GEOHYDROLOGY OF THE WELLINGTON-ALLUVIAL AQUIFER SYSTEM AND EVALUATION OF POSSIBLE LOCATIONS OF RELIEF WELLS TO DECREASE SALINE GROUND-WATER DISCHARGE TO THE SMOKY HILL AND SOLOMON RIVERS, CENTRAL KANSAS

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CONTENTS

FIGURES

CONTENTS--Continued

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 Units.

Inch-pound units	Multiply by	SI unit
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	hectare
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 day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.0929	meter squared per day
pound per square inch (lb/in^2)	6.895	kilopascal

GLOSSARY

Aquifer - A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Confining layer - A layer of rock material that retards but does not necessarily prevent the flow of water from or to an adjacent aquifer.

Evapotranspiration - Water withdrawn from a land area by evaporation from water surfaces and moist soil, and by transpiration of plants.

Fluid level - The distance from the top of a well down to the surface of the fluid in the well.

Gaining stream - A stream whose flow is being increased by the inflow of ground water from springs and seeps along its course.

Hydraulic conductivity - The rate at which water is transmitted through a unit cross-sectional area under a unit hydraulic gradient. Hydraulic conductivity describes the ability of the aquifer material to transmit water and may have substantially different values for horizontal and vertical flow through the same material.

Hydraulic head - The height above a standard datum at which the upper surface of a column of water or other fluid can be supported by static pressure at a given point.

Porosity - The ratio of the volume of the voids in a rock to the total volume, expressed as a decimal fraction or as a percentage.

Saturated thickness - That part of an aquifer that is saturated.

Specific conductance - A measure of the ability of a water to conduct an electrical current. It is expressed in microsiemens per centimeter at 25 °Celsius. Specific conductance is related to the type and concentration of ions in solution and can be used for approximating the dissolved-solids concentration in the water.

Specific yield - The volume of water that will drain by gravity from a unit volume of saturated material. Specific yield reflects storage in pores within the aquifer material and approximates the storage coefficient of an unconfined aquifer.

Storage coefficient - The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in hydraulic head. The storage coefficient of a confined aquifer reflects storage due to pressure exerted on the water and rock.

Transmissivity - The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity describes the ability of the entire thickness of an aquifer to transmit water and is the product of hydraulic conductivity and saturated thickness.

Water table - The surface in an unconfined aquifer below which the rocks are saturated with water and at which the water pressure is atmospheric.

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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 Solomon in central Kansas. Chloride concentrations in the Smoky Hill River sometimes exceed 1,000 milligrams per liter during low-flow conditions.

The source of saline water is the underlying Wellington aquifer, a zone of halite and gypsum dissolution, subsidence, and collapse along the eastern margin of the Permian Hutchinson Salt Member of the Wellington Formation. Locally, brine from the Wellington aquifer flows upward through collapse structures in the confining layer into the overlying alluvium. Estimated brine discharge averages about 0.8 cubic foot per second.

Control of the saline ground-water discharge to the Smoky Hill and Solomon Rivers is desirable to improve the quality of water in the rivers. The upward discharge of natural brine into the alluvium could be partly controlled by relief wells installed in the Wellington aquifer. The wells need to be located in the area of greatest saline ground-water discharge to the rivers and near the eastern end of the Wellington aquifer between New Cambria and Solomon. The relief wells could be pumped just enough to reverse the hydraulic gradient between the Wellington and alluvial aquifers, thus decreasing the upward flow of brine into the alluvium and, thence, into the rivers. The brine could be disposed into brine aquifers underlying the area at depth or pumped into surface evaporation-storage reservoirs.

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INTRODUCTION

Deterioration of the chemical quality of water in the Smoky Hill River occurs east of the city of Salina, between the communities of New Cambria and Solomon, in central Kansas. In this area, saline ground water is discharged to the river from the alluvial aquifer in the valleys of the Smoky Hill and the Solomon Rivers. The chloride concentrations in the Smoky Hill River sometimes exceed 1,000 mg/L (milligrams per liter) during low-flow conditions. During low flows, chloride concentrations in downstream reaches may exceed 250 mg/L, the recommended drinking-water-quality standard for chloride established by the U.S. Environmental Protection Agency (1977). The Smoky Hill River is one of the major tributaries of the Kansas River, which supplies water for several of the largest urban and industrial centers in Kansas (Topeka, Lawrence, Kansas City, and Johnson County). Large concentrations of chloride that periodically occur have a significant adverse effect on the usability of the Smoky Hill and Kansas Rivers as a source of water for municipal, industrial, and irrigation supplies.

Several large multipurpose reservoirs have been constructed within the Kansas River basin to decrease the risks of floods and effects of droughts. However, the conservation storage available in the reservoir system is not adequate, nor is it dedicated, to diluting saline ground water discharging into the Smoky Hill River during an extended drought. Although water has been released on a voluntary basis for dilution purposes at no cost to downstream water users, future demands may require that water supplies be purchased through a water-storage contract with the Kansas Water Office. Thus, saline ground-water discharge to the Smoky Hill River may need to be controlled if fresh surface and ground waters are to be available for future public supplies, industrialization, and the general economic development of the eastern Kansas River basin.

From 1975 to 1978, a study (Gillespie and Hargadine, 1981) was conducted by the U.S. Geological Survey, in cooperation with the Kansas Water Office, to determine the source, location, and extent of saline ground-water discharge to the Smoky Hill and Solomon Rivers, and to determine possible measures that could be taken to control or alleviate the deterioration of the water quality of the rivers. The source of the saline ground-water discharge is the underlying Wellington aquifer, along the eastern margin of the Hutchinson Salt Member of the Wellington Formation. Locally, brine from the Wellington aquifer moves upward into the alluvium in the valleys of the Smoky Hill and Solomon Rivers, thence, into the rivers. Starting in July 1980, a follow up to the first study was conducted by the U.S. Geological Survey, also in cooperation with the Kansas Water Office.

The area for this second study included the valleys of the Smoky Hill, Solomon, and Saline 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 junction of the Saline and Smoky Hill Rivers, and Solomon is near the junction of the Solomon and Smoky Hill Rivers.

Purpose and Scope

The overall objective of the second study was to provide more geohydrologic information to water-resources planners and managers in Kansas. This information, which is described in this report, would allow them to more effectively plan for the future water needs of Kansas as related to the deterioration of the water quality in the Smoky Hill and Kansas Rivers.

The specific objectives of the second study were to: (1) Define more accurately the area under which the brine was flowing eastward in the Wellington aquifer; (2) determine the volume of brine moving eastward through the Wellington aquifer; (3) delineate any areas of saline-water contamination in the alluvial aquifer in the Salina area; and (4) evaluate possible locations for installation of relief wells in the Wellington

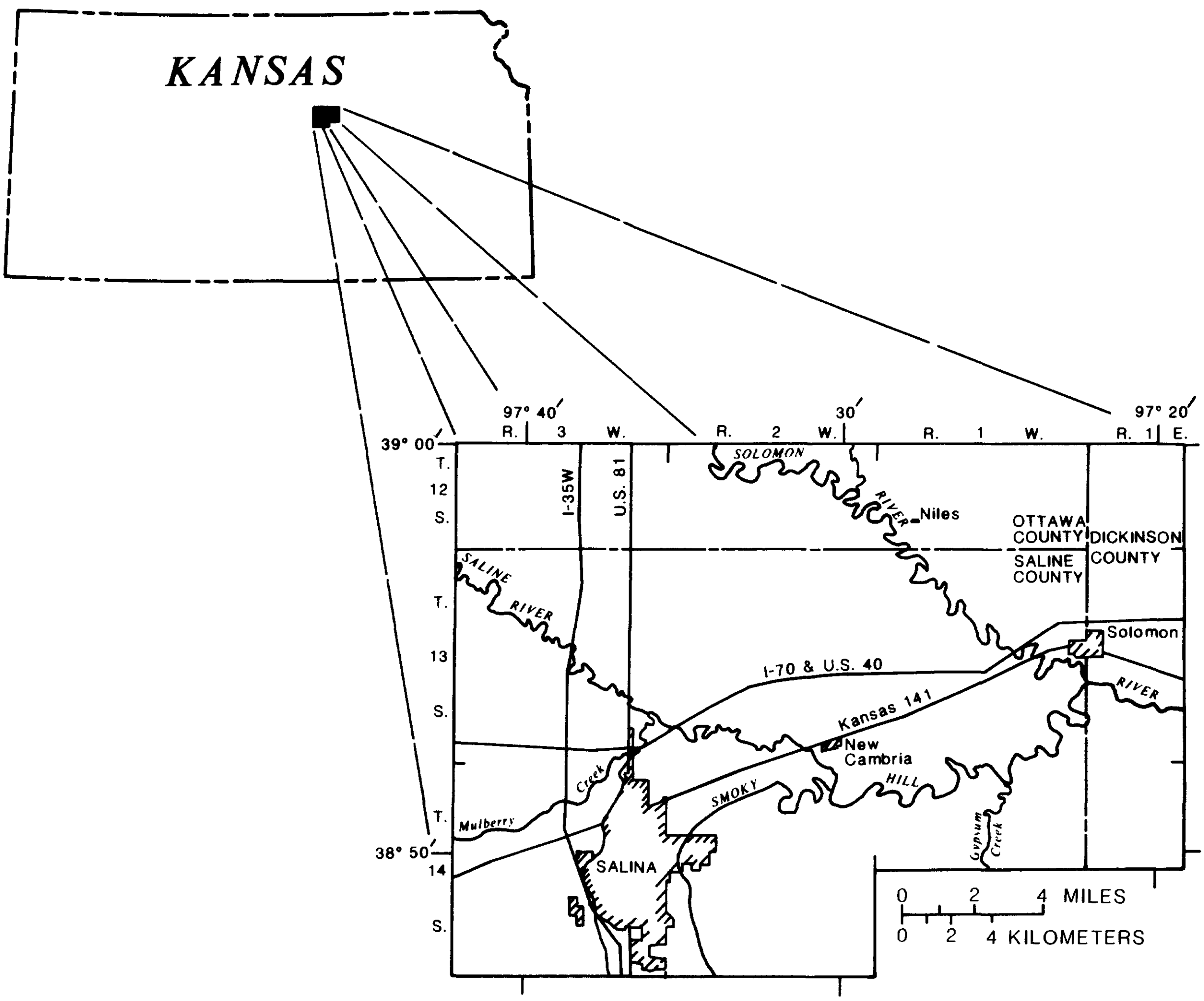


Figure 1.--Location of study area.

aquifer to decrease the quantity of brine that flows upward from the Wellington aquifer into the alluvial aquifer and, thence, into the Smoky Hill and Solomon Rivers. Results of the investigation pertaining to objectives 1, 2, and 4 are included in this report.

The third objective of the study was the responsibility of the Kansas Water Office, which contracted for a surface-resistivity investigation to be conducted in the Salina area by G.H Rothe, University of Kansas, Department of Geology. Results of the surface-resistivity investigation are contained in an unpublished report to the Kansas Water Office (Rothe, 1981).

Because chloride concentration is of particular interest to the study, natural waters are classified in this report as fresh, saline, or brine on the basis of chloride concentration. Freshwater is classified as having less than 250 mg/L chloride; saline water, as having from 250 to 20,000 mg/L chloride; and brine as having more than 20,000 mg/L chloride. Most of the ground- and surface-water samples collected in the area during this study contained chloride in excess of the recommended limit of 250 mg/L for drinking water as established by the U.S. Environmental Protection Agency (1977).

Methods of Investigation

Using the data, information, and interpretations from a previous study of the area (Gillespie and Hargadine, 1981), additional geohydrological data were collected from selected locations in the study area. All data obtained during this investigation are available for examination at the U.S. Geological Survey office in Lawrence, Kansas. Twenty-one test wells were installed in the Wellington aquifer within the Smoky Hill River and Saline River valleys at 11 sites; wells at 5 sites were installed by the U.S. Geological Survey and wells at 6 sites by the U.S. Army Corps of Engineers, Kansas City District. In addition, 15 observation wells were installed in the alluvial aquifer with a hollow-stem auger in and near the city of Salina. Gamma-ray logs were obtained for each test and observation well. Aquifer tests were conducted on the Wellington aquifer. Also, a line of eight continuously screened observation wells were installed by a hollow-stem auger in the alluvium near Solomon, where the Smoky Hill River meanders from a course along the south side of the Smoky Hill valley to the north side and the rate of saline ground-water discharge to the river is the greatest. The line of wells started at the edge of the river and was oriented perpendicular and upgradient from the river to determine the upconing of brine and saline water toward the river.

Water levels in the network of observation wells established during the previous study in the area, plus the additional test and observation wells installed during this study were measured monthly. Samples of ground water collected during 1981 from each of these test and observation wells were analyzed for chloride; specific conductance was measured at the time of sample collection. River stage was measured monthly at bridges over the Smoky Hill, Solomon, and Saline Rivers in the study area. Water samples for determination of chloride concentration were collected on October 26, 1982, from the Saline River about every mile within the reach between the U.S. Highway 81 bridge north of Salina to the junction with the Smoky Hill River.

Previous and Ongoing Studies

Numerous studies have been made in regard to the geology, ground water, and quality of ground and surface waters in the study area. Studies and activities prior to 1980 are reviewed in a report by Gillespie and Hargadine (1981). Their report identified the location, extent, source, and movement of the saline ground-water discharge to the Smoky Hill River between Salina and Abilene to a greater detail than any previous reports of the area. Geologic top-and-thickness maps and geologic sections of the Hutchinson Salt Member of the Wellington Formation were compiled by Watney and Paul (1980). Gogel (1981) described the geology and ground water in the salt and gypsum deposits of the Wellington Formation. McElwee and others (1981) used a digital ground-water-flow model to estimate the effects of hypothetical relief wells near Salina on the saline discharge to the Smoky Hill River and also studied the mechanism by which the saline water enters the river. A detailed examination of the ratios of sodium, bromide, and iodide versus chloride of the ground-water samples collected during the study to help determine the source of the brines in the area was conducted by Whittemore and others (1981).

The U.S. Army Corps of Engineers, Kansas City District, as part of their Kansas and Osage Rivers, Kansas study, conducted a drilling program and surface-resistivity survey in relation to the saline-water discharge to the Smoky Hill River. They coordinated and cooperated very closely with the U.S. Geological Survey, the Kansas Water Office, and the Kansas Geological Survey during the study period and funded several items of work by those agencies. Currently (1985), a more detailed study in the Solomon area on the upconing of brine and saline water into the Smoky Hill River is being conducted by P. Allen MacFarlane and Carl McElwee of the Kansas Geological Survey. Their study will continue and expand on the line of continuously screened wells perpendicular to the Smoky Hill River established during this study.

Well-Numbering System

The system of numbering production, test, and observation wells 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 following the section number 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 1 well in a 10-acre tract, consecutive numbers are added, beginning with 2, in the order in which the wells are inventoried. For example, 13-02W-35DBB indicates the first well inventoried in the northwest quarter of the northwest quarter of the southeast quarter of sec. 35, T. 13 S., R. 2 W. (fig. 2).

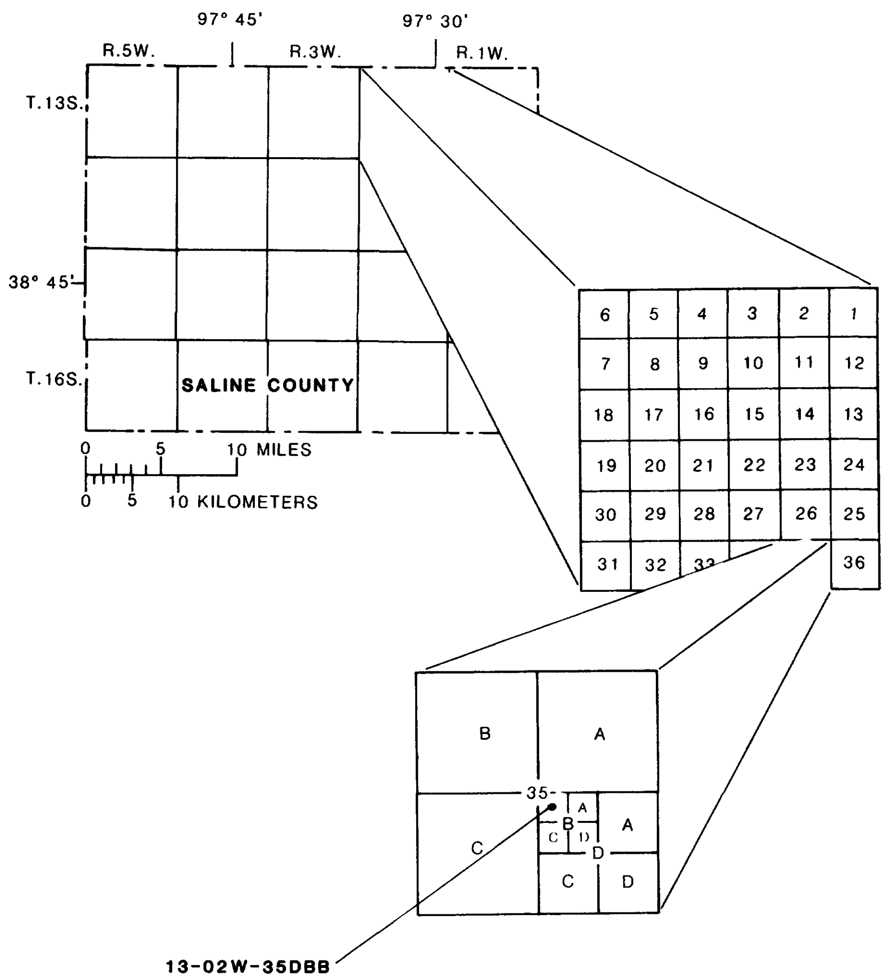


Figure 2.--Well-numbering system.

GEOHYDROLOGIC SETTING

The Smoky Hill River valley in eastern Saline and western Dickinson Counties is underlain by Pleistocene alluvial deposits (fig. 3). The adjacent uplands are underlain by Permian and Cretaceous rocks with some thin Pleistocene terrace deposits (fig. 3). The formations that pertain to this study, in ascending order, are the Odell Shale, Nolans Limestone, and the Wellington Formation (Permian), the Kiowa Shale and Dakota Formation (Cretaceous), and terrace deposits, dune sand, and alluvium (Quaternary). The Odell Shale and Nolans Limestone are only in the subsurface of the study area (fig. 4). The Kiowa and Dakota are referred to in the illustrations as undifferentiated Cretaceous rocks. The general dip and thicknesses

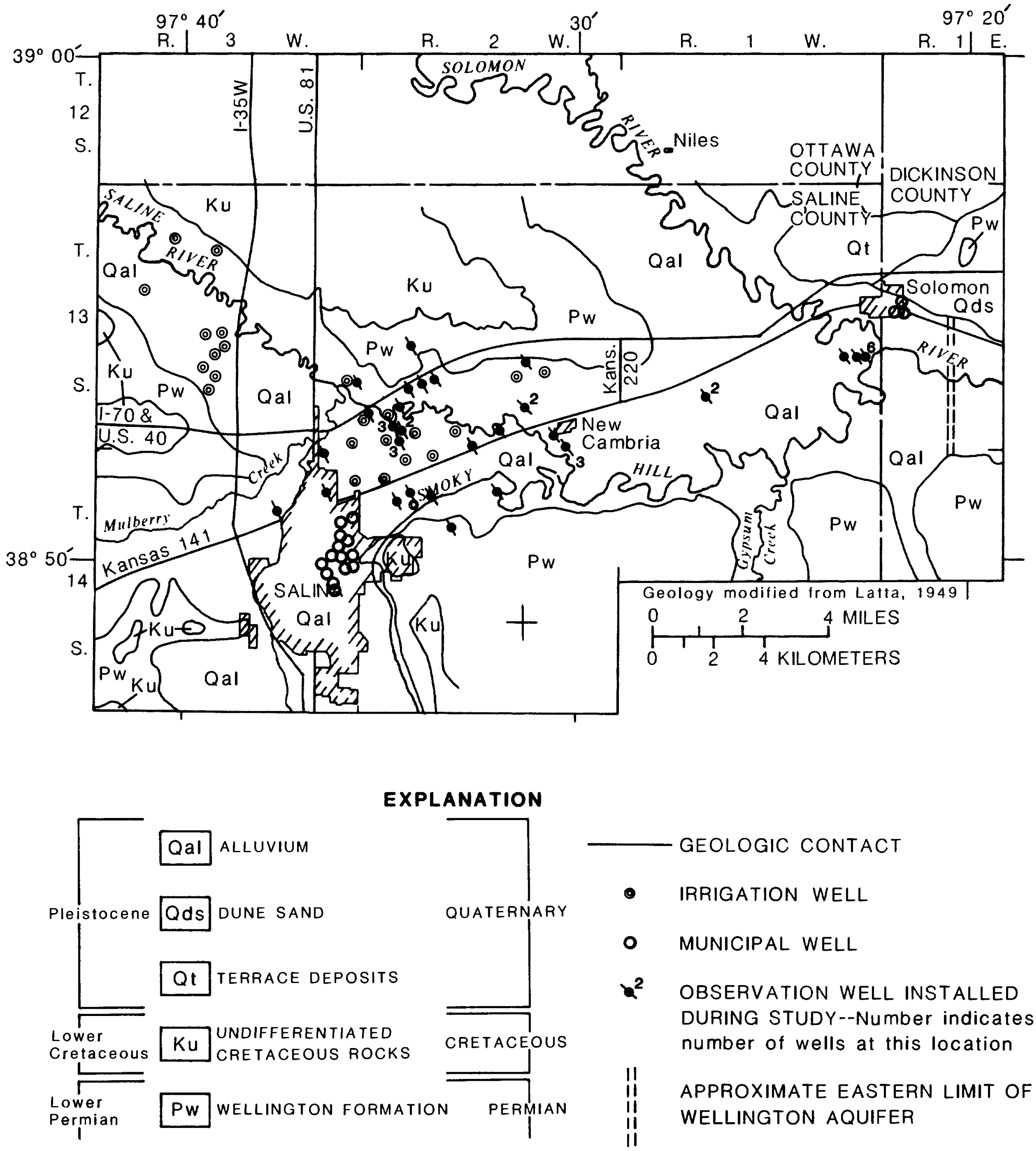


Figure 3.--Surficial geology in study area and location of large-capacity and observation wells installed during study.

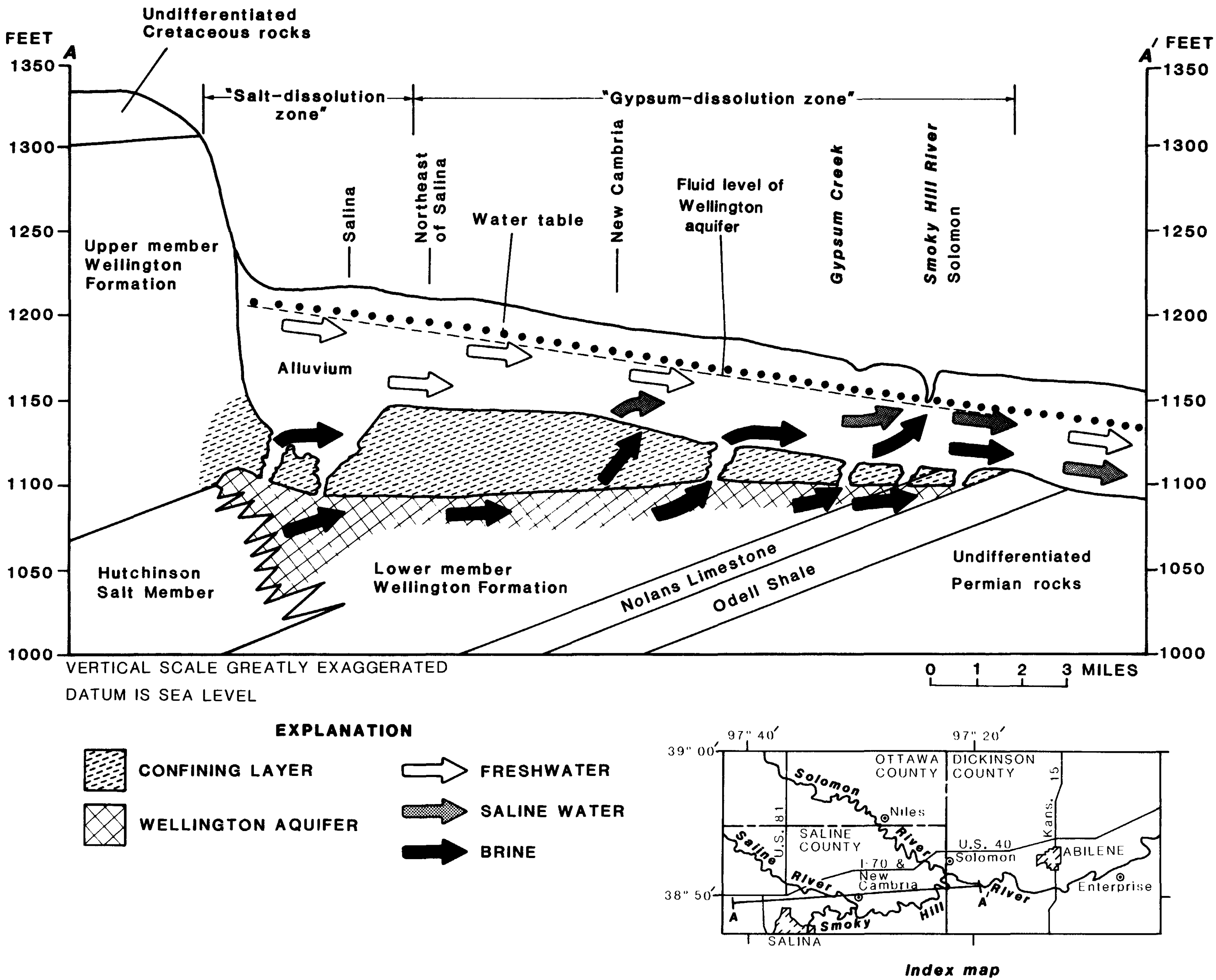


Figure 4.--Geohydrologic section along the Smoky Hill River valley showing geology and ground-water-flow patterns.

of the formations are shown in a geohydrologic section in figure 4. A more detailed description of these formations, including the two formations that contain the major aquifers in the area, the Wellington Formation and the alluvium, is given by Gillespie and Hargadine (1981).

The Wellington Formation crops out on the adjacent uplands and underlies the alluvial deposits in the river valleys, except at the eastern limit 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. 4). The Wellington Formation can be divided conveniently into three members (Lee, 1956). The lower member, which may be as much as 200 ft thick, consists of discontinuous beds of shale, gypsum, and anhydrite with a few thin limestone and dolomite beds. Near the outcrop and subcrop, the anhydrite beds have hydrated to gypsum. The Hutchinson Salt Member of the Wellington Formation, overlying the lower member, predominantly is salt (halite) interbedded with anhydrite and shale. Thicknesses in the study area range from 0 to about 150 ft. The upper member, overlying the Hutchinson Salt Member, consists of about 110 ft of gray shale interbedded with some gypsum and anhydrite overlain by about 120 ft of predominantly gray shale. Thicknesses in the study area range from 0 to about 230 ft.

In the area along the eastern margin of the Hutchinson Salt Member and the lower member of the Wellington Formation, which in Kansas extends to Salina from the northwest and then southward into Oklahoma, circulation of freshwater from the overlying alluvial aquifer 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 associated subsidence, slumping, collapse, and fracturing of overlying shale. Thus, the dissolution process has created a permeable zone along the eastern margin of the Hutchinson Salt Member for the lateral and vertical movement of brine. Gogel (1981) named this permeable unit the Wellington aquifer (fig. 4); that part of the solution zone in the Hutchinson Salt Member was named the "salt-dissolution zone," and the part in the gypsum and anhydrite of the underlying lower member of the Wellington was named the "gypsum-dissolution zone" (fig. 4).

In this report the Wellington aquifer also includes the underlying Nolans Limestone in the Solomon area. The Nolans is about 15 ft thick and is composed of gypsum, anhydrite, dolomite, and shale in the subsurface in this area. Underlying the alluvium in the Smoky Hill River valley near Solomon, the Nolans has a dissolution zone similar to that of the lower member of the Wellington and is actually an extension of the Wellington aquifer. The underlying Odell Shale is the confining layer against which the Wellington aquifer pinches out underneath the Smoky Hill River valley.

Local drillers and geologists use the term "lost-circulation zone" to describe the Wellington aquifer. The terms "lose circulation," "lost-circulation," "circulation loss," or "circulation was lost" refer to the drilling of wells using rotary methods during which circulation of the drilling fluid is lost when solution cavities or very permeable materials are encountered. The "lost-circulation zone" also has been called the "shallow disposal zone" because of the large volumes of oilfield brines that formerly were disposed into it.

In the study area, the Wellington aquifer underlies parts of the valleys of the Smoky Hill, Solomon, and Saline Rivers at a depth of 50 to 150 ft. The "gypsum-dissolution zone" in the Wellington aquifer extends from northeast of Salina to Solomon, and is estimated to be 5 to 15 ft thick. The thickness was determined from lithologic logs, test-hole cores, drilling characteristics, water loss during drilling, drilling time, and gamma-ray logs. The basic determining factors from test-hole information as to the thickness of the Wellington aquifer are water loss between the bottom of the overlying shale, or weathered shale, and the top of the hard-drilling anhydrite beds. The anhydrite is almost impermeable and has few fractures. Geologists from the U.S. Army Corps of Engineers, Kansas City District, also have determined the same approximate thickness of the Wellington aquifer in the "gypsum-dissolution zone" by examination of cores collected in the study area (John Moylan, U.S. Army Corps of Engineers, Kansas City District, oral commun., 1985). The effective porosity of the Wellington aquifer was determined mainly from visual inspection of the cores and was estimated to be 1 to 5 percent.

In the uplands adjacent to the river valleys, data collected during the previous study from a test hole (13-02W-20CAC) cored by the U.S. Army Corps of Engineers, Kansas City District, to a depth of 333 ft and from a test hole (14-02W-9CCB) drilled by the Hydraulic Drilling Co. to a depth of 150 ft indicate that dissolution of evaporite deposits is minimal and that stratigraphically comparable sections in the Wellington Formation to the Wellington aquifer underlying the valley alluvium are relatively impermeable. Thus, the Wellington aquifer probably does not occur under the adjacent uplands areas; however, a few domestic and stock wells completed in the shale and gypsum yield small quanities of calcium sulfate type water.

The alluvium overlies the Wellington Formation in most of the Smoky Hill River valley but directly overlies the Nolans Limestone and Odell Shale in the eastern part. The alluvium consists of clay, silt, sand, and gravel deposits that range in thickness from a few feet to about 120 ft and average about 60 ft. Coarse-grained deposits of sand and gravel generally occur in the lower part of the alluvium, range in thickness from about 30 to 80 ft, and average about 40 ft thick. Fine-grained deposits of silt and clay occur in the upper part and range in thickness from about 10 to 40 ft and average about 20 ft. In general, the alluvium in the Solomon River valley has a greater percentage of fine-grained deposits than the alluvium of the Smoky Hill River valley. Irrigation and municipal wells completed in the alluvial deposits yield 200 to 900 gal/min in areas where the ground water is fresh. The average depth to water is about 20 ft, and the average saturated thickness is about 40 ft.

The bedrock surface under the valley alluvium is more irregular and the alluvium is thicker in the areas overlying the Hutchinson Salt Member or the "salt-dissolution zone." The dissolution of the thick halite beds has caused deeper subsidence and collapse depressions than the dissolution of the thinner layers of interbedded shale and gypsum in the "gypsum-dissolution zone." An example of deep subsidence and subsequent filling with thick alluvium is in the area at the northern edge of Salina, where the alluvium is about 120 ft thick (fig. 4). East of Salina, the bedrock surface is more regular; however, there are numerous smaller depressions and collapse structures, most of which are located between New Cambria and Solomon, that are associated with dissolution and collapse of cavities in the gypsum beds in the lower member of the Wellington Formation or "gypsum-dissolution zone." Landowners in the area reported the location of many sinkholes they have observed over the years. These sinkholes were caused by collapse of the overlying shale of the confining layer into a gypsum cavity, allowing the alluvial sand and gravel to fall into the collapse structure with subsequent collapse of the overlying silt and clay, thereby creating a sinkhole at the surface. Since the previous study of the area, the authors have observed at least four recent sinkholes.

The confining layer between the Wellington and alluvial aquifers from the eastern edge of Salina to the pinching out of the Wellington aquifer near Solomon consists of shale and weathered shale of the Wellington Formation. The confining layer is about 45 to 50 ft thick near Salina and decreases in thickness to 10 ft or less near Solomon at the eastern limit of the Wellington aquifer (fig. 5). From New Cambria to Solomon the confining layer decreases in thickness and also becomes increasingly interbedded with gypsum, therefore, more permeable. Locally, collapse structures penetrate the confining layer, especially in the thinner areas. The sand and gravel mixed with shale fragments in these collapse structures create a more permeable conduit for hydraulic connection between the Wellington and alluvial aquifers.

For the remainder of this report, discussion emphasis will be on the "gypsum-dissolution zone" of the Wellington aquifer and the overlying alluvial aquifer in the area from northeast of Salina to Solomon because this is the major area where brine from the Wellington aquifer moves upward into the alluvium, thence, into the Smoky Hill and Solomon Rivers.

Wellington Aquifer

Fluid-Level Surface and Water Movement

The configuration of the fluid-level surface in the Wellington aquifer in the study area (October 1981), as determined from water-level measurements in observation wells, is shown in figure 6. Because both the Wellington and alluvial aquifers contain ground water of variable density, 1.00 to 1.18 g/cm^3 (grams per cubic centimeter), the hydrostatic method given by Jorgensen and others (1982) was used to determine the direction of ground-water flow between the Wellington and alluvial aquifers in the study area. Data for the fluid level and density of the ground water in

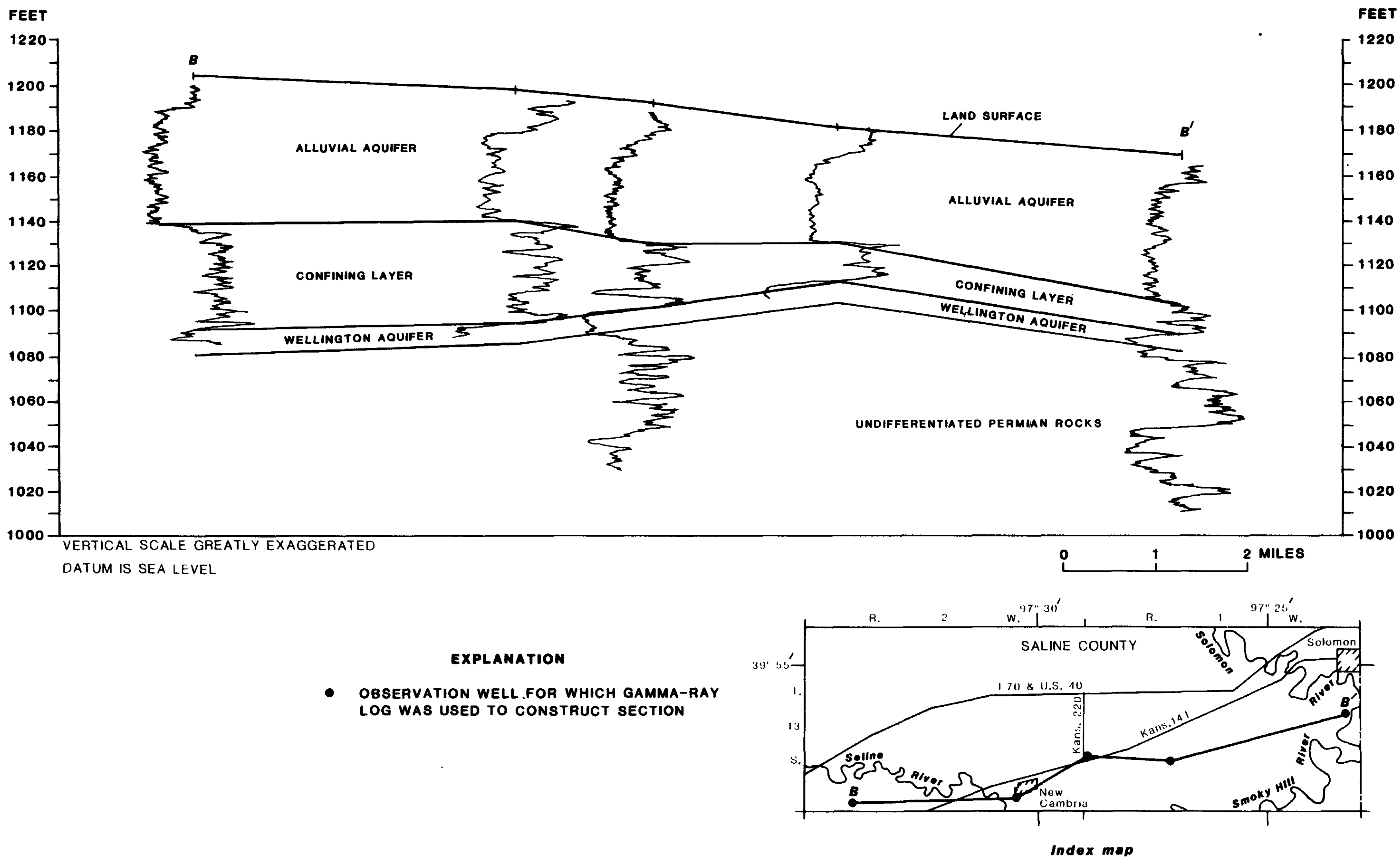
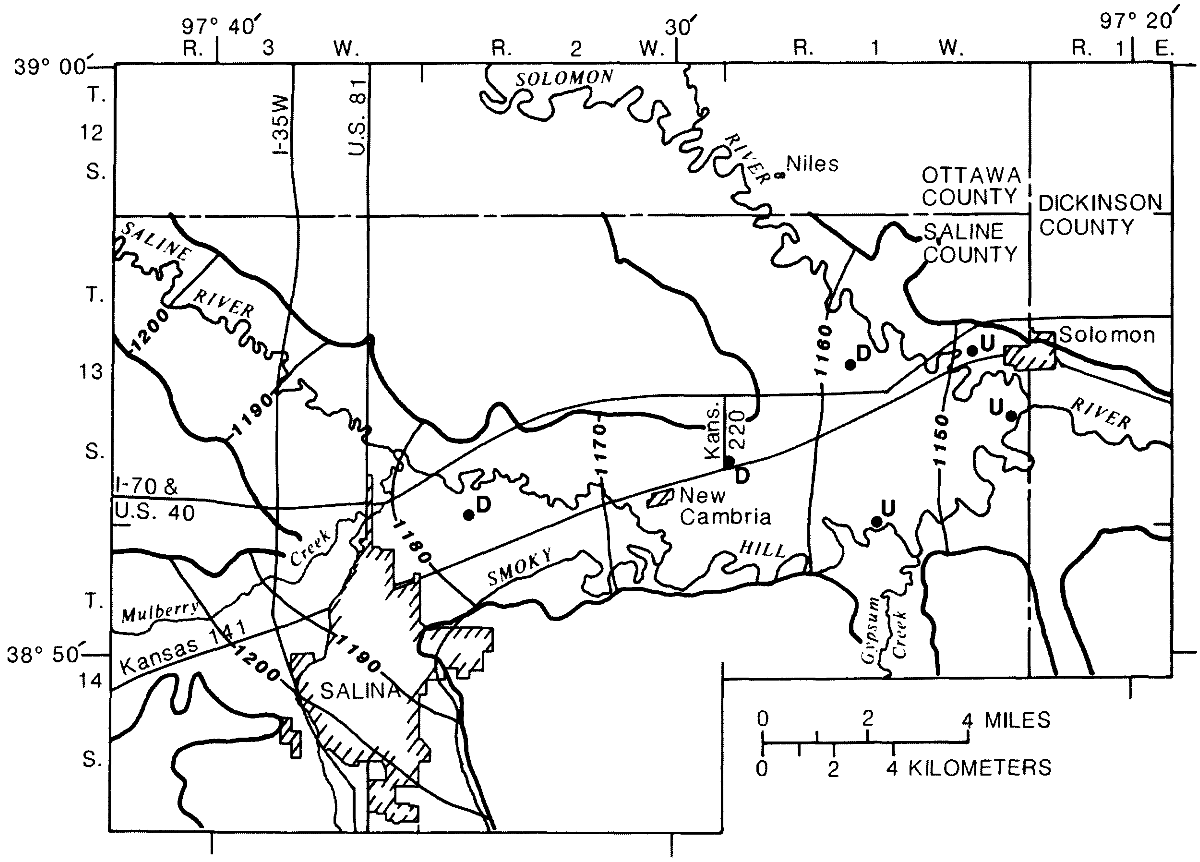


Figure 5.--Geohydrologic section along the Smoky Hill River valley showing thinning of confining layer in eastern Saline County.



EXPLANATION

—*1200*— FLUID-LEVEL CONTOUR OF THE WELLINGTON AQUIFER--Shows altitude of fluid level in the Wellington aquifer, October 1981. Contour interval 10 feet. Datum is sea level

•U OBSERVATION WELL--Letter indicates direction of flow from (U) or to (D) the Wellington aquifer

——— BOUNDARY OF ALLUVIAL DEPOSITS

Figure 6.--Altitude of fluid levels in the Wellington aquifer, October 1981, and direction of flow between the Wellington and alluvial aquifers.

both aquifers at the same location were available only at six locations. The vertical-flow directions of the component of flow from the Wellington aquifer or to the Wellington aquifer were calculated at each location (fig. 6). These flow directions were calculated during relatively hydrologically stable conditions. The flow directions at some of these locations can change temporarily due to recharge from excessive precipitation or inundating floods.

Within the study area, the Wellington aquifer, as shown in figure 4, can be divided into three hydrologic areas: (1) A recharge area, south and northwest of Salina, (2) a transmission area between Salina and New Cambria, and (3) a discharge area between New Cambria and Solomon (Gillespie and Hargadine, 1981).

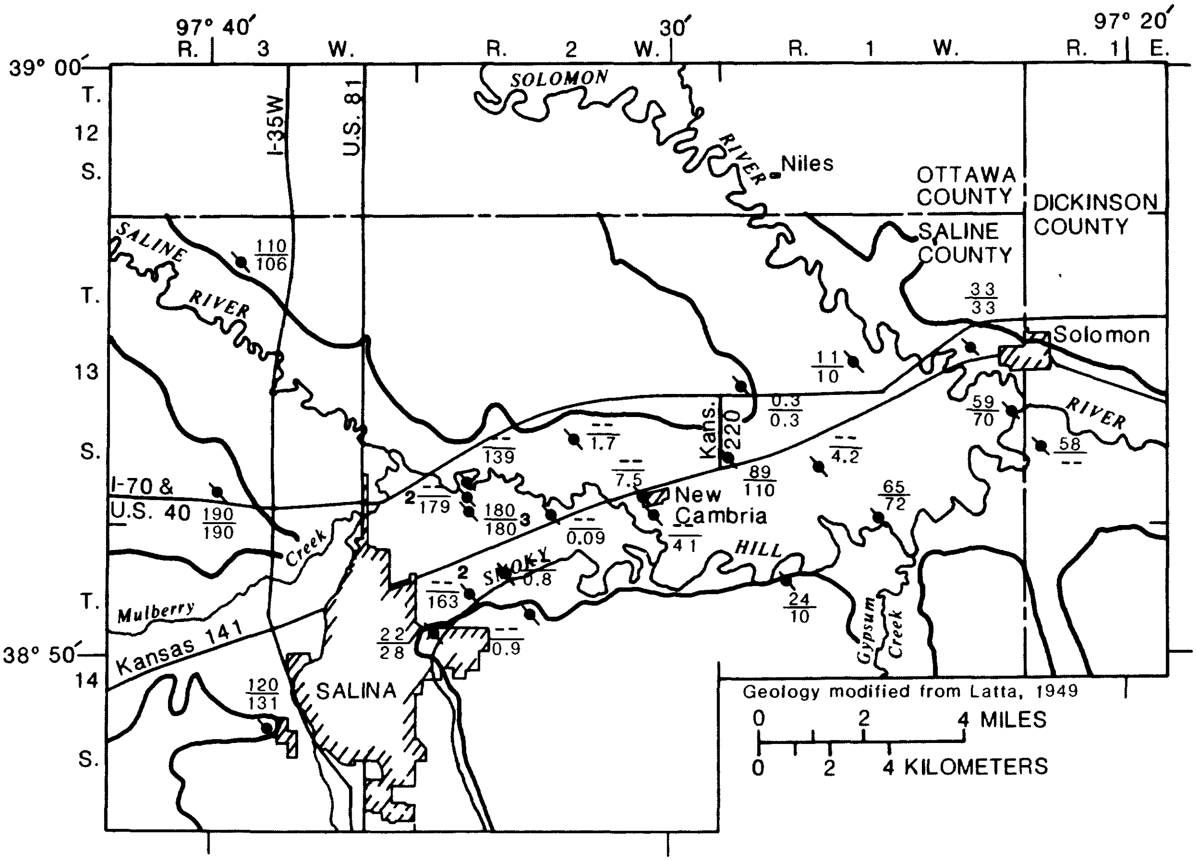
The Wellington aquifer receives recharge from the alluvial aquifer in the area south and northwest of Salina (Gogel, 1981). In that area, freshwater flows downward because the hydraulic head in the alluvial aquifer is higher than the hydraulic head in the Wellington aquifer. This continuous recharge of freshwater results in the dissolution of the halite and gypsum and a continuous formation of brine in the Wellington aquifer.

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

In the area between New Cambria and Solomon, the confining layer is thinner and more permeable, and many localized collapse structures have provided breaches in the confining layer. Also, the Wellington aquifer pinches out near Solomon. Because of the relatively more permeable confining bed and 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 in the alluvium. Thus, the brine discharged from the Wellington aquifer is the source of the saline ground-water discharge from the alluvial aquifer to the Smoky Hill and Solomon Rivers. The brine discharge from the Wellington aquifer to the alluvial aquifer was estimated in the previous study of the area (Gillespie and Hargadine, 1981) to average 0.8 ft^3/s.

Chloride Distribution

Chloride distribution in the Wellington aquifer for 1976 and 1981 is shown in figure 7 (Gillespie and Hargadine, 1981; Whittemore and others, 1981). The brine in the "salt-dissolution zone" of the Wellington aquifer at Salina is saturated (about 190,000 mg/L of chloride at 20 °C) or nearly saturated with respect to chloride. Chloride concentration in the brine in the "gypsum-dissolution zone" varies from 180,000 mg/L, northeast of Salina at the eastern edge of the "salt-dissolution zone," to as much as 58,000 mg/L at the eastern end and major discharge area of the Wellington aquifer. Ground water in the Solomon River valley



EXPLANATION

$3\frac{180}{180}$ OBSERVATION WELL COMPLETED IN WELLINGTON AQUIFER --Upper number indicates 1976 chloride concentration, in grams per liter (milligrams per liter x 1000) (Gillespie and Hargadine, 1981). Lower number indicates 1981 chloride concentration, in grams per liter (Whittemore and others, 1981). Single digit number indicates number of wells at this location

——— BOUNDARY OF ALLUVIAL DEPOSITS

Figure 7.--Chloride concentration in water samples from the Wellington aquifer.

generally has a smaller concentration of chloride when compared to that in the Smoky Hill River valley. Calcium sulfate type water in the Wellington aquifer underlying the Solomon River Valley mixes with and dilutes the sodium chloride type water at the junction of the Smoky Hill River and Solomon River valleys.

The main reason for the dilution of the brine as it flows eastward probably is the periodic freshwater inflow from the overlying alluvial aquifer when it is suddenly recharged by floods that partly or completely inundate the valley between New Cambria and Solomon. During these floods, the hydraulic heads in the Wellington and alluvial aquifers are reversed, and fresher water probably flows downward into the Wellington aquifer through the collapse structures. Inundating floods are less frequent since the construction of the large multipurpose reservoirs upstream on the Smoky Hill, Solomon, and Saline Rivers. More frequent peak flows that stay within the rivers' main channels also may force freshwater into the Wellington aquifer through collapse structures that may be under or near the rivers. A relatively small quantity of calcium sulfate type water probably enters the Wellington aquifer from the adjacent upland all along the edge of the Smoky Hill River valley.

Chloride data from the previous study (Gillespie and Hargadine, 1981) were used to show the progressive decrease in chloride concentration in the "gypsum-dissolution" zone down valley to the major discharge area at the eastern limit of the Wellington aquifer. It was interpreted that the dilution was relatively uniform, and by using the chloride-concentration map (fig. 7), the chloride concentration at any location could be estimated.

As part of this study, 8 test wells were drilled along a north-trending line through well 13-2W-32CCB northeast of Salina, where the chloride concentration was 180,000 mg/L during 1976. Chloride concentrations of samples from these wells ranged from 139,000 to 180,000 mg/L during 1981 (fig. 7). However, chloride concentrations of samples from an additional 6 test wells drilled between the well at 13-2W-32CCB to 3 mi east of New Cambria were not as large as anticipated. The water samples were expected to have chloride concentrations ranging from 89,000 to 180,000 mg/L, but these chloride concentrations ranged from 90 to 41,000 mg/L (fig. 7). The 2 test wells at 13-2W-33DDC and 14-2W-8AAB were drilled to a depth of 125 ft, with circulation being lost in the first test well. The hydraulic head and chloride concentration in the Wellington and alluvial aquifers are approximately the same at these 2 sites (90 and 80 mg/L, respectively); therefore, these 2 wells probably are not hydraulically connected to the Wellington aquifer. Two test wells at 13-1W-29DDD and 13-2W-28DAA, which have a chloride concentration of 4,200 and 1,700 mg/L, respectively, are relatively shallow and, therefore, may not have reached a possibly denser brine deeper in the Wellington aquifer below the bottom of the wells. The two test wells at 13-2W-35DBB and 13-2W-35DCC (chloride concentration of 7,500 and 41,000 mg/L, respectively) were drilled into the Wellington aquifer and were pumped sufficiently to collect a sample of natural formation water. The great variation in chloride concentrations of the water samples from these test wells indicates the heterogeneity of the cavernous and fractured Wellington aquifer.

The 1981 chloride concentrations in three wells between New Cambria and Solomon in the Smoky Hill River valley have increased since 1976 (fig. 7). This probably represents recovery from major dilution effects during the floods of 1973, which inundated the Smoky Hill River valley from New Cambria to Solomon.

The six 5-in. diameter test wells in the Wellington aquifer northeast of Salina (fig. 7) were pumped using the air-injection method. After pumping, the column of brine in each well was of a constant density. The wells were not pumped or disturbed for about 1 year. Ground-water samples were collected from the test wells at various depths in the screened interval of the wells using a grab or thief sampler. The results indicated that the ground water is stratified, with some wells having saline water overlying nearly saturated brine (fig. 8). The conversion of chloride concentration to density of the ground water in the study area is shown in figure 9. The curve shown in figure 9 was developed from densities of the ground-water samples collected from test wells during the study.

Transmissivity and Storage Coefficient

The transmissivity of the Wellington aquifer was estimated from an aquifer test conducted on test well 13-2W-32CCB4 (figs. 3 and 7). The well, located about 1 mile northeast of Salina near the western edge of the "gypsum-dissolution zone," is completed in a gypsum cavity in which circulation was lost. Water samples from the well contained a maximum chloride concentration of 180,000 mg/L (fig. 8). The brine pumped during the aquifer test was disposed into a deep brine-disposal test well (3,300 ft in depth). The problem of brine disposal limited the sites at which Wellington aquifer tests could be conducted. Data from only the first 150 minutes of the aquifer test were used because of suspected variation of the density of the water pumped from the well after that time. Transmissivity ranged from 6,100 to 7,900 ft^2/d, with an average of 7,000 ft^2/d, at the 2 observation wells located 15 and 50 ft from well 12-02W-32CCB4. However, 20 test wells were drilled at 16 sites in the Wellington aquifer in the "gypsum-dissolution zone" from Salina to Solomon, and total circulation was lost in only 8 of these wells, including the pumped well and 1 observation well at the aquifer-test site. The other test wells lost varying quantities of drilling fluid during drilling. In several cases, while drilling test wells 15 to 50 ft apart, 1 well would lose circulation, while the other would lose very little drilling fluid. Therefore, the average transmissivity of the Wellington aquifer in the study area is assumed to be somewhat less than 7,000 ft^2/d. A value of 6,000 ft^2/d will be assumed to represent the average aquifer transmissivity. Storage coefficients from the aquifer tests ranged from 1.0×10^{-3} to 2.0×10^{-3}.

Vertical Hydraulic Conductivity of Confining Layer

A core of the confining layer from a test well (14-2W-8BAC, fig. 3) drilled by the U.S. Army Corps of Engineers, Kansas City District, was analyzed by the U.S. Geological Survey in Reston, Virginia. The vertical hydraulic-conductivity values ranged from 1.2×10^{-3} to 3.4×10^{-4} ft/d

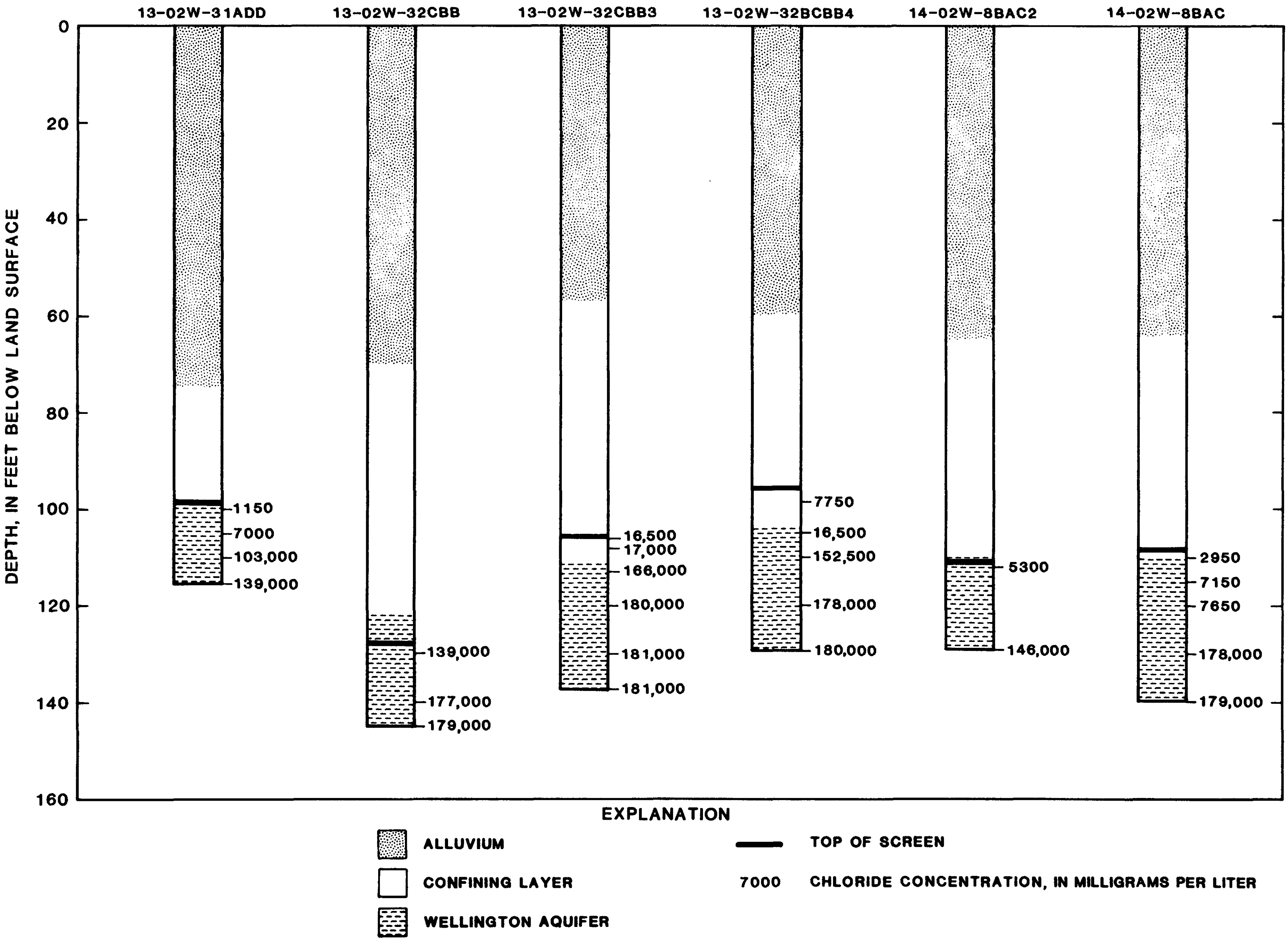


Figure 8.--Stratification of ground water in 5-inch diameter test wells northeast of Salina.

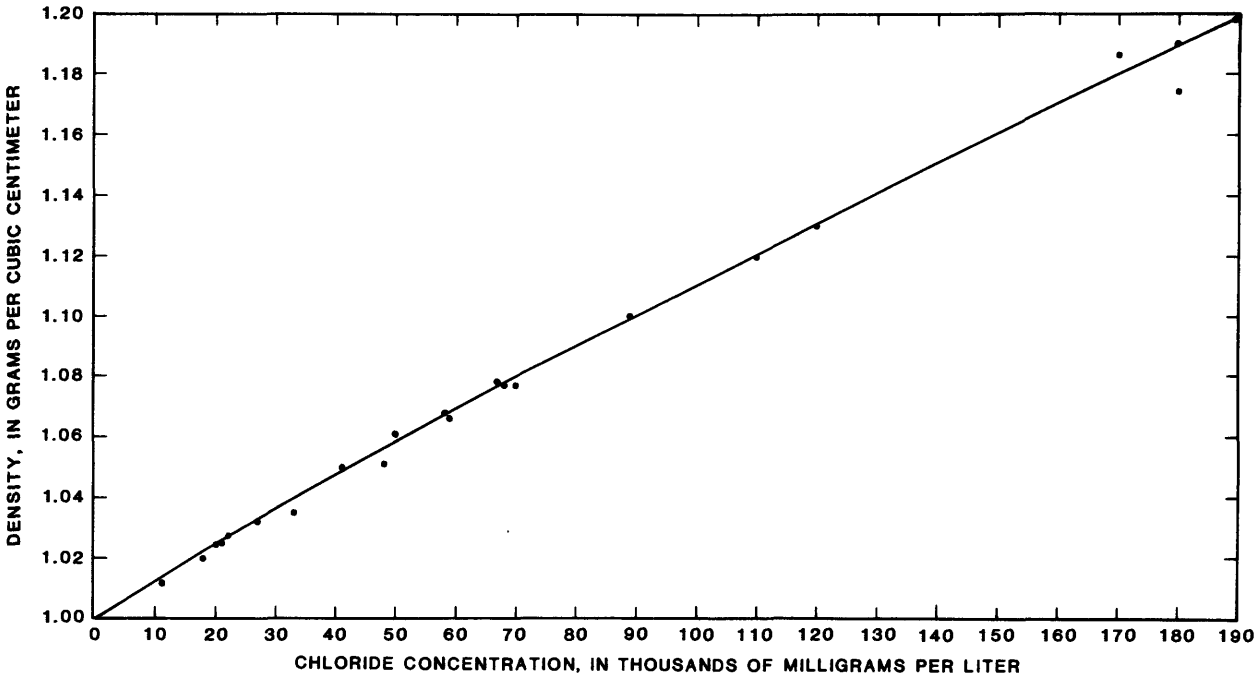


Figure 9.--Relationship of chloride concentration to density of ground water in study area.

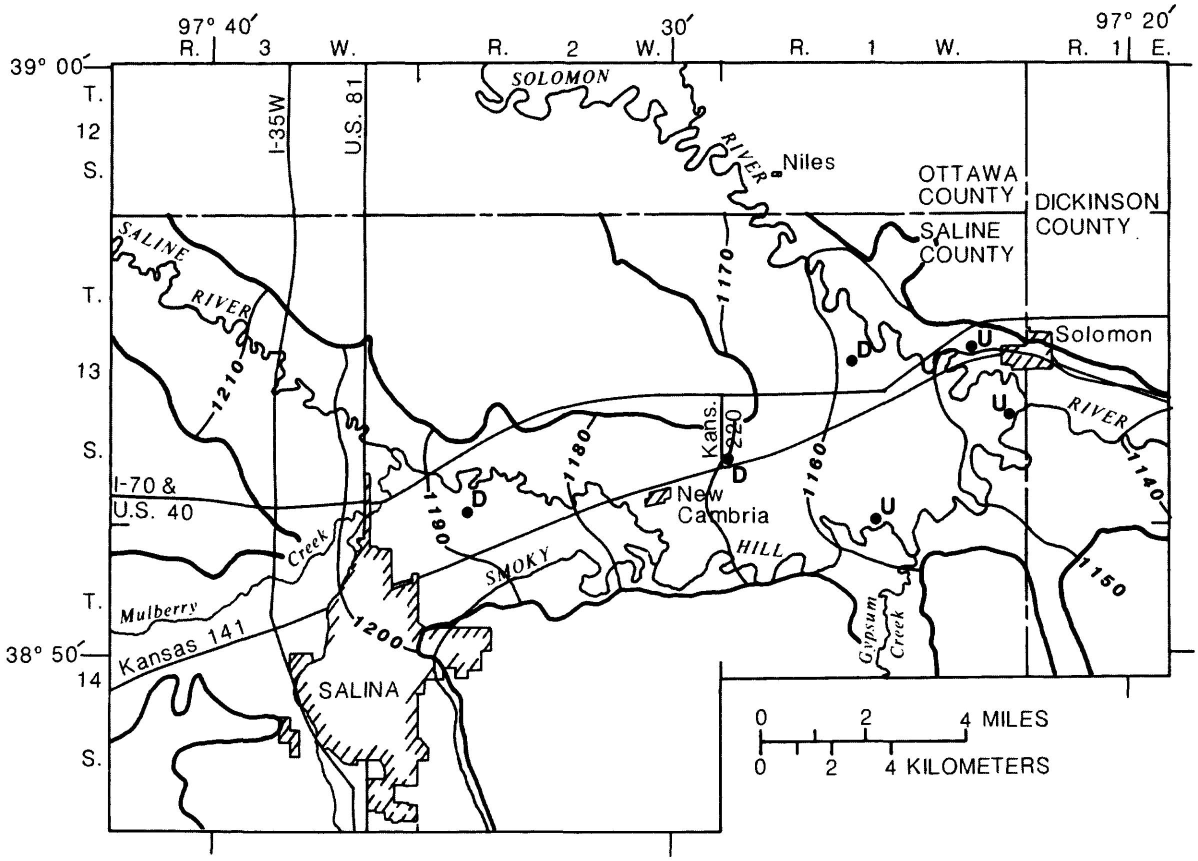
(S.E. Silliman, U.S. Geological Survey, written commun., 1980). However, since these laboratory tests were conducted with no loading added to simulate overburden pressures, these values are considered an upper limit (C.E. Neuzil, U.S. Geological Survey, oral commun., 1985). The porosity of the confining layer is estimated to be about 30 percent (C.E. Neuzil, U.S. Geological Survey, oral commun., 1985).

The confining layer, as previously discussed, varies in thickness from about 50 ft near Salina to 10 ft or less at Solomon (fig. 5). In the area between Salina and New Cambria, the confining layer is mainly shale and weathered shale and relatively impermeable. From New Cambria to Solomon, the shale of the confining layer becomes increasingly interbedded with gypsum and, therefore, is more permeable.

Alluvial Aquifer

Fluid-Level Surface and Water Movement

The configuration of the fluid-level surface (water table) in the alluvial aquifer in the study area is shown in figure 10. The major source of water in the alluvial aquifer is recharge from precipitation and periodic flooding of the Smoky Hill, Solomon, and Saline Rivers. However, a small quantity of brine is contributed from the underlying Wellington aquifer. The vertical component of ground-water flow between the Wellington and alluvial aquifers is upward at the eastern end of the study area. Ground water in the alluvial aquifer flows eastward, and in the Smoky Hill River



EXPLANATION

—*1200*—FLUID-LEVEL CONTOUR OF THE ALLUVIAL AQUIFER--Shows altitude of fluid level in the alluvial aquifer, October 1981. Contour interval 10 feet. Datum is sea level

•U OBSERVATION WELL--Letter indicates direction of flow from (U) or to (D) the Wellington aquifer

——— BOUNDARY OF ALLUVIAL DEPOSITS

Figure 10.--Altitude of fluid levels in the alluvial aquifer, October 1981, and direction of flow between the Wellington and alluvial aquifers.

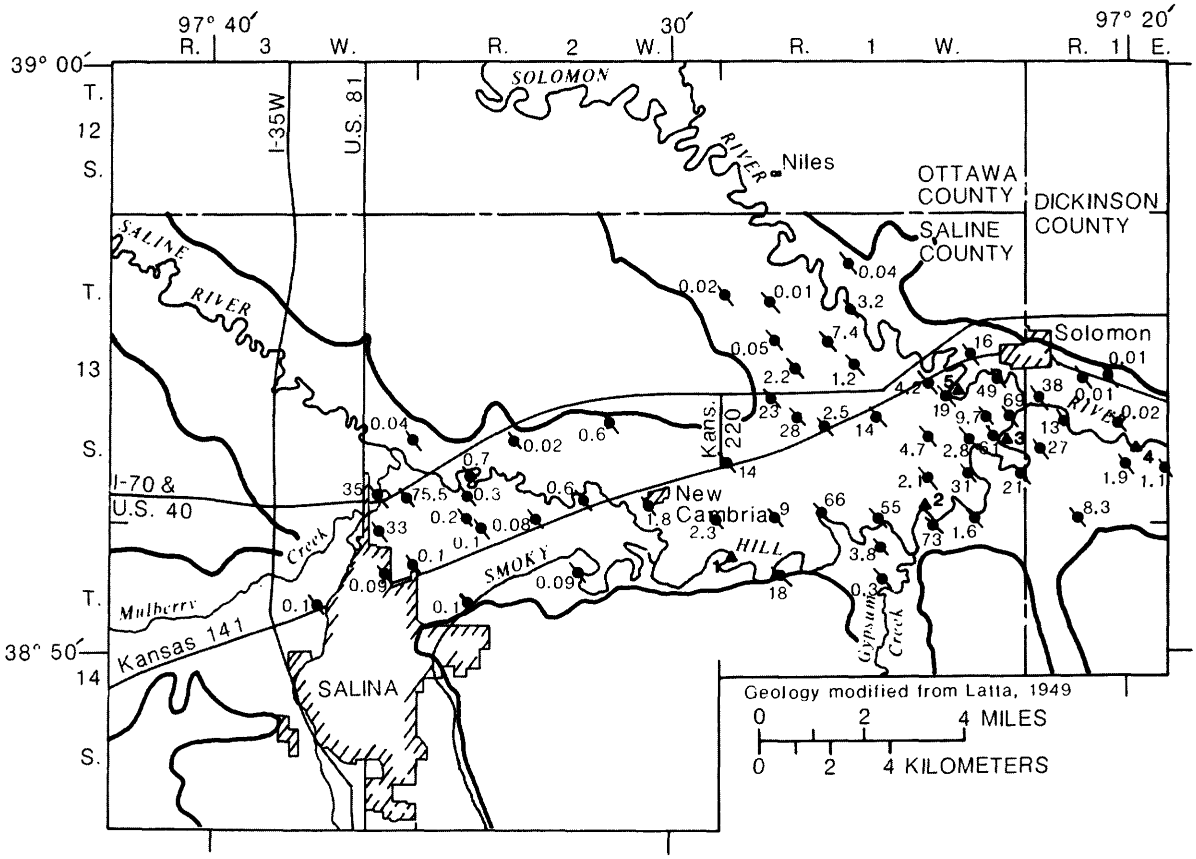
valley, the flow primarily is straight down the valley parallel to the valley sides, except near the river, where there is a flow component toward the river. Along most of the valley, the Smoky Hill River channel is located near the south valley wall; however, near Solomon the river meanders northward across the valley to the junction with the Solomon River and, hence, eastward down the valley.

Chloride Distribution

Water in the alluvial aquifer ranges from fresh to brine in the study area. Chloride concentrations of water samples from observation wells screened at the base of alluvial aquifer are shown in figure 11. The alluvial aquifer in much of the study area is stratified with freshwater overlying saline water or brine. Many shallow domestic and stock wells produce water from the upper freshwater zone. The alluvial-aquifer chloride concentrations in the study area ranged from 10 to 75,500 mg/L in 1981 (Whittemore and others, 1981).

In the Salina area, the water in the alluvial aquifer is fresh except for that found in a deep depression in the bedrock located at the northern edge of Salina, which has brine at the bottom of the thick alluvium (fig. 4). In 3 wells in that area, chloride concentrations ranged from 33,000 to 75,500 mg/L (1981). Other than this local area of large chloride concentrations, the alluvial aquifer in the Smoky Hill River and Saline River valleys from Salina to New Cambria generally contains freshwater or slightly saline water. From New Cambria to Solomon in the Smoky Hill River valley, brine flowing upward from the underlying Wellington aquifer through the thinning confining layer mixes with the freshwater. Chloride concentrations here ranged from 1,600 to 73,000 mg/L (1981). Chloride concentrations vary randomly and greatly in this area of the Smoky Hill River valley. The largest concentrations are associated with nearby collapse structures in the underlying confining layer and in the deeper alluvium.

Near Solomon where the Smoky Hill River meanders from a course along the south side of the Smoky Hill River valley to the north side and the rate of saline ground-water discharge to the river is the greatest, a line of 8 continuously screened wells was installed in the alluvium. The wells were located about 1 mi south of Solomon and upstream from the junction of the Smoky Hill and Solomon Rivers (fig. 3). The line of 8 wells started at the west edge of the river and extended about 0.6 mi to the west perpendicular to the river. Specific-conductance logs were made in the continuously screened wells about 9 months after they were installed and developed. The probe was very insensitive in the range of the specific conductances of the brine encountered in most of the wells; however, the data are sufficient to show the configuration of the unstable upconing of saline water and brine to the Smoky Hill River at this location (fig. 12). Most of the brine upconing to the river appears to be flowing from the Wellington aquifer through the confining layer or a collapse structure. The Kansas Geological Survey currently (1985) is conducting a detailed study at this site. A similar line of continuously screened wells has been installed on the east side of the river. Wells also have been installed in the Wellington aquifer and at different depths



EXPLANATION

OBSERVATION WELL COMPLETED IN ALLUVIAL AQUIFER--Number indicates chloride concentration, in grams per liter (milligrams per liter x 1000)

SALINITY-SURVEY REFERENCE SITE AND NUMBER

BOUNDARY OF ALLUVIAL DEPOSITS

Figure 11.--Chloride concentration in water samples from the alluvial aquifer and location of salinity-survey reference sites in 1981.

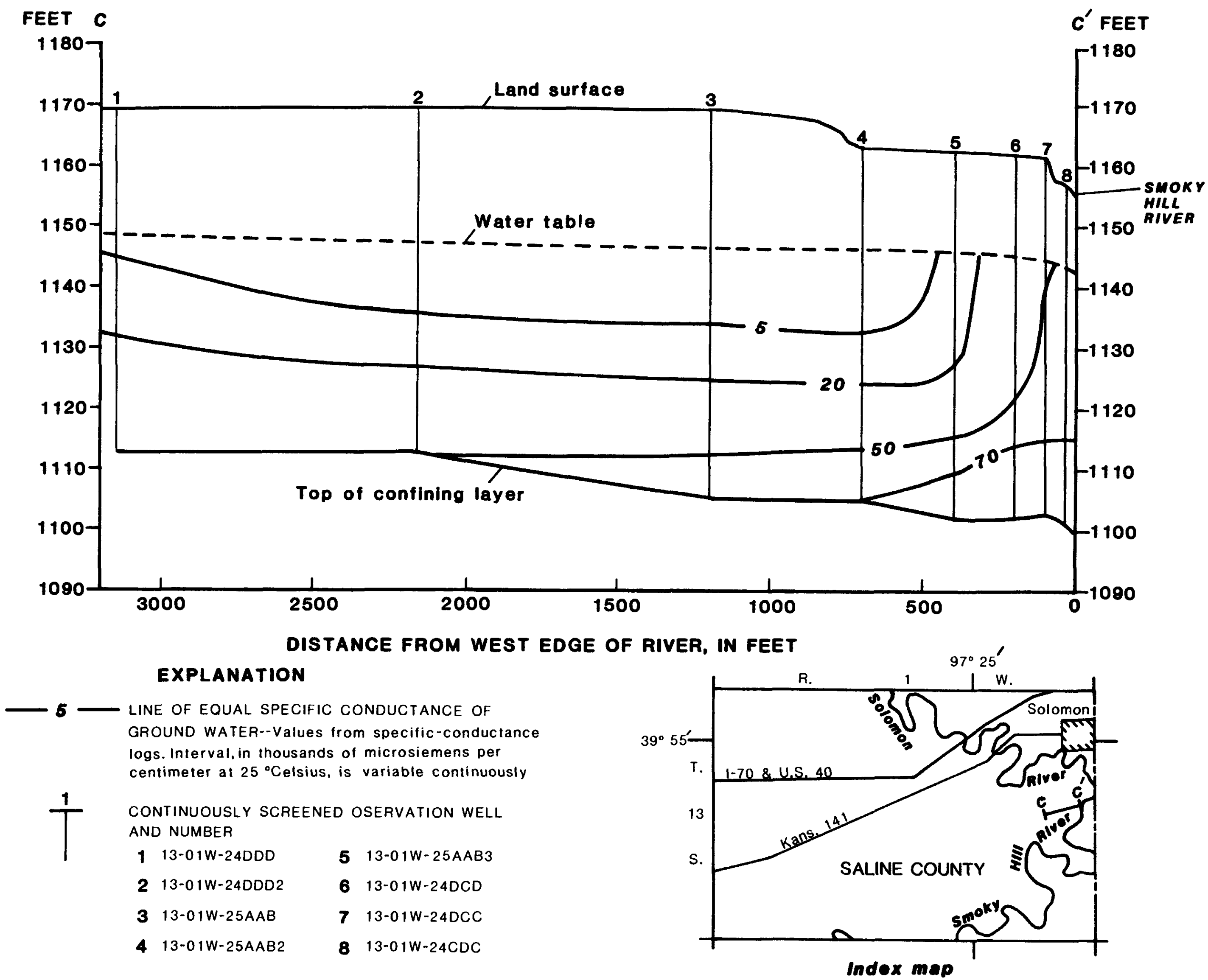


Figure 12.--Geohydrologic section in vicinity of the Smoky Hill River showing specific conductance in observation wells near Solomon demonstrating unstable upconing of saline water and brine to the Smoky Hill River.

in the alluvium. The upconing is being monitored in relation to time and varying river stage.

Transmissivity, Hydraulic Conductivity, and Specific Yield

Only a few large-capacity wells are completed in the alluvium between Salina and Solomon because most of the area contains saline water (fig. 11). In the area northeast of Salina, an aquifer test was conducted on an irrigation well (14-02W-5ABA), which penetrated the full thickness of the alluvium (60 ft). Transmissivities, determined from data from 3 nearby observation wells, were 9,200, 13,800, and 17,200 ft^2/d. The average transmissivity and hydraulic conductivity were 13,400 ft^2/d and 375 ft/d, respectively. The alluvial aquifer is considered to be generally unconfined and similar to aquifers in other river valleys in Kansas for which specific yields of 0.15 and 0.20 have been estimated.

Surface Water

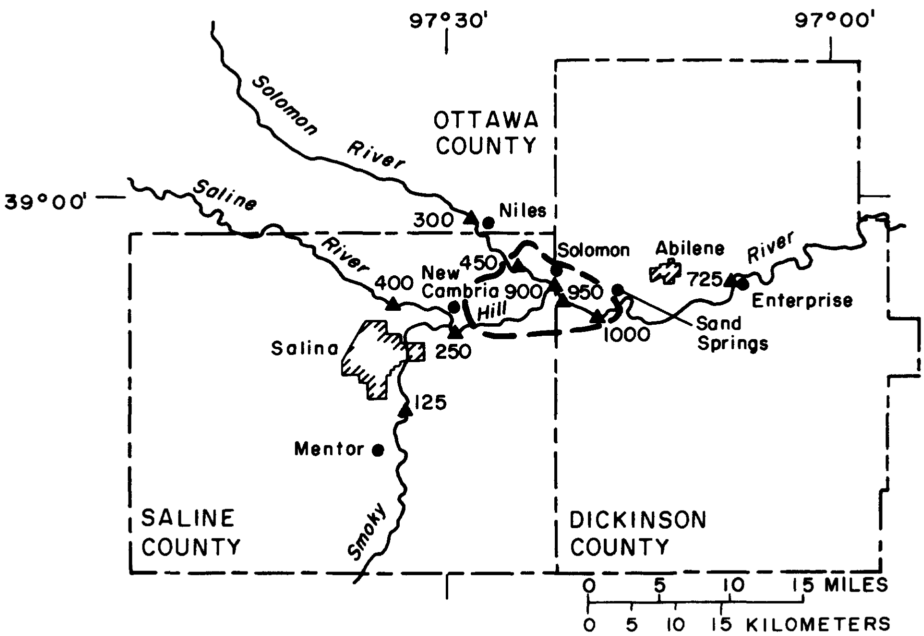
No streamflow or salinity data were collected specifically for this study of the Smoky Hill and Solomon Rivers. However, water samples were collected on March 17, 1982, about every mile along the Saline River from the U.S. Highway 81 bridge north of Salina to the junction with the Smoky Hill River and analyzed for chloride concentration. The chloride concentration at the U.S. Highway 81 bridge was 330 mg/L and decreased uniformly downstream to 250 mg/L at the junction with the Smoky Hill River. This reach of the Saline River is a gaining stream due to ground-water discharge from the alluvial aquifer. Thus, the data indicate that there is little if any saline ground-water discharge in this reach of the Saline River, and little if any brine is flowing up from the Wellington aquifer into the alluvial aquifer under the river in this area.

The following discussion is based on extensive collection and interpretation of data during a previous study (Gillespie and Hargadine, 1981) to emphasize the heterogeneity of the hydrologic system. Salinity-survey reference sites referred to in the discussion are shown in figure 11.

The area of saline ground-water discharge to the Smoky Hill and Solomon Rivers and the median chloride concentrations of base flow in the Smoky Hill, Solomon, and Saline Rivers are shown in figure 13. The average gain from ground-water discharge to the Smoky Hill River between New Cambria (site 1, fig. 11) and Sand Springs, which is about 4 mi east of Solomon, was 25.1 ft^3/s or 1 ft^3/s per river mi. These data were determined from four seepage investigations made during base-flow conditions from 1972-77 (Gillespie and Hargadine, 1981). There also were four salinity surveys made on the Smoky Hill River from 1974-76. The results indicated a definite pattern of chloride-concentration changes in specific reaches of the river.

Along most of the valley, the Smoky Hill River channel is near the south valley wall, and then from the junction of Gypsum Creek (see fig. 11) the river meanders northward across the valley to the junction with the

Solomon River and, hence, eastward down the valley. On August 26, 1976, the chloride concentration of the river water increased from 300 to 675 mg/L from site 1 near New Cambria to site 2, about 1 mi downstream from the junction with Gypsum Creek (fig. 11). About one-third of the increase in the chloride concentration in the Smoky Hill River occurs in this reach. In the reach from site 2 to site 3 about 1 mi upstream from the junction of the Solomon River, there is little change in the chloride concentration of the river. In this reach, the chloride concentration of the ground-water discharge to the river was approximately equal to the chloride concentration of the river because the chloride concentration was stable (675 mg/L). Starting at site 3, there was a marked increase from 675 to 1,100 mg/L in the chloride concentration in the river to site 4, about 1.5 mi east of Solomon. The remaining two-thirds of the increase in the chloride concentration in the Smoky Hill River occurs in this reach. The chloride concentration of the river decreased downstream from site 4 to 1,050 mg/L 6 mi downstream. Site 4 is the approximate location of the end of the Wellington aquifer. A large increase in the chloride concentration from 300 to 600 mg/L in the Solomon River was noted at site 5.



EXPLANATION

MAJOR AREA OF SALINE GROUND-WATER DISCHARGE

▲725 SAMPLING SITE--Number is chloride concentration, in milligrams per liter

Figure 13.--Major area of saline ground-water discharge and median chloride concentrations of base flow in Smoky Hill, Solomon, and Saline Rivers (modified from Hargadine and others, 1979).

The assumption prior to the salinity surveys was that the largest increase in the saline ground-water discharge to the Smoky Hill River would occur along the large meanders between sites 2 and 3. Even though there is brine with a maximum chloride concentration of 73,000 mg/L in the alluvium under the river in this area, there was little change in the chloride concentration of the river (fig. 11). Most of the saline ground-water discharge to the Smoky Hill and Solomon Rivers is believed to be related to collapse structures, under and near the rivers, where brine is flowing upward through openings in the confining layer.

When infrequent floods inundate all or part of the valley, the surface water infiltrates as recharge, thus raising the water levels, increasing storage, and reversing the relatively stable hydraulic-head relationship between the aquifers. As the flooding recedes, the greater differential in the hydraulic heads between the alluvial aquifer and the rivers causes a flushing of brine from the Wellington and alluvial aquifers in which the chloride discharge to the rivers is increased significantly. If there are no succeeding floods, the Wellington-alluvial aquifer system will return to a stable condition in about 1 or 2 years (Gillespie and Hargadine, 1981).

Water Budget for Wellington-Alluvial Aquifer System

The water budget of a hydrologic system accounts for all the inflows, outflows, and changes in storage. The sum of all inflows less the sum of all outflows equals the change in storage. If inflow equals outflow, the change in storage is zero, and the hydrologic system is in equilibrium or steady state. The Wellington-alluvial aquifer system in the Smoky Hill River valley is considered over the long term to be in equilibrium; that is, inflow equals outflow. The Wellington-alluvial aquifer system in the study area is replenished continuously by subsurface underflow, periodically by infiltration from precipitation, and infrequently by water from floods that partly or completely inundate the flood plains of the valleys. Because the water level in the alluvial aquifer is higher most of the time than the water level in the river channel, most of the ground-water discharge from the alluvial aquifer in the area is to the rivers as base flow. Water in the alluvial aquifer also moves downgradient in the valley where part is discharged as subsurface underflow. Discharge from the Wellington aquifer is upward through the confining layer into the alluvial aquifer.

Inflow

Over the long term, recharge from infiltration of periodic precipitation and infrequent inundating floods is assumed to be equal to the ground-water discharge to the rivers. From the four seepage investigations made on the Smoky Hill and Solomon Rivers from 1972-77, the average ground-water discharge to the rivers was calculated to be 32.3 ft^3/s for 46 river mi or 0.7 ft^3/s per river mi (Gillespie and Hargadine, 1981). The average recharge was estimated to be about 5 in. per year.

Underflow to the alluvial aquifer northeast of Salina in the Smoky Hill River valley was calculated to be about 1.1 ft^3/s. About 1.0 ft^3/s of underflow from the Solomon River valley was calculated on the north side of the area. As determined from the previous study (Gillespie and Hargadine, 1981), the average brine underflow to the Wellington aquifer northeast of Salina is about 0.8 ft^3/s.

Outflow

The ground-water discharge from the Wellington aquifer in the study area is the equivalent 0.8 ft^3/s of saturated brine that leaks upward through the confining layer to the alluvial aquifer. Most of the leakage is through collapse structures in the confining layer. No water is pumped from the Wellington aquifer in the study area.

As previously mentioned, most of the ground-water discharge from the alluvial aquifer is to the rivers. The average discharge to the rivers is 32.3 ft^3/s for 46 river mi or 0.7 ft^3/s per river mi. Because of saline water, withdrawals from the alluvial aquifer for municipal, industrial, and irrigation are limited to the Salina area. A few irrigation wells are found northeast of Salina and have an estimated annual pumpage of less than 1.4 ft^3/s. Many stock and domestic wells obtain small quantities from the freshwater layer in the upper part of the alluvial aquifer. The city of Solomon pumps an average of 0.2 ft^3/s from 3 municipal wells. The total pumpage from all wells is estimated to be less than 5 percent of the total ground-water discharge from the alluvial aquifer in the study area. Subsurface outflow to the east as underflow in the alluvium was about 1.3 ft^3/s. Discharge by evapotranspiration from the alluvial aquifer probably is small because vegetation along the rivers and on the valley floors is relatively sparse, and the water table generally is about 20 ft below the land surface.

EVALUATION OF POSSIBLE LOCATIONS OF RELIEF WELLS

Because of additional future demands for water from the Kansas River system, it may become necessary to control saline ground-water discharge to the Smoky Hill and Solomon Rivers. The natural-brine discharge to the alluvial aquifer could be partly alleviated or controlled by installing interceptor or relief wells in the Wellington aquifer in the "gypsum-dissolution zone" in the area between Salina and Solomon. The brine intercepted by the relief wells 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 rivers during high flows at a rate that would have little effect on the chemical quality of the streamflow.

In the previous study (Gillespie and Hargardine, 1981), it was postulated that the most efficient location of a line of relief wells to intercept the brine in the Wellington aquifer would be northeast of Salina at the western edge of the "gypsum-dissolution zone." The brine pumped from this area would be nearly saturated with respect to chloride; therefore, it was assumed there would be a minimum quantity of brine to be disposed because of its large concentration of chloride.

During the first year of this study, Carl McElwee, Kansas Geological Survey, conducted a preliminary ground-water model study in the area (McElwee and Butt, 1981; McElwee and others, 1981) in cooperation with the U.S. Army Corps of Engineers, Kansas City District. As part of the preliminary study, McElwee simulated the effects of relief wells completed in the Wellington aquifer using the U.S. Geological Survey's two-dimensional digital ground-water-flow model (Trescott and others, 1976), and data collected by the authors during this and the previous study (Gillespie and Hargadine, 1981). The major conclusions of McElwee's study as related to the relief wells in the Wellington aquifer were:

1. In the area northeast of Salina, the optimum well-field configuration would be a north-trending line of 6 relief wells spaced 2,000 ft apart, with an individual well discharge of 100 gal/min of brine.

2. This well configuration would produce a 12- to 20-percent decrease of saltwater leakage from the Wellington aquifer, with about a 245- to 382-percent increase in freshwater leakage from the alluvial aquifer into the Wellington aquifer.

3. The estimated time for the full effect of the dilution due to freshwater leakage to reach the brine-discharge area would be from 16 to 160 years, depending on the transmissivity, thickness, and porosity of the Wellington aquifer and the vertical hydraulic conductivity of the confining layer and the overall effect of the collapse structures.

McElwee (McElwee and others, 1981) stated that more accurate data are needed to conduct a qualitative modeling study and that the results of the study should not be regarded as exact but sufficient to indicate general trends.

In consideration of McElwee's results (McElwee and others, 1981) and based on data collected during this study, the authors agree that relief wells near Salina, which is far from the major brine-discharge area, is not the proper location for several reasons:

1. The estimated time interval before the pumpage and dilution would affect the saline ground-water discharge to the rivers is too long.

2. The heterogeneity of the Wellington aquifer and the confining layer greatly increases the uncertainty of any predictions of the effects of relief wells on the saline ground-water discharge to the Smoky Hill and and Solomon Rivers, and this uncertainty increases with distance from the brine-discharge area.

3. The potentially large volume of freshwater leakage from the alluvial aquifer to the Wellington aquifer may dilute the brine, but also may increase natural dissolution and subsidence. This would be especially critical if pumping would increase freshwater leakage into the "salt-dissolution zone" under the urban area in and around Salina. The location of the deep depression in the bedrock at the northern edge of Salina makes this a possibility.

Also, it is concluded by the authors that the optimum geohydrological location of relief wells probably would be in the area of the greatest saline ground-water discharge to the rivers and the pinching out of the Wellington aquifer. If the wells were located in this area, the effects would be evident in the rivers in a much shorter time after pumping started.

SUMMARY

Saline ground water is discharged to the Smoky Hill and Solomon Rivers east of Salina between New Cambria and Solomon in central Kansas. Chloride concentrations in the Smoky Hill River sometimes exceed 1,000 mg/L during low-flow conditions. The chloride concentration in the rivers downstream during low flows may exceed the recommended drinking-water-quality standard of 250 mg/L for chloride established by the U.S. Environmental Protection Agency (1977). Large concentrations of chloride may have a significant adverse effect on the use of the Smoky Hill and Kansas Rivers as a source of water for municipal, industrial, and irrigations supplies, and this effect could increase as more demands are placed in the future on these rivers for water supplies.

The source of the saline water entering the Smoky Hill River is the Wellington aquifer. The Wellington aquifer is a zone of dissolution, subsidence, and collapse along the eastern margin of the Permian Hutchinson Salt Member and the lower member of the Wellington Formation. In the "salt-dissolution zone," the water in the Wellington aquifer is saturated or nearly saturated with respect to chloride. The "gypsum-dissolution zone" of the Wellington aquifer extends eastward from Salina to Solomon where the aquifer pinches out. Brine flows eastward in the Wellington aquifer under the Smoky Hill River valley. In the area from New Cambria to Solomon, the hydraulic head in the Wellington aquifer is higher than the hydraulic head in the alluvial aquifer. Thus, brine moves upward through the confining layer and collapse structures into the alluvium and, thence, into the Smoky Hill and Solomon Rivers. The estimated long-term brine outflow from the Wellington aquifer to the alluvium in the area averages about 0.8 ft^3/s.

When infrequent floods inundate the valley, recharge to the alluvium reverses the long-term relatively stable hydraulic-head relationship between the two aquifers. As the flooding recedes, the greater differential in the hydraulic heads between the alluvial aquifer and the rivers causes a temporary flushing of brine from the Wellington and alluvial aquifers and a significant increase in the quantity and chloride concentration of the ground-water discharge (Gillespie and Hargadine, 1981). This reversal in the hydraulic gradient between these aquifers probably is the main cause of the dilution of the brine in the Wellington aquifer between New Cambria and Solomon.

In the future, it may become necessary to control the saline ground-water discharge to the Smoky Hill and Solomon Rivers. The natural-brine discharge to the alluvium from the Wellington aquifer could be partly alleviated or controlled by installing relief wells in the Wellington aquifer between Salina and Solomon. On the basis of previous studies and

data collected during this study, the optimum geohydrological location of relief wells probably would be in the area of the greatest saline ground-water discharge to the rivers and the pinching out of the Wellington aquifer. Here, the effects on water quality would be evident in the rivers in the shortest time after pumping started. Relief wells installed in the area between New Cambria and Solomon could be pumped just enough to reverse the hydraulic gradient between the Wellington and alluvial aquifers, thus decreasing or stopping the upward flow of brine into the alluvium, and then into the Smoky Hill and Solomon Rivers.

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