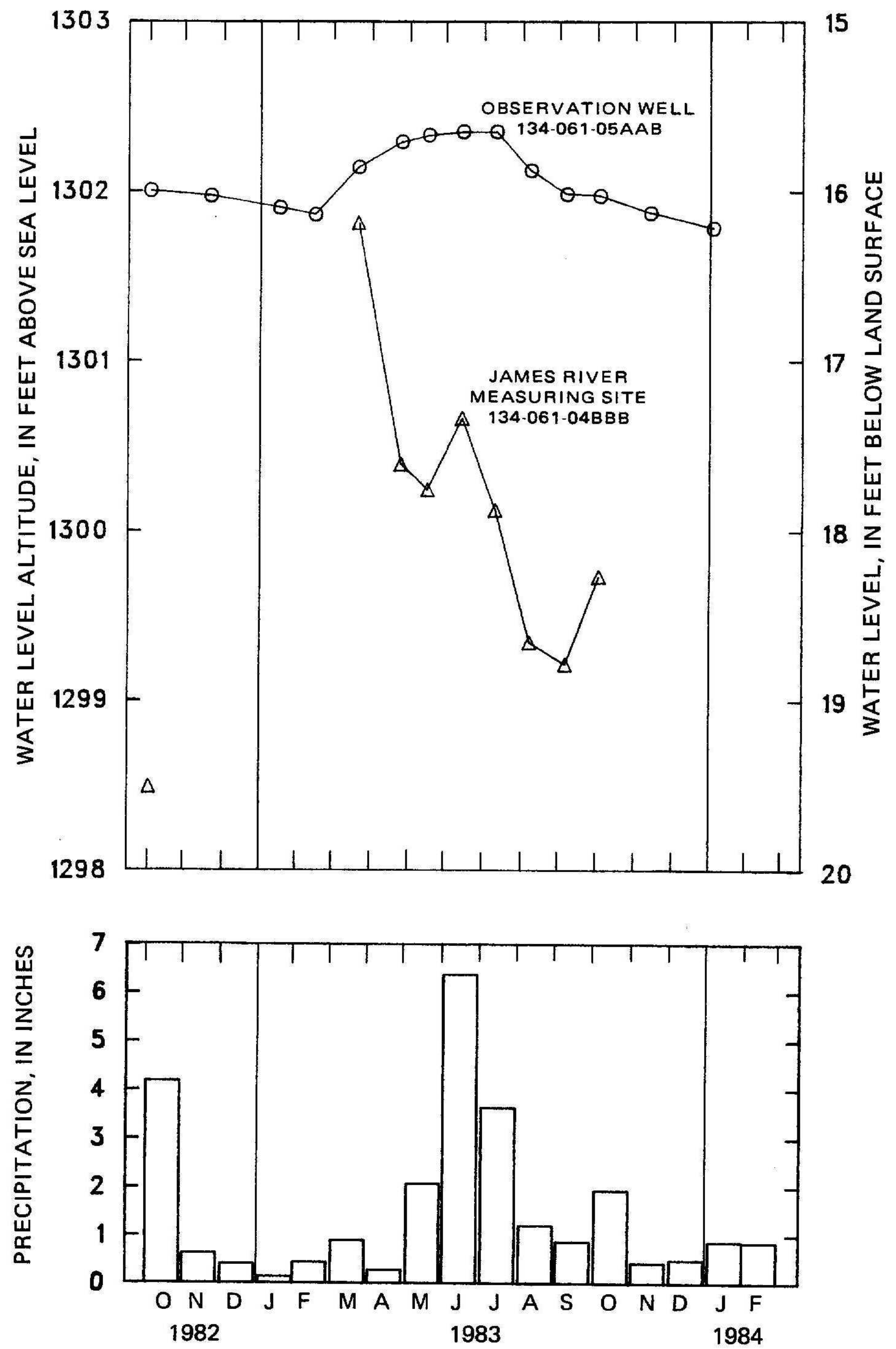


Figure 30.—Water levels in the central unit of the LaMoure aquifer, river stage above Grand Rapids, and precipitation at LaMoure, 1982-84.

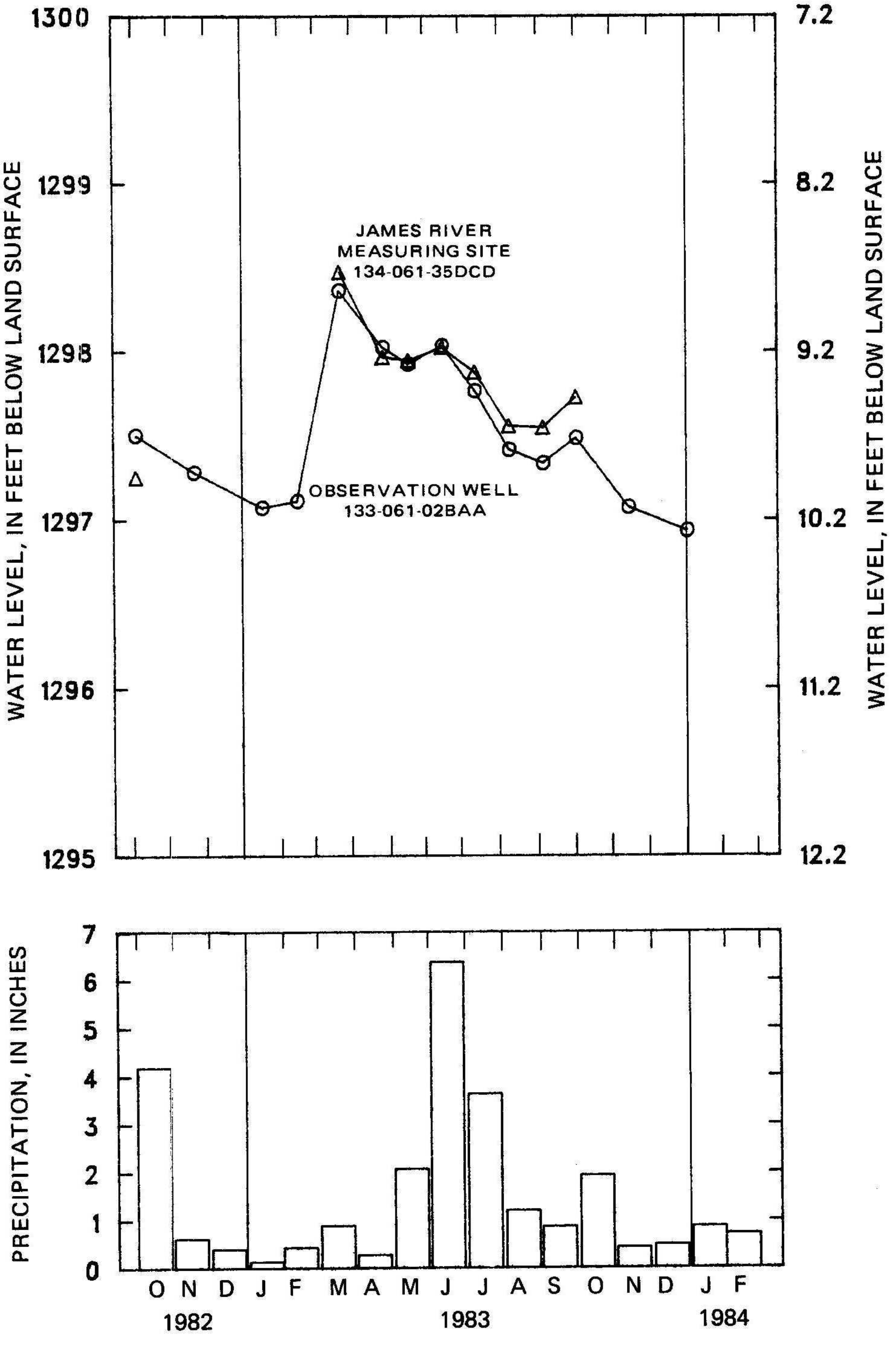


Figure 31.--Water levels in the central unit of the LaMoure aquifer, river stage above LaMoure, and precipitation at LaMoure, 1982-84.

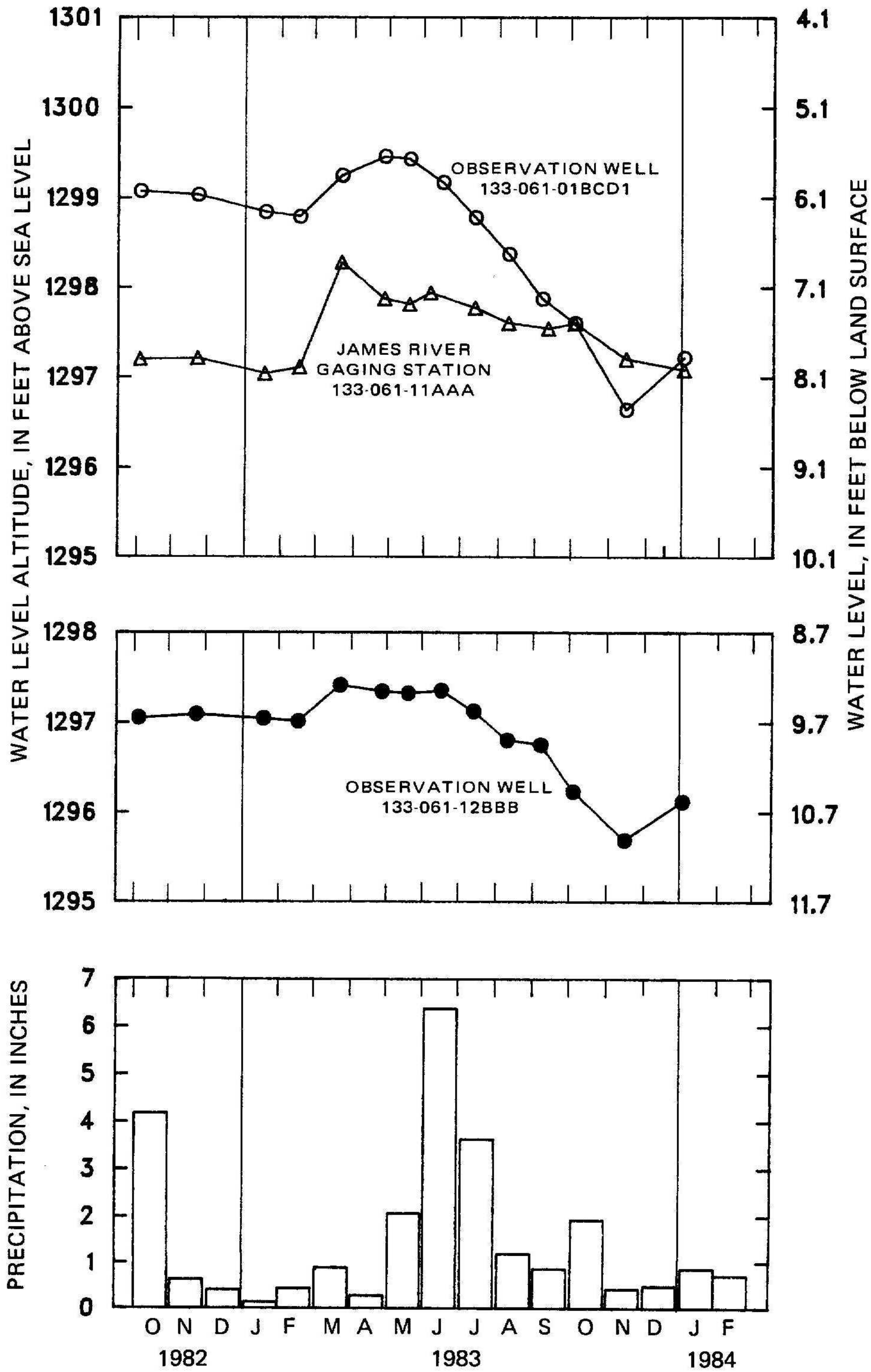


Figure 32.—Water levels in the central unit of the LaMoure aquifer, and river stage and precipitation at LaMoure, 1982-84.

The hydrographs of observation wells 133-060-19ABA1 and 133-060-19ABA3 and stage measuring site 133-060-19ADD are shown in figure 33. Well 133-060-19ABA1 is completed in the central unit of the LaMoure aquifer (pl. 1) and is screened from 81 to 86 ft below land surface. The aquifer and river are separated by about 50 ft of silt and clay. Well 133-060-19ABA3 is completed in glaciolacustrine silt and clay and is screened from 20 to 25 ft below land surface. The wells are located 20 ft east of the James River. The hydrographs indicate that water levels in the silt and clay deposits near the river respond to fluctuations of river stage and perhaps also to precipitation. The water levels in well 133-060-19ABA1 respond to irrigation pumpage, and, thus, indicate that the aquifer is not hydraulically connected to the river at this location.

The hydrographs of observation well 133-060-28DAB, completed in the central unit of the LaMoure aquifer, and stage measuring site 133-060-33CCC are shown in figure 34. Observation well 133-060-28DAB is screened from 23 to 28 ft below land surface and is located 50 ft east of the James River. The water levels in the observation well nearly mimic the river-stage fluctuation.

Geologic, ground-water-level, and river-stage data indicate that the central unit of the LaMoure aquifer interacts with the James River (pl. 1, fig. 25, and table 9). The interaction may be insignificant locally due to zones of low transmissivity between the aquifer and the river. The zones of low transmissivity are due to intervening silt and clay. The central unit of the LaMoure aquifer generally is separated vertically from the James River by 30 to 100 ft of silt and clay or is absent beneath the river in the east half of 133-061-11 and from 133-060-18C downstream to the south unit of the LaMoure aquifer. However, the central unit is in hydraulic connection with the James River in the west half of 133-060-21, the north half of 133-060-28, and in 133-060-29A.

The lowermost reach of Cottonwood Creek overlies the central unit of the LaMoure aquifer (pl. 1). The channel of the creek is above the water levels of the aquifer unit in 133-060-32. The creek, when flowing, probably loses water to the aquifer unit in this reach. The channel of the creek is below the ground-water level in 132-061-01 and 132-061-12 except during the irrigation season when the ground-water levels are lowered by withdrawals for irrigation use. The creek may interact with the aquifer unit in parts of 132-061-01. The creek, however, is separated from the aquifer unit by as much as 55 ft of silt and clay in 132-061-12.

The Ellendale aquifer does not interact with the James River because the base of the aquifer is about 50 to 70 ft above the valley floor of the James River. The Guelph aquifer also does not interact with the James River because the base of the aquifer is about 10 to 40 ft above the valley floor.

Irrigation withdrawals in the central unit caused seasonal drawdowns of 1 to 4 ft in areas of irrigation in 1983. The withdrawals may have induced seepage from the James River into the aquifer in 133-060-21, 134-061-09, and 134-061-16.

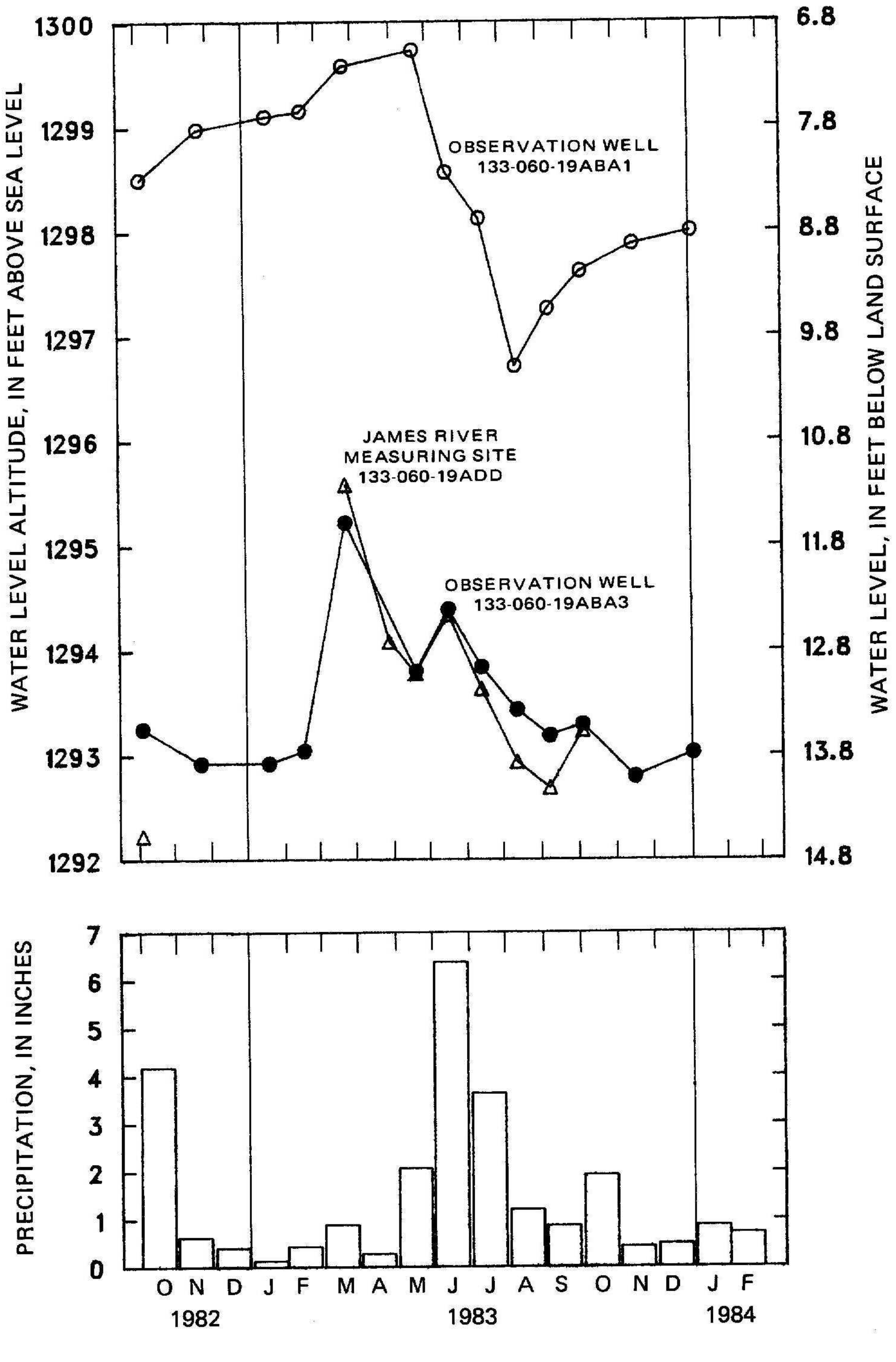


Figure 33.—Water levels in the central unit of the LaMoure aquifer and overlying clay, river stage below LaMoure, and precipitation at LaMoure, 1982-84.

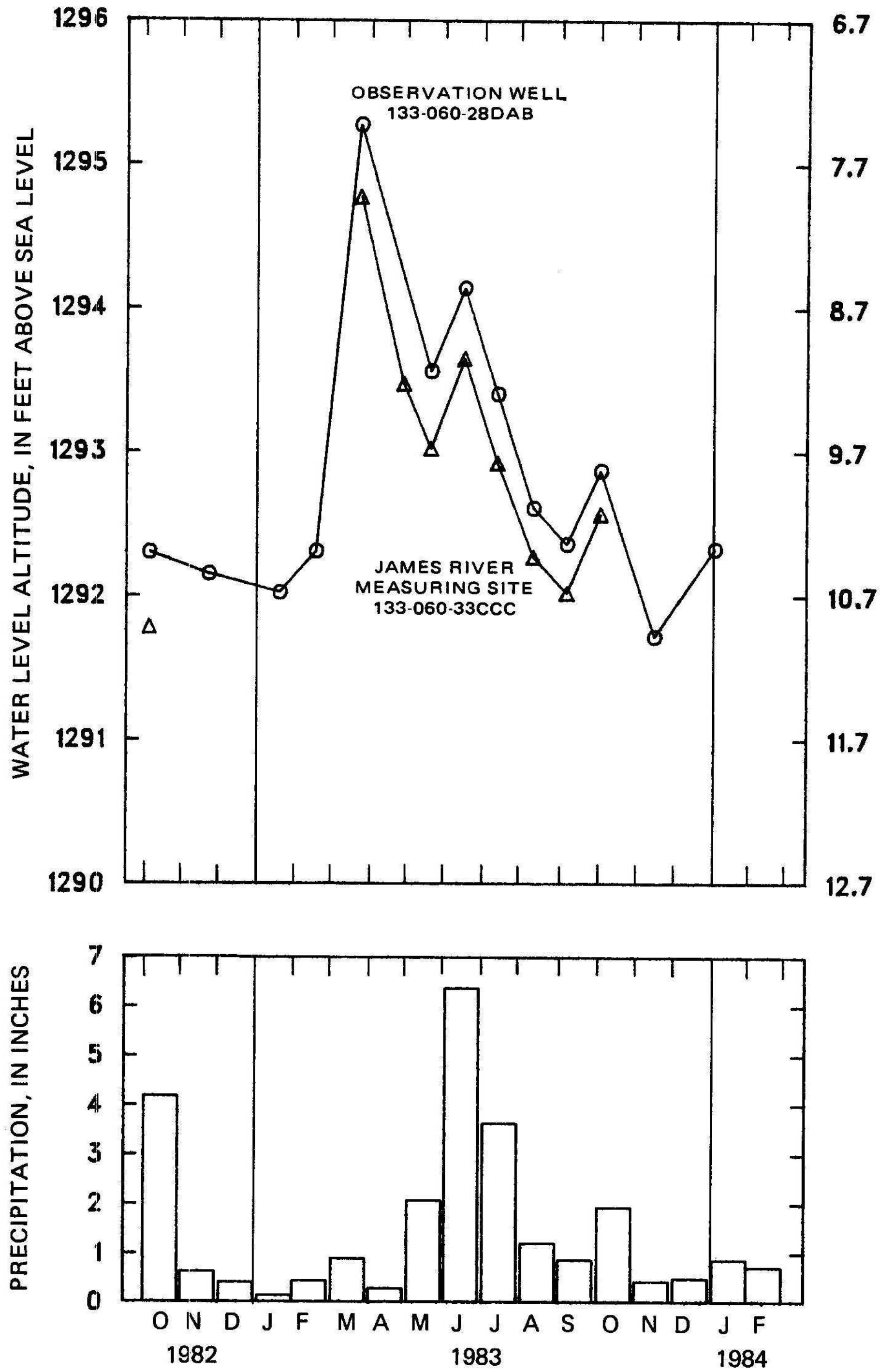


Figure 34.—Water levels in the central unit of the LaMoure aquifer, river stage near the LaMoure-Dickey county line, and precipitation at LaMoure, 1982-84.

The hydrograph of observation well 133-060-16DAA (fig. 35) shows that an overall long-term decline in water levels has occurred in parts of the central unit of the LaMoure aquifer. This well is located about 1 mi from the river. The water-level decline in the aquifer unit is due to irrigation and probably has caused a decrease in ground-water outflow from the unit to the river.

The hydrographs of observation well 132-060-34ADD in the south unit of the LaMoure aquifer and stage measuring site 132-059-31CCC are shown in figure 36. The well is screened from 68 to 73 ft below land surface and is located about 250 ft from the James River. The silt and clay vertically separating the aquifer from the river is about 35 ft thick at the well site. The large fluctuation in ground-water level is due to withdrawals for irrigation and the confined conditions of the aquifer. Although the water levels in the south unit rise and fall below the stage levels of the river, the glaciolacustrine silt and clay confining the aquifer in the James River valley preclude significant aquifer-stream interaction. Geologic, ground-water-level, and river-stage data indicate that the south unit of the LaMoure aquifer generally does not interact significantly with the James River. Interaction, however, may occur locally in T. 132 N., R. 60 W.

Area of the Oakes Aquifer

Depressions are common in the topography overlying the west unit of the Oakes aquifer. Eolian activity created some of the depressions, and other depressions are abandoned river channels partially filled with sediments. Ground-water-level fluctuations beneath the depressions primarily are controlled by hydrologic factors other than river-stage fluctuations. The depressions cause local ground-water flow systems.

The hydrographs of observation well 131-059-20BBB, completed in the west unit of the Oakes aquifer, and river-stage measuring site 131-059-30AAB are shown in figure 37. The observation well, completed in silty sand, is screened from 25 to 30 ft below land surface and is located about 500 ft east of the James River. It is located in a large topographic depression, which functions both as a recharge area and as a discharge area. The river stage generally is above ground-water levels. Silt and clay separate the aquifer from the river and preclude significant interaction of the aquifer with the river. Water levels in the observation well responded to: (1) Standing water percolating into the aquifer in spring and early summer, (2) evapotranspiration in summer, (3) excessive precipitation percolating to the aquifer in October 1982, and (4) frost accumulation in winter.

The west unit of the Oakes aquifer probably interacts with the James River, but the interaction generally is insignificant due to: (1) The low hydraulic conductivities of the west unit; (2) the predominance of local flow systems due to topographic depressions; and (3) intervening silt, clay, or till separating the river and the aquifer unit.

Bear Creek in Dickey County is separated from the underlying Spiritwood aquifer system by about 60 to 100 ft of intervening glacial

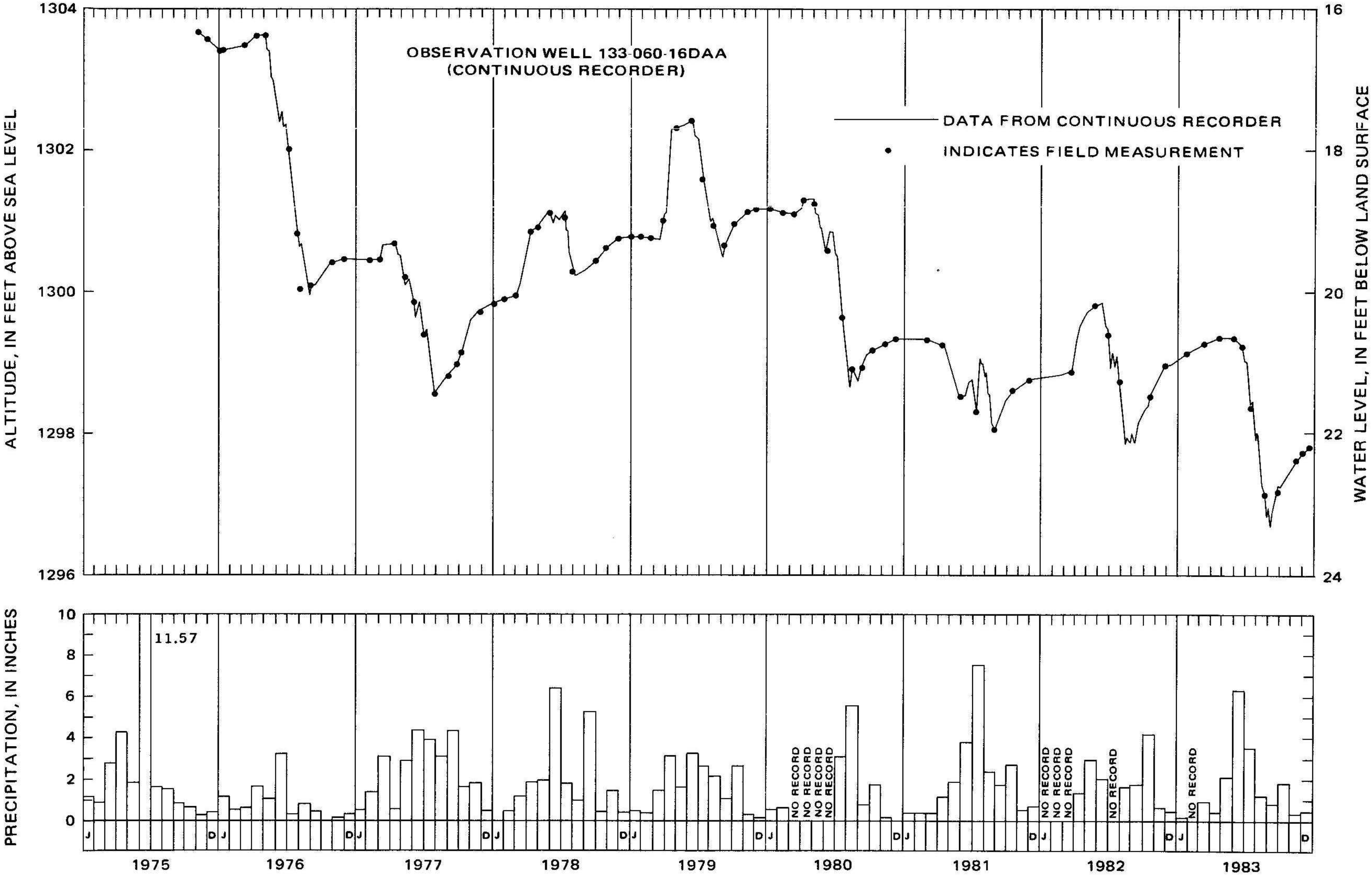


Figure 35.—Water levels in the central unit of the LaMoure aquifer near LaMoure and precipitation at LaMoure, 1975-83.

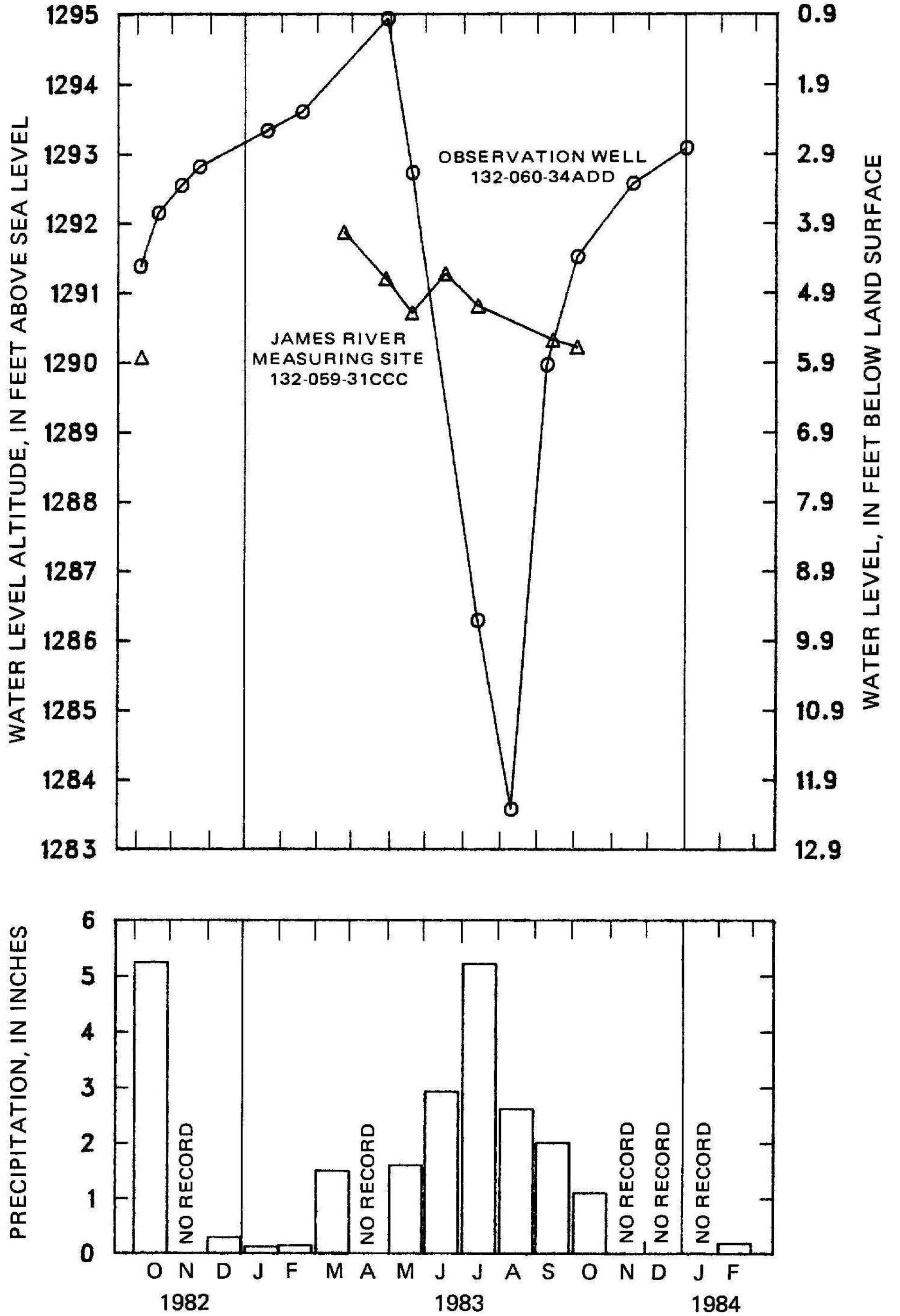


Figure 36.—Water levels in the south unit of the LaMoure aquifer, river stage above Oakes, and precipitation at Oakes, 1982-84.

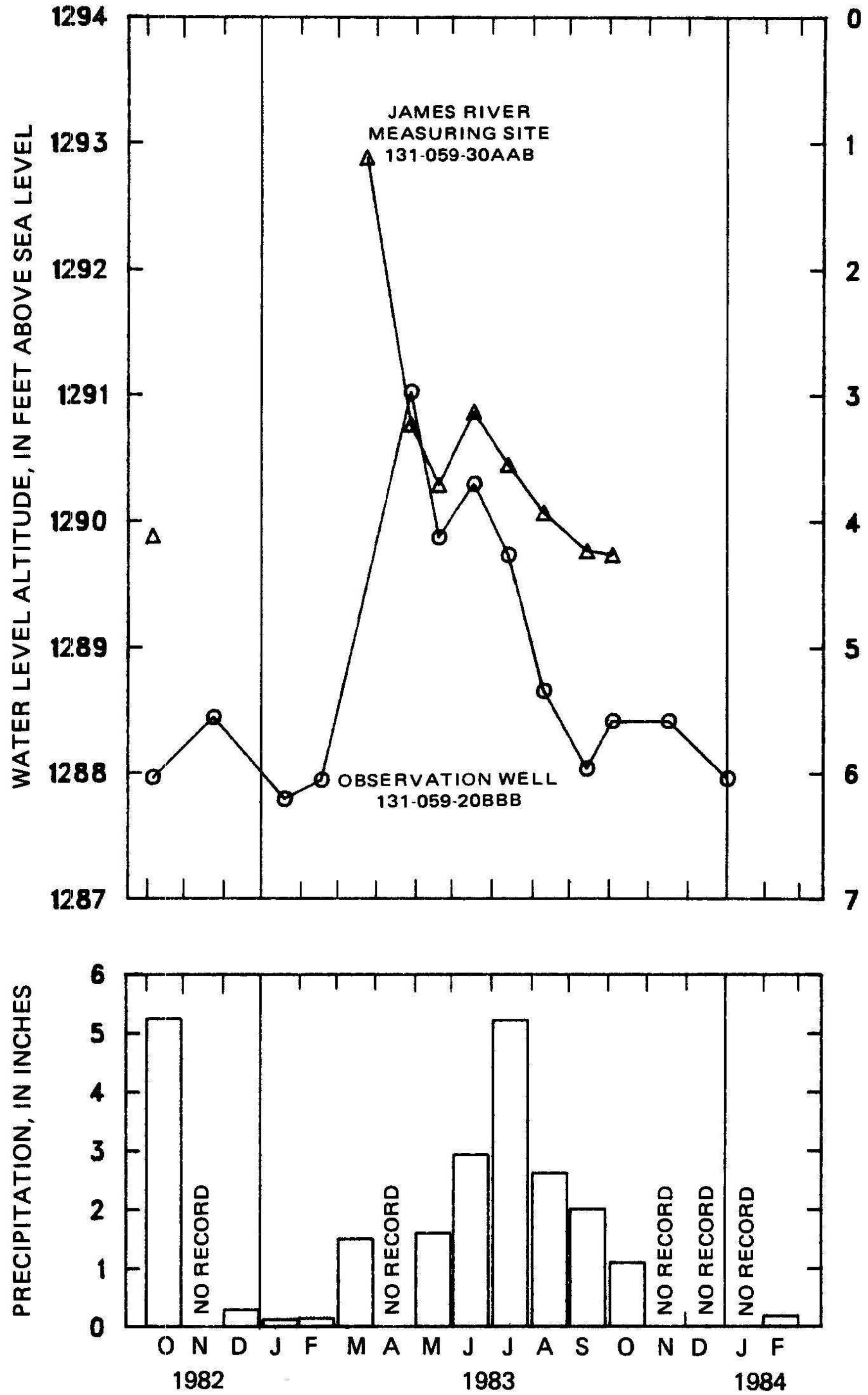


Figure 37.—Water levels in west unit of the Oakes aquifer, and river stage and precipitation at Oakes, 1982-84.

drift, which mostly consists of glacial till, silt, and clay. The thick intervening unit precludes significant interaction between Bear Creek and the Spiritwood aquifer system. Seepage from aquifers through overlying semipervious glacial drift and alluvium maintains water in pools in the creek during late summer.

Seepage Analysis

Four seepage evaluations were made to determine the location and significance of ground-water inflow to the James River during low-flow periods. A seepage evaluation consists of a number of discharge measurements at selected points on a stream. Measurement sites were located in certain reaches of the stream as determined by the geohydrology of the basin.

The seepage evaluations were designed to obtain measurements at the beginning and ending of each stream reach where the geohydrology of the basin indicated a possibility of an exchange of water between aquifers and the river. The geohydrology was determined from the results of previous studies and the test drilling program incorporated in this study.

In steady-state conditions, variations in discharge within a reach result from tributary inflow, inflow to the stream from aquifers, outflow to aquifers, bank storage, and evapotranspiration. If steady-state conditions have not been reached, variations in discharge may be due to a small wave of water moving through the reach or to changes in storage in the small reservoirs within the study reach.

Steady-state conditions on the James River seldom occur because releases from the upstream reservoirs rarely are steady. About 3 days are required for an increase in discharge to move through the study reach, and an even longer period of time is required for water to drain out of the study reach after the discharge has decreased. Strong wind effects can disrupt a steady-state condition locally for short periods of time.

Slow velocities and wind effects on vertical velocity profiles prohibited the use of standard current-meter discharge-measurement methods during low-flow conditions on the James River from Grand Rapids to the North Dakota-South Dakota State line. Therefore, a volumetric measuring method was used at the low-head dams at LaMoure and at Dakota Lake Dam near the State line. This method is accurate, but it limits the locations where discharge measurements can be made in this reach of the river.

Two seepage runs were conducted--one in October 1981 and one in October 1982. An attempt was made to maintain constant releases from the reservoirs for about 2 weeks prior to both seepage runs. The results of the two seepage runs (fig. 38) indicate that 2 weeks (a short-term low-flow period) was not a sufficient length of time to drain either the higher flows or bank storage out of the system. The general increase in discharge apparently is due to bank-storage discharge. Unsteady effects, however, masked the changes in discharge due to ground-water outflow. Wind effects rendered the results inconclusive on the lower reaches near the State line.

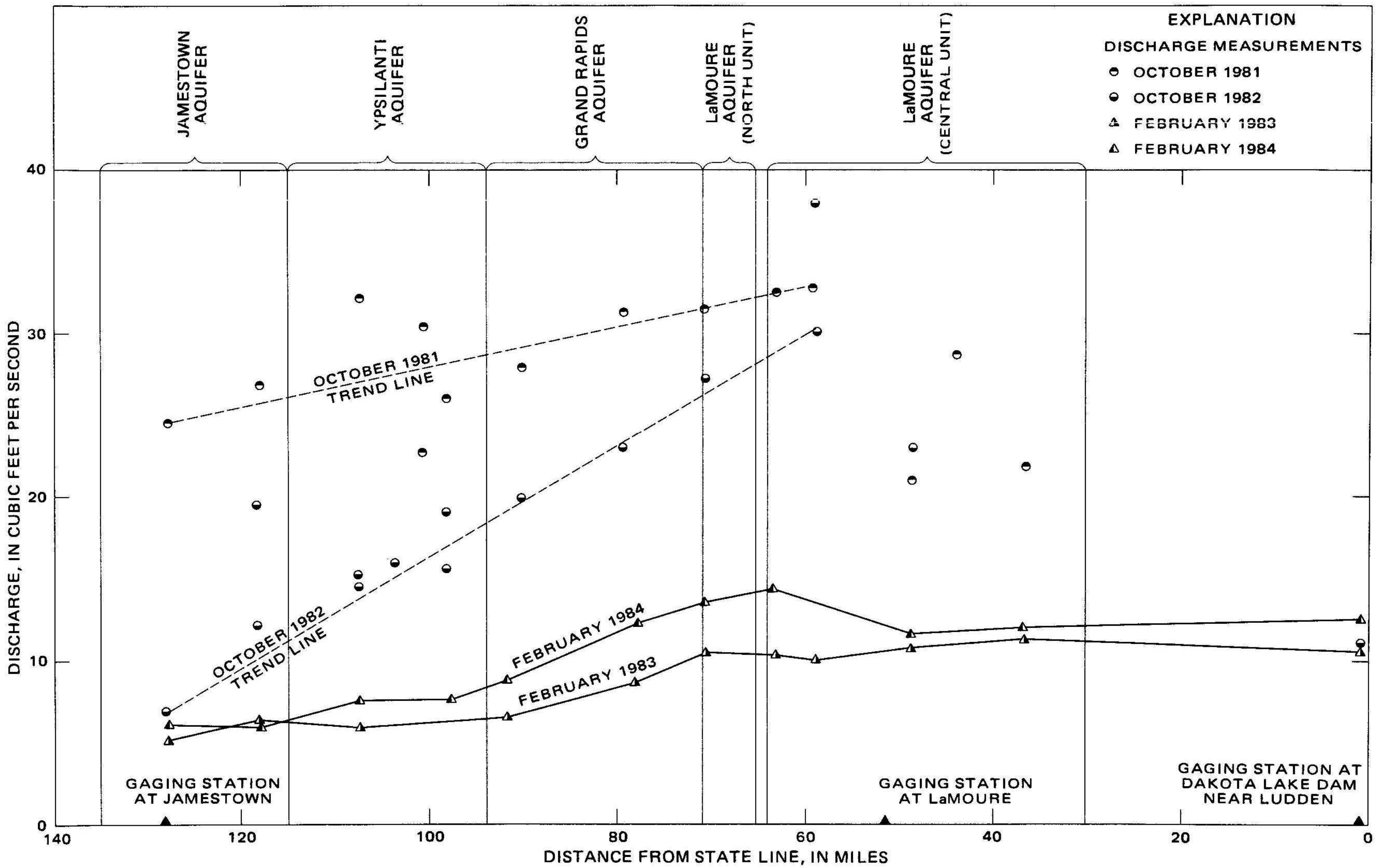


Figure 38.—Discharge along the James River during low-flow periods showing reaches and interactive aquifers and aquifer systems.

Further evaluation of hydrographs of the James River showed that the only long-term periods (about 5 weeks) in which steady-state conditions could be reached occur during winter periods under ice. Therefore, two additional seepage runs were conducted--one in February 1983 and one in February 1984. The locations of the aquifers and aquifer systems interactive with the James River, and measurement sites for the February 1983 and February 1984 seepage evaluations are shown in figure 39.

Prior to the February 1983 seepage evaluation, discharge at the Jamestown gage was relatively steady and at low-flow conditions for 5 weeks. A continuous ice cover reduced wind effects. The February 1983 measurements indicated that the Jamestown aquifer, the Grand Rapids aquifer of the Spiritwood aquifer system, and the central unit of the LaMoure aquifer contributed to the low flows on the James River (fig. 38). The most significant contribution was from the Grand Rapids aquifer of the Spiritwood aquifer system, the largest aquifer or aquifer system in areal extent. The flow in the James River increased from about 5 ft^3/s to about 11 ft^3/s within the study area and the Grand Rapids aquifer accounted for more than 4 ft^3/s of the increase. The other aquifers may not be large enough areally to contribute after a long period of low flow. Leakage from Jamestown and Pipestem Dams and perhaps ground-water seepage from the Midway aquifer northwest of Jamestown maintained low flows in the James River at Jamestown. The hydrograph at the gaging station at Dakota Lake Dam (located at the most downstream measuring site for the February 1983 seepage evaluation) suggests that storage upstream of the low-head dam may not have reached the same steady-state condition as the rest of the reach.

Prior to the February 1984 seepage evaluation, discharge at the Jamestown gaging station was at low-flow conditions (little precipitation or snowmelt runoff and constant reservoir releases) for 10 weeks. A continuous ice cover reduced wind effects during the seepage evaluation. The measurements indicated that the total flow of the James River increased from about 6 ft^3/s at Jamestown to about 14 ft^3/s at Grand Rapids (fig. 38). This increase of about 8 ft^3/s is about 3 ft^3/s more than the increase observed in this reach in February 1983. Some part of the total increase probably was caused by a wave of water moving down the stream caused by observed melting snow and ice in the Jamestown urban area. As in the February 1983 seepage evaluation, the discharge of the river increased significantly where the Grand Rapids aquifer underlies the river. The Grand Rapids aquifer apparently contributed about 6 ft^3/s to the flow of the river. The wave had not yet reached the measurement site at LaMoure, which explains the drop in discharge at the next downstream site. Water-level altitudes in the central unit of the LaMoure aquifer do not indicate seepage to the aquifer in this reach.

Stream-discharge measurements made on the major tributaries to the James River during seepage evaluations are shown in table 10. The discharge of the tributaries in February 1983 and February 1984 ranged from 0 to 0.16 ft^3/s.

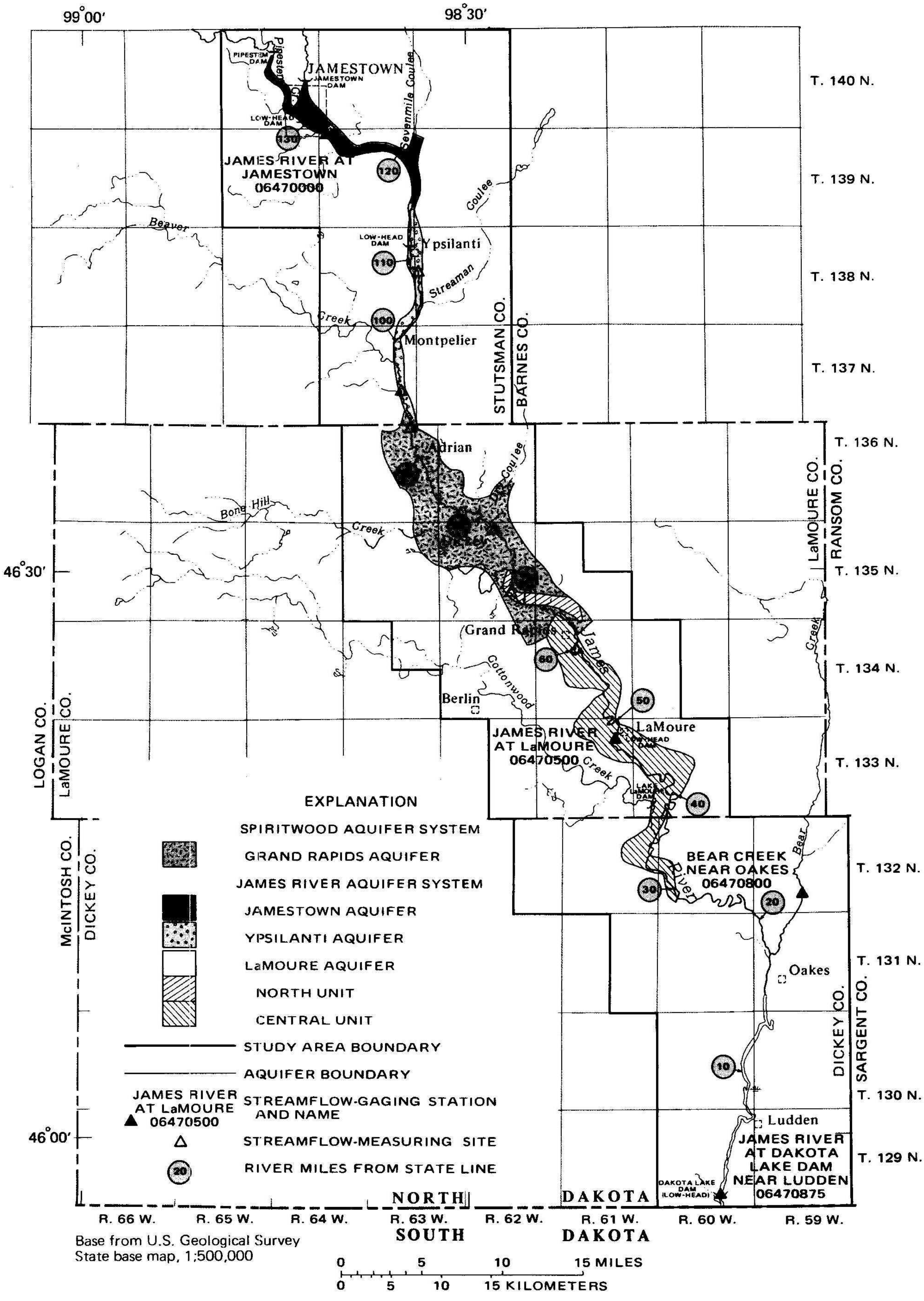


Figure 39.—Aquifers and aquifer systems interactive with the James River and locations of streamflow measurements made during the February 1983 and the February 1984 seepage evaluations.

Table 10.--Discharge measurements of selected tributaries to the James River

Tributary	Location	Date	Discharge (cubic feet per second)
Pipestem Creek	140-064-09DDD	10/26/81	3.05
Seven Mile Coulee	139-063-12ADB	10/26/81	.65
		10/27/82	.80
		2/08/83	.16
Streaman Coulee	138-062-30ADD	10/27/81	.10
		10/27/82	[1].15
		2/08/83	0
		2/09/84	0
Beaver Creek	137-063-10BAB	10/27/81	[1].05
		10/27/82	.09
		2/07/83	0
		2/08/84	.01
Bone Hill Creek	135-062-16CDB	10/27/81	0
		2/08/83	0
		2/09/84	0
Cottonwood Creek	133-060-32BBC	10/28/82	1.4
	132-061-01BAA	10/28/81	0
		2/09/84	0
	132-061-12ABA	10/28/82	.7
Bear Creek	131-059-08DCC	10/28/81	0
	131-059-08AAA	2/10/84	0

[1]Estimated.

Aquifer Parameters from Stream Hydrographs

Rorabaugh (1964) presented a method to determine approximate aquifer parameters from stream hydrographs. The method assumes that: (1) A drainage basin is underlain by a uniformly thick, homogeneous, isotropic aquifer; (2) that the distances from the stream to ground-water divides or to geologic boundaries of no flow are equal everywhere; and (3) that ground-water levels everywhere lie at stream level. Based on these assumptions, if a uniform increment of recharge is suddenly added, the ground-water discharge to the stream per unit of stream length on one side of the stream is

$$q = 2T(h_o/a)(e^{-\pi^2Tt/4a^2S}+e^{-9\pi^2Tt/4a^2S}+e^{-25\pi^2Tt/4a^2S}+\ldots),$$

where q is the ground-water discharge per unit of stream length (one side) at any time, t, after an instantaneous water-table rise of h_o at time t_o; T is aquifer transmissivity; S is the storage coefficient; and a is the distance from the stream to the ground-water boundary or divide. When t is large enough that Tt/a^2S is greater than 0.2, all terms except the first become very small and the equation becomes

$$q = 2T(h_o/a)e^{-\pi^2Tt/4a^2S}.$$

If the above equation is written for two points on the recession curve, (t_1, q_1) and (t_2, q_2), subtracted, and converted to base 10 logarithms, the following equation is obtained:

$$\frac{T}{S} = 0.933a^2(\frac{\log(q_2/q_1)}{t_1-t_2}).$$

The term in the parentheses can be evaluated by measuring on semilog paper the slope of the recession curve for a stream in terms of 1/(day per log cycle) of discharge depletion.

A number of the assumptions made in the development of above the equation are not true for the James River basin. Daniel (1976, p. 363) described the effects of the simplifying assumptions on a relatively complex aquifer. The major assumptions for application to the James River basin are as follow:

1. The James River interacts with more than one aquifer. The Grand Rapids aquifer of the Spiritwood aquifer system, however, is the most important aquifer contributing to low flow. This aquifer is, therefore, assumed to control the shape of the hydrograph recession.
2. Aquifer parameters vary greatly in space although a straight-line semilogarithmic recession does occur. The slope of the recession is then the integrated effect of the entire range of values of T and S in the aquifer.
3. The distance, a, from the stream to the ground-water boundary is not everywhere equal for the Grand Rapids aquifer. The effective distance from the stream to the boundary is assumed to be the average of the distances along the aquifer. The effect of the partially penetrating stream probably also is included in the effective distance.
4. The recharge to the aquifer does not result from a sudden uniform increment of recharge. After recharge ceases, the hydrograph recession, in time, becomes a straight line on a semilogarithmic plot. Whether or not recharge occurred as a sudden increment makes little difference if the recession curve straightens.

Interpretation of the James River hydrographs is difficult due to the complexity of the surface-water system. If the recession is modified due to reservoir releases or wind effects, the results of the analysis would be invalid. The effects of reservoir releases were removed from the record by subtracting the flows at Jamestown (just downstream of the reservoirs) from the flows at LaMoure. The impact of wind effects on the record at LaMoure was lessened by averaging the flows for 5 days. The flows at Jamestown were lagged by one time interval (5 days) to approximate water-wave movement downstream. Hydrographs for the period 1954-81 reveal that flows are highly variable due to reservoir releases for all periods except December, January, and February. Winter hydrographs were, therefore, chosen for the analysis.

Hydrographs for the years 1955, 1956, 1958, 1960, 1967, and 1974 were chosen for analysis because these years of record exhibited straight-line recessions without recharge due to rainfall or snowmelt in January and February. The recession slope ranged from 175 to 230 days per log cycle, averaging 200 days per log cycle. The hydrograph analysis for 1955 is shown in figure 40.

The equation for T/S can be solved if the slope of the hydrograph recession and the distance from the stream to the ground-water boundary (a) are known. Because the Grand Rapids aquifer is assumed to control hydrograph recessions, the value for "a" was estimated to be between 3,000 and 7,000 ft, which is the approximate distance from the stream to the boundary of the aquifer. This is not a directly measurable value because of variations in thickness and width of the aquifer. The results of the hydrograph analysis are shown in table 11. Values for transmissivity, T, were computed based on an estimate of average unconfined storage coefficient, S, of 0.2. For this analysis, values for hydraulic conductivity, K, were computed based on an approximated average saturated thickness of 90 ft.

The range in transmissivities and hydraulic conductivities is reasonable compared with values from aquifer tests in the Spiritwood aquifer system that range from 120 to 600 ft/d (table 2) and, thus, indicate that the Grand Rapids aquifer of the Spiritwood aquifer system controls the recession of low flows on the James River.

Water Quality

The distribution of common ions for the Grand Rapids aquifer of the Spiritwood aquifer system, the LaMoure aquifer, and the James River is shown in figure 41. There is little variability in the distribution of common ions in the James River from Jamestown to the North Dakota-South Dakota State line. The distribution of common ions in the aquifers and the distribution of common ions during low flow in the river in February 1983 show little variation and substantially overlap. Because there is little variation, it is not possible to correlate changes in common ions with the increase in flow in the river.

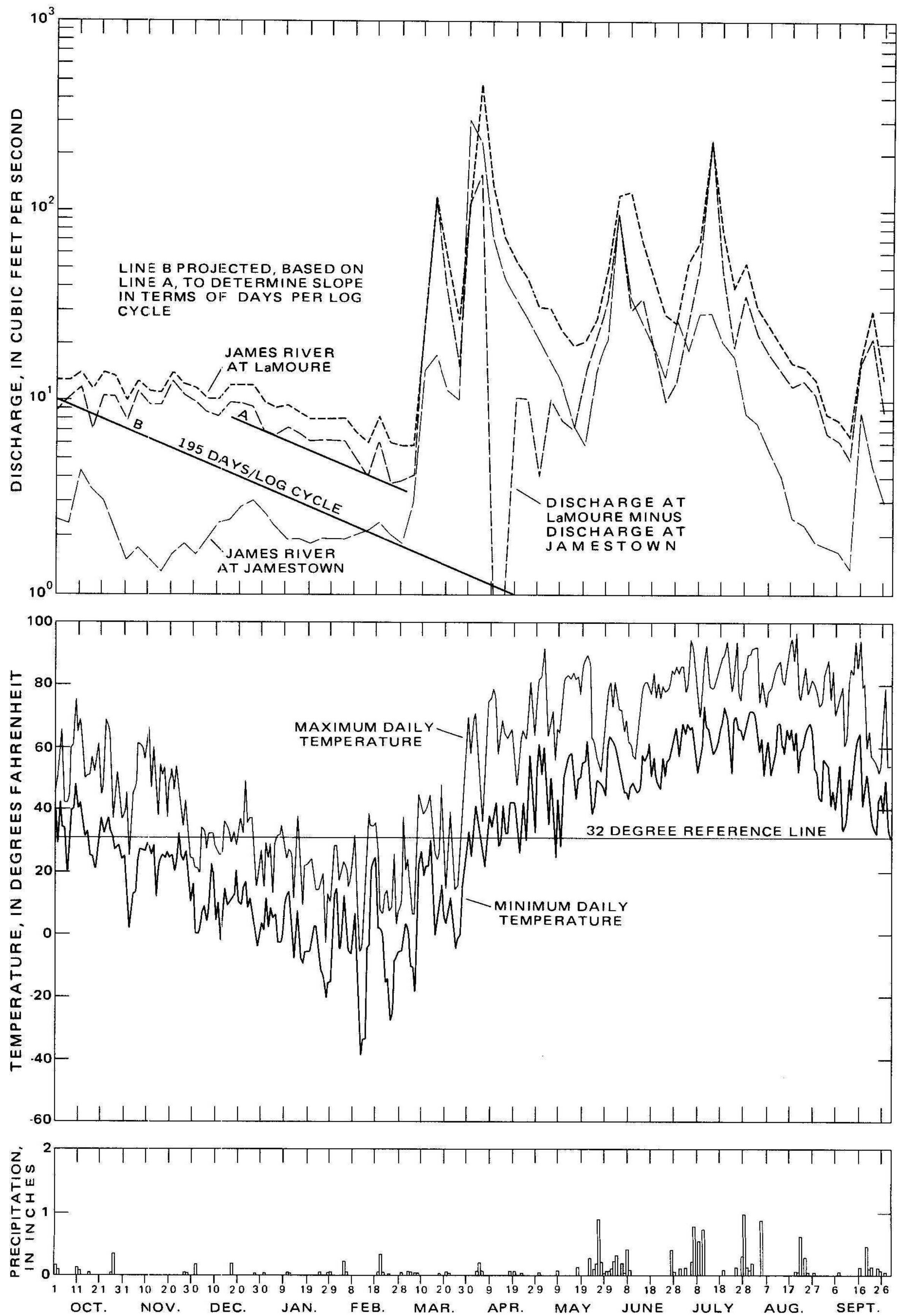


Figure 40.—Hydrograph analysis for determination of aquifer parameters based on climatological and 5-day average discharge data at Oakes for water year 1955.

Table 11.--Aquifer parameters for the Grand Rapids aquifer of the Spiritwood aquifer system, based on hydrograph analysis for the lower James River in North Dakota

Distance from stream to ground-water boundary, *a* (feet)	Aquifer transmissivity/storage coefficient, *T/S* (feet squared per day)[1]	Transmissivity, *T* (feet squared per day)[2]	Hydraulic conducivity, *K* (feet per day)[3]
3,000	42,000	8,400	93
5,000	117,000	23,000	255
7,000	229,000	46,000	511

[1]Based on a recession slope of 200 days per log cycle.
[2]Based on an average unconfined storage coefficient of 0.2.
[3]Based on an average saturated aquifer thickness of 90 feet.

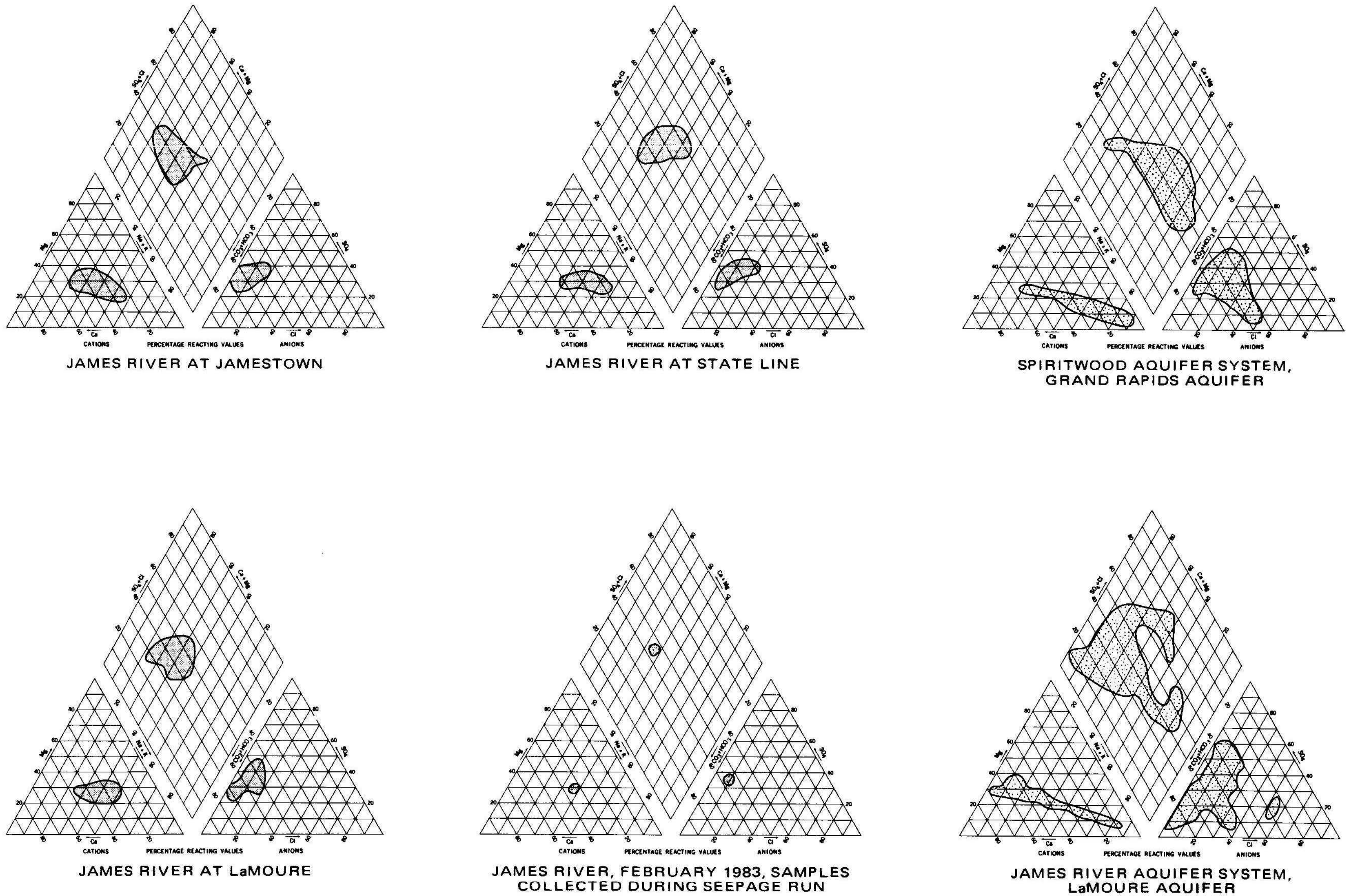


Figure 41.—Distribution of common ions for selected aquifers and the James River.

SUMMARY AND CONCLUSIONS

The development of ground-water and surface-water resources along the lower James River in North Dakota has increased significantly in the 1970's and early 1980's. This report describes the results of a study designed to obtain additional geologic and hydrologic data to better define the hydrologic system along the lower James River to provide a basis for water-resources management.

The lower James River study area extends from Jamestown to the North Dakota-South Dakota State line and consists of about 1,080 square miles in the lower part of the James River basin. The study area is characterized by low topographic relief; altitudes range from about 1,500 feet west of Jamestown to about 1,290 feet at the North Dakota-South Dakota State line. The climate of the area is subhumid. Annual precipitation averages about 19 inches, average annual temperature is about 40 degrees Fahrenheit, and total annual evaporation is about 38 inches.

The James River basin lies within the young glaciated plain of the Central Lowland province. The James River flows through a large melt-water trench that dissects the glaciated plain. The valley of the James River broadens in the southern part of the study area and coalesces with the lake plain of glacial Lake Dakota. The James River valley is steep sided, nearly flat bottomed, and ranges in width from about 0.5 mile near Montpelier to about 3 miles near LaMoure. It ranges in depth from about 150 feet near Dickey to about 40 feet where it coalesces with the Lake Dakota plain.

The Niobrara and Pierre Formations of Cretaceous age underlie the glacial drift of Pleistocene age in the study area. Glacial drift covers most of the area; however, major alluvial deposits of Holocene age occur on the flood plain of the James River.

The Niobrara and Pierre Formations consist of marine shale. The shale locally may yield small quantities of water to wells, but is considered to be an insignificant aquifer in the study area. Where fractured, the shale in the Pierre Formation, the Pierre aquifer, may yield as much as 50 gallons per minute to wells.

Glacial-drift deposits yield the largest quantities of water to wells (yields may exceed 1,000 gallons per minute) and, thus, comprise the major aquifers located along the lower James River. These glacial-drift aquifers are composed largely of sand and gravel interbedded with silt and clay. Alluvial sand deposits beneath the flood plain of the James River and its tributaries locally are contiguous with underlying glacial-drift aquifers and hydrologically are part of the underlying aquifers. In other areas, the alluvial sand deposits form local minor aquifers separated from the glacial-drift aquifers. The glacial-drift aquifers and aquifer systems include the Spiritwood aquifer system, the Homer, Montpelier, Adrian, Dickey, Ellendale, Guelph, and Oakes aquifers and the James River aquifer system. The Spiritwood aquifer system includes the Midway, North, West, Grand Rapids, and South aquifers. The James River aquifer system includes the Jamestown, Seven Mile Coulee, Ypsilanti, and LaMoure aquifers.

The glacial-drift aquifers that underlie or abut the James River and interact with the river are the Grand Rapids aquifer of the Spiritwood aquifer system, the west unit of the Oakes aquifer, and the Jamestown, Ypsilanti, and LaMoure aquifers of the James River aquifer system.

The Spiritwood aquifer system is the largest glacial-drift aquifer system in the study area. The system ranges from 1 to 9 miles in width and has an area of about 425 square miles. Six aquifer tests conducted on the aquifer system indicate transmissivity values range from 9,000 to 37,700 feet squared per day, storage-coefficient values range from 0.0002 to 0.0004, and mean hydraulic conductivity values range from about 120 to 600 feet per day.

The Grand Rapids aquifer of the Spiritwood aquifer system ranges from 1.5 to 6 miles in width, has an area of about 60 square miles, and an average saturated thickness of about 90 feet. Silt and clay of Pleistocene and Holocene age overlie the deposits of the aquifer beneath the flood plain of the James River from the Stutsman-LaMoure county line to near Dickey. These silt and clay deposits are as much as 26 feet thick, but have an average thickness of about 15 feet. From near Dickey downstream to Grand Rapids, glacial drift separates the Grand Rapids aquifer from the James River and from the LaMoure aquifer, which lies above the Grand Rapids aquifer. The thickness of this glacial drift ranges from 30 to 60 feet, but it is thinner in parts of 135-062-23. The North and West aquifers of the Spiritwood aquifer system and the Ypsilanti aquifer discharge water into the Grand Rapids aquifer. The potentiometric surface of the Grand Rapids aquifer indicates that the aquifer discharges into the James River. Concentrations of dissolved solids in water samples collected from the Grand Rapids aquifer ranged from 348 to 2,170 milligrams per liter and had a mean of 984 milligrams per liter. Bicarbonate was the major anion and sodium was the major cation in the water samples.

The Oakes aquifer is located beneath the Lake Dakota plain east of the James River in the southern part of the study area. The aquifer ranges from 1 to 8 miles in width, has an area of about 122 square miles, and an average saturated thickness of about 30 feet. The west unit of the Oakes aquifer ranges from 0.5 to 5 miles in width and has an area of about 29 square miles. Holocene silt and clay deposits of variable thickness overlie the aquifer unit beneath the flood plain of the James River. The deposits that comprise the west unit of the Oakes aquifer are much finer grained than those of the east unit and consist mostly of fine sand. The south unit of the LaMoure aquifer discharges into the west unit of the Oakes aquifer. Concentrations of dissolved solids in water samples collected from the west unit of the Oakes aquifer were 351, 457, and 794 milligrams per liter. Bicarbonate was the major anion and calcium was the major cation in the water samples.

The James River aquifer system is located in the James River valley from the northern end of the study area to near Oakes, and in the valleys of Pipestem Creek and Seven Mile Coulee. The aquifer system ranges from 0.25 to 2.5 miles in width, has an area of about 66 square miles, and a saturated thickness that ranges from 0 to about 120 feet. The potentiometric surface of the aquifer system slopes toward streams, steepening locally in zones of low transmissivity.

The Jamestown aquifer of the James River aquifer system ranges from 0.25 to 1.5 miles in width, has an area of about 9 square miles, and an average saturated thickness of about 30 feet. Holocene silt and clay deposits overlie the aquifer beneath the flood plain of the James River. These silt and clay deposits are as much as 20 feet thick but have an average thickness of about 10 feet. The Pierre, Midway, Homer, and Seven Mile Coulee aquifers discharge into the Jamestown aquifer. Concentrations of dissolved solids in water samples collected from the Jamestown aquifer ranged from 491 to 1,190 milligrams per liter and had a mean of 858 milligrams per liter. Bicarbonate was the major anion in the samples, and calcium and magnesium were the major cations.

The Ypsilanti aquifer of the James River aquifer system ranges from 0.3 to 0.8 mile in width, has an area of about 8 square miles, and an average saturated thickness of about 18 feet. Holocene silt and clay deposits overlie the aquifer beneath the flood plain of the James River. These silt and clay deposits are as much as 22 feet thick but have an average thickness of about 10 feet. The Pierre and Montpelier aquifers and the North aquifer of the Spiritwood aquifer system discharge into the Ypsilanti aquifer. Concentrations of dissolved solids in water samples collected from the Ypsilanti aquifer ranged from 534 to 852 milligrams per liter and had a mean of 705 milligrams per liter. Bicarbonate was the major anion in the water samples but none of the three major cations was dominant.

The LaMoure aquifer of the James River aquifer system is located in the James River valley from the junction of the James River and Bone Hill Creek downstream to near Oakes. The aquifer ranges from 0.5 to 2.5 miles in width, has an area of about 45 square miles, and an average saturated thickness of about 40 feet. Silt and clay of Pleistocene and Holocene age overlie the deposits of the aquifer beneath the flood plain of the James River. These silt and clay deposits are as much as 104 feet thick but have an average thickness of about 32 feet. The greatest thickness occurs near and downstream from the LaMoure-Dickey county line. Concentrations of dissolved solids in water samples collected from the LaMoure aquifer ranged from 236 to 1,720 milligrams per liter and had a mean of 625 milligrams per liter. Bicarbonate was the major anion in the water samples and calcium and sodium were the major cations.

The north unit of the LaMoure aquifer ranges from 0.25 to 1 mile in width and has an area of about 4 square miles. The Grand Rapids aquifer of the Spiritwood aquifer system discharges water into the north unit through intervening glacial drift.

The central unit of the LaMoure aquifer ranges from 0.5 to 2.5 miles in width and has an area of about 30 square miles. The South aquifer of the Spiritwood aquifer system discharges water into the central unit through intervening glacial drift. The Ellendale aquifer also discharges into this unit. One aquifer test indicates a transmissivity of 101,000 feet squared per day, a mean horizontal hydraulic conductivity of 1,100 feet per day, and a vertical hydraulic conductivity of 241 feet per day. The determined specific yield of 0.10 probably is lower than the actual specific yield. The potentiometric surface of the central unit of the LaMoure aquifer indicates that the unit discharges water into the James River.

The south unit of the LaMoure aquifer ranges from 0.5 to 2.5 miles in width and has an area of about 11 square miles. The South aquifer of the Spiritwood aquifer system discharges water into the south unit of the LaMoure aquifer through intervening glacial drift.

The lower James River in North Dakota generally is a perennial stream, although periods of no flow may occur. The contributing drainage area of the river is about 1,170 square miles at Jamestown and 2,180 square miles at the State Line. Average annual runoff is about 0.7 inch, and average annual discharge of the river at LaMoure is about 66,300 acre-feet. Tributaries to the lower James River include Pipestem Creek, Seven Mile Coulee, Beaver Creek, Bone Hill Creek, Cottonwood Creek, and Bear Creek. Flows in the lower James River are regulated by Jamestown Dam on the James River and by Pipestem Dam on Pipestem Creek. Outflow from the two reservoirs and direct surface runoff account for most of the annual discharge of the lower James River. Four small reservoirs behind low-head dams also exist on the James River.

The slope of the channel of the lower James River is about 1.3 feet per mile from Jamestown to Grand Rapids, about 0.28 foot per mile from Grand Rapids to the LaMoure-Dickey county line, and about 0.09 foot per mile from the county line to the State line. From Grand Rapids to the State line, the river is characterized by slow velocities, poorly defined stage-discharge relationships, long and numerous storage areas, and wide, exposed channels that are subject to wind effects. Evaporation in the lowermost reaches of the river may be significant during summer low-flow periods because of the wide river channel and frequent high winds.

The quality of water in the lower James River varies seasonally. The concentrations of dissolved solids in water samples collected from the river at LaMoure ranged from 141 to 1,200 milligrams per liter and had a mean of 574 milligrams per liter. Bicarbonate was the major anion in the samples and sodium and calcium were the major cations.

Large quantities of water are withdrawn from aquifers near the lower James River (7,749 acre-feet in 1983) and from the lower James River (2,032 acre-feet in 1983) for irrigation and municipal use. In 1983, 2,833 acre-feet of water was withdrawn from the Jamestown aquifer and 4,249 acre-feet of water was withdrawn from the LaMoure aquifer. Since 1973, withdrawals from aquifers near the river and from the river have increased more than 300 percent. In 1983, about 80 percent of the withdrawals from the lower James River occurred in the river reach from LaMoure downstream to the State line.

The total reported simultaneous pumping rate from the lower James River has increased from 21.1 cubic feet per second in 1973 to 44.5 cubic feet per second in 1983, an increase of more than 200 percent. Flow-duration curves for the James River at LaMoure indicate that a discharge of 50 cubic feet per second (approximately the 1983 total reported simultaneous pumping rate) was equaled or exceeded 52 percent of the time in May, 54 percent of the time in June, 40 percent of the time in July, 24 percent of the time in August, and 28 percent of the time in September.

During the summer irrigation period, streamflows in the lower James River adequate to meet irrigation demands are maintained by reservoir releases, releases from bank and channel storages, and outflow from aquifers to the river. Aquifer outflow to the river is only about 18 percent of the 1983 total reported simultaneous pumping rate. Since 1976, periods of no flow in the James River have been reported by irrigators downstream from LaMoure.

The nature and significance of the aquifer-stream interaction depends on the areal extent of interactive aquifers, the geology of the hydraulic connection between aquifers and the lower James River, and the annual withdrawal rate from interactive aquifers. The James River generally overlies the Jamestown aquifer. Silt and clay locally separate the aquifer from the river. The quantity of water contributed by the Jamestown aquifer to the James River during low-flow periods is unknown. The effects that large withdrawals of water (2,833 acre-feet in 1983) have on the small Jamestown aquifer probably are counteracted by induced seepage from the James River and by discharge from the Midway aquifer to the Jamestown aquifer. These withdrawals probably have substantially reduced the annual outflow from the Jamestown and Midway aquifers to the James River. Further ground-water appropriations from the Jamestown and Midway aquifers will reduce ground-water outflow to the river and induce more seepage from the river.

The James River generally overlies the Ypsilanti aquifer. Silt and clay locally separate the aquifer from the river. Most of the water discharged from the Ypsilanti aquifer probably occurs where: (1) The North aquifer of the Spiritwood aquifer system lies beneath the James River valley at Ypsilanti and provides leakage to the Ypsilanti aquifer, and (2) where the Montpelier aquifer discharges into the Ypsilanti aquifer. Because of the small areal extent of the aquifer, the quantity of water contributed by the Ypsilanti aquifer to the James River during low-flow periods probably is very small.

The James River generally overlies the Grand Rapids aquifer of the Spiritwood aquifer system from the Stutsman-LaMoure county line downstream to 135-062-23. In this reach, silt and clay locally separate the aquifer from the river. The North and West aquifers of the Spiritwood aquifer system discharge into the Grand Rapids aquifer, making the Grand Rapids aquifer the largest contributor (about 4 to 6 cubic feet per second) to the lower James River during low-flow periods. Further ground-water appropriations from the Grand Rapids aquifer will reduce ground-water outflow to the river and induce more seepage from the river.

The north unit of the LaMoure aquifer discharges into the James River in 135-062-25 and 135-062-26. The north unit is separated from the James River by silt and clay in 134-061-04, parts of 135-061-31, 135-061-32, and 135-061-33. Because of the small areal extent of the unit (about 4 square miles) and limited direct hydraulic connection with the river, the quantity of water contributed by the unit to the river during low-flow periods probably is very small.

The James River generally overlies the central unit of the LaMoure aquifer. Silt and clay locally separate the aquifer from the river. The central unit is separated vertically from the James River by 30 to 100 feet of silt and clay or does not underlie the river in the east half of 133-061-11 and from 133-060-18 downstream to the boundary of the south unit of the LaMoure aquifer. The quantity of water contributed by the central unit to the river during low-flow periods probably is less than 1 cubic foot per second. The hydrograph of well 133-060-16DAA indicates that an overall long-term decline in water levels has occurred in part of the unit. Irrigation withdrawals from the central unit may induce seepage from the James River in 133-060-21, 134-061-09, and 134-061-16. Large irrigation withdrawals (3,427 acre-feet in 1983) probably have reduced the annual outflow from the unit to the river. Further ground-water appropriations from the central unit of the LaMoure aquifer will reduce ground-water outflow to the river and induce more seepage from the river.

Thick silt and clay deposits separate the south unit of the LaMoure aquifer from the James River. The unit locally may interact with the river in T. 132 N., R. 60 W. The quantity of water contributed by the south unit to the river during low-flow periods probably is very small.

The James River generally lies above the west unit of the Oakes aquifer and is separated from the unit by silt and clay. Because of low hydraulic conductivity and the predominance of local flow systems in this unit, the quantity of water contributed by the west unit of the Oakes aquifer to the river during low-flow periods probably is very small.

In low-flow periods, the lower James River is a gaining stream. During peak irrigation use, the river possibly may become a losing stream, but this has not been noted during the course of this study because of large fluctuations in reservoir releases. Reservoir releases are common and provide periodic high flows that contribute to temporary bank and channel storage. Water released from these storages can support low flows for as much as 2 weeks. Long-term low-flow periods occur in winter and short-term low-flow periods occur in the summer and fall. From November through February, the releases from the reservoirs usually are reduced to a minimum, and a long-term low-flow period usually is attained by late February.

The Grand Rapids aquifer of the Spiritwood aquifer system discharges about 4 to 6 cubic feet per second of water to the James River during long-term low-flow periods. Other aquifers and undetermined sources discharge another 2 to 4 cubic feet per second of water to the James River. The base flow of tributaries to the lower James River is much smaller than the base flow of the James River, amounting to less than 0.2 cubic foot per second. In an extended low-flow period, nearly all flow in the lower James River is derived from leakage at Jamestown and Pipestem Dams and discharge from the Grand Rapids aquifer.

Transmissivity values ranging from 8,400 to 46,600 feet squared per day and hydraulic conductivity values ranging from 93 to 511 feet per day were estimated from stream hydrographs for the Grand Rapids aquifer. These values are similar to those derived from aquifer tests. The Grand Rapids aquifer apparently controls the recession of low flows in the lower James River. No correlation was noted for the distribution of common ions sampled from aquifers and from the river during low-flow periods.

NEED FOR FURTHER STUDY

J. E. Miller (U.S. Geological Survey, written commun., 1985, in a preliminary model documentation) coupled the modular three-dimensional finite-difference ground-water model developed and documented by M. G. McDonald and A. W. Harbaugh (1984) with a simple one-dimensional flow accounting procedure for surface water. Time and financial constraints on this investigation did not allow an adequate application of the coupled model to the ground-water and surface-water system of the lower James River. Application of the model to parts of the James River ground-water and surface-water system may provide pertinent insights into the operation of the system.

The modeling effort should include a study of the effects of data error or uncertainty on model results, such as the effect of errors in stream stage, ground-water levels, and aquifer hydraulic properties on the seepage fluxes from and to the stream. Experimentation with various node sizes would be necessary to determine which node size and which process approximation adequately simulate the aquifer-stream interface and bank-storage effects. Cross-section models also might be included in order to examine the two-dimensional vertical flow in the flow systems.

The major processes affecting the hydrologic system in the lower James River valley probably are recharge, evapotranspiration, and bank storage. The magnitude and distribution of the major processes are poorly understood. The North Dakota State Water Commission and the U.S. Geological Survey have initiated studies of the recharge and evapotranspiration processes in the Oakes aquifer. The results of the studies will provide a better understanding of these two processes and the rates of the two processes in unconfined conditions.

An investigation is needed to identify the occurrence of bank storage and discharge from the glacial-drift aquifers and the alluvium. This investigation is needed throughout the study reach.

Very little is known about the hydraulic conductivity and thickness of semipervious riverbed, glaciolacustrine, and alluvial deposits that locally separate the glaciofluvial aquifers from the river. The collection of this hydraulic conductivity and thickness data would greatly reduce uncertainties in the coupled model.

Continued monitoring of observation wells and river stage would be desirable in the river reaches where the Grand Rapids aquifer of the Spiritwood aquifer system underlies the James River. The continued monitoring of the Grand Rapids aquifer would supply further data for long-term analysis of aquifer-stream interaction and modeling activities.

Stage measurements off bridges were not made during the winter because of an ice cover. Measurements through the ice at the stage measuring sites would provide valuable stage altitudes for the analysis of aquifer-stream interaction.

Conventional stream-gaging methods do not allow the measurement of low flows in the James River from LaMoure downstream to the North Dakota-South Dakota State line. The river channel is wide and the velocities of the river are very slow in this reach. The U.S. Bureau of Reclamation and the U.S. Geological Survey are considering the construction of a gaging station between the gaging stations at LaMoure and at Dakota Lake Dam. The new gaging station would be located in 132-060-35A and would provide additional data to determine possible aquifer-stream interaction in this reach.

The large ground-water withdrawals by the city of Jamestown from wells near the river have induced seepage from the James River to the Jamestown aquifer or have reduced the seepage from the aquifer to the river. Little is known about the relationship of the Midway aquifer northwest of Jamestown with the James River. An observation-well network in the Jamestown aquifer and the adjoining Midway aquifer and stage measuring sites off bridges on the James River would provide data for assessing the stream-aquifer relationship in this area.

Jamestown Reservoir and Pipestem Lake probably have affected the water levels in the Pierre and Midway aquifers and, thus, may influence the low flow of the James River in the area. A study is suggested to investigate the effect of the reservoirs on the two aquifers.

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