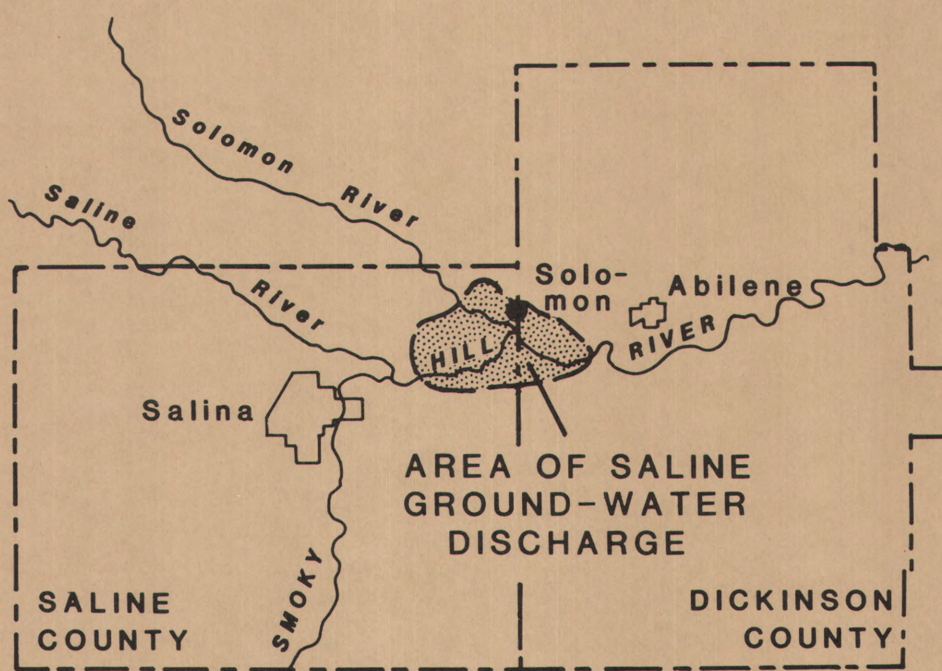
SALINE GROUND-WATER DISCHARGE TO THE SMOKY HILL RIVER BETWEEN SALINA AND ABILENE, CENTRAL KANSAS

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 81-43



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Saline water discharges from the alluvium into the Smoky Hill and Solomon Rivers near Salina, Kansas, at about 32 cubic feet per second. Chloride concentrations at base flow increased about 800 milligrams per liter in the Smoky Hill River and 550 milligrams per liter in the Solomon River during 1976-77.

The source of the saline water is the underlying Wellington aquifer, a zone of dissolution, subsidence, and collapse that occurs along the eastern margin of the Wellington Formation. Locally brine from the aquifer moves upward through collapse structures in the confining layer at the base of the alluvium. The brine discharge ranges from 0.3 to 0.8 cubic foot per second, and the chloride load ranges from 150 to 370 tons per day.

Results from a mathematical model of the flow system indicated that recharge from periodic flooding, as in 1973, was sufficient to reverse the normal (1976-77) hydraulic gradient between aquifers. Although brine discharge was temporarily reduced, saline-water discharge to the river was increased.

Brine in the Wellington aquifer could be intercepted by wells and pumped to deep formations or stored for release to the river during high flows. The freshwater in upstream base flow could be diverted, and saline-water discharge could be retained by low-head dams in the river channel for release during high flows.

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By

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and

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KANSAS WATER OFFICE

Lawrence, Kansas
1981

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CONVERSION FACTORS

Inch-pound units of measurement and abbreviations used in this report are listed with the factors for conversion to the International System (SI) of Metric Units.

Inch-pound unit	Multiply by	SI unit
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
acre	0.4047	hectare
square mile	2.59	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
foot per second (ft/s)	0.3048	meter per second
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.09290	meter squared per day
ton per day (ton/d)	0.09072	megagram per day
degree Fahrenheit (°F)	(1)	degree Celsius (°C)

1 °C = (°F - 32) /1.8.

SALINE GROUND-WATER DISCHARGE TO THE SMOKY HILL RIVER BETWEEN SALINA AND ABILENE, CENTRAL KANSAS

By

J.B. Gillespie[1] and G. D. Hargadine[2]

ABSTRACT

Saline water discharges from the alluvial aquifer into the Smoky Hill and Solomon Rivers between New Cambria and Sand Springs, Kansas. During relatively stable base flow in 1976-77, the discharge was about 32 cubic feet per second. Chloride concentrations at base flow increased about 800 milligrams per liter in the Smoky Hill River and 550 milligrams per liter in the Solomon River.

The source of the saline water is the underlying Wellington aquifer, a zone of dissolution, subsidence, and collapse along the eastern margin of the Wellington Formation. Locally, brine from the aquifer moves upward through collapse structures in the confining layer at the base of the alluvium. The brine discharge ranges from 0.3 to 0.8 cubic foot per second, and the chloride load ranges from 150 to 370 tons per day.

Results from a mathematical model of the flow system indicated that recharge from periodic flooding, as in 1973, was sufficient to reverse the normal (1976-77) hydraulic gradient between aquifers. Although brine discharge was temporarily reduced, saline-water discharge to the rivers increased.

The discharge of brine could be intercepted by pumping wells completed in the Wellington aquifer to lower the potentiometric head and reduce upward flow. The intercepted brine could be discharged into formations underlying the area at depth or piped to a storage reservoir from which the brine would be evaporated or released to the rivers during peak flows. Also, the freshwater in upstream base flow could be diverted by canal, and the saline-water discharge could be retained by low-head dams in the river channel for release during peak flows.

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[1] U.S. Geological Survey, Lawrence, Kansas.
[2] Kansas Water Office, Topeka, Kansas.

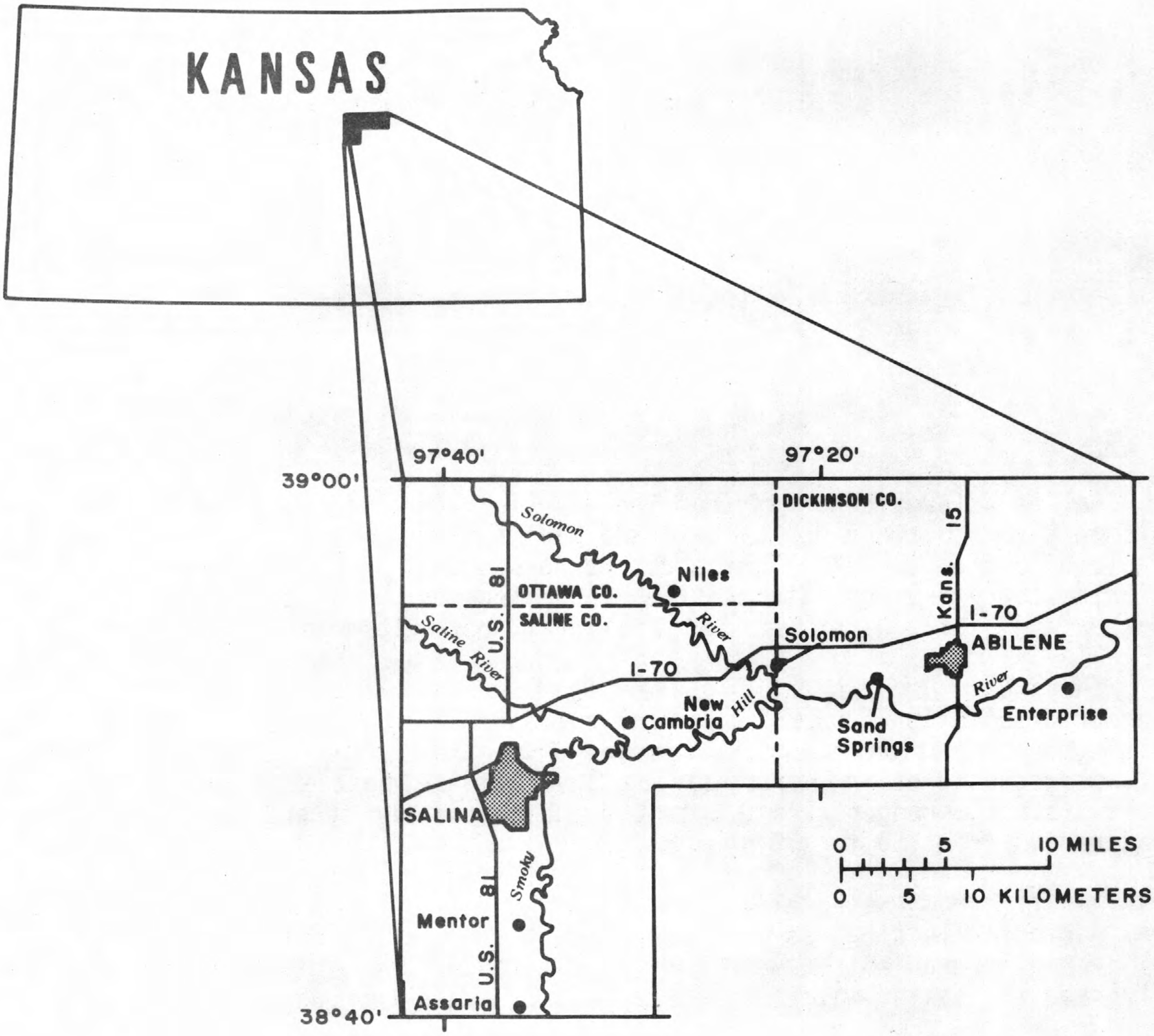


Figure 1.--Location of study area.

INTRODUCTION

Degradation of the chemical quality of water in the Smoky Hill River occurs between Salina and Abilene in central Kansas. Ground water having large concentrations of sodium chloride is discharged to the river from the alluvial aquifer in the valleys of the Smoky Hill and Solomon Rivers. These large concentrations have a direct effect on the usability of the Smoky Hill River as a source of water for municipal, industrial, and irrigation supplies.

During recent years, large multipurpose reservoirs have been constructed within the basin to reduce the risk and hazard of floods and droughts. However, the conservation storage available in the reservoir system is not adequate to dilute saline ground-water discharging along the Smoky Hill River during an extended drought. Although water currently is released on a voluntary basis for dilution purposes at no cost to the users, future demands may require that water be purchased through a water-storage contract with the Kansas Water Office. Thus, saline ground-water discharge needs to be controlled if fresh surface and ground waters are to be available for public supplies, industrialization, and economic development of the Smoky Hill River valley.

During July 1975, a study of the saline ground-water discharge to the Smoky Hill River was started by the U.S. Geological Survey in cooperation with the Kansas Water Office. The study area included the valleys of the Smoky Hill, Saline, and Solomon Rivers and adjacent uplands in eastern Saline and western Dickinson Counties, central Kansas (fig. 1). Salina, the county seat of Saline County and one of the largest cities in Kansas, is located in the western part of the area. New Cambria is near the confluence of the Smoky Hill and Saline Rivers, and Solomon is near the confluence of the Smoky Hill and Solomon Rivers. Abilene, the county seat of Dickinson County, is near the eastern end of the study area.

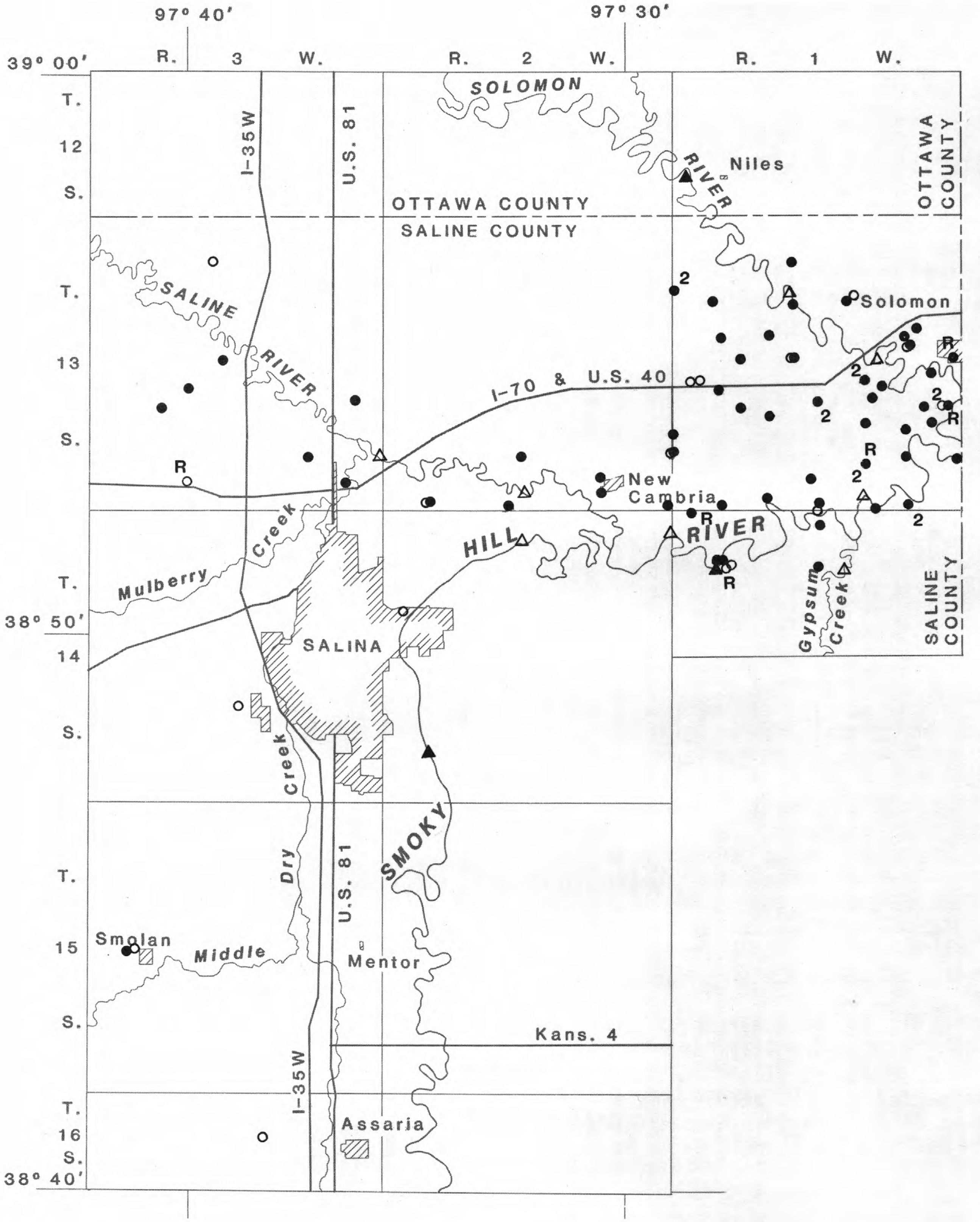
Purpose and Scope of Study

The purpose of the study was to determine: (1) The location and extent of saline ground-water discharge to the Smoky Hill and Solomon Rivers, (2) the source and movement of the saline water, and (3) the measures that may be taken to control or alleviate degradation of the streams by the naturally occurring discharge of saline ground water.

Water samples were collected during float trips down the Smoky Hill and Solomon Rivers to determine specific locations where saline ground water discharges to the streams. Records of surface-water discharge and water-quality data were obtained from U.S. Geological Survey streamflow-gaging stations on the Smoky Hill, Saline, and Solomon Rivers. Seepage (gain-loss) surveys were made on the Smoky Hill and Solomon Rivers during periods of base flow.

The Kansas Geological Survey participated in the study by assisting with drilling and installation of observation wells in the Permian rocks and in the alluvium of the valleys. Gamma-ray logs were obtained for each observation well. Geophysical logs of oil tests and wells in the area were obtained from the Oil and Gas Library, Kansas Geological Survey. Other lithologic data were obtained from the Kansas Department of Transportation, the U.S. Bureau of Reclamation, the Hydraulic Drilling Co. in Salina, and from previous reports.

A network of observation wells, as shown in figure 2, was established for monthly measurements of ground-water levels (including seven wells measured con-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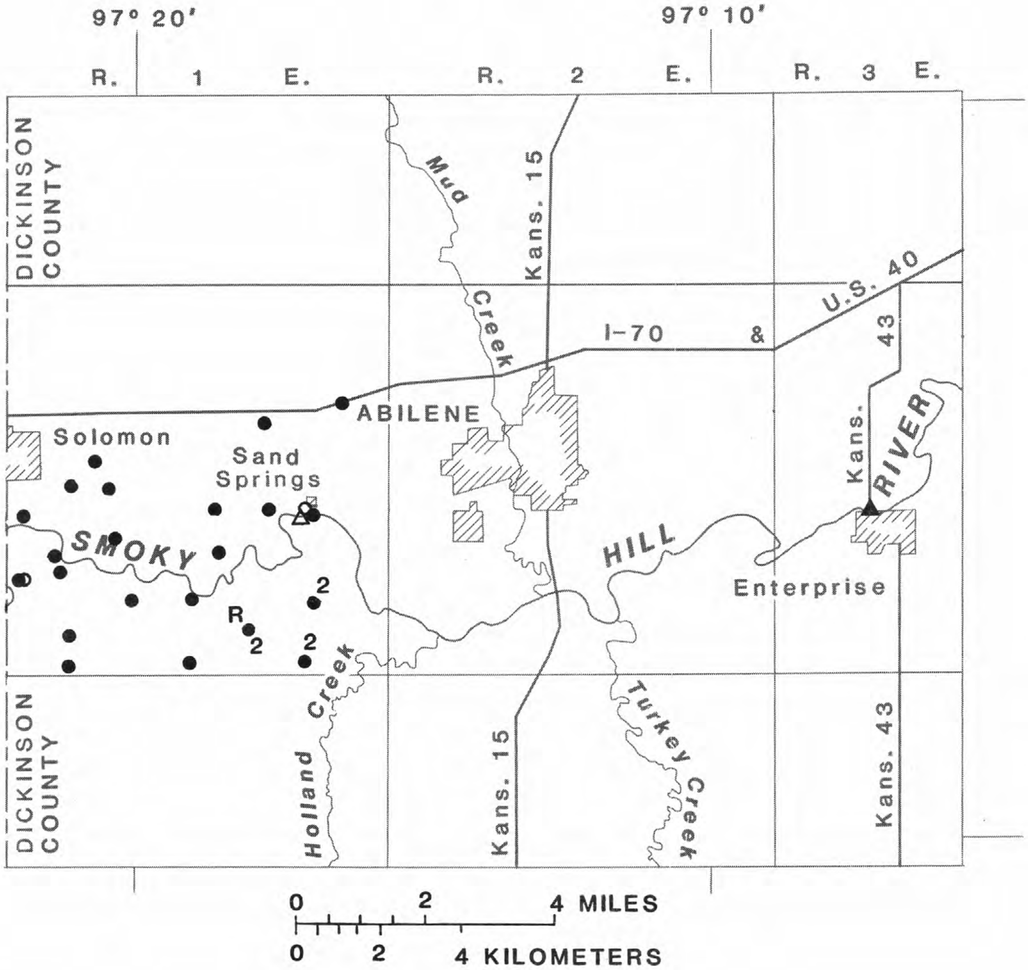
R. 2 W.
R. 1 W.
T. 12 S.
T. 13 S.
T. 14 S.
T. 15 S.
T. 16 S.
38° 50'
38° 40'
SOLOMON RIVER
Niles
OTTAWA COUNTY
SALINE COUNTY
I-35W
U.S. 81
SALINE RIVER
Solomon
I-70 & U.S. 40
New Cambria
SMOKY HILL RIVER
Mulberry Creek
SALINA
Gypsum Creek
Dry Creek
Middle
Smolan
Mentor
Kans. 4
Assaria



EXPLANATION

Observation well

2●R

Well drilled into alluvium

2○R

Well drilled into Permian

R indicates well equipped with recorder. Number indicates number of wells at that location

▲

Streamflow-gaging station

△

Nonrecording river stage measurement site

Figure 2.--Location of data-collection sites.

tinuously from December 1975 to October 1978). Samples of ground water collected from each of these observation wells were analyzed for chloride, sulfate, specific conductance, and density. River stage was measured, and samples of surface water were collected for analysis at bridges over the Smoky Hill, Saline, and Solomon Rivers in the study area.

Because sodium chloride is of particular interest to the study, natural waters are classified in this report as fresh, saline, or brine on the basis of their chloride concentration in milligrams per liter (mg/L). Freshwater is classified as having less than 250 mg/L of chloride, saline water as having from 250 to 20,000 mg/L, and brine as having more than 20,000 mg/L. Data also are presented for areas where the sulfate concentrations exceed the recommended limits in drinking water as established by the U.S. Environmental Protection Agency (1977).

All data obtained during the investigation are available for examination in the office of the U.S. Geological Survey, Lawrence, Kans.

Previous Studies

Numerous studies have been made in regard to the geology, ground water, and quality of ground and surface water in the area. Studies have been made of the geology and ground water in the Smoky Hill River valley by Latta (1949), in the Saline and Solomon River valleys by Mack (1962), and in the adjacent areas by Dunlap (1977). The geology of the Salina Basin was described by Lee (1956), and the geology and ground water in the salt and gypsum deposits of the Wellington Formation were described by Kulstad, Fairchild, and McGregor (1956) and Gogel (1981). The effects of natural contamination from ground water were reported by Bell (1974).

During recent years, the U.S. Geological Survey has been collecting data on the quantity and quality of streamflow in the Smoky Hill, Saline, and Solomon Rivers, and the Kansas Water Office has been monitoring the surface-water quality at key locations along the Smoky Hill and Solomon Rivers. Using low-level aerial photography and imagery, areas of saline ground-water discharge were located, and selected seeps and springs were measured for quantity and quality of discharge. The Kansas Water Office also has prepared a report on non-point source mineral intrusion for surface water (Hargadine, Balsters, and Luehring, 1979) that includes the valleys of the Smoky Hill and Solomon Rivers in Saline and Dickinson Counties.

Acknowledgments

The authors express their appreciation to Mr. and Mrs. Chester Kirtland for the use of their land as a storage and staging area during the investigations of the study. Recognition is given to the Kansas Geological Survey for assistance and consultation and to the drilling supervisor, Mr. M. K. Kleinschmidt. Recognition also is given to the Engineering Departments of Dickinson and Saline Counties, the Salina City Engineering Department, and the Kansas Department of Transportation (Salina District) for their cooperation

in securing drilling sites; to the Kansas Department of Transportation (Topeka Headquarters) for geologic data along Interstate Highways I-70 and I-35 West; and to the many land owners for giving permission to drill test holes on their land. Thanks are given to Mr. Wayne Leidwanger of the U.S. Army Corps of Engineers for arranging a flight over the project area in a U.S. Army helicopter. The authors are particularly grateful to Mr. William Biegler, District Geologist for the Kansas Department of Health and Environment, for consultation, and to Mr. O. S. Fent, Hydraulic Drilling Co., Salina, for use of his drillers' logs and consultation.

Well-Numbering System

The system of numbering wells and test holes in this report is based on the U.S. Bureau of Land Management's system of land subdivision. The first number indicates the township; the second indicates the range west or east of the Sixth Principal Meridian; and the third indicates the section in which the well is located. The first letter denotes the quarter section or 160-acre tract; the second, the quarter-quarter section or 40-acre tract; and the third, the quarter-quarter-quarter section or 10-acre tract. The 160-acre, 40-acre, and 10-acre tracts are designated A, B, C, and D in a counterclockwise direction beginning in the northeast quarter of the section. Where there is more than one well in a 10-acre tract, consecutive numbers are added beginning with 2 in the order in which the wells are inventoried. For example, 13-01W-35BBC indicates a well in the southwest quarter of the northwest quarter of the northwest quarter of sec.35, T.13 S., R.1 W. (fig. 3).

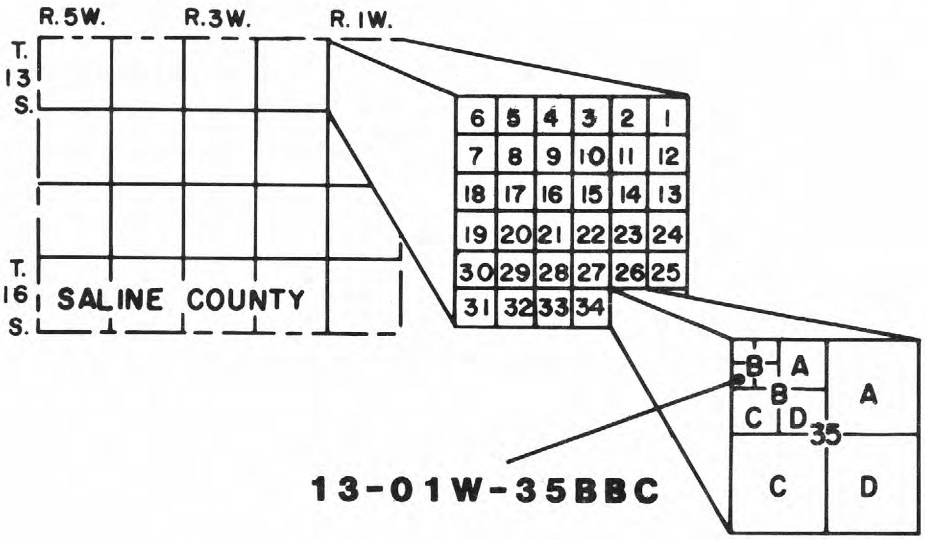
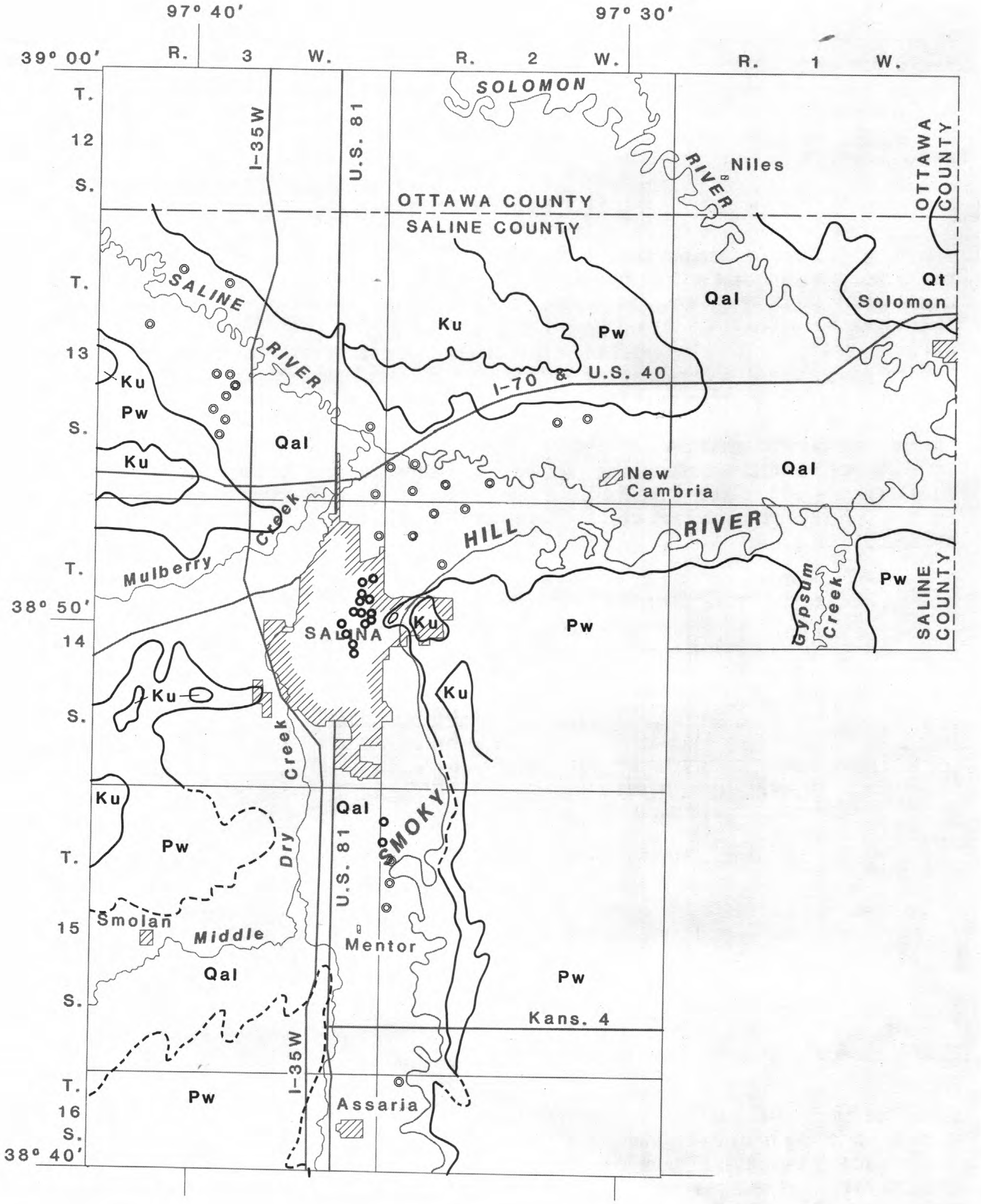


Figure 3.--Well-numbering system.

GEOHYDROLOGIC SETTING

The Smoky Hill River valley in eastern Saline and western Dickinson Counties is underlain by Pleistocene alluvial, terrace, and dune deposits (fig. 4). The adjacent uplands are underlain by Permian and Cretaceous rocks (fig. 4). Structurally, the area is located near the middle of the Salina Basin (Lee, 1956, pl. 12). The general dip and thicknesses of the formations are shown in figure 5.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39° 00'
R. 3 W.
R. 2 W.
R. 1 W.
T. 12 S.
T. 13 S.
T. 14 S.
T. 15 S.
T. 16 S.
38° 50'
38° 40'
SOLOMON RIVER
Niles
OTTAWA COUNTY
SALINE COUNTY
I-35W
U.S. 81
SALINE RIVER
Ku
Pw
Qal
Qt
Solomon
I-70 & U.S. 40
New Cambria
Mulberry Creek
HILL RIVER
SMOKY
Gypsum Creek
SALINA
Dry Creek
Smolan
Middle
Mentor
Kans. 4
Assaria

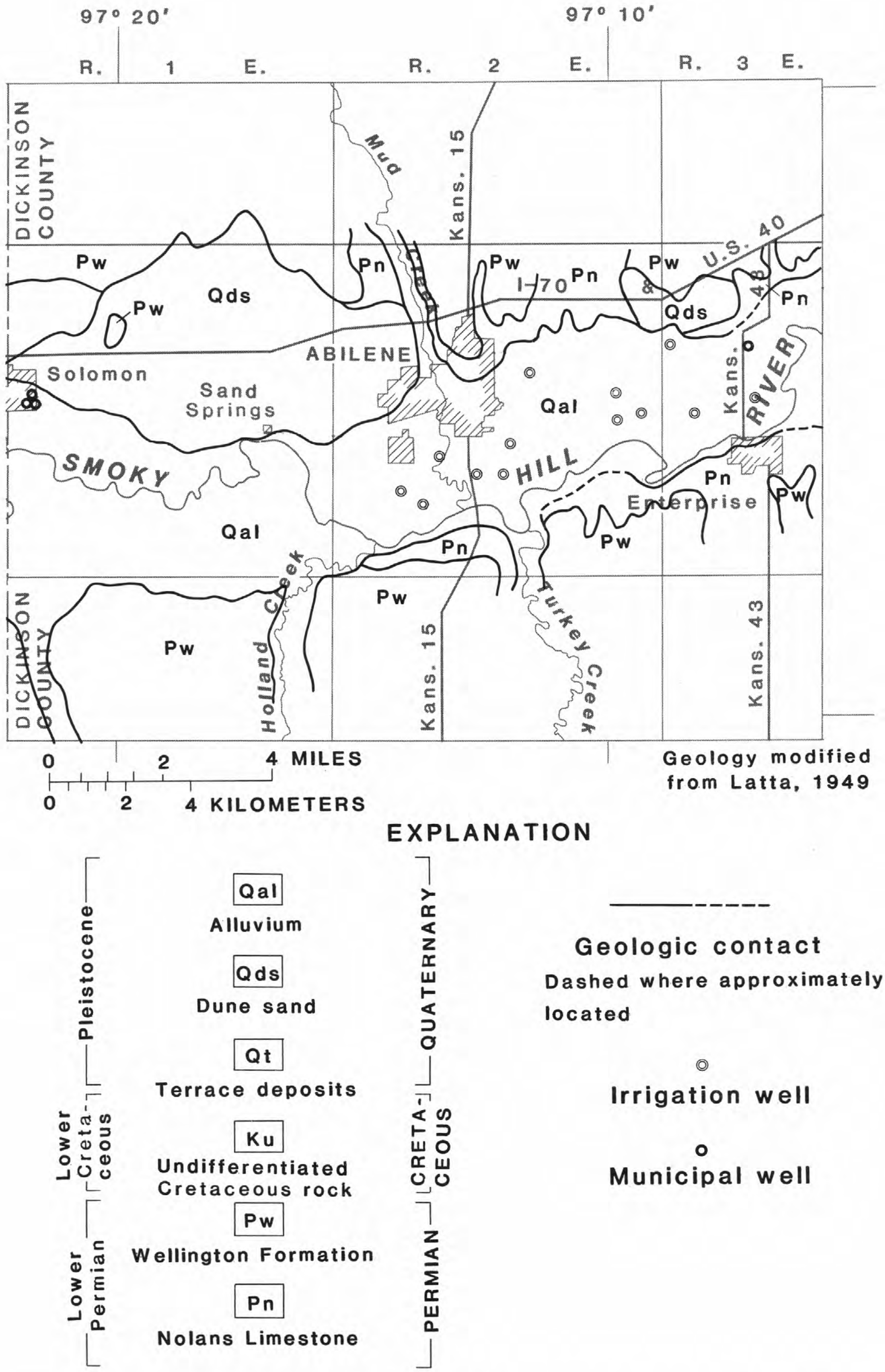


Figure 4.--Geology and location of large-capacity wells.

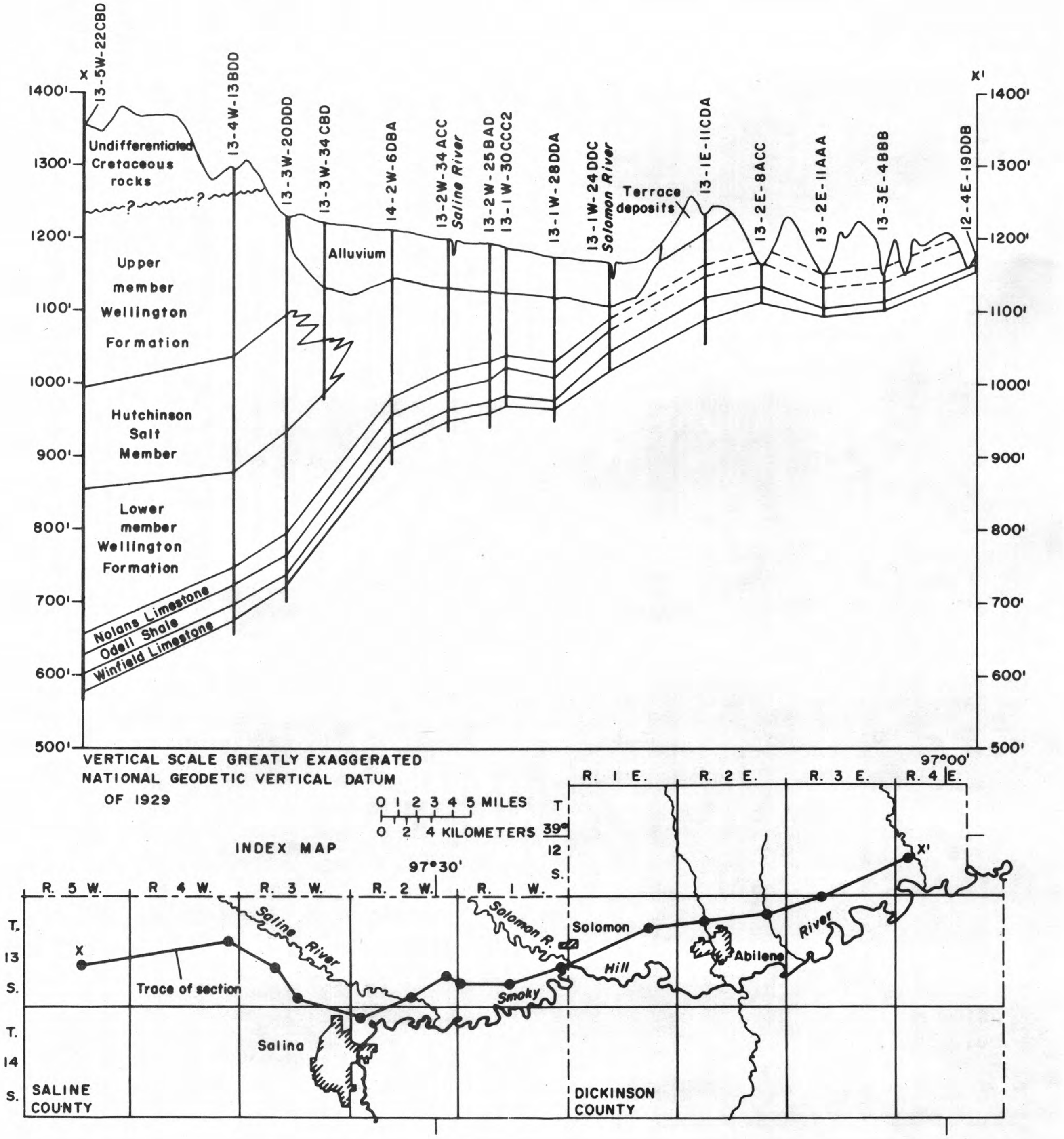


Figure 5.--Geologic section, eastern Saline County to western Dickinson County.

Permian System

Chase Group

Winfield Limestone

The lower part of the Winfield contains a thin, dense gray limestone with abundant black chert (Stovall Limestone Member) at the base that is overlain by a gray calcareous shale. In the upper part, a massive, cavernous gray limestone is overlain by thin-bedded limey shale and shaley limestone. The upper unit commonly occurs as an anhydrite or dolomite in the deep subsurface. Thicknesses of the formation range from about 30 to 36 feet. Wells completed in the upper limestone member yield an adequate supply of water for the city of Abilene.

Odell Shale

The Odell is a red, gray, and green shale having a thickness of about 30 to 35 feet. This formation is not known to yield water in the area.

Nolans Limestone

The Nolans Limestone crops out on the adjacent uplands and underlies alluvial deposits in the river valleys at the eastern end of the study area. The formation consists of a thin gray limestone overlain by a gray shale unit in the lower part. The upper unit is a cavernous yellowish-tan dolomitic limestone that may occur as an anhydrite or gypsum in the subsurface. The thickness of the formation is about 15 feet. The formation is not known to yield water in the area.

Sumner Group

Wellington Formation

The Wellington Formation crops out on the adjacent uplands and underlies alluvial deposits in the river valleys, except at the eastern end of the study area. The formation is thickest toward the west where it dips beneath Cretaceous rocks and is thinnest toward the east where it has been partly removed by erosion (fig. 5). The Wellington can be divided conveniently into three members (Lee, 1956).

The lower member of the Wellington consists of a sequence of alternating gray to maroon shale, gypsum, and anhydrite beds with a few thin limestone and dolomite beds, as shown by the gamma-ray log in figure 6. Near the outcrop and subcrop, the anhydrite beds have hydrated to gypsum. Although most of the anhydrite and gypsum beds are discontinuous, a massive bed is indicated in figure 6 at a depth of 100 to 112 feet. Thicknesses of the lower member in the study area range from 0 to about 200 feet (fig. 5).

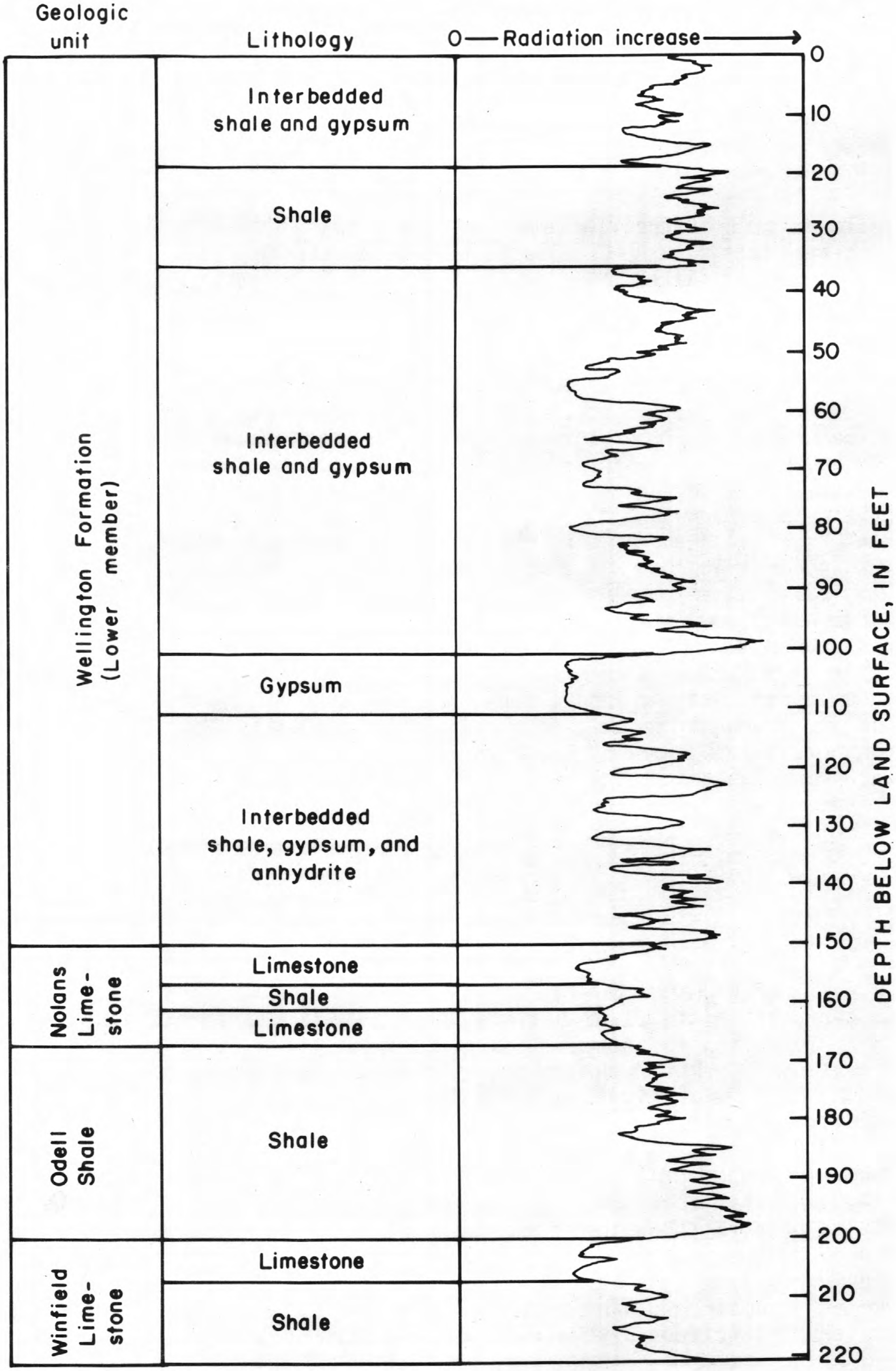


Figure 6.--Gamma-ray log of observation well 13-01W-19BDC.

The Hutchinson Salt Member is predominantly salt (halite) interbedded with minor amounts of anhydrite and shale (fig. 7). Thicknesses in the study area range from 0 to about 150 feet (fig. 5).

The upper member, as shown above the Hutchinson Salt Member in figure 7, consists of about 110 feet of gray shale interbedded with some gypsum and anhydrite overlain by about 120 feet of predominantly gray shale. Thicknesses in the study area range from 0 to about 230 feet (fig. 5).

In some areas along the eastern margin of the Hutchinson Salt Member and the lower member of the Wellington, circulation of freshwater from overlying alluvial aquifers has dissolved and removed halite, gypsum, and anhydrite from the Permian rocks. This continuing dissolution process has been accompanied by the formation of cavities and by the subsidence, slumping, and fracturing of overlying shales. Thus, the dissolution process has created a permeable zone for the lateral and vertical movement of brine. This zone of permeability in the Wellington Formation has been reported in other studies of the Smoky Hill and Little Arkansas River basins. Gogel (1981) named this permeable unit the Wellington aquifer (fig. 8); the solution zone in the salt was named the "salt-dissolution zone", and the solution zone in the gypsum and anhydrite was named the "gypsum-dissolution zone." Local drillers and geologists use the term "lost-circulation zone" to describe the Wellington aquifer because a rapid loss of drilling fluids generally occurs when wells are drilled into the solution cavities. The interval also has been called the "shallow disposal zone" owing to the large volumes of oilfield brines that formerly were discharged into it.

In the study area, the Wellington aquifer underlies parts of the valleys of the Smoky Hill, Saline, and Solomon Rivers at depths of 50 to 150 feet. In the uplands adjacent to the river valleys, data from test wells drilled during this study and from O. S. Fent (Hydraulic Drilling Co., Salina, oral commun., 1976) indicate that dissolution of evaporites is minimal and that stratigraphically comparable sections in the Wellington Formation are relatively impermeable. Thus, the Wellington aquifer probably does not occur in the upland areas, although a few domestic and stock wells completed in the shales and anhydrites have yielded small quantities of calcium sulfate type water.

Cretaceous System

Kiowa Shale and Dakota Formation

The Kiowa Shale and Dakota Formation, which crop out only on the uplands in the study area, consist of gray shale with sandy shale and sandstone lenses in the lower part and varicolored shale and sandstone in the upper part. The maximum combined thickness of the formations in the area is about 200 feet. The sandstones yield from 5 to 75 gal/min to wells. In the areas overlain by the Kiowa Shale, the Hutchinson Salt Member of the Wellington Formation generally has no dissolution cavities.

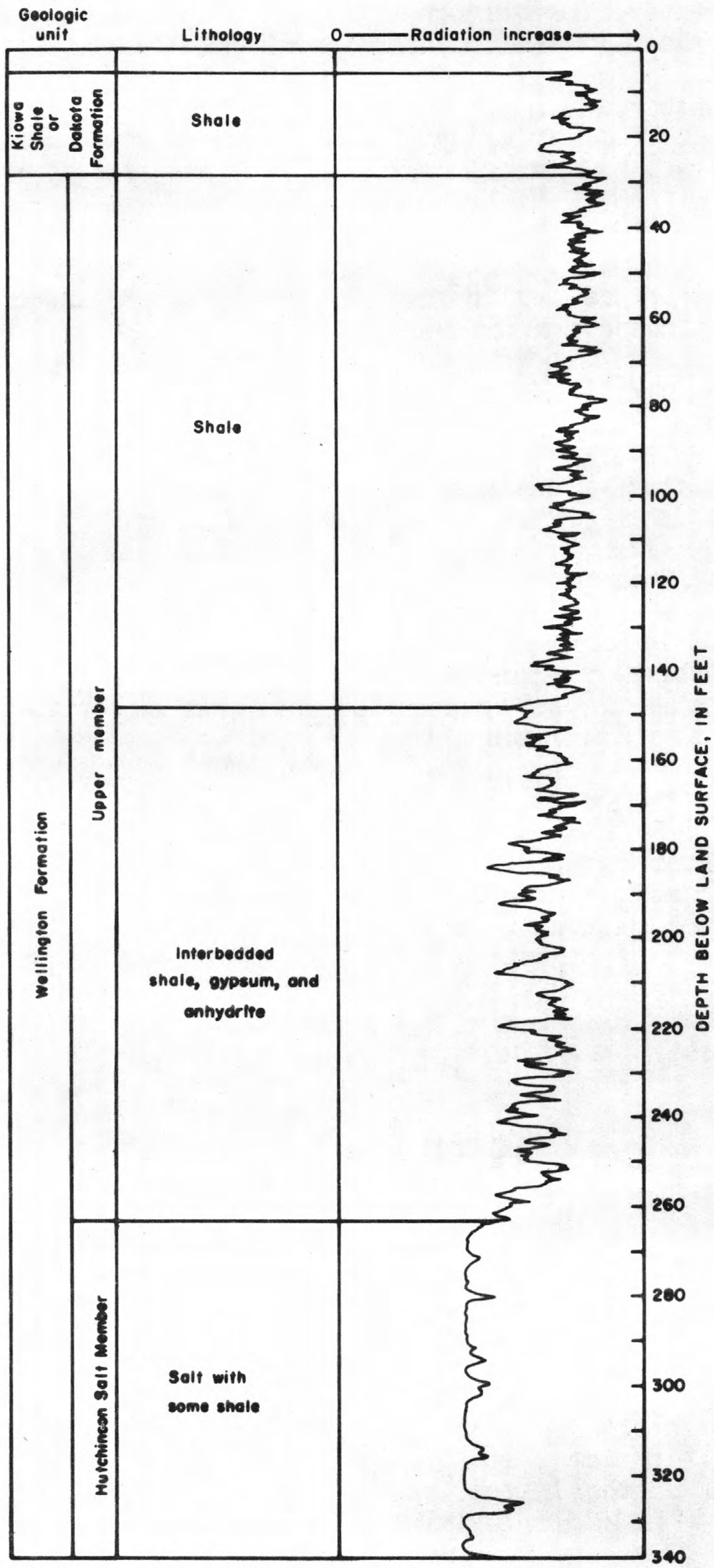


Figure 7.--Gamma-ray log of observation well 15-03W-07BAA.

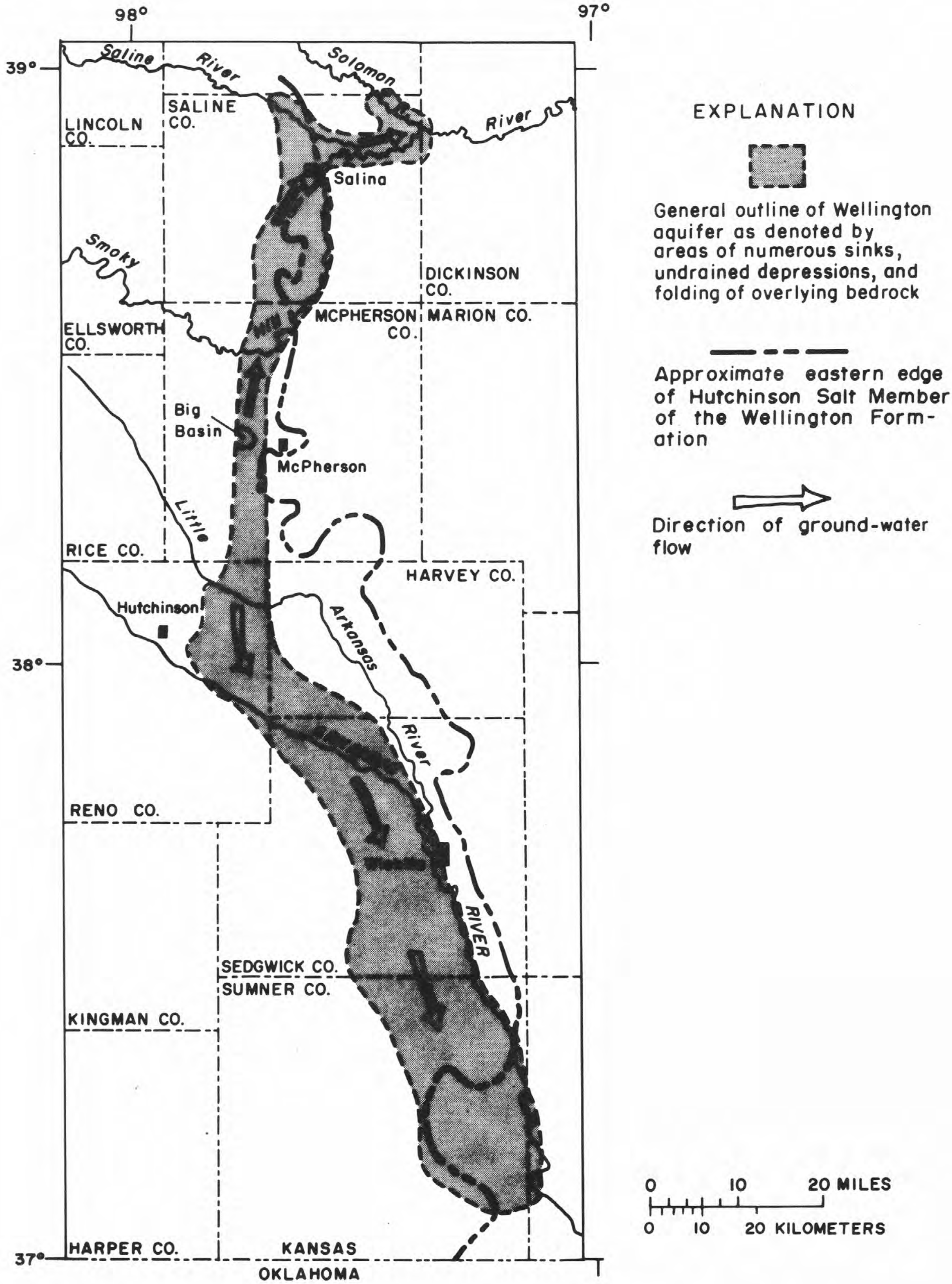


Figure 8.--General outline of Wellington aquifer and eastern edge of the Hutchinson Salt Member of the Wellington Formation in central and south-central Kansas (modified from Gogel, 1981).

Quaternary System

Pleistocene Series

Terrace Deposits

Stream-laid terrace deposits unconformably overlie the Wellington Formation and are most prominent along the northern margins of the valleys of the Solomon and Smoky Hill Rivers from near Niles to Abilene. The deposits consist of poorly sorted unconsolidated sand, gravel, silt, and clay and yield 5 to 50 gal/min to wells.

Alluvium

The alluvium overlies the Wellington Formation in most of the valley area, but directly overlies the Nolans Limestone and the Odell Shale in the eastern part. The alluvium consists of sand, gravel, silt, and clay deposits that range in thickness from a few feet to about 120 feet and average about 55 feet. Coarse-grained deposits of sand and gravel occurring in the lower part of the alluvium range in thickness from about 30 to 80 feet and average about 35 feet. Fine-grained deposits of silt and clay generally occur in the upper part and range in thickness from about 10 to 40 feet and average about 20 feet. In general, the alluvium in the Solomon River valley has a greater percentage of fine deposits than the alluvium of the Smoky Hill River valley. The alluvial deposits yield 200 to 900 gal/min to wells.

The configuration of the Permian bedrock surface beneath the alluvium in the river valleys is shown in figure 9. The irregular nature of this surface indicates that depressions or sinks have been formed as a result of subsidence. Geologic data show that depressions in the Salina area are associated with dissolution and collapse in the Hutchinson Salt Member; depressions in the area from New Cambria to Solomon are associated with dissolution and collapse of gypsum deposits in the lower member of the Wellington. The location of a few of these gravel-filled depressions, as well as other small collapse structures reported by landowners, are shown in figure 9.

Dune Sand

Dune sand overlies much of the terrace deposits between Solomon and Abilene on the north slope of the Smoky Hill River valley. The dunes consist of fine to medium quartz and locally contain considerable silt, and the thickness ranges from 3 to 40 feet (Latta, 1949, p. 31). The dune sand, which generally is above the water table, provides an excellent recharge area for the underlying terrace deposits and caverneous limestone. Wells penetrating the dune sand, terrace deposits, and cavernous limestone yield some of the best quality ground water in Kansas.

HYDROLOGIC SETTING

Conceptual Model

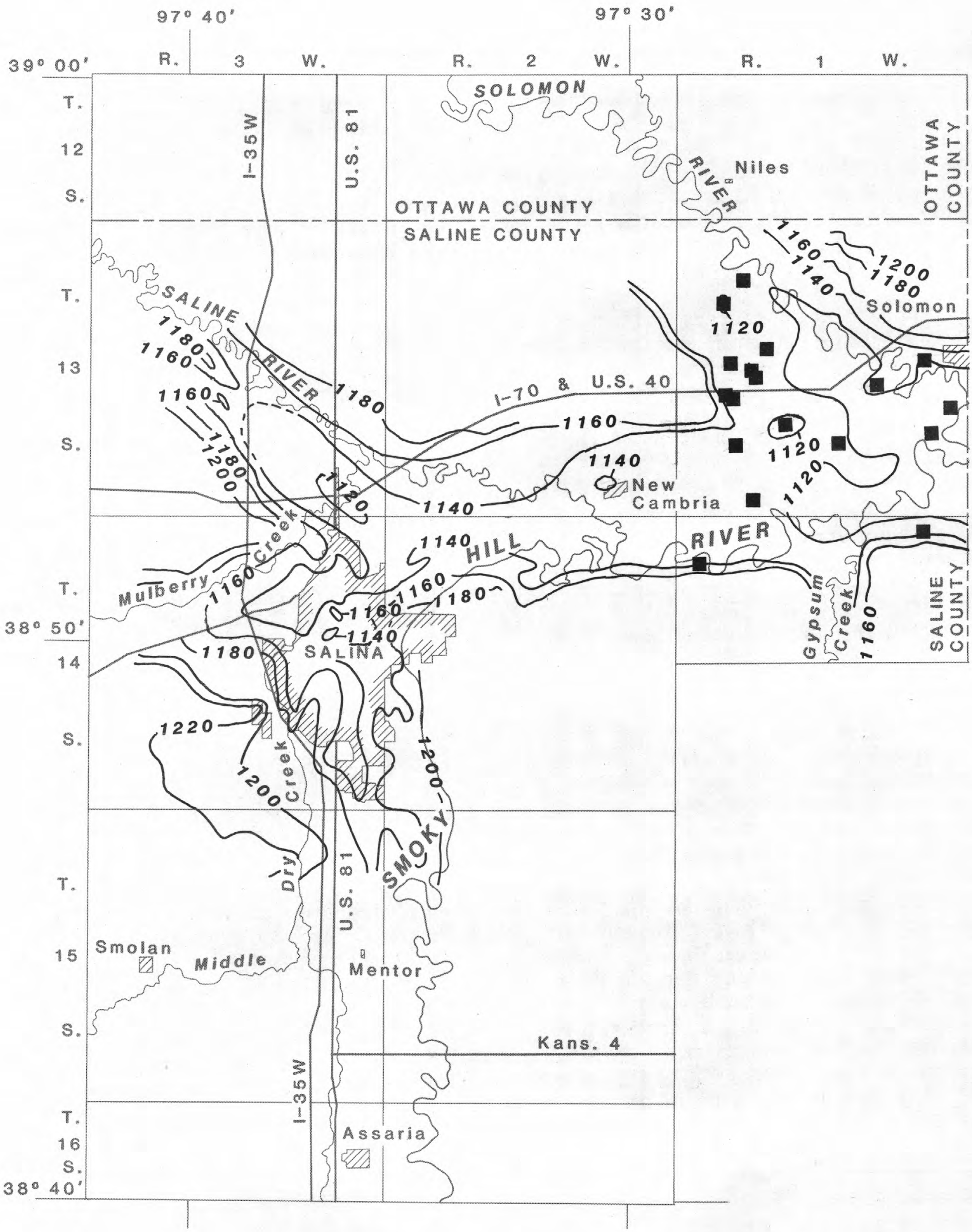
The ground-water system in the study area may be described as consisting of three principal units: the alluvial aquifer in the valleys of the Smoky Hill, Saline, and Solomon Rivers, the intervening layer of less-permeable shale that has been breached in localized areas by collapse or fracturing to permit the vertical flow of water, and the underlying Wellington aquifer. The limiting boundaries are formed by the less-permeable shales (of Permian formations) that underlie the flow system in the valleys and occur in the valley walls along the sides.

According to records of the U.S. Department of Commerce (1933-77), average annual precipitation in eastern Saline and western Dickinson Counties is about 30 inches, and the average annual potential evaporation is about 55 inches. Most of the precipitation falls during the spring and summer. The amount of precipitation that is contributed to ground water as recharge depends largely on the intensity and duration of the rainfall and the antecedent condition of the soil.

The hydrologic system in the alluvial aquifer is considered to be in balance on a long-term basis; that is, recharge equals discharge. The alluvial aquifer is recharged continuously by subsurface inflow, periodically by infiltration from precipitation, and infrequently by water from floods that partly or completely inundate the flood plains of the valleys. Water in the alluvial aquifer moves downgradient in the valley where part is discharged as subsurface outflow. Because the water table in the aquifer commonly is higher than the water stage in the river channel, part of the ground water also is discharged to the river as base flow.

The Wellington aquifer, as described by Gogel (1981), extends from near Salina southward into the Smoky Hill and Little Arkansas River basins (fig. 8). The permeable zone generally falls along the eastern margin of the Hutchinson Salt and lower members of the Wellington Formation. Within the study area, the flow system of the aquifer, as shown in figure 10, may be described as consisting of three hydrologic units: (1) A recharge area along the western part of the system near Salina, (2) a transmission area between Salina and New Cambria, and (3) a discharge area between New Cambria and Solomon.

The Wellington aquifer receives recharge from the alluvial aquifer in the area along the Smoky Hill River valley near Salina and in southern Saline County (fig. 8). Collapse and brecciation of the overlying shale provide a conduit through which fluid may move vertically to or from the Wellington aquifer. In that area, the direction of flow generally is downward because the hydraulic head in the alluvial aquifer is higher than the hydraulic head in the Wellington aquifer. This continuous recharge of freshwater results in the dissolution of halite and gypsum and a continuous formation of brine in the aquifer.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Niles
OTTAWA COUNTY
SALINE COUNTY
I-35W
U.S. 81
SALINE RIVER
I-70 & U.S. 40
Solomon
New Cambria
SMOKY HILL RIVER
Mulberry Creek
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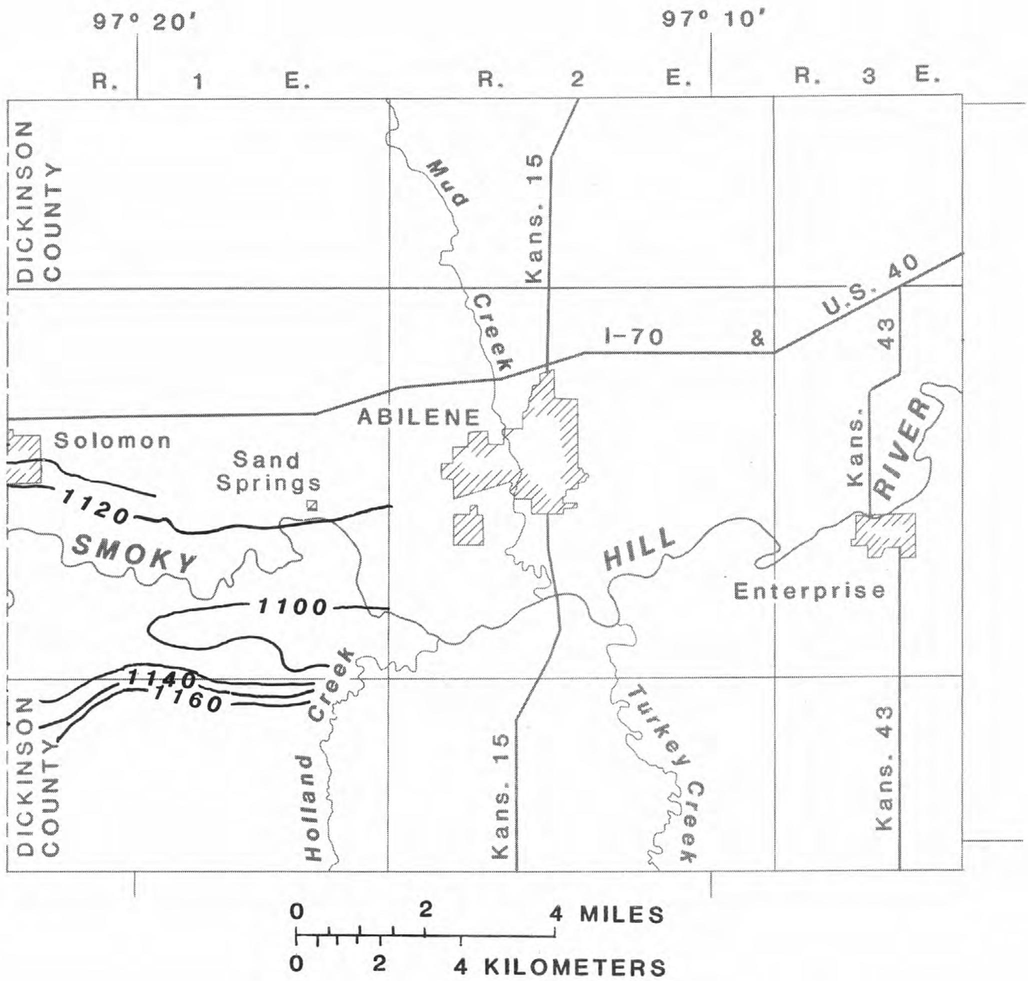

EXPLANATION

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Bedrock contour

Shows altitude of bedrock surface. Dashed where approximately located. Contour interval 20 feet. National Geodetic Vertical Datum of 1929

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Collapse structure

Figure 9.--Configuration of the bedrock surface.

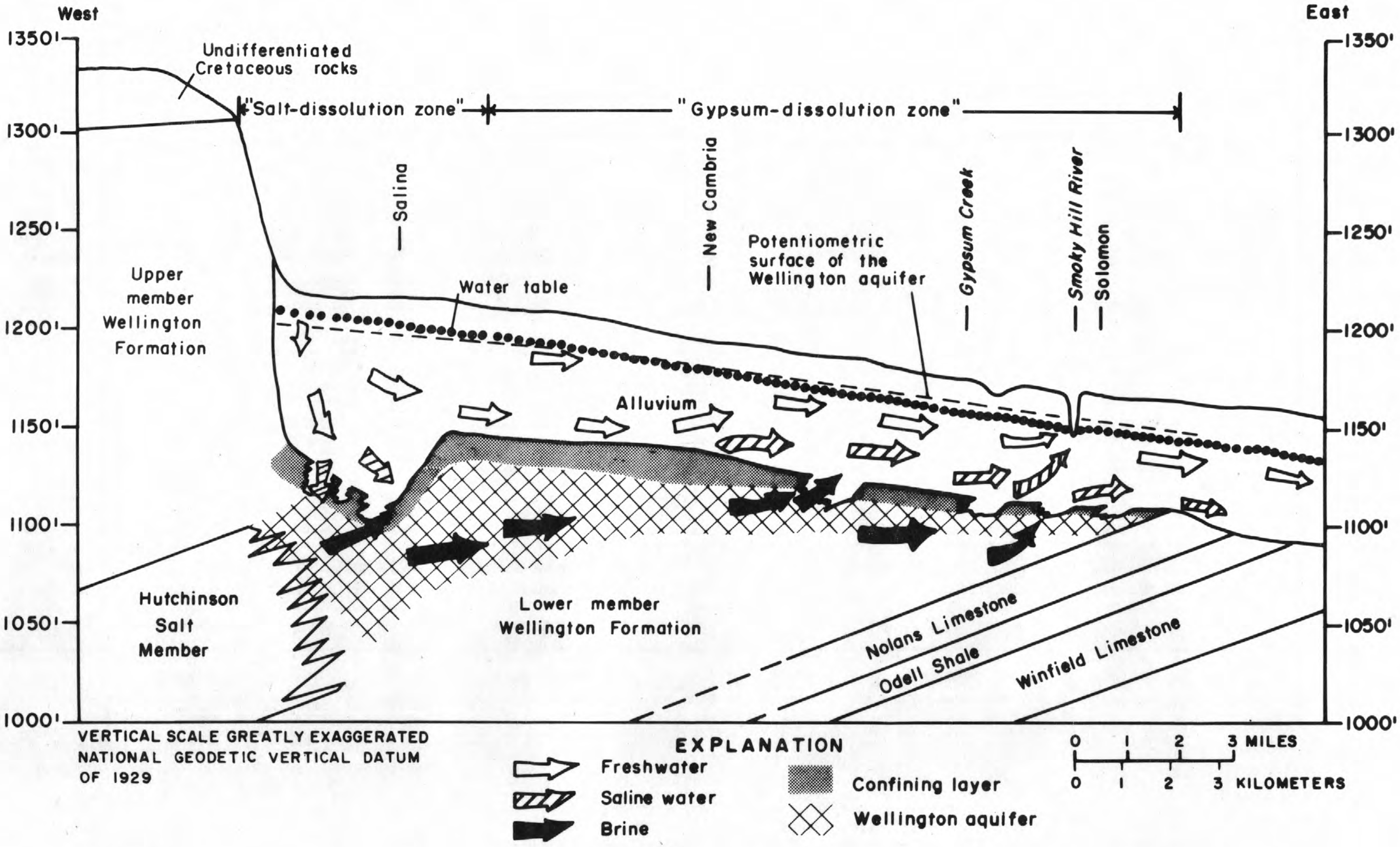


Figure 10.--Diagrammatic section along the Smoky Hill River valley showing ground-water flow patterns.

In the transmission area between Salina and New Cambria, most of the flow is by movement of brine downgradient (eastward) through the aquifer. Vertical flow to or from the aquifer in this area probably is not significant because the overlying shale layer is less permeable.

In the area between New Cambria and Solomon, the dissolution of gypsum in the aquifer has resulted in subsequent collapse of overlying beds. These localized collapse structures have provided breaches in the confining shale layer through which fluid may move vertically to or from the Wellington aquifer. Because the hydraulic head in the Wellington aquifer in this area generally is higher than the hydraulic head in the alluvial aquifer, brine is discharged upward to mix with the freshwater. Thus, the brine discharged from the Wellington aquifer is a contributing factor in the discharge of saline water from the alluvial aquifer to the river.

During a single year, or shorter period, recharge from rainfall and flooding may increase significantly the quantity of water stored in the alluvial aquifer. If the increase in the area between New Cambria and Solomon is sufficient to raise the water level in the alluvial aquifer higher than the potentiometric surface in the Wellington aquifer, the hydraulic gradient could be reversed temporarily. The upward discharge of brine would be reduced as the freshwater moves downward. As the water levels rise in the alluvial aquifer, the increased head would result in an increased discharge of saline water to the river. Data indicate that the greatest concentrations of dissolved solids occur in water discharged to the river during the several months after floods have partly inundated the valley.

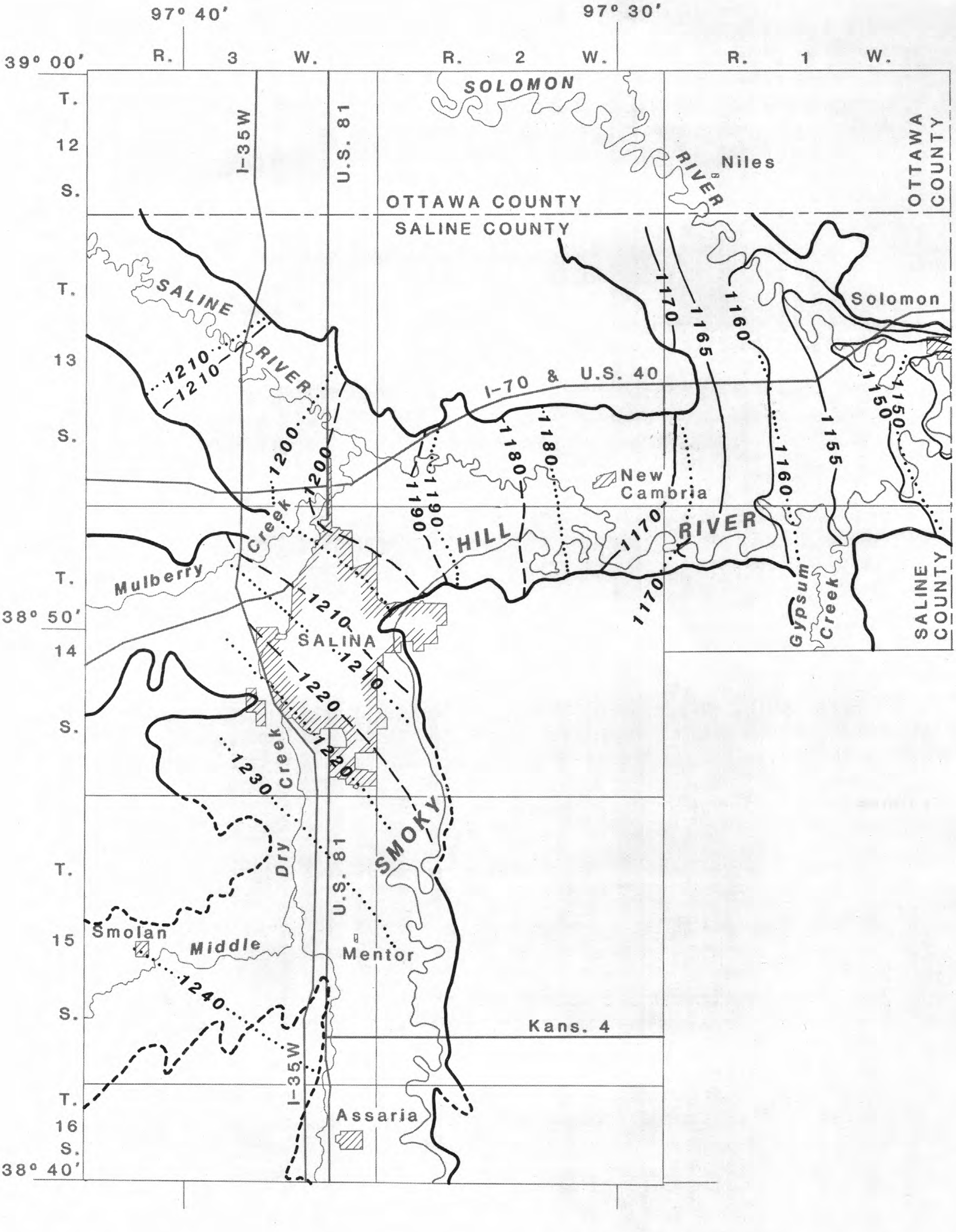
Ground Water

The following discussion of ground water in eastern Saline and western Dickinson Counties is devoted principally to the Wellington aquifer and the overlying alluvial aquifer in the valleys of the Smoky Hill, Saline, and Solomon Rivers.

Wellington Aquifer

Water Movement and Aquifer Characteristics

The configuration of the potentiometric surface of the Wellington aquifer in the study area, as determined from water-level measurements in observation wells, is shown in comparison to the potentiometric surface of the alluvial aquifer in figure 11. Because of the difference in densities between freshwater and brine, the measured fluid levels in wells have been adjusted to reflect the equivalent altitude of freshwater for comparison (Leonard and Kleinschmidt, 1976).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OTTAWA COUNTY
SALINE COUNTY
I-35W
U.S. 81
SALINE RIVER
Solomon
I-70 & U.S. 40
New Cambria
HILL RIVER
SMOKY
Mulberry Creek
SALINA
Gypsum Creek
Dry Creek
Middle
Smolan
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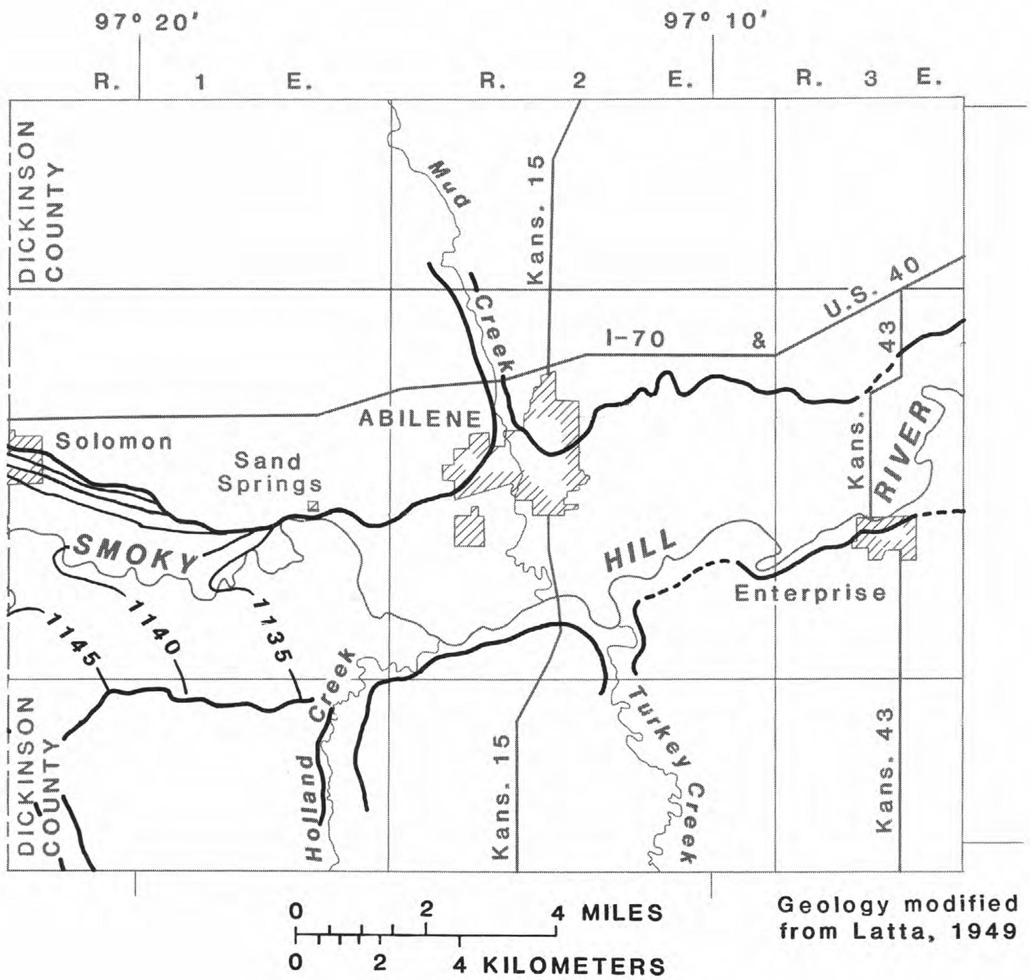

EXPLANATION

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Potentiometric contour of the alluvial aquifer

Shows altitude of potentiometric surface in the alluvial aquifer April 1977. Dashed where approximately located. Contour interval 5 and 10 feet. National Geodetic Vertical Datum of 1929

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Potentiometric contour of the Wellington aquifer

Shows altitude of potentiometric surface in the Wellington aquifer, April 1977. Contour interval 10 feet. National Geodetic Vertical Datum of 1929

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Boundary of alluvial deposits in the Smoky Hill and Solomon River valleys and tributaries

Dashed where approximately located

Figure 11.--Altitudes of potentiometric surfaces in the alluvial and Wellington aquifers, April 1977.

In the area south and west of Salina, freshwater moves downward through collapsed and brecciated shales in the confining layer to recharge the Wellington aquifer. The brine formed moves northward through the "salt-dissolution zone" of the Wellington aquifer beneath the Smoky Hill River valley to its confluence with the Saline River valley (fig. 11). Then, the brine in the aquifer moves eastward through the "gypsum-dissolution zone" beneath the Smoky Hill River valley toward the eastern boundary of the Wellington Formation near Solomon. In the area between New Cambria and Solomon, brine from the aquifer is discharged upward through collapse structures in the confining shale layer.

Lithologic data from test holes indicate that the shales overlying the Wellington aquifer generally form a confining layer. These shales consist of compact residual material that has slumped or collapsed after the interbedded evaporite deposits have been removed by dissolution. No tests were made during this study to determine the characteristics of the Wellington aquifer. However, an aquifer test in the "salt-dissolution zone" at Conway, about 34 miles south of Salina, indicated confined conditions. Results of this test also indicated an average transmissivity of 2,500 ft^2/d and an average storage coefficient of 1.0×10^{-5} (Gogel, 1981). The hydraulic conductivity of the confining bed ranged from 1.0×10^{-7} to 1.0×10^{-8} ft/d.

Chemical Quality

The brine in the "salt-dissolution zone" of the Wellington aquifer is saturated (approximately 190,000 mg/L of chloride at 20°C) or nearly saturated with respect to sodium chloride. The brine in the "gypsum-dissolution zone" is from 30 to 50 percent saturated with respect to sodium chloride because of periodic freshwater inflow when floods partly inundate the valley between New Cambria and Solomon. A map depicting the chloride and sulfate concentrations in water samples collected from observation wells in the Wellington aquifer is shown in figure 12.

Two wells, drilled into salt cavities southwest and northwest of Salina, yielded samples of brine with chloride concentrations of 170,000 to 190,000 mg/L. Two other wells in the same general area, and one well at the northeast edge of Salina were drilled into shale where no salt was present. Samples from these wells had chloride concentrations ranging from 22,000 to 120,000 mg/L. A well about 1 mile northeast of Salina is believed to be completed in a gypsum cavity near the eastern edge of the "salt-dissolution zone." Samples from this well contained chloride concentrations of 180,000 mg/L.

Four wells, in the Smoky Hill River valley between New Cambria and Solomon, were completed in sand-filled cavities in the gypsum. Chloride concentrations in samples from these wells decreased eastward from 89,000 to 58,000 mg/L. In the Solomon River valley near Solomon, water samples from two wells completed in sand-filled cavities had chloride concentrations of 11,000 and 33,000 mg/L. Reduced chloride concentrations in samples from these wells may indicate dilution by calcium sulfate water in the Wellington aquifer underlying the alluvium of the Solomon River valley. Two wells were drilled on the valley slope near New Cambria. Water from the well completed in shale on the south side had a chloride concentration of 24,000 mg/L; water from the well completed in a gypsum cavity on the north side had a chloride concentration of 310 mg/L.

Based on the relatively small chloride concentrations indicated in water from wells located on the valley slopes and on similar results reported by O.S. Fent, Hydraulic Drilling Co., Salina (oral commun., 1976), it is concluded that very little brine flows through the lower member of the Wellington underlying the uplands adjacent to the river valley. Thus, most of the brine in the Wellington aquifer flows eastward through the more permeable "gypsum-dissolution zone" beneath the alluvium of the Smoky Hill River valley.

Alluvial Aquifer

Water Movement and Aquifer Characteristics

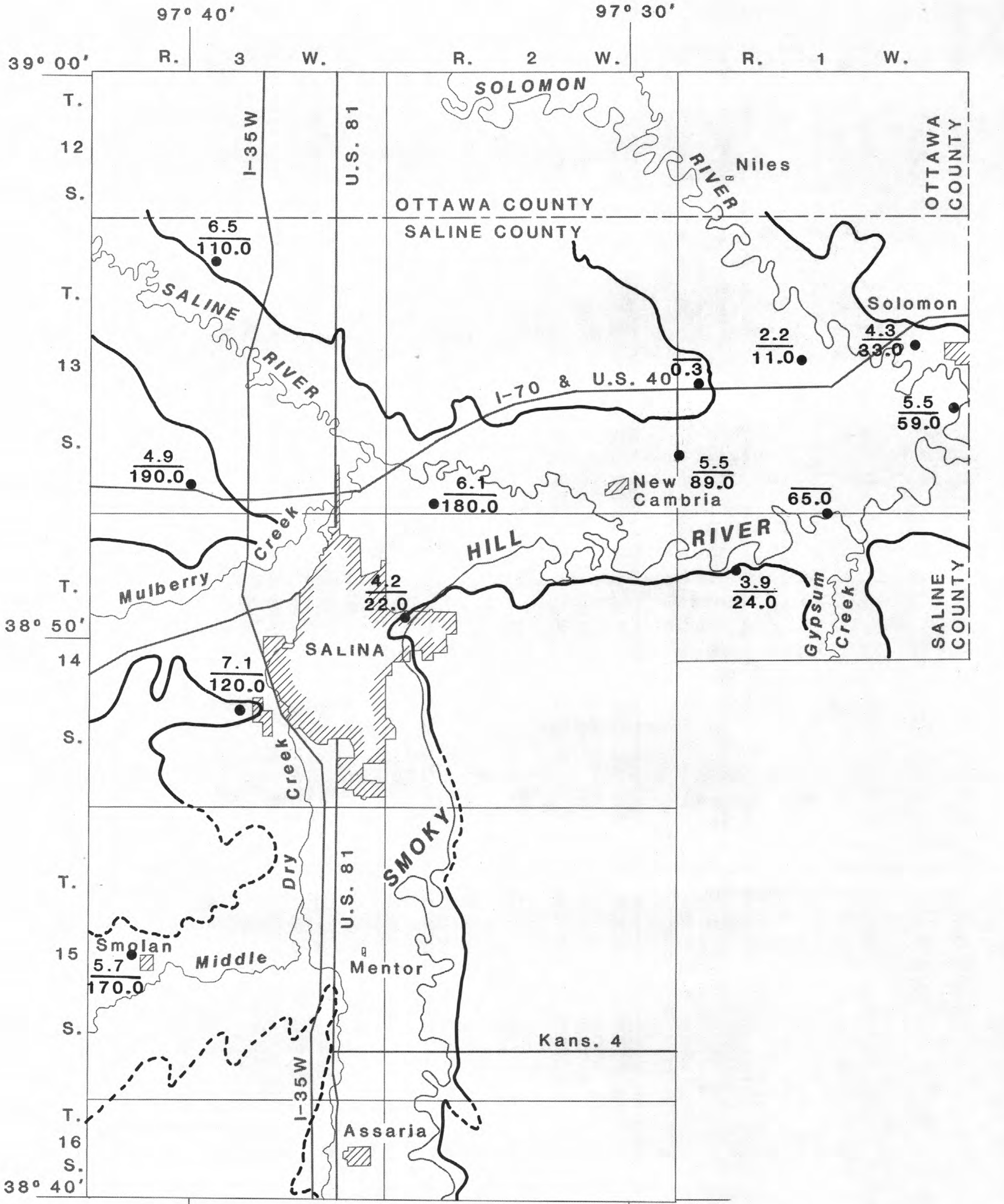
The major source of water in the alluvial aquifer is from precipitation and periodic flooding by the Smoky Hill, Saline, and Solomon Rivers. However, a small amount of brine is contributed from the underlying Wellington aquifer.

There were 58 observation wells located in the area downstream from New Cambria where the saline ground water is discharged into the Smoky Hill and Solomon Rivers. Only 12 observation wells were located in the area from Salina to New Cambria and in the downstream reach of the Saline River valley (fig. 2).

Water in the alluvial aquifer flows downgradient in the valleys of the Smoky Hill, Saline, and Solomon Rivers. As in most similar alluvial aquifers, the water also has a flow component toward the river that acts as a drain for the hydrologic system. In the river valleys upstream from the northeast edge of Salina, the water table in the alluvial aquifer is higher than the potentiometric surface of the underlying Wellington aquifer. In the area from about 3 miles east of Salina to directly east of Solomon, the potentiometric surface of the Wellington aquifer was about 2 feet higher than the water table in the alluvial aquifer during April 1977 (fig. 11).

Most wells in the study area extend only into the upper part of the alluvial aquifer to avoid saline water in the lower part. An irrigation well (14-02W-05ABA) northeast of Salina, which penetrates the full thickness of the alluvium, was used for a 24-hour aquifer test. Results of the test indicated an average transmissivity of 13,000 ft^2/d and a hydraulic conductivity of 330 ft/d. Mack (1962) conducted an aquifer test in the alluvium of the Solomon River valley 12 miles northwest of Niles that indicated a transmissivity of 8,000 ft^2/d and a hydraulic conductivity of 230 ft/d. Drill and auger cuttings show that the alluvium of the Solomon River valley has a larger proportion of fine-grained deposits than the alluvium of the Smoky Hill River valley.

The alluvial aquifer is considered to be generally unconfined and similar to aquifers in other Kansas stream valleys for which storage coefficients of 0.15 and 0.20 have been estimated.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38° 40'
SOLOMON RIVER
Niles
OTTAWA COUNTY
SALINE COUNTY
I-35W
U.S. 81
SALINE RIVER
SMOKY HILL RIVER
I-70 & U.S. 40
Solomon
New Cambria
SALINA
Mulberry Creek
Gypsum Creek
Dry Creek
Middle
Smolan
Mentor
Assaria
Kans. 4
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110.0
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190.0
6.1
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0.3
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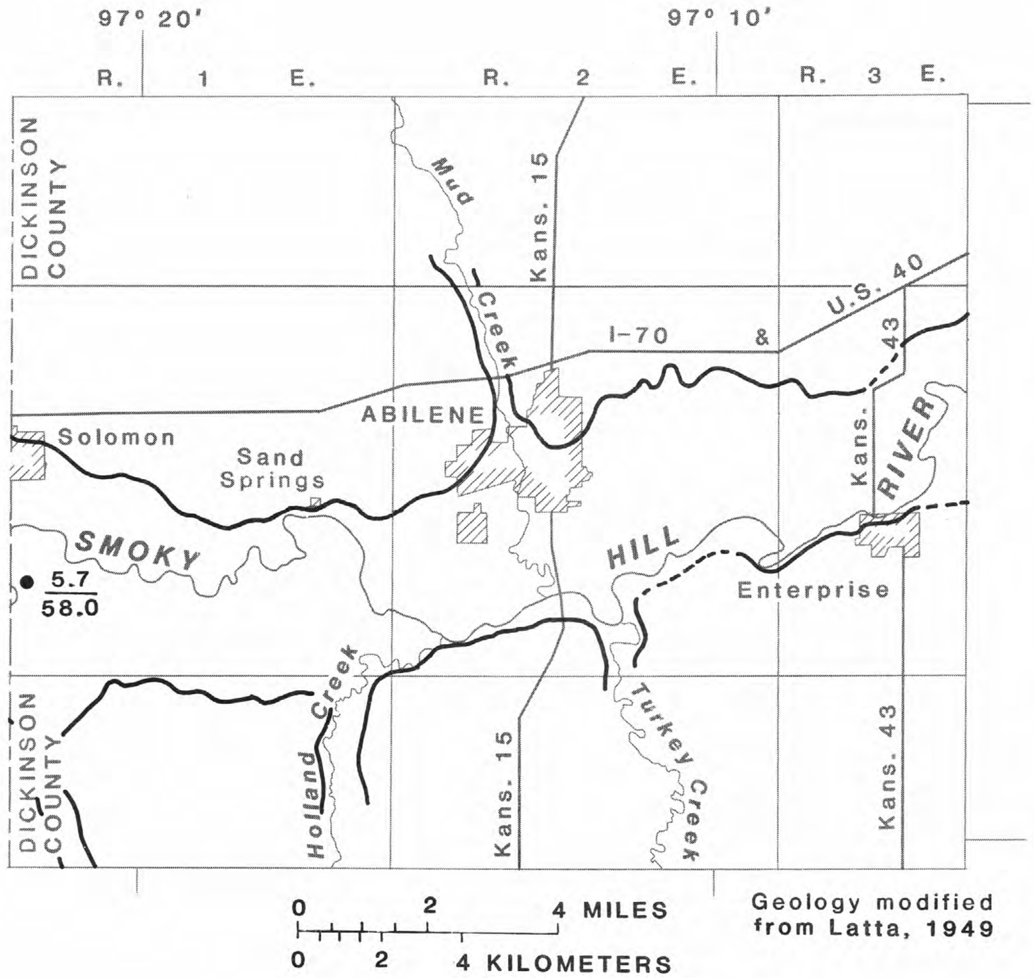

EXPLANATION

● 5.7 / 58.0

Observation well completed in the Wellington aquifer

Upper number indicates sulfate concentration, in grams per liter (milligrams per liter ÷ 1,000). Lower number indicates chloride concentration, in grams per liter

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Boundary of alluvial deposits in the Smoky Hill and Solomon River valleys and tributaries

Dashed where approximately located

Figure 12.--Chloride and sulfate concentrations in water samples from the Wellington aquifer, 1976.

Chemical Quality

Water in the alluvial aquifer ranges from fresh to brine in the study area. The chloride concentrations of water samples pumped from observation wells screened at the base of the alluvial aquifer are shown in figure 13; the sulfate concentrations of water samples are shown in figure 14. The observation wells were screened in the base of the alluvium in order to sample the greatest chloride concentration at each site, as well as to establish a general datum for sampling. The alluvial aquifer is stratified with freshwater overlying saline water or brine. According to local landowners and well drillers, the interface between freshwater and saline water generally is about 35 feet below land surface. Many shallow domestic and stock wells produce from this upper freshwater zone. The chloride concentrations in the study area ranged from 27 to 68,000 mg/L, and the sulfate concentrations ranged from 35 to 6,300 mg/L.

In the area north of Salina, the chloride concentration in a sample from well 13-03W-36CBA was 48,000 mg/L. This well does not fully penetrate the alluvium at a depth of 94 feet, but data from a nearby Kansas Department of Transportation test hole indicate that the Wellington Formation occurs at a depth of about 120 feet. The great thickness of alluvium at this location indicates a bedrock depression associated with a subsidence or collapse caused by differential dissolution of the underlying salt (fig. 9).

Samples of water from wells in the area between Salina and New Cambria had chloride concentrations ranging from 210 to 310 mg/L. In this area, the confining layer is sufficiently impermeable to prevent the brine in the Wellington aquifer from flowing upward into the alluvial aquifer.

In the area from New Cambria to Solomon, the chloride concentrations in the alluvial aquifer vary greatly. The largest concentrations of chloride are associated with nearby collapse structures in the subcrop through which brine from the Wellington aquifer flows upward into the alluvial aquifer in the Smoky Hill River valley. The small chloride and relatively large sulfate concentrations in the Solomon River valley (figs. 13 and 14) indicate that saline water of a calcium sulfate type is flowing upward from the "gypsum-dissolution zone" of the Wellington aquifer into the alluvial aquifer.

In the area east of Solomon, the chloride concentrations in water samples decrease. The dilution in the alluvial aquifer east of Solomon is associated with the absence of the underlying Wellington Formation and inflow of fresh ground water from the sand-dune area on the north side of the valley.

In the small area of fresh ground water northeast of Salina, the gamma-ray log for well 13-02W-32CCB indicates 54 feet of alluvial sand and gravel overlying the Wellington Formation (fig. 15). A relatively impervious shale, about 45-feet thick, separates the alluvium from beds of cavernous gypsum in which the observation well is completed. The chloride concentration in water at the base of the alluvium is 210 mg/L; the concentration in brine from the gypsum cavity, at a depth of 112 feet, is 180,000 mg/L. Measurements indicate that the hydraulic head in the Wellington aquifer is about 2 feet higher than the hydraulic head in the alluvial aquifer. The hydraulic conductivity of the shale layer is small enough to prevent upward movement of brine into the alluvial aquifer.

In the area east of New Cambria, where the alluvial aquifer contains mostly saline water or brine, the thick relatively impervious shale is not present above the "gypsum-dissolution zone." The gamma-ray log for well 13-01W-30CCC2 indicates 47 feet of alluvial sand and gravel overlying the Wellington Formation (fig. 16). The log also indicates a very thin shale layer between the bottom of the alluvium and the cavernous gypsum beds. At this site, the hydraulic head in the Wellington aquifer is about 2 feet higher than the hydraulic head in the alluvial aquifer. The chloride concentration in water at the base of the alluvium is 21,000 mg/L; the concentration in brine from the gypsum cavities is 89,000 mg/L. Both the hydraulic gradient and the large chloride concentration indicate upward movement of brine into the alluvial aquifer.

Surface Water

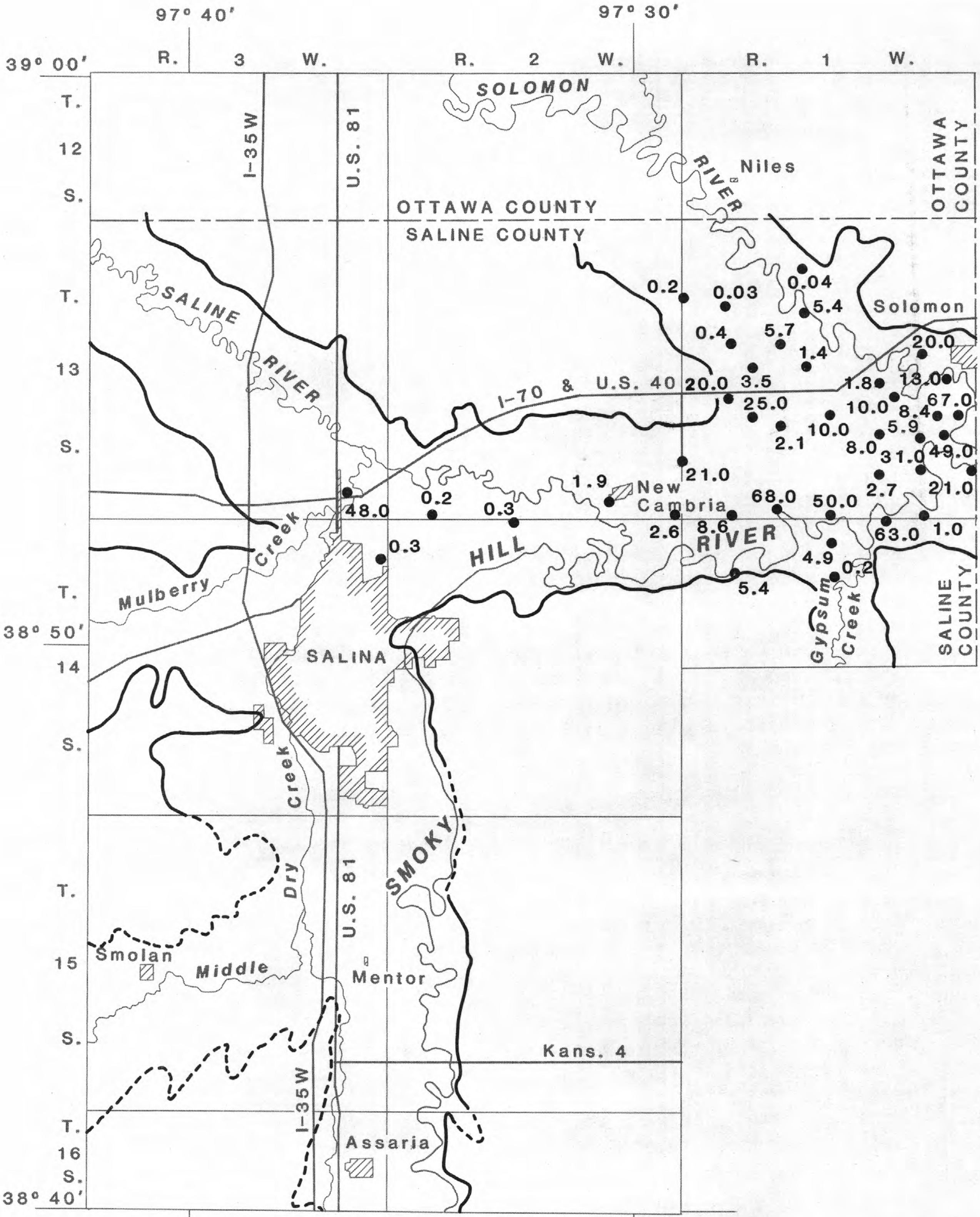
Streamflow

The four streamflow-gaging stations in the areas, as shown in figure 2, are Smoky Hill River near Mentor, Smoky Hill River at New Cambria, Smoky Hill River at Enterprise, and Solomon River at Niles. The Saline River at Tescott streamflow-gaging station (not shown in fig. 2) is about 18 miles northwest of Salina.

The duration or percentage of time that different rates of streamflow were equaled or exceeded at the five streamflow-gaging stations from October 1962 to September 1977 are shown in table 1. As an example, a mean daily flow of 110 ft^3/s was equaled or exceeded about 50 percent of the time at the Smoky Hill River at New Cambria streamflow-gaging station. The base period for table 1 was selected using the streamflow-gaging station with the shortest period of record, which was the Smoky Hill River at New Cambria station. The discharge at all the streamflow-gaging stations is affected by regulation due to upstream reservoirs.

Seepage Surveys

Base flow in the Smoky Hill and Solomon Rivers consists mainly of ground-water discharge, presumably from the upper part of the alluvial aquifer. Seepage surveys were made in the area where saline ground-water discharge enters the rivers. Single discharge measurements were made at 12 sites to determine channel gains or losses--6 Smoky Hill River sites, 5 Solomon River sites, and 1 Gypsum Creek site. The locations of the measurement sites are shown in figure 17. The seepage-survey reach on the Smoky Hill River extended from the New Cambria streamflow-gaging station to Sand Springs, and the Solomon River reach extended from the Niles streamflow-gaging station to the mouth. The measurements were made during periods of nearly constant base flow of the streams, and no measurable contribution from precipitation within the reach. Tributary flow was considered a contribution and not a gain.



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SOLOMON
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OTTAWA COUNTY
SALINE COUNTY
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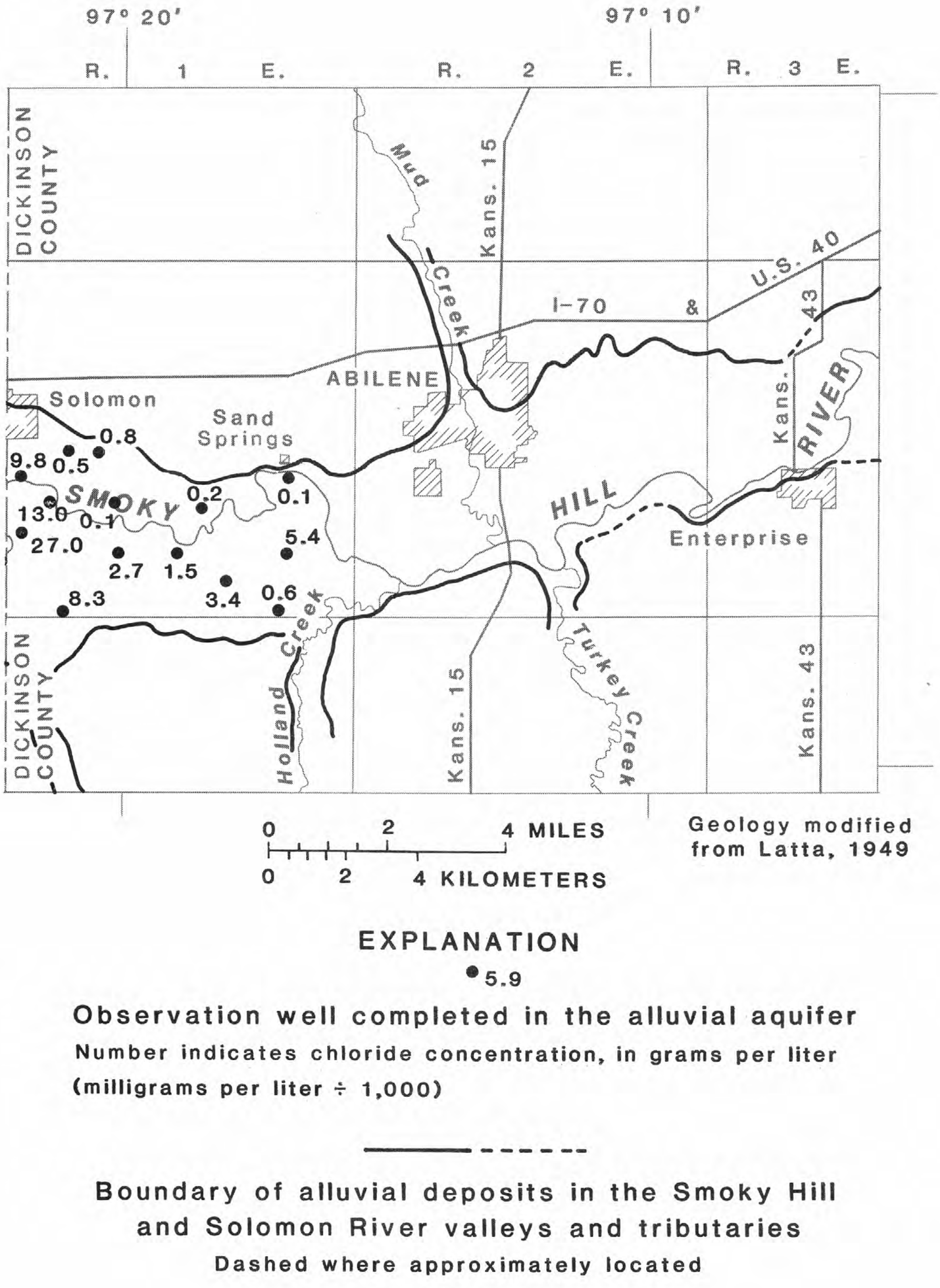
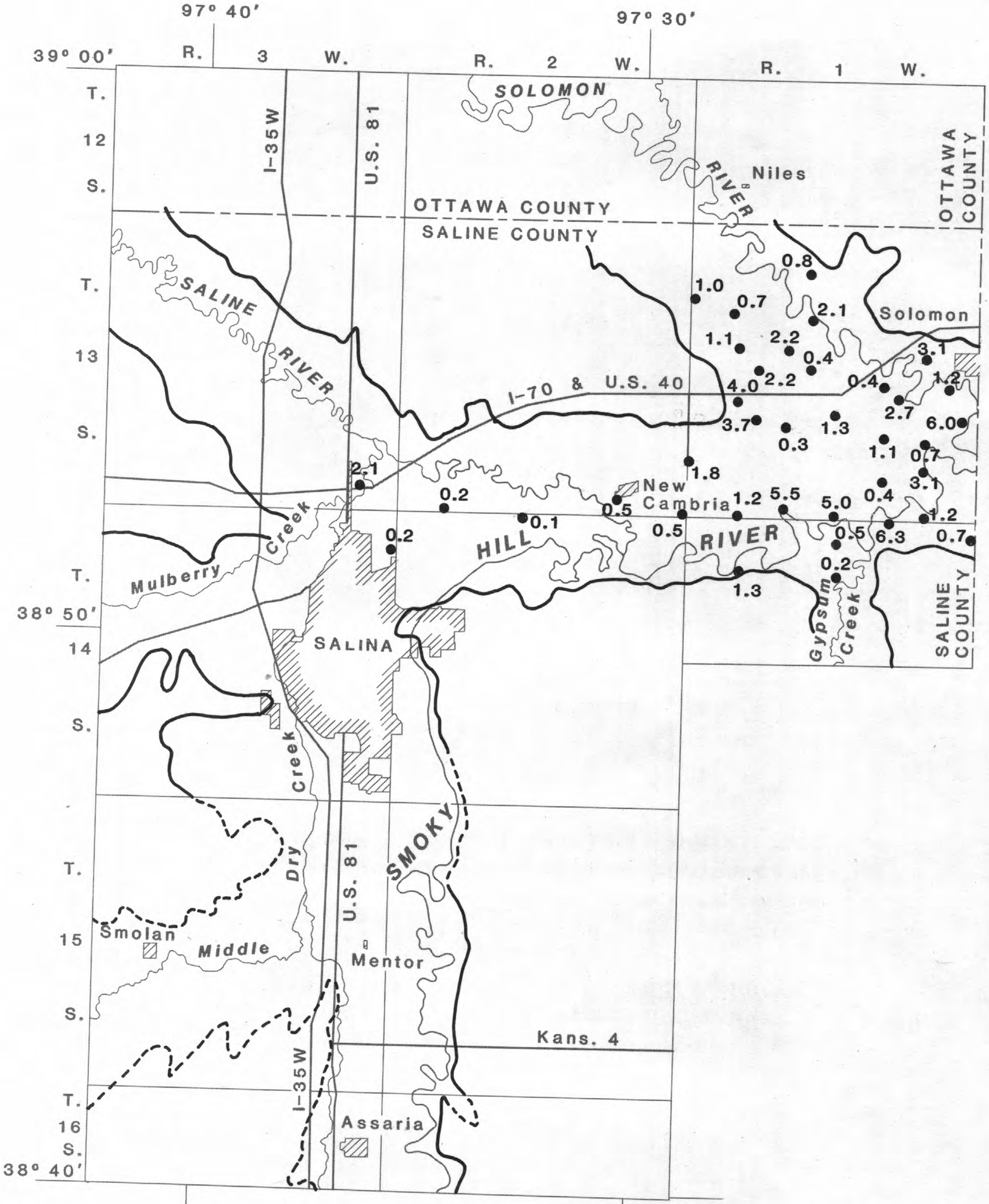


Figure 13.--Chloride concentrations in water samples from the alluvial aquifer, 1977.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SOLOMON RIVER
Niles
OTTAWA COUNTY
SALINE COUNTY
SALINE RIVER
I-35W
U.S. 81
I-70 & U.S. 40
Solomon
New Cambria
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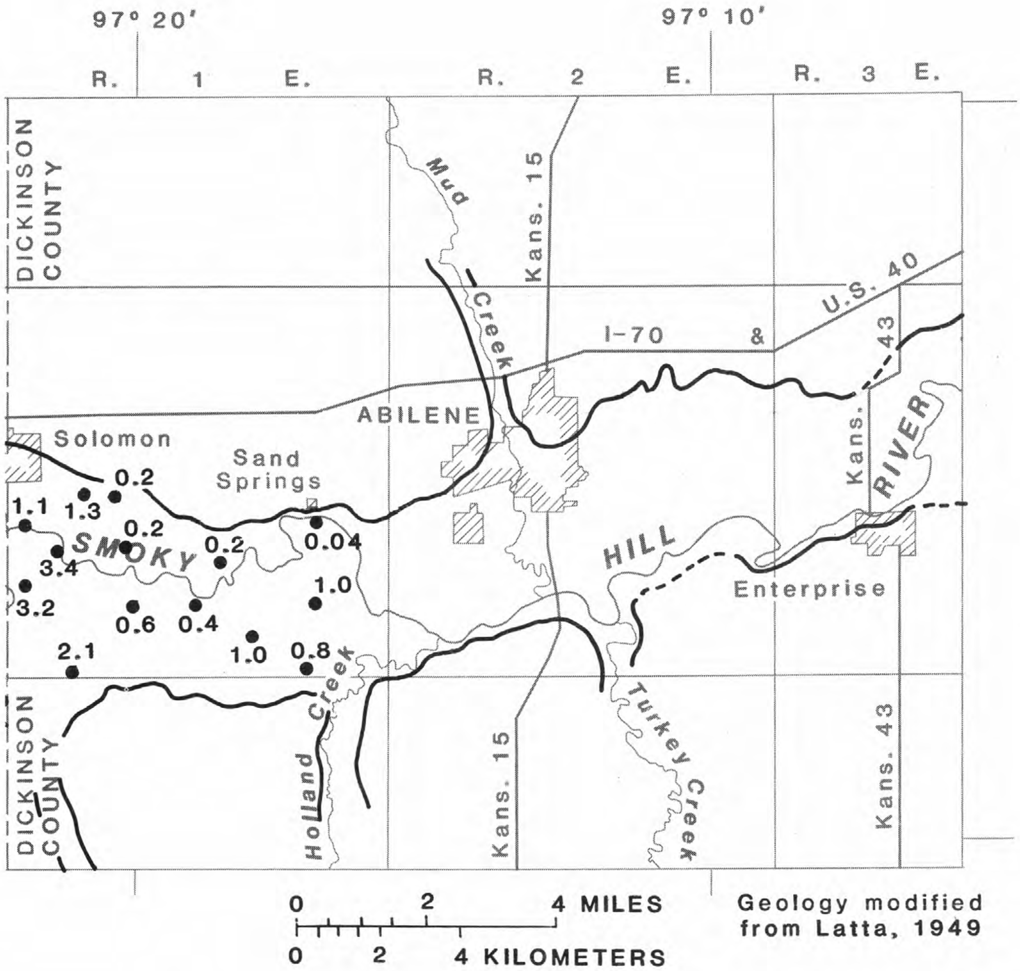

EXPLANATION

●2.7
Observation well completed in the alluvial aquifer
Number indicates sulfate concentration, in grams per liter (milligrams per liter ÷ 1,000)

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Boundary of alluvial deposits in the Smoky Hill and Solomon River valleys and tributaries
Dashed where approximately located

Figure 14.--Sulfate concentrations in water samples from the alluvial aquifer, 1977.

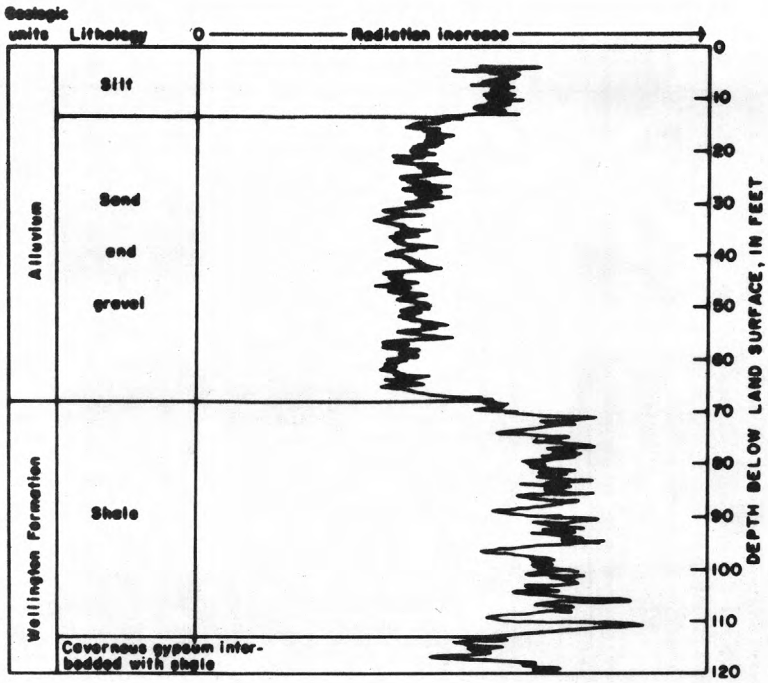


Figure 15.--Gamma-ray log of observation well 13-02W-32CCB.

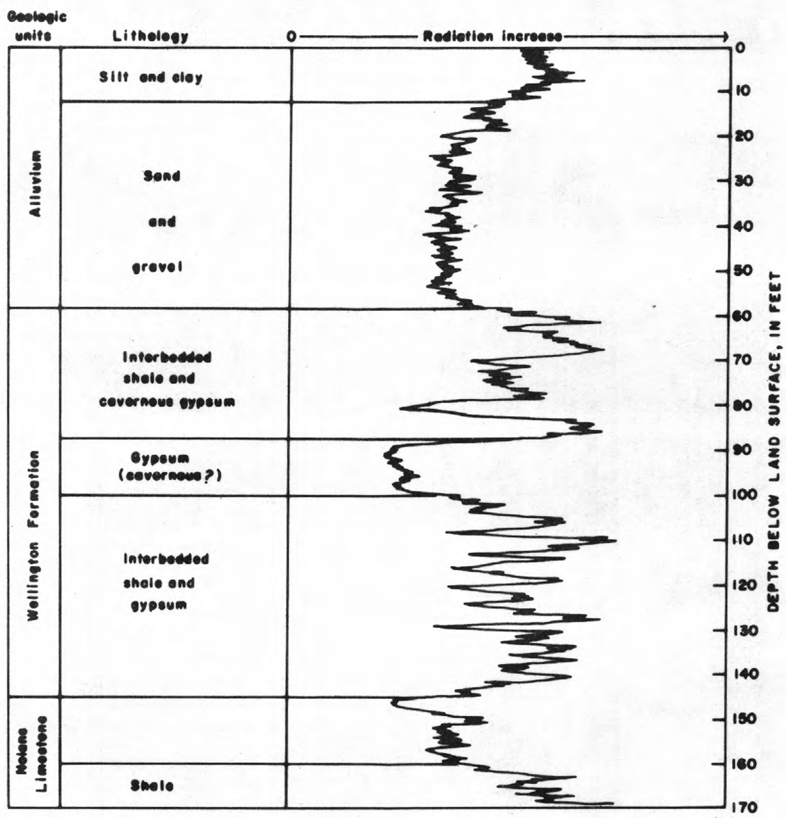


Figure 16.--Gamma-ray log of observation well 13-01W-30CCC2.

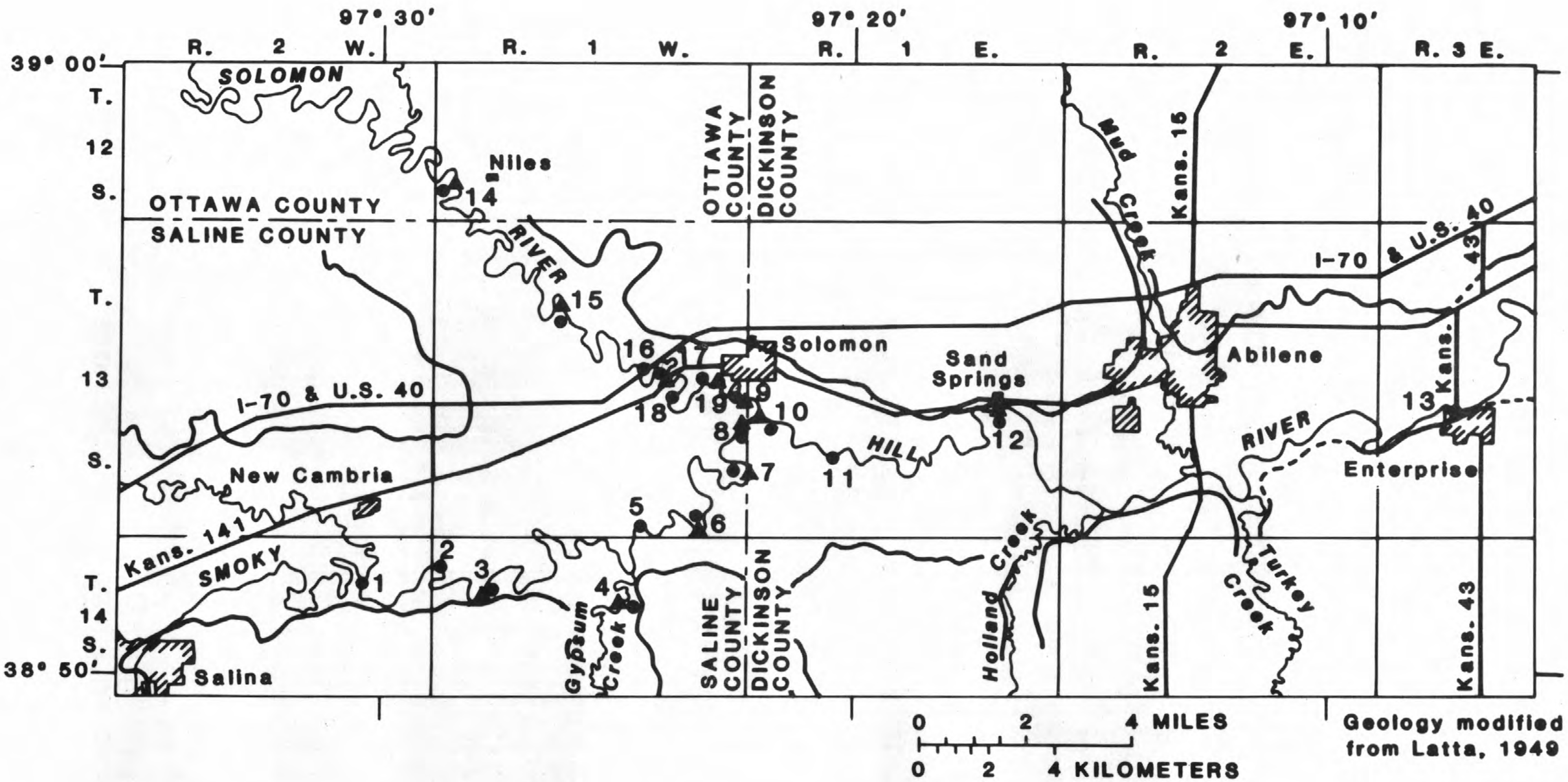
Table 1.--Duration of mean daily discharge for 1963-77 water years

Streamflow-gaging station	Percentage of time discharge was equaled or exceeded						
	90	75	50	30	25	10	5
	Mean daily discharge, in cubic feet per second						
Smoky Hill River near Mentor (A)	37	46	71	82	120	290	1100
Saline River at Tescott (B)	9.3	12	17	20	33	76	260
Smoky Hill River at New Cambria (A)	57	75	110	130	200	490	1800
Solomon River at Niles (C)	41	52	74	82	120	280	740
Smoky Hill River at Enterprise (ABC)	150	180	280	300	450	1000	3000

(A) Discharge values affected by regulation of flow from Cedar Bluff and Kanopolis Reservoirs.

(B) Discharge values affected by filling of Wilson Reservoir from 1964-73 and by regulation from 1973-77.

(C) Discharge values affected by regulation from Kirwin and Webster Reservoirs from 1963-67, by filling of Waconda Reservoir from 1967-69, and by regulation from 1969-77.



EXPLANATION

▲12
Seepage-survey measurement site and number

•11
Salinity-survey reference point and number

——— - - - -
Boundary of alluvial deposits in the Smoky Hill and Solomon River valleys and tributaries
Dashed where approximately located

Figure 17.--Location of seepage-survey measurement sites and salinity-survey reference points.

The results of four seepage surveys made during 1972-77 by the U.S. Geological Survey and the Kansas Water Office are given in table 2. Indicated gains or losses may be in error as affected by small inaccuracies in open-channel measurements. The streamflow loss shown for the August 26, 1976, seepage survey on the Solomon River probably was due to measurement error.

The Smoky Hill River between the New Cambria streamflow-gaging station (site 3) and Sand Springs (site 12) had an average gain in streamflow from ground-water discharge of 25.1 ft^3/s. The average gain between the New Cambria streamflow-gaging station (site 3) and the site immediately upstream from the confluence with the Solomon River (site 8) was 15.6 ft^3/s, and from the site immediately downstream from the confluence with the Solomon River (site 10) to Sand Springs (site 12) the average gain was 9.5 ft^3/s.

The Solomon River between the Niles gaging station (site 14) and the mouth (site 9) had an average gain in streamflow of 7.2 ft^3/s. The average gain from the old U.S. 40 highway bridge (site 17) west of Solomon to the mouth (site 9) was 2.1 ft^3/s.

Chemical Quality

Discussion of the chemical quality of surface water in this section is limited to the concentrations of chloride and sulfate in relating the effect of saline-water discharge from the alluvial aquifer to the rivers at different locations and under various conditions of flow. Data obtained for the study included chemical analyses of water samples collected during the seepage-salinity surveys. Daily chloride-concentration data also are available from the Smoky Hill River at New Cambria and at Enterprise and from the Solomon River at Niles from October 1973 to the present (1981).

Chloride concentrations during medium to peak flows in the Smoky Hill, Saline, and Solomon Rivers, generally were less than the 250-mg/L recommended maximum limit for drinking water established by the U.S. Environmental Protection Agency (1977). Data indicate that the median chloride concentration during base flow in the Smoky Hill River upstream from the confluence with the Saline River was about 125 mg/L and in the Saline River was about 400 mg/L, as shown in figure 18. Because the Smoky Hill River has a greater base flow than that of the Saline River (table 1), the diluted chloride concentration of the combined flow at New Cambria was about 250 mg/L.

The area of saline ground-water discharge to the rivers and median chloride concentrations at base flow in the Smoky Hill, Saline, and Solomon Rivers in the study area are shown in figure 18. At base flow, the median chloride concentration in the Smoky Hill River increases from 250 mg/L at New Cambria to 1,000 mg/L at Sand Springs. Downstream from Sand Springs, the chloride concentration in the Smoky Hill River decreases because ground water discharging to the river contains relatively small concentrations of chloride. Sulfate concentration in the area from New Cambria to Sand Springs also may exceed the 250-mg/L recommended maximum limit for use in drinking water established by the U.S. Environmental Protection Agency (1977).

Table 2.--Results of seepage surveys on the Smoky Hill and Solomon Rivers during 1972-77.

[Discharge and gain or loss are measured in cubic feet per second (ft^3/s). Chloride concentration is measured in millgrams per liter (mg/L)]

Site no. on fig. 17	Site description	Measured discharge (ft^3/s)	Gain or loss (ft^3/s)	Cl (mg/L)	Measured discharge (ft^3/s)	Gain or loss (ft^3/s)	Cl (mg/L)	Measured discharge (ft^3/s)	Gain or loss (ft^3/s)	Cl (mg/L)	Measured discharge (ft^3/s)	Gain or loss (ft^3/s)	Cl (mg/L)	Average gain or loss (ft^3/s)
		March 29-30, 1972			October 15, 1975			August 26, 1976			March 23, 1977			
		Smoky Hill River seepage-salinity investigation												
3	Streamflow-gaging station at New Cambria	98	--	261	145	--	200	56.3	--	--	88.5	--	260	
4	Tributary, Gypsum Creek	14.8	--	141	8.2	--	140	1.2	--	--	8.4	--	--	
6	Southwest of Solomon	--	--	--	156	+2.8	370	60.5	+3	--	103	+6.1	320	
7	South of Solomon	--	--	--	168	+12	385	64.1	+3.6	--	109	+6	350	
8	Upstream from confluence with Solomon River	123	+10.2	368	175	+7	515	72	+7.9	--	113	+4	470	
9	Tributary, Solomon River	--	--	--	86.1	--	710	45.3	--	--	76.9	--	550	
10	Downstream from confluence with Solomon River	210	--	552	261	--	582	117	--	--	189	--	510	
12	At Sand Springs	223	+13	622	266	+5	665	133	+16	--	193	+4	560	
	Overall net gain or loss		+23.2			+26.8			+30.5			+20.1		+25.1
		Solomon River seepage-salinity investigation												
14	Streamflow-gaging station at Niles	72.6	--	--	1/ 76	--	2/ 380	38.6	--	--	1/ 72	--	2/ 390	
15	Northwest of Solomon	--	--	--	--	--	--	43	+4.4	--	--	--	--	
17	West of Solomon	--	--	--	84.5	+8.5	455	45.7	+2.7	--	75.1	+3.1	400	
19	At Solomon	78.2	+5.6	--	85.4	+0.9	620	45.2	-0.5	--	76.6	+1.5	500	
9	Mouth of Solomon River	--	--	--	86.1	+0.7	710	45.3	+0.1	--	76.9	+0.3	550	
	Overall net gain or loss					+10.1			+6.7			+4.9		+7.2

1/ Mean daily value.

2/ Sample collected by observer.

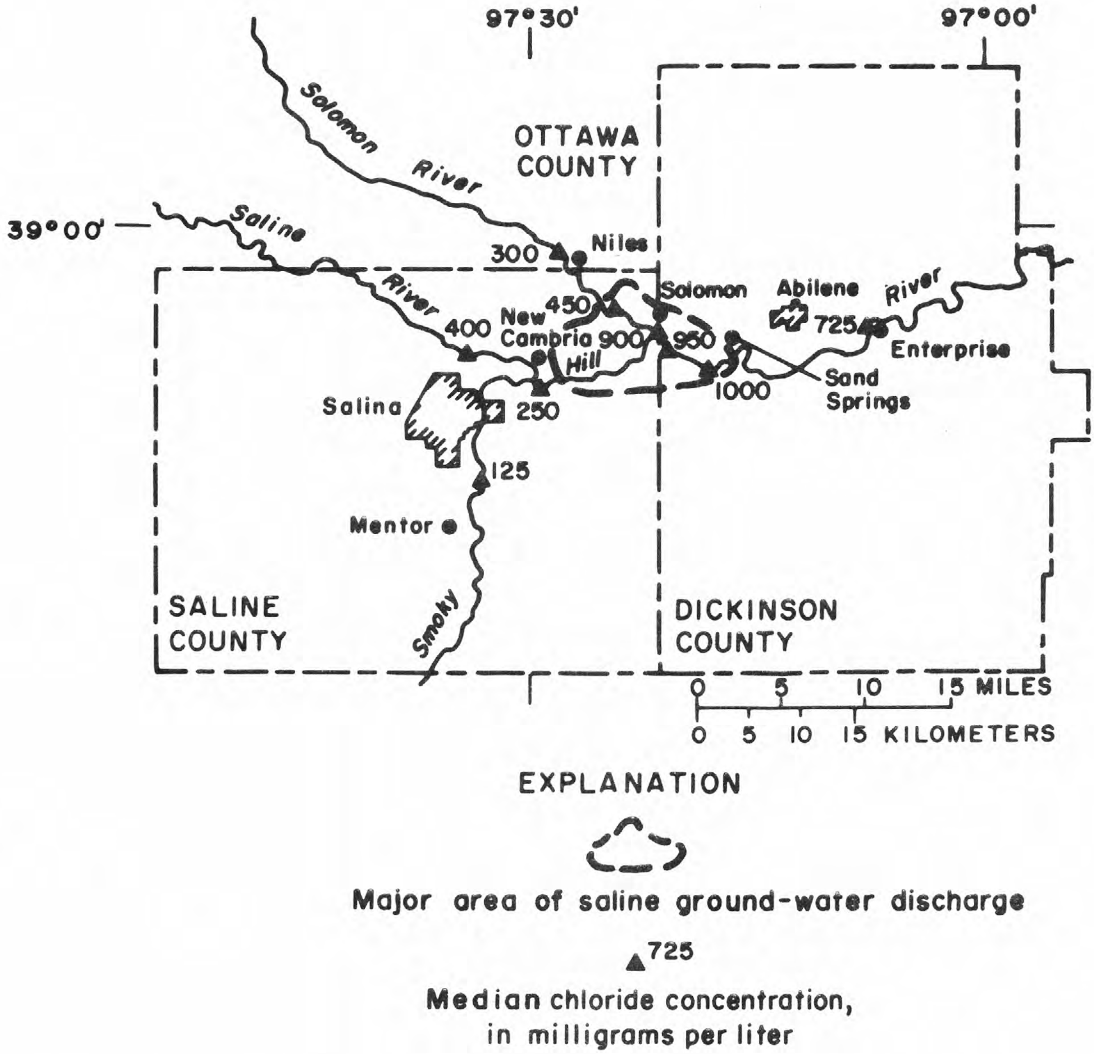


Figure 18.--Median chloride concentrations of base flow in the Smoky Hill, Saline, and Solomon Rivers (modified from Hargadine, Balsters, and Luehring, 1979).

The Solomon River between Niles and the confluence with the Smoky Hill River near the city of Solomon also gains rapidly in chloride concentrations. The median chloride concentration increases from about 300 mg/L at Niles to to 900 mg/L at the mouth.

Although the median chloride concentration during base flow decreases downstream from Sand Springs, the chloride concentration in the Smoky Hill River at Enterprise is nearly three times greater than the recommended maximum limit for drinking water. As a result of saline-water discharge from the alluvial aquifer, water in the Smoky Hill River during most base-flow conditions is reported to be unuseable for most domestic, municipal, industrial, and irrigation purposes in the reach from New Cambria to Junction City (about 22 miles east-northeast of Abilene).

Chloride-concentration-duration curves for the Smoky Hill River near Mentor, at New Cambria, and at Enterprise; the Solomon River at Niles; and the Saline River at Tescott are shown in figures 19 and 20. These duration curves were modified from duration curves compiled by the Kansas Water Office (Hargadine, Balsters, and Luehring, 1979) and were developed from chemical-quality analyses of water samples collected monthly at each streamflow-gaging station. In the Smoky Hill River, for example, a chloride concentration of 250 mg/L is equaled or exceeded less than 1 percent of the time near Mentor, 30 percent of the time at New Cambria, and 54 percent of the time at Enterprise. A chloride concentration of 250 mg/L is equaled or exceeded 62 percent of the time in the Saline River at Tescott and 22 percent of the time in the Solomon River at Niles.

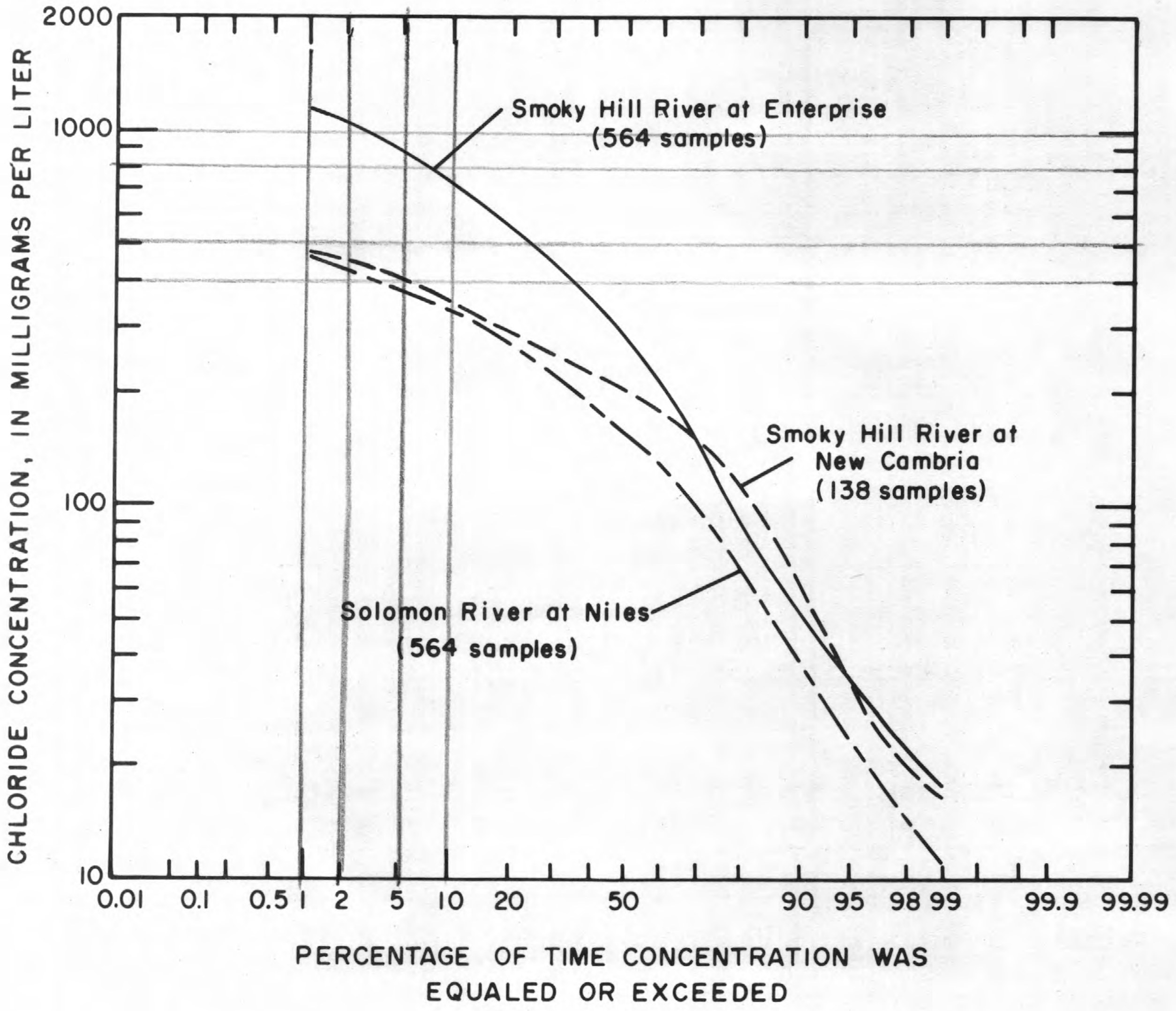


Figure 19.--Chloride-concentration-duration curves for the Smoky Hill River at New Cambria, the Smoky Hill River at Enterprise, and the Solomon River at Niles.

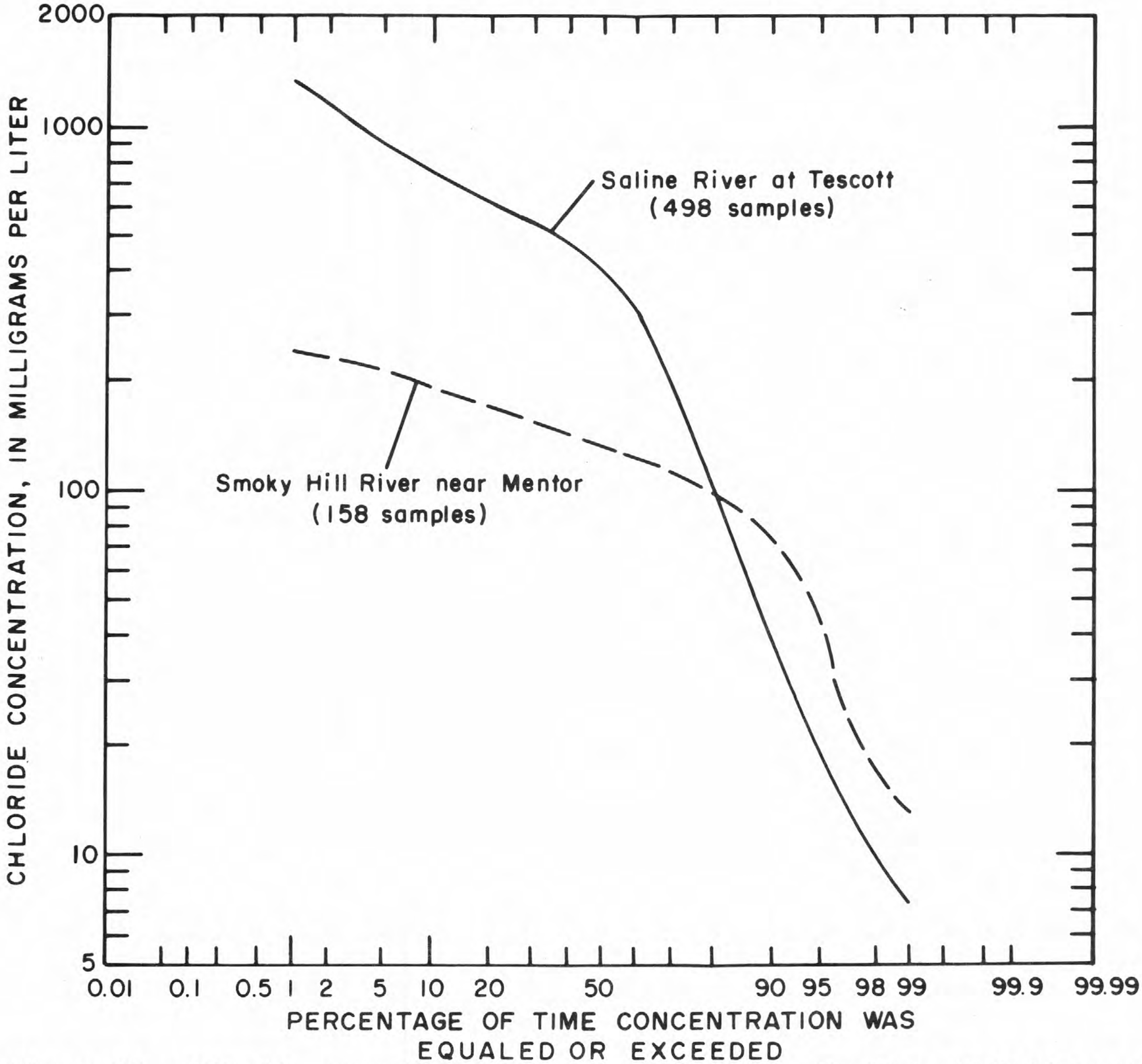


Figure 20.--Chloride-concentration-duration curves for the Smoky Hill River near Mentor and the Saline River at Tescott.

Salinity Surveys

Float trips were made on the Smoky Hill and Solomon Rivers to collect water samples for determination of where saline ground water was discharging to the rivers. Samples, collected at 0.5-mile intervals along the rivers, were analyzed for specific conductance and chloride concentrations. The location of reference sites used in the following discussions are shown in figure 17.

Four float trips were made on the Smoky Hill River; three started at the New Cambria streamflow-gaging station (site 3) and ended 24.5 river miles downstream at Sand Springs (site 12), and the fourth started at the mouth of the Saline River (site 1) and ended 42 river miles downstream at the Enterprise streamflow-gaging station (site 13). Chloride concentrations of the water along the reach floated and the discharge for the Smoky Hill River at New Cambria (site 3) and at Enterprise (site 13) and the Solomon River at Niles (site 14) are shown in figure 21. The figure shows the reaches where saline ground water is entering the Smoky Hill River. The graphs for each float trip show a definite pattern of an increase in chloride concentration in the Smoky Hill River from just west of the New Cambria streamflow-gaging station (site 2) to near the county bridge southwest of Solomon (site 5), then little change in the chloride concentration to near site 7. In the 2-mile reach from site 7 to the mouth of the Solomon River (site 8), the chloride concentration increases rapidly. The increase in chloride concentration at the mouth of the Solomon River (site 10) reflects the inflow from the Solomon River, which has a larger chloride concentration than that of the Smoky Hill River. The chloride concentration continues to increase in the reach from the mouth of the Solomon River to about 2 miles downstream (site 11) and changes little in the reach from site 11 to Sand Springs (site 12). From site 12 to the Enterprise streamflow-gaging station (site 13), the chloride concentration decreases.

Results of the survey indicate that saline ground water is discharged to the Smoky Hill River mostly in the reach from just west of the New Cambria streamflow gaging station (site 2) to about 2 river miles downstream from the mouth of the Solomon River (site 11). Site 11 is located at the approximate eastern margin of the Wellington Formation in the subsurface.

Three float trips were made on the Solomon River. The chloride concentration of the river along the reach floated and the discharge from the Solomon River at Niles (site 14) are shown in figure 22. The figure shows that the chloride concentration increases in the reach from the county bridge northwest of Solomon (site 15) to the location of an old evaporation-type saltworks (site 18). In the reach from site 18 to the mouth (site 9), there is a marked increase in the chloride concentration.

Discharge

Wellington Aquifer

The "salt-dissolution zone" of the Wellington aquifer is the source of most of the sodium chloride in the brine that moves upward into the alluvial aquifer between New Cambria and Solomon. It is assumed that the amount of chloride discharge from the alluvial aquifer to the Smoky Hill and Solomon Rivers between New Cambria and Sand Springs is approximately equal to the chloride discharge from the Wellington aquifer in the study area.

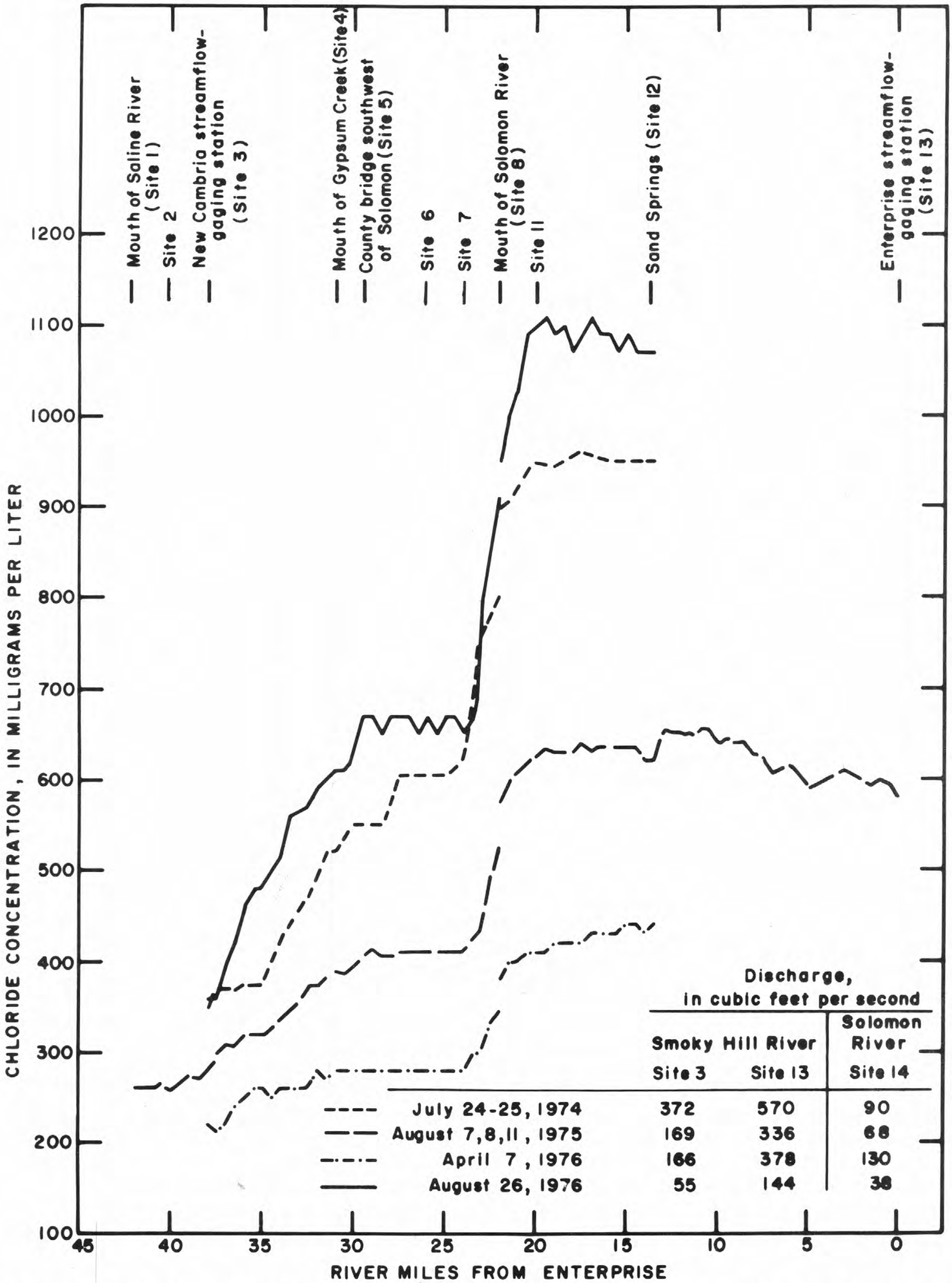


Figure 21.--Chloride concentrations and selected discharges in the Smoky Hill River between the mouth of the Saline River and Enterprise during base-flow conditions.

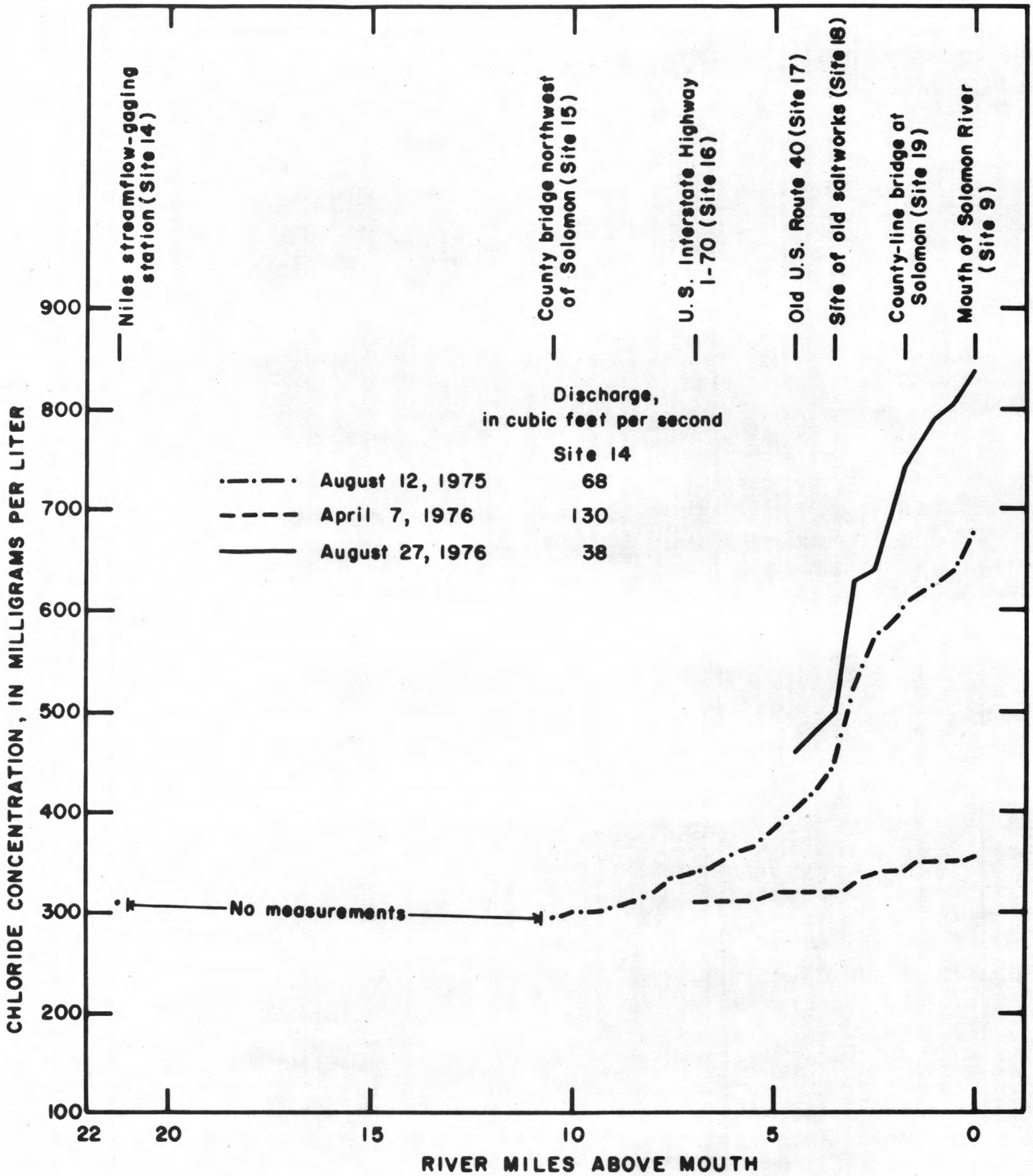


Figure 22.--Chloride concentrations in the Solomon River from Niles to the mouth during base-flow conditions.

Daily chloride concentrations and streamflow data from the Smoky Hill River at New Cambria and the Solomon River at Niles streamflow-gaging stations were used to compute the surface-water and chloride discharges entering the area of interest. Data from the Smoky Hill River at Enterprise station was used to compute the surface-water and chloride discharges that leave the study area. The difference in the inflow and outflow is considered to be approximately the total chloride discharge from the Wellington aquifer in the study area. Using records for 1973-77, as shown in figure 23, the relation is indicated among: (A) A hydrograph of alluvial well 13-01W-35BBC, which is about 0.6 mile from the Smoky Hill River, and a hydrograph of the mean monthly stage of the Smoky Hill River near the well, (B) a graph of the mean monthly chloride discharge to the Smoky Hill and Solomon Rivers in the study area, and (C) a graph of the mean monthly precipitation at Salina.

On April 1, September 29, and October 12, 1973, floods occurred along the Smoky Hill, Saline, and Solomon Rivers that inundated a large part of the river valleys in the study area. As a result of the recharge from flooding, the water table in the alluvial aquifer was increased, as much as 18 feet, to within a few feet of the land surface. After the flooding subsided, the water table steadily receded in response to drainage from the alluvial aquifer to the rivers. Thus, the temporarily large differential in the hydraulic heads between the alluvial aquifer and the rivers decreased with time.

After the 1973 floods receded, the streamflow in the rivers was sustained at intermediate stages by releases from the upstream reservoirs. During this period, the chloride discharge from the alluvial aquifer was very large. The great differential in the hydraulic heads between the alluvial aquifer and the river and the reversal of the hydraulic heads between the Wellington and alluvial aquifers caused a flushing of the aquifers and a subsequent increase in chloride discharged to the rivers.

Using 1973-77 records, as shown in figure 24, the relation is indicated among mean biweekly values of: (A) Chloride discharge to the Smoky Hill and Solomon Rivers from New Cambria to Enterprise, (B) streamflow discharge in the Smoky Hill River at Enterprise, and (C) chloride concentration in the Smoky Hill River at Enterprise. From October 1973 to June 1974, the relation of river discharge to chloride discharge is readily apparent. When the streamflow increases, water moves from the river into the alluvial aquifer, and the chloride discharge decreases. As streamflow decreases, ground water moves toward the river, and chloride discharge increases. The large streamflow and large chloride discharges during May and June 1974 resulted from peak flows in Gypsum Creek. Sustained peak-flow releases from reservoirs during June and July 1975 also increased the streamflow in the rivers and retarded the chloride discharge to the rivers. The chloride concentration in the Smoky Hill River at Enterprise (fig. 24C) has a relatively poor correlation with the stream discharge.

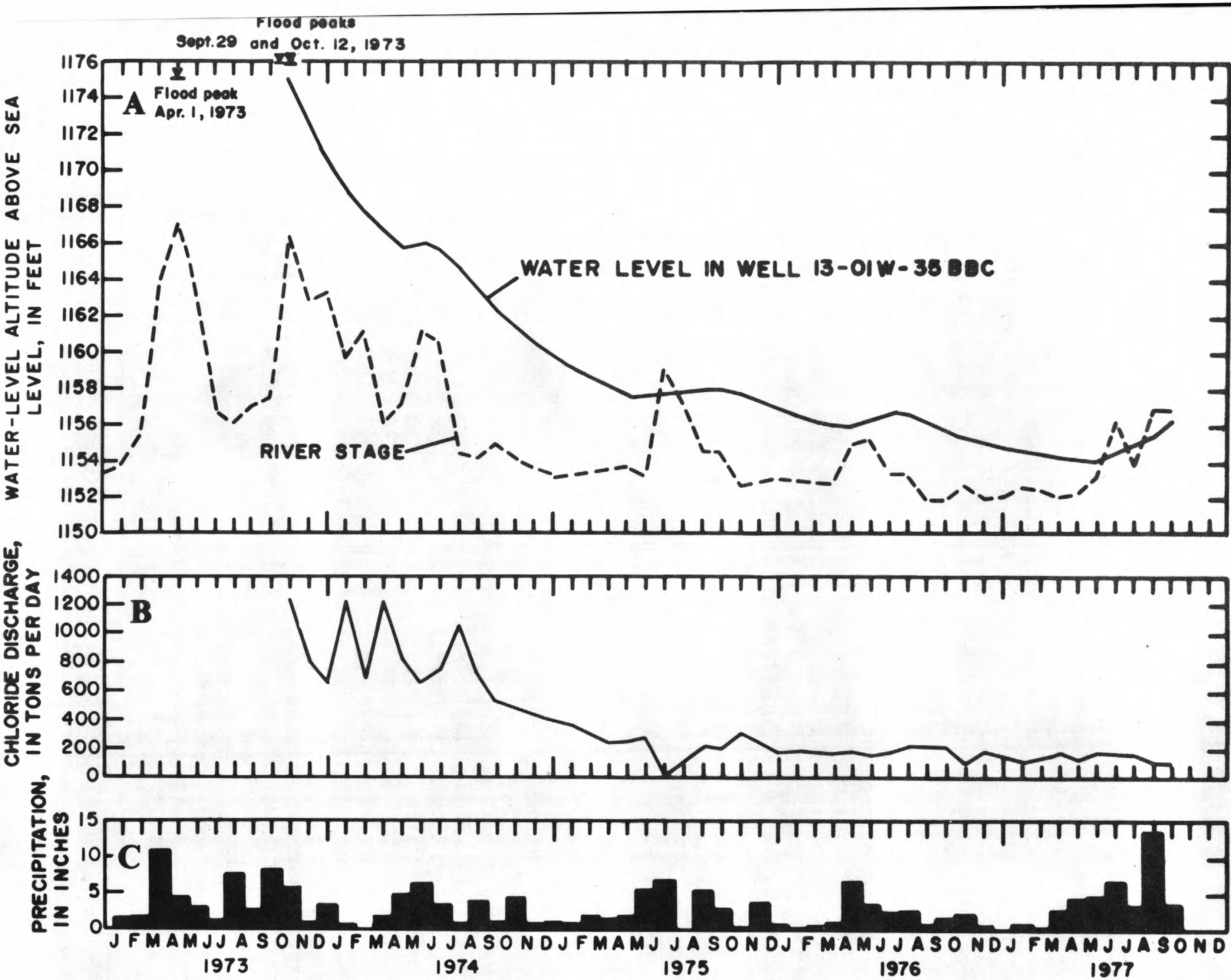


Figure 23.--Relations among: (A) Hydrograph of alluvial well 13-01W-35BBC and mean monthly stage in the Smoky Hill River near the well, (B) mean monthly chloride discharge to the Smoky Hill and Solomon Rivers from New Cambria to Enterprise, and (C) mean monthly precipitation at Salina.

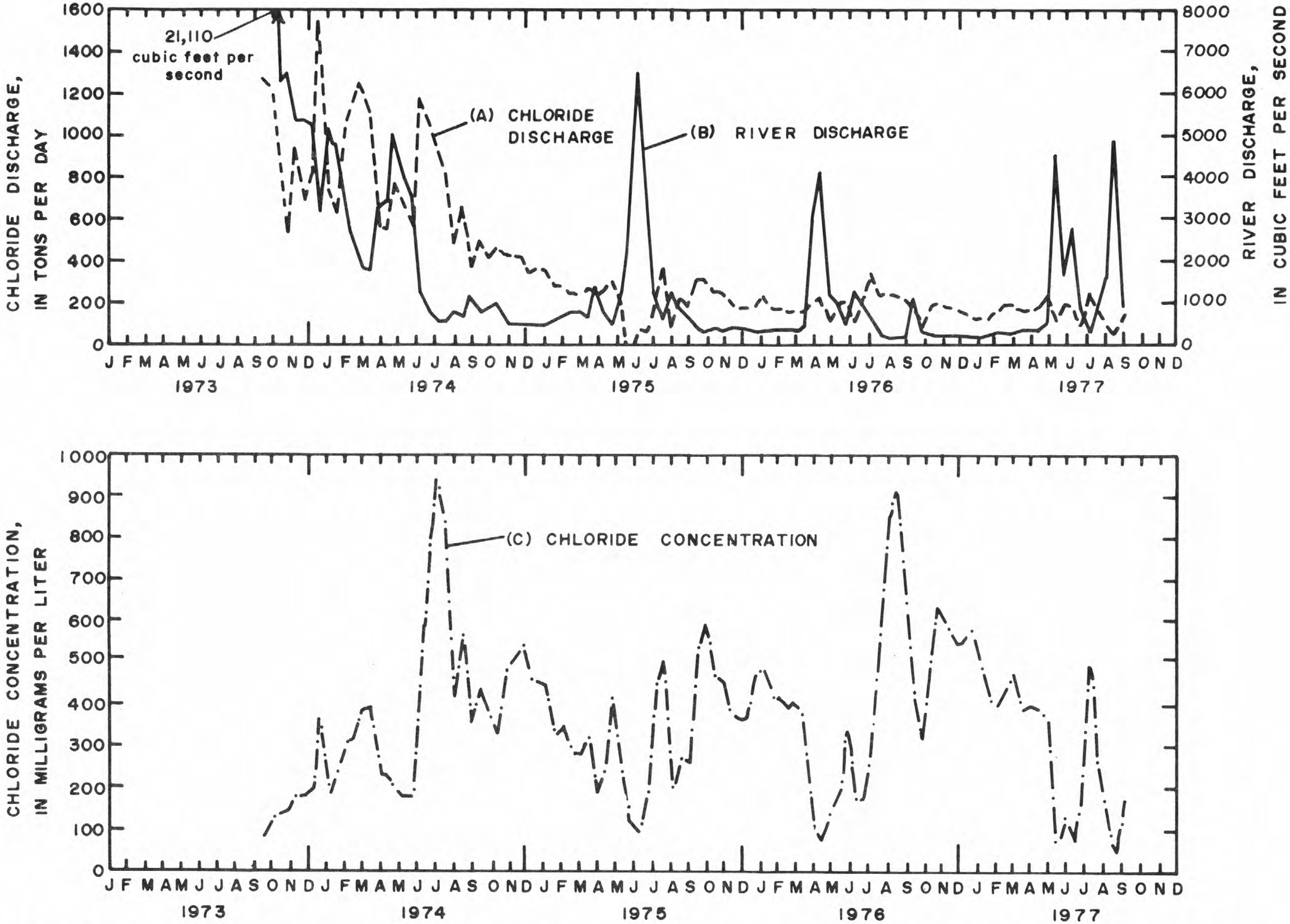


Figure 24.--Relations of mean biweekly values of: (A) Chloride discharge to the Smoky Hill and Solomon Rivers from New Cambria to Enterprise, (B) stream discharge in the Smoky Hill River at Enterprise, and (C) chloride concentration in the Smoky Hill River at Enterprise.

The mean daily chloride discharge for water years 1974-77, and the average for the period are given in table 3. The mean daily chloride discharge has decreased each successive year after the October 1973 flood. It is assumed that the brine outflow from the "salt-dissolution zone" at Salina (fig. 10) is approximately equal to the brine outflow from the Wellington aquifer in the study area. Assuming an overall chloride concentration of 180,000 mg/L in the "salt-dissolution zone," the brine discharge from the Wellington aquifer to the alluvial aquifer decreased from 1.77 ft^3/s during 1974 to 0.31 ft^3/s during 1977, with an average of 0.77 ft^3/s. Several more years of data without floods will be required to determine if the chloride discharge continues to decrease, eventually increases, or approaches a constant discharge. If there are no large floods to increase recharge to the alluvial aquifer, the water table will continue to decline, the recharge to the Wellington aquifer will be less, and brine outflow will decrease. The long-term average brine outflow from the Wellington aquifer is probably within the range of 0.3 to 0.8 ft^3/s.

Table 3.--Brine discharge from the Wellington aquifer to the alluvial aquifer in the study area

Water year	Mean daily chloride discharge (tons per day)	Equivalent brine discharge [1/]	
		cubic feet per second	gallons per minute
1974	858	1.77	795
1975	270	0.56	251
1976	206	.42	191
1977	152	.31	141
Average (1974-77)	371	.77	344

1/ Assuming the source of the brine discharge to be the "salt-dissolution zone" near Salina with a chloride ion concentration of 180,000 milligrams per liter.

Streamflow and chemical-quality data were collected by the U.S. Public Health Service (written commun., 1949) during April-May 1948 on the Smoky Hill and Solomon Rivers in the study area. The data indicate that the average chloride discharge was about 136 tons/d or approximately 0.28 ft^3/s of brine outflow from the Wellington aquifer. Examination of monthly chemical-quality samples collected from the Smoky Hill River at New Cambria and Enterprise and the Solomon River at Niles from 1963-70 indicates that larger chloride discharges occur after floods.

Only one well is known to yield water from the Wellington aquifer in the area of study. The well pumps about 15 gal/min of brine for a water-flood operation in an oilfield near Smolan. Several wells also dispose a small amount of oilfield brine into the Wellington aquifer near Smolan.

Alluvial Aquifer

The major discharge from the alluvial aquifer is the ground-water seepage to the Smoky Hill, Saline, and Solomon Rivers. The seepage differs with the height of the water table above the river. During several seepage runs, made when the water table was relatively stable, the average gain to the Smoky Hill River between New Cambria and Sand Springs was 25.1 ft^3/s (table 2). The average gain to the Solomon River between Niles and the mouth was 7.2 ft^3/s. The total gain for the Smoky Hill and Solomon Rivers in the area of saline-water discharge was 32.3 ft^3/s for 46 river miles, or 0.7 ft^3/s per mile.

Because of the saline water, withdrawals from the alluvial aquifer for municipal, industrial, and irrigation use are small. The average annual pumpage (1972-77) from 16 of Salina's municipal wells is 4.1 ft^3/s. Eleven irrigation wells northeast of Salina, which are used only for supplemental irrigation during dry years, have an estimated average annual pumpage of less than 1.4 ft^3/s. Many stock and domestic wells pump small quantities from the freshwater layer in the upper part of the alluvial aquifer. The city of Solomon pumped an average of 0.2 ft^3/s from three municipal wells during 1978. The total pumpage from all wells is estimated at less than 10 percent of the total ground-water discharge from the alluvial aquifer in the study area.

Discharge by evapotranspiration from the alluvial aquifer probably is small. Vegetation along the streams is relatively sparse because the water table, which generally is more than 20 feet below land surface, is below the root zone of the plants.

MATHEMATICAL SIMULATION OF THE GROUND-WATER SYSTEM

A mathematical model was constructed to simulate the hydrologic system for testing the credibility of conditions described by the conceptual model. A quasi-three-dimensional, finite-difference digital model, as described by Trescott (1975) and by Trescott and Larson (1976), was used to simulate the system of ground-water flow. Initially, a steady-state model was used to determine the magnitude of the various parameters that are significant factors in a stable or equilibrium condition. Subsequently, results of the steady-state simulation were used as initial conditions in a transient-state simulation of changing conditions. The transient model was used to determine the effects of a large, short-term increase of recharge to the hydrologic system, such as that when floods inundate the river valleys.

The area modeled includes 104 square miles of the Smoky Hill River and Solomon River valleys and the adjacent uplands extending from New Cambria to Sand Springs, as shown in figure 25. Although the recharge and transmission areas of the Wellington aquifer (as described in the conceptual model) are not included, the hydrologic significance of those units is incorporated into the model. In general, the model area includes those parts of the valleys where: (1) The potentiometric surface of the Wellington aquifer normally is higher than the potentiometric surface of the alluvial aquifer, (2) the Wellington aquifer discharges brine into the alluvial aquifer, and (3) the alluvial aquifer discharges saline water into the rivers.

The modeled area was subdivided into a finite-difference grid consisting of 16 rows and 26 columns, each element being 0.5-mile square. Values applied to the model were distributed to the appropriate nodes located at the center of each element and representative of the entire area in the block. The alluvial aquifer was simulated by the upper layer of the model, as shown in figure 26A, and the Wellington aquifer was simulated by the lower layer, as shown in figure 26B. The intervening shale layer was simulated in the model by a quasi-layer having vertical hydraulic conductivity but no storage. In this scheme, vertical flow in the confining layer is incorporated into the model as a TK layer using:

$$TK = K'/b, \qquad (1)$$

where

K' = vertical hydraulic conductivity of the confining layer, in feet per second; and

b = thickness of the confining layer, in feet.

Recharge from subsurface inflow was simulated in the model as a constant flow applied to nodes at the aquifer boundary (fig. 26). Recharge at these nodes was used to represent inflow from adjacent alluvial aquifers in: (1) The valleys of the Smoky Hill and Solomon Rivers on the west and southwest, (2) the valleys of Gypsum Creek and an unnamed tributary on the south, and (3) the terrace deposits along the north. Constant flow also was simulated at nodes representing the inflow of brine to the Wellington aquifer from the recharge areas on the west and northwest. In a similar manner, constant flow was simulated at nodes representing discharge from the alluvial aquifer by subsurface outflow to the east (fig. 26A). It was determined that only small amounts of water move across the aquifer boundaries from the uplands to the alluvial valleys where no terrace deposits are present. Thus, these areas were considered as zero-flow boundaries in the model.

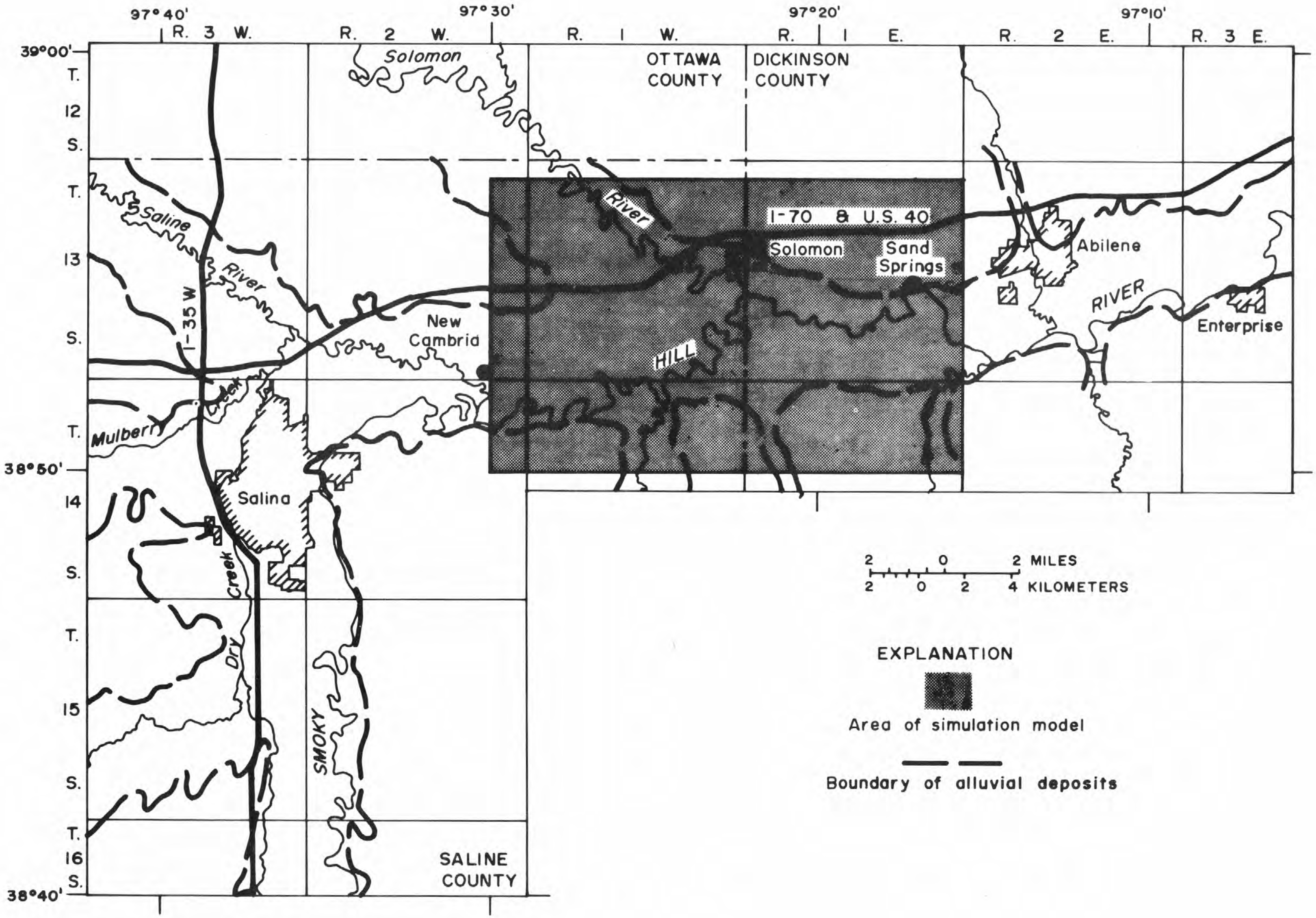


Figure 25.--Location of simulation model.

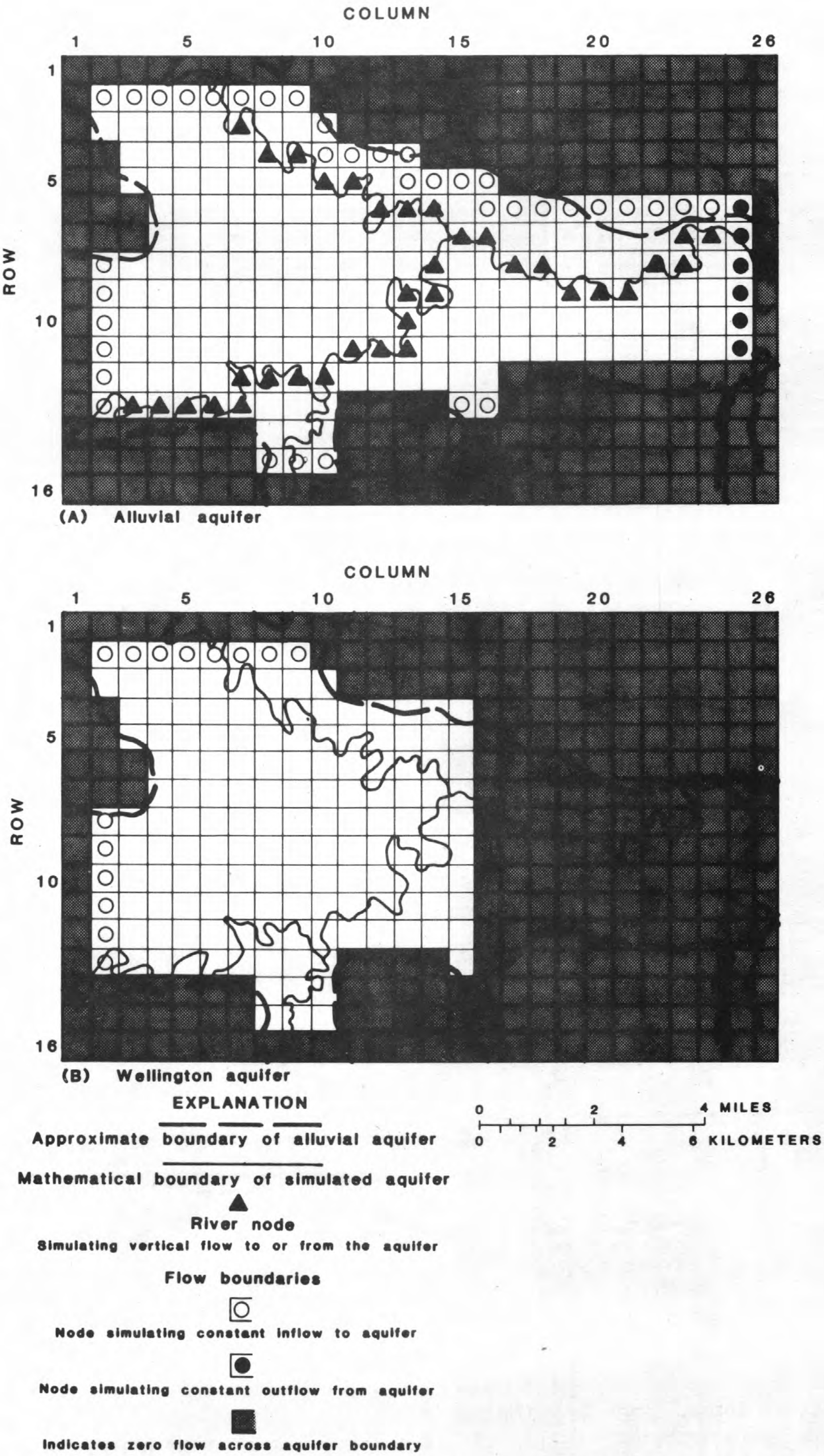


Figure 26.--Finite-difference grid and boundary conditions in the model for (A) the alluvial aquifer and the (B) Wellington aquifer.

An option was added to the model that permited the simulation of leakage between the rivers and the alluvial aquifer (S. P. Larson, U.S. Geological Survey, written commun., 1976). Leakage was simulated at nodes along the Smoky Hill and Solomon Rivers where water would move to or from the aquifer through a simulated confining streambed (fig. 26A). The rate of leakage was simulated in the model using the equation:

$$Q = \frac{K'}{b} \Delta hA, \tag{2}$$

where

Q = leakage, in cubic feet per second;
K' = vertical hydraulic conductivity of streambed, in feet per day;
b = thickness of streambed, in feet;
Δh = difference in hydraulic head between water level in the stream and water level in the aquifer, in feet; and
A = area of streambed.

Other factors considered in the simulation were the effects on the alluvial aquifer of recharge from precipitation and of discharges from evapotranspiration and pumpage of wells. Recharge from precipitation was estimated during calibration of the model. Evapotranspiration from the aquifer was considered to be insignificant because the water table generally is more than 20 feet below land surface and vegetation along streams is sparse. Annual pumpage by wells was also considered to be insignificant because most ground water reportedly is unusable for most purposes.

Aquifer Properties

The aquifer properties initially were estimated on the basis of available information. Subsequently, the values were adjusted within reasonable limits until the model was calibrated to adequately reproduce both measured streamflow gains and potentiometric surfaces interpreted from measured ground-water levels. The aquifer properties given in this section are the final values used in the simulation model.

Wellington Aquifer

The only data available for the Wellington aquifer were the results from a test made in the "salt-dissolution zone" at Conway, about 34 miles south of Salina. Results of the test indicated an average transmissivity of 2,500 ft^2/d and an average storage coefficient of 1.0×10^{-5} (Gogel, 1981). It was assumed, however, that the transmissivity of the "gypsum-dissolution zone" in the model area would be increased because the cavities in the interbedded gypsum and shale would be less susceptible to collapse than the cavities in the massive salt beds. Thus, the Wellington aquifer in the model area was assigned a constant transmissivity value of 3,000 ft^2/d and a storage coefficient value of 1.0×10^{-4}. The subsurface brine inflow to the model area, determined on the basis of seepage and salinity measurements, was 0.7 ft^3/s.

A value for the constant rate of vertical leakance through the overlying TK layer or confining bed was determined in the calibration of the steady-state model. Assuming uniform values of vertical hydraulic conductivity and bed thickness, the resulting value of vertical leakance was 8.6×10^{-7} ft/d.

Alluvial Aquifer

Lithologic data from drill cuttings and gamma-ray logs of test holes in the area were used to estimate the hydraulic conductivity and transmissivity of the alluvial aquifer. The data indicate that the alluvial material in the Smoky Hill River valley is coarser and thicker than that in the Solomon River valley. Estimated hydraulic conductivities ranged from 130 to 210 ft/d in the Smoky Hill River alluvium, 100 to 130 ft/d in the Solomon River alluvium, and 20 to 30 ft/d in the terrace deposits. A transmissivity value for each node was derived by multiplying the saturated thickness by the average hydraulic conductivity at each site. Transmissivities in the model area ranged from nearly zero to about 8,000 ft^2/d, as shown in figure 27.

A value of 0.07 was used for the specific yield of the alluvium in the model area. A value of this magnitude commonly is representative of a silty clay similar to that in the upper part of the aquifer. However, it was assumed that the most significant water-level changes considered in the study were those occurring near the land surface as a result of the recharge from periodic flooding.

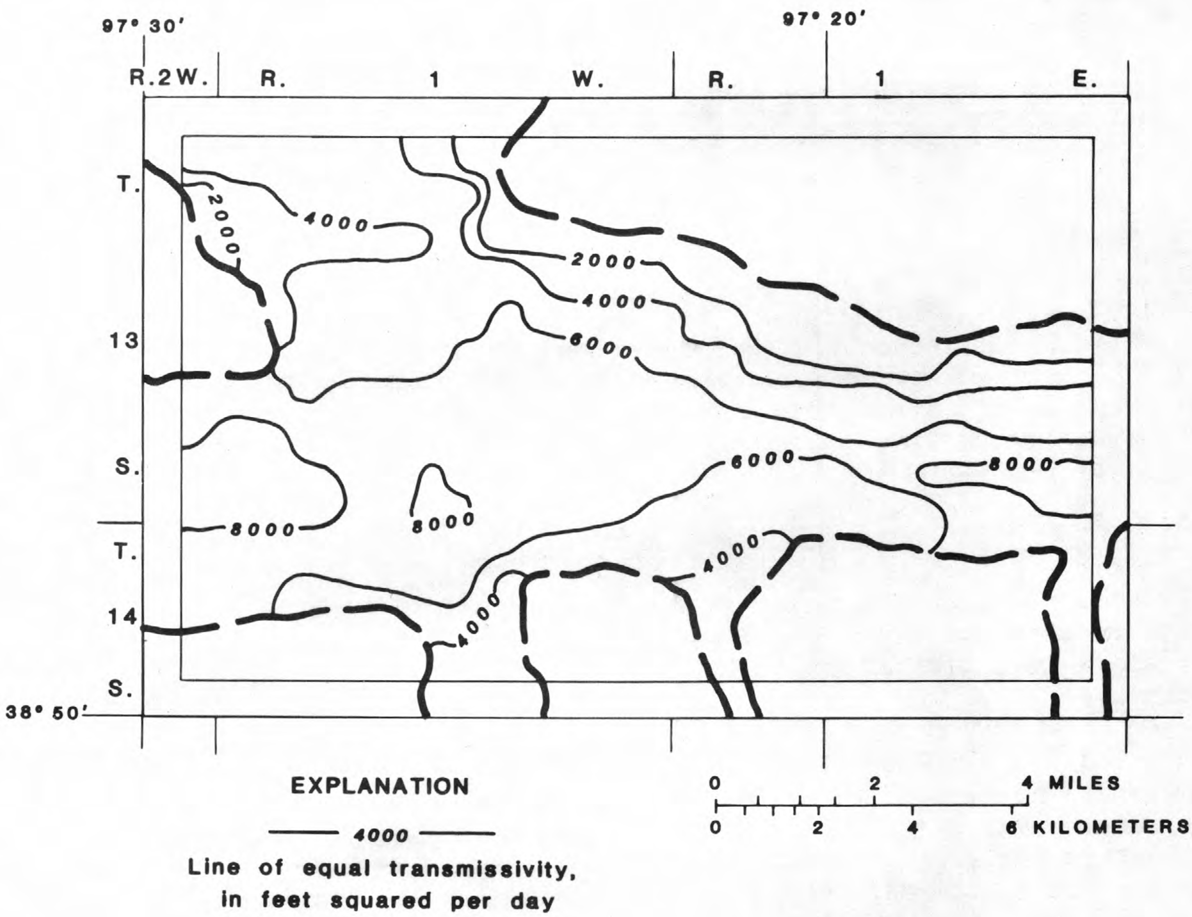


Figure 27.--Transmissivity of the alluvial aquifer used in simulations.

The subsurface inflow to the aquifer in the model area from alluvium in the valleys on the south, west, and northwest and from terrace deposits on the north was determined to be 3.5 ft^3/s. Subsurface outflow to the alluvium on the east was 0.7 ft^3/s. Recharge from precipitation, applied uniformly over the model area, was determined to be 5.6×10^{-4} ft/d, or about 8 percent of the annual precipitation.

The rate of leakage between the aquifer and the rivers was calculated in the model using an estimated vertical hydraulic conductivity for the streambed of 0.6 ft/d (typical of silt and clay materials) and assuming the average bed thickness to be 1 foot. Application of leakage at each river node was proportional to the length of streambed represented. Leakage at each river node was dependent on the difference in hydraulic head between the water level in the aquifer and the water level in the river.

Model Calibration

Results from the simulation model should be compared to actual measurements from the hydrologic system to determine if the model is realistic. The hydrologic system was considered to be relatively stable during 1976 and 1977 when most of the data were collected for determining the potentiometric surfaces of the Wellington and alluvial aquifers. Data also were available for determining relatively stable base flow in the Smoky Hill and Solomon Rivers during April 1977 (fig. 23). Thus, a steady-state model was used to simulate 1977 hydrologic conditions.

In calibrating the model, input data (aquifer properties, boundary conditons, and hydraulic stresses) were adjusted to minimize differences between the measured and computed values of potentiometric head and ground-water discharge to the rivers. Although the large number of interrelated factors affecting ground-water flow makes this a highly subjective procedure, the amount of adjustment of any aquifer property generally should be relative to the uncertainty of its value.

In the calibration of the steady-state model, the initial values of transmissivity, storage coefficient, specific yield, and the subsurface flow into and out of the model area required only minor adjustment. The greatest adjustment was required in determining the rate of flow through the TK or confining layer. Assumed values for the TK rate of flow were applied and adjusted uniformly until an acceptable match was obtained between measured and calculated values of the potentiometric surface of the alluvial aquifer, the potentiometric surface of the Wellington aquifer, and the ground-water discharge to the rivers. The calculated potentiometric surfaces of the alluvial aquifer, shown in figure 28A, and of the Wellington aquifer, shown in figure 28B, acceptably matched the measured surfaces, shown in figure 11. The computed ground-water discharge from the alluvial aquifer to the rivers was 25 ft^3/s, as compared to a measured discharge of 32 ft^3/s.

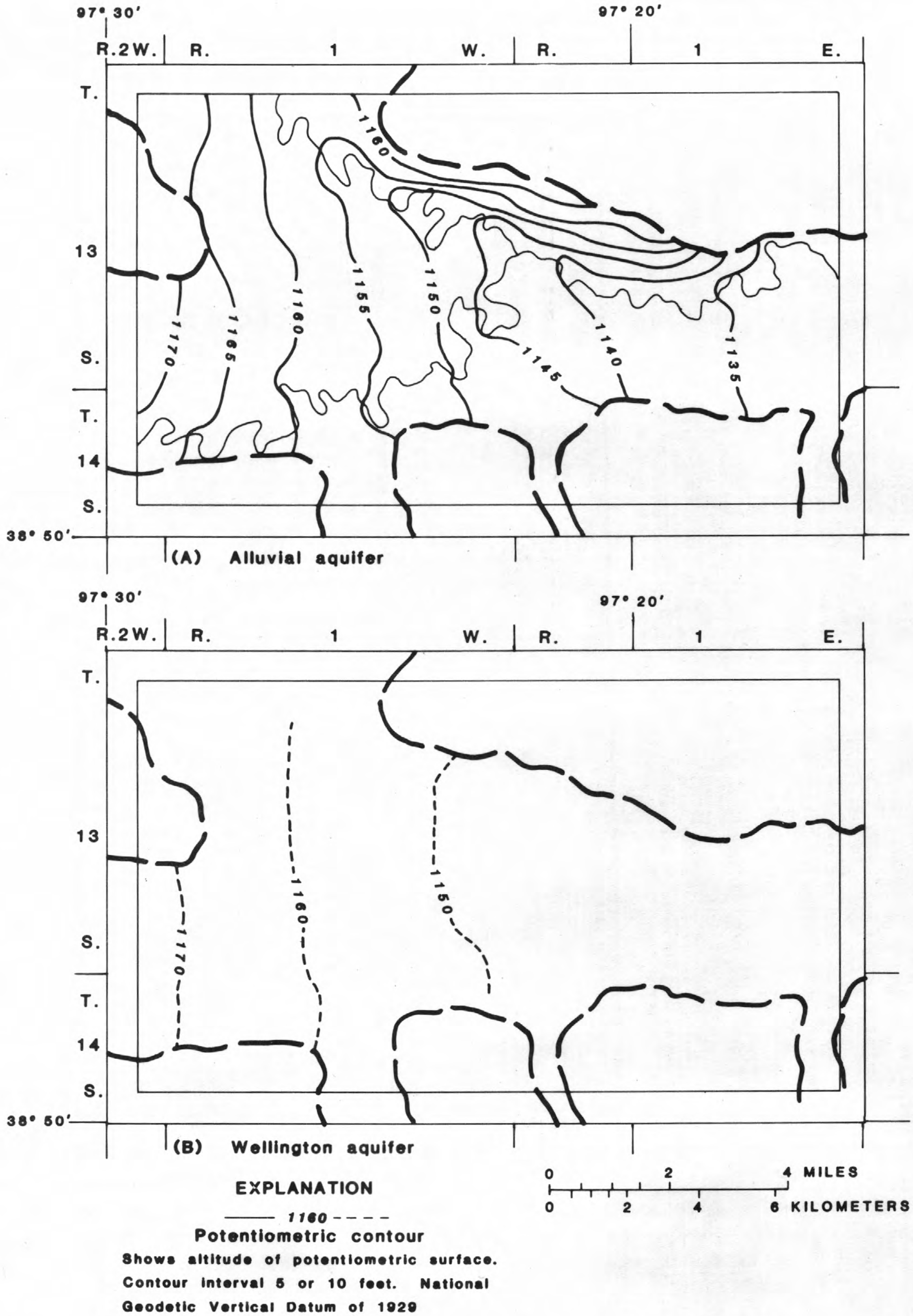


Figure 28.--Altitudes of potentiometric surfaces (April 1977) computed by the steady-state model for (A) the alluvial aquifer and (B) the Wellington aquifer.

A comparison was made of potentiometric surfaces of the alluvial aquifer and the Wellington aquifer resulting from the steady-state simulation (representing April 1977). The computed differences in hydraulic head between the two surfaces are shown in figure 29. The hydraulic head of the Wellington aquifer generally ranged from 0.2 to 3.5 feet higher than the hydraulic head of the alluvial aquifer, except in areas along the edge of the valley.

Transient Simulation and Results

Although the steady-state model adequately depicts the normal or long-term condition of the flow system in the model area, it cannot depict adequately the short-term effects of increased recharge from periodic flooding. As discussed previously, data indicate that the flood of 1973 altered steady-state conditions and temporarily raised the hydraulic heads in the alluvial aquifer as much as 18 feet. An increased recharge of this magnitude in the alluvial aquifer could have a significant impact on the flow system. It is desirable to determine the magnitude and duration of this impact on flow from the Wellington aquifer and on flow from the alluvial aquifer to the rivers.

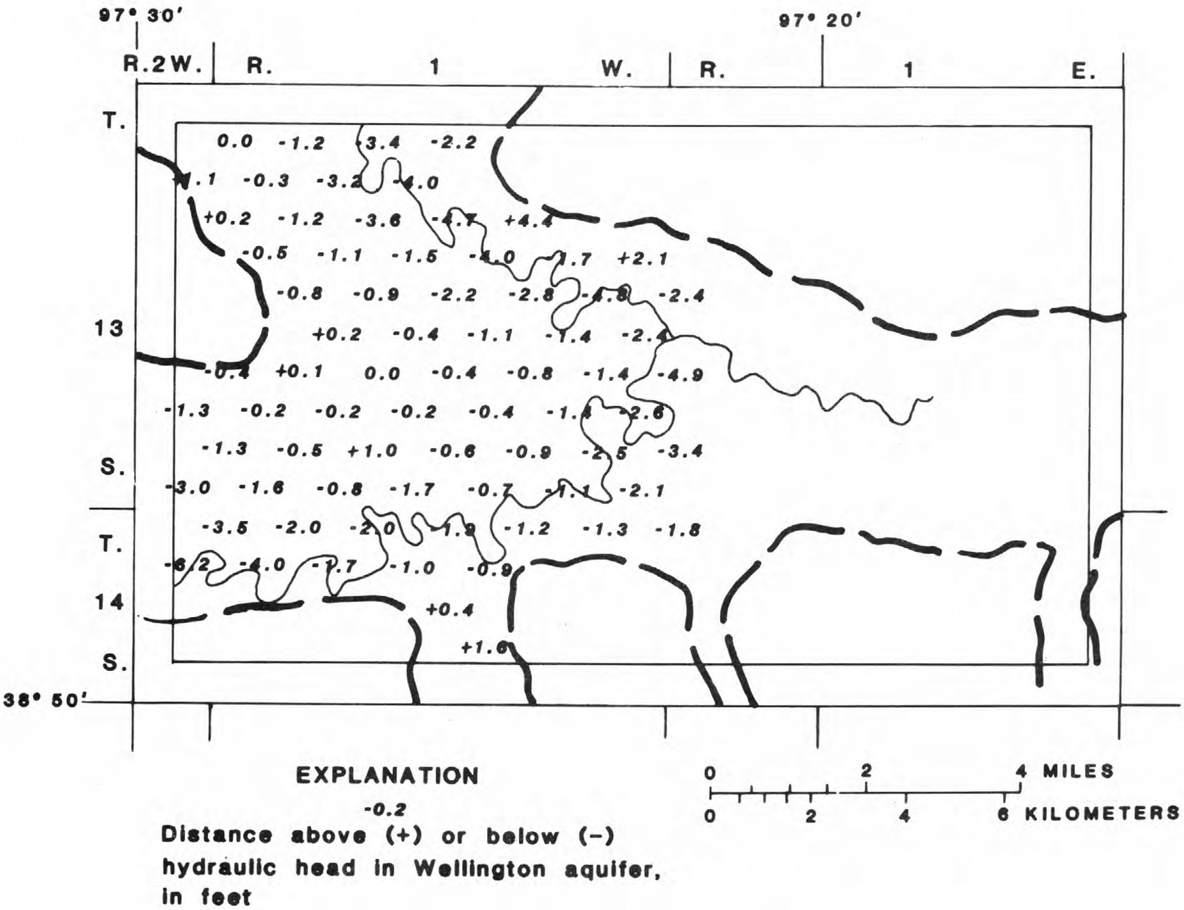


Figure 29.--Relation of hydraulic heads in the alluvial aquifer to those in the Wellington aquifer (April 1977), computed by the steady-state model.

The transient simulation indicated that the effect of increased recharge to the alluvial aquifer from flooding (1973) raised the hydraulic heads in both aquifers. By the end of this recharge period, however, the hydraulic head in the alluvial aquifer generally was higher than that of the Wellington aquifer. The difference, as shown in figure 30A, generally ranged from about 2 to 9 feet, except along the river channel. Thus, the normal hydraulic-head relationship indicated by the steady-state simulation was reversed.

After the period of increased recharge in the transient simulation, the flow system was allowed to stabilize. Because the hydraulic head in the alluvial aquifer had increased with respect to the head in the rivers, discharge to streamflow increased. As the rivers continued to drain water from aquifer storage, the head relationship between aquifers eventually approached the condition that existed in April 1977, as shown in figure 30B.

Actual water-level measurements in alluvial well 13-01W-35BBC, located about 0.6 mile from the Smoky Hill River, were compared with hydraulic heads computed in the model at about the same site, as shown in figure 31. Hydrographs of actual and computed heads in the alluvial aquifer from October 1973 to April 1977 are reasonably similar. Because water-level measurements from wells in the Wellington aquifer were not available for a comparable period, the computed heads are shown in figure 31 to indicate the general relationship between aquifers.

POTENTIAL ALLEVIATION OR CONTROL OF BRINE INTRUSION

Several methods have been proposed for the elimination or reduction of natural brine discharges in various basins by agencies such as the U.S. Army Corps of Engineers. Engineering structures include dams, dikes, storage reservoirs, canals, and pumping systems for the collection, storage, suppression, transmittal, and disposal of the brines. Even though engineering and design practices are well advanced for water-resources development projects, the control of large volumes of brine is basically untried.

The U.S. Army Corps of Engineers has proposed the following brine control classifications, which are used in this report:

1. Subsurface disposal of brines,

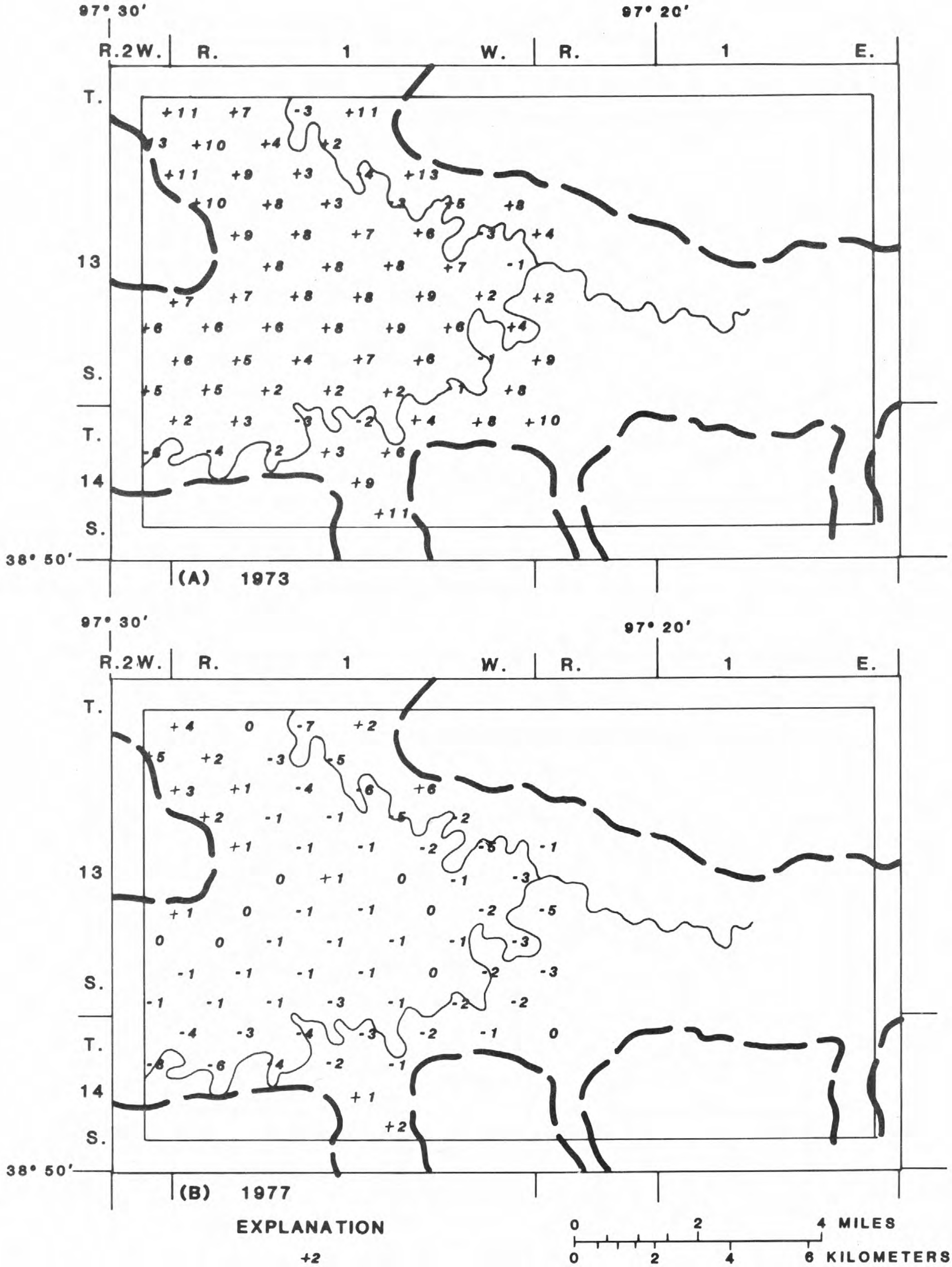
2. In-channel brine storage and diversion of good quality water,

3. Elimination of reduction of recharge to the Wellington aquifer,

4. Temporary reduction of saline water by low-head dams,

5. Transport to nondamaging disposal site, and

6. Dilution.



EXPLANATION

+2
Distance above (+) or below (−) hydraulic head in Wellington aquifer, in feet

Figure 30.--Relation of hydraulic heads in the alluvial aquifer to those in the Wellington aquifer (A) 0.01 years after flooding (1973) and (B) 3.5 years after flooding (1977), computed by transient model.

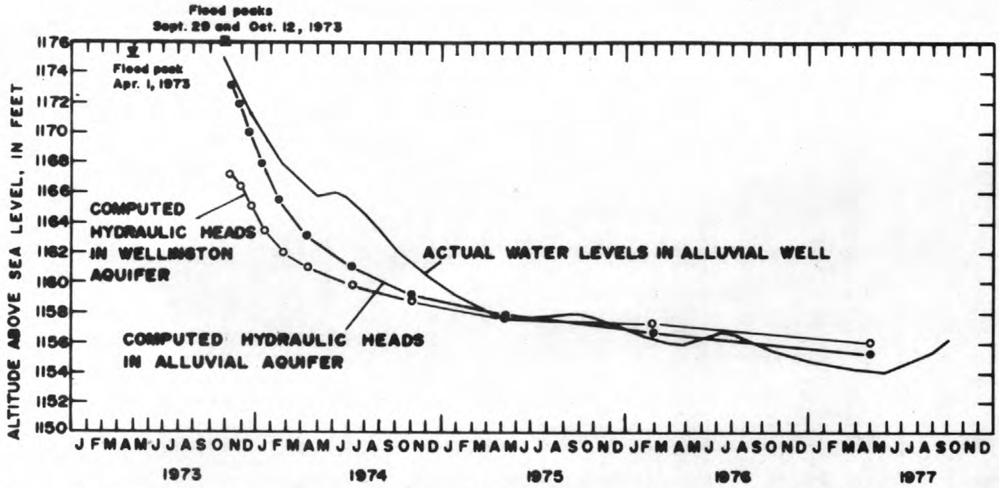


Figure 31.--Actual water levels in alluvial well 13-01W-35BBC and hydraulic heads computed for the alluvial and Wellington aquifers at the same location, 1973-77.

Subsurface Disposal of Brines

In Kansas, nearly all the brines from oil and gas production are discharged into the deep formations from which the oil and gas are produced. In the study area, most brine disposal is into the Maquoketa Shale of Ordovician age.

In the Smoky Hill River valley northeast of Salina, most of the brine in the Wellington aquifer moves eastward beneath the alluvial aquifer. Although the hydraulic head in the Wellington aquifer is higher than the hydraulic head in the alluvial aquifer, upward leakage of the brine is minimal because a tight confining shale layer exists between the two aquifers. The eastward movement of brine is virtually confined to this limited cross section under the alluvium of the river valley.

A line of relief wells in the Wellington aquifer across the valley in this area would create a trough in the potentiometric surface, and thus, intercept most of the eastward-moving brine. The confining shale layer would restrict downward flow of freshwater from the alluvial aquifer to the Wellington aquifer in the vicinity of the trough to a minimum. This method has the potential to improve the chemical quality of the ground water downgradient, as well as the streamflow in the Smoky Hill and Solomon Rivers.

The brine pumped from the Wellington aquifer possibly could be disposed of into the deep formations of early Paleozoic age underlying the area--the Hunton Formation, Maquoketa Shale, Viola Limestone, Simpson Group, and Arbuckle Group. The storage potential of the deep formations is believed to be adequate; however, further study is needed to determine the transmissive and storage parameters and the potentiometric heads of these formations. Several oil tests in the area lost circulation of drilling fluid in the Hunton Formation, which is about 3,300 feet below land surface. The Salina oilfield, producing mainly from the Maquoketa Shale, is located just to the south of the area. Disposing of brine into the Maquoketa Shale on the southern flank of the Salina oilfield is possible, but consideration needs to be given to the effect of water flooding on the producing wells in the oilfield.

In-Channel Brine Storage and Diversion of Good-Quality Water

Improvement in the chemical quality of water in the river may be accomplished by diverting the base flow of the Smoky Hill River through a concrete-lined canal from near New Cambria to near Sand Springs. The base flow of the Solomon River also could be diverted through a canal from a point upstream from the I-70 highway bridge crossing on the Solomon River to near Sand Springs. A series of low-head dams would be necessary to retain the saline ground-water discharge in the main channel of the rivers during the diversion of the good-quality base flows. The saline water retained by the low-head dams could be released during intermediate and peak-flow conditions. No adverse effects of these releases are anticipated downstream. The diversion would be used only when the chloride concentration of the base flow at Sand Springs reached a predetermined limit. The low-head dams, used for long periods, could effectively stop the saline water from entering the river from the alluvial aquifer.

Temporary Reduction of Saline-Water Discharge By Low-Head Dams

Under natural low- or base-flow conditions, the rivers act as a drain for the alluvial aquifer. The lowest position of the water table is at the river channel. Low-head dams could be constructed in the river channel that could be closed temporarily when the chloride concentration of the base flow at Sand Springs reached a predetermined limit. The increased hydraulic head created by the ponding would reduce the upward brine flow from the Wellington aquifer in the vicinity of the rivers and reduce the ground-water discharge from the alluvial aquifer to the rivers.

It is possible that a stratification might develop between the saline ground water entering the bottom of the ponded channel and the fresh streamflow on top of the ponds. Thus, the fresh streamflow from upstream might flow through the area without mixing with the saline water in the bottom of the ponds.

The dams would be needed only a small proportion of the time, according to past records, and would be opened during peak-flow conditions to flush and dilute the saline water in the bottom of the ponds.

Transport To Nondamaging Disposal Site

The brine pumped from the interceptor wells in the Wellington aquifer in the cross section northeast of Salina could be pumped via pipeline to a brine-detention reservoir. The water in the brine could be disposed of by solar evaporation, and salts would precipitate in the pond. The salts contained in the brine could be extracted and sold commercially; however, the economic feasibility of this method in relation to the common mining methods is doubtful at the present time. The U.S. Air Force Smoky Hill Bombing Range southwest of Salina might contain a good brine-detention reservoir site.

Brine stored in the reservoir could be drained back into the Smoky Hill River during peak flows at a rate that would not seriously effect the overall chemical quality of the streamflow.

The brine could be piped to a distant disposal site. The U.S. Army Corps of Engineers has made a study on the use of a pipeline to carry brines from Oklahoma and Texas to the Gulf of Mexico. The economic feasibility of a pipeline is very doubtful.

Dilution

To date, sufficient improvement further downstream in the quality of water for municipal use at Topeka, Lawrence, and Johnson County has been accomplished by blending freshwater from Milford, Tuttle Creek, and Perry Reservoirs with Kansas River water (Hargadine, Balsters, and Luehring, 1979). This dilution is inexpensive and is not controversial as long as adequate water exists in the reservoirs for this purpose. In the future, when the water in the reservoirs has been sold or allocations have been made for other purposes, there may not be adequate water for the dilution process. Thus, other alternatives need to be considered.

SUMMARY

Saline water entering the Smoky Hill River affects the water supply for municipal, industrial, and irrigation uses. Most of the saline waters is discharged from the alluvial aquifer into the Smoky Hill and Solomon Rivers between New Cambria and Sand Springs. During relatively stable periods of base flow, ground-water discharge in the rivers is about 32 ft^3/s, and the chloride concentration increases from 300 to 1,100 mg/L.

Saline water in the alluvial aquifer results from mixing of freshwater in the alluvial aquifer with brine from the underlying Wellington aquifer that is saturated or nearly saturated with respect to sodium chloride. The Wellington aquifer is a zone of dissolution, subsidence, and collapse along the eastern margin of the Hutchinson Salt Member and lower member of the Wellington Formation. In the area from New Cambria to Solomon, the hydraulic heads in the Wellington aquifer are greater than hydraulic heads in the alluvial aquifer. Thus, brine moves upward into the alluvial aquifer through collapse structures at the base of the alluvium. The estimated long-term brine outflow from the Wellington aquifer in the area ranges from 0.3 to 0.8 ft^3/s, corresponding to a chloride discharge of 150 to 370 tons/d.

When periodic floods inundate part of the valley, water moves into the alluvial aquifer as recharge, raising the water levels, increasing the storage, and reversing the steady-state hydraulic-head relationships between aquifers. As the flooding recedes, the great differential in hydraulic heads between the aquifer and the river causes a significant increase in the quantity and the chloride concentrations in ground-water discharge. When the aquifer is sufficiently drained to be in hydrologic balance (inflow equals outflow with little change in storage), the discharge and chloride contribution to streamflow decrease.

During the periods when the hydraulic heads in the alluvial aquifer are greater than the hydraulic heads in the Wellington aquifer, saline water moves downward into the Wellington aquifer through collapse structures. When the hydraulic-head differential is reversed, brine is flushed out through collapse structures and into the alluvial aquifer in the areas near the rivers. This reversal in the hydraulic-head relationship probably causes the dilution of brine discharged from the Wellington aquifer.

The natural-brine discharge to the alluvial aquifer could be alleviated or partly controlled by installing interceptor wells in the Wellington aquifer across the Smoky Hill River valley northeast of Salina. In this area, the brine is confined in the aquifer and restricted to movement through a 3-mile cross section underlying the valley. The wells could be pumped to intercept part of the eastward-flowing brine and sufficiently reduce the potentiometric head to eliminate much of the brine discharge.

The brine could be disposed into the deep formations underlying the area. Brine also could be piped to a storage reservoir for disposal by solar evaporation or for return to the Smoky Hill River during peak flows at a rate that would have little effect on the chemical quality of the streamflow. A combination of the above methods of disposal would be the most effective.

Base flow containing relatively small chloride concentrations in the Smoky Hill and Solomon Rivers could be diverted via canals around the saline ground-water discharge area. Low-head dams could be constructed to retain the saline water in the main channel of the rivers for subsequent release during intermediate and peak-flow conditions.

Base flows in the Kansas River downstream from the saline ground-water discharge area have been diluted by freshwater releases from Milford, Tuttle Creek, and Perry Reservoirs. In the future, there may not be an adequate supply of water available for the dilution process. Thus, other alternatives need to be considered.

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