GEOHYDROLOGY AND SALINE GROUND-WATER DISCHARGE TO THE SOUTH FORK NINNESCAH RIVER IN PRATT AND KINGMAN COUNTIES, SOUTH-CENTRAL KANSAS

By J.B. Gillespie and G.D. Hargadine

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	*By*	*To obtain*
inch (in.)	2.54	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre	4,047	square meter
inch per year (in/yr)	2.54	millimeter per year
foot per day (ft/d)	0.3048	meter per day
foot per mile (ft/mi)	0.1894	meter per kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
ton per day (ton/d)	0.0105	kilogram per second
foot squared per day[1] (ft^2/d)	0.09290	meter squared per day
degree Fahrenheit (°F)	([2])	degree Celsius(°C)

[1]The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness. This expression reduces to foot squared per day, and is the unit of measurement used in this report.

[2]Temperature can be converted to degrees Celcius (°C) or degrees Fahrenheit (°F) by the equations:

$$°C=5/9\ (°F-32)$$
$$°F=9/5\ (°C) + 32.$$

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

DEFINITION OF TERMS

Discharge — The quantity of any individual constituent, as measured by dry mass or volume, that passes through a stream cross section per unit time. The term needs to be qualified, such as "chloride discharge," "sediment discharge," and so on.

Equipotential line — A line in a two-dimensional, ground-water flow field such that the total hydraulic head is the same for all points along the line.

Fluid density — The mass of water per unit volume, stated in grams per cubic centimeter. The density for freshwater is 1.0 gram per cubic centimeter.

Hydraulic conductivity — The volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Hydraulic gradient — Rate of change in total hydraulic head per unit of distance of flow in a given direction.

Hydraulic head — Height above a standard datum of a column of water that can be supported by the static pressure at a given point.

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.

Tons per day — The quantity of a substance in solution or suspension that passes a stream section during a 24-hour period.

Transmissivity — The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient measured at right angles to the direction of flow.

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by

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

ABSTRACT

Saline ground water discharges to the South Fork Ninnescah River in Pratt and Kingman Counties, Kansas, from the adjacent alluvial aquifer. Electromagnetic terrain surveys in this area indicate that the saline ground water is entering the river in intermittent reaches along the channel rather than along the entire reach. The chloride concentration in the South Fork Ninnescah River near Murdock exceeds 250 milligrams per liter 75 percent of the time. During stable base flow in November 1988, the stream discharge increased 67 cubic feet per second, and the chloride concentration increased 360 milligrams per liter from Pratt to the Pratt-Kingman County line. The chloride load to the river along this reach was 82 tons per day.

The source of the saline water probably is dissolution of salt in the Permian Ninnescah Shale, about 600 feet below land surface. Subsidence and collapse into salt-dissolution cavities probably has caused fracturing in overlying siltstone, fine sandstone, and shale. Brine moves upward through the Permian rocks and discharges into the alluvial aquifer. The brine discharge to the alluvium is about 0.7 cubic foot per second. In the area of major saline-water discharge to the river, the fluid-potential levels in the Permian rocks are higher than the fluid-potential levels in the alluvial aquifer.

Several methods for reducing the saline ground-water discharge to the South Fork Ninnescah River have been suggested. The most effective of these methods appears to be interception of brine flow in the Permian rocks by pumping of relief wells. Brine could be disposed by injection into deeper formations, by storage in evaporation reservoirs, or by desalinization.

INTRODUCTION

Water quality in the South Fork Ninnescah River in eastern Pratt and western Kingman Counties in south-central Kansas is affected by the discharge of saline ground water from the adjacent alluvial aquifer. During low flows, chloride concentrations in downstream reaches in eastern Kingman County exceed 250 mg/L (milligrams per liter)--the Secondary Maximum Contaminant Level established for chloride in drinking-water supplies by the U.S. Environmental Protection Agency (1986). The large saline concentrations in the ground water have made the river unsuitable as a source of municipal, industrial, and irrigation water supplies.

Sedgwick County and Wichita officials are concerned about future water supplies. The South Fork Ninnescah River remains a potential source of water if chloride concentrations in the river could be reduced. The U.S. Bureau of Reclamation has completed a preliminary geologic study of a potential dam site (Norwich dam site) on the river in southeastern Kingman County (Shirley Shadix, U.S. Bureau of Reclamation, oral commun., 1991). The U.S. Army Corps of Engineers also has considered several potential dam sites on the river. A reservoir at one of these locations could supplement the Wichita water supply currently furnished by Cheney Reservoir on the North Fork Ninnescah River and the Wichita well field in the *Equus* beds aquifer.

In July 1988, the U.S. Geological Survey, in cooperation with the City of Wichita and Sedgwick County, began a 3-year investigation of saline ground-water discharge to the South Fork Ninnescah River in Pratt and Kingman Counties. In July 1989, the Kansas Water Office succeeded Wichita and Sedgwick County as the cooperator in this investigation.

Because sodium chloride is of particular interest to this study, natural water was classified as fresh, saline, or brine on the basis

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[2]Kansas Water Office, Topeka, Kansas.

of its chloride concentration in milligrams per liter (mg/L). Freshwater was 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 (Gillespie and Hargadine, 1981).

The study area was divided into two parts (fig. 1). The western part of the study area includes the valley of the South Fork Ninnescah River and the adjacent plains in eastern Pratt and westernmost Kingman County. In this area, where it was known that most of the saline ground-water discharge occurs, a detailed study of the geology, surface- and ground-water relationships, and water quality was conducted.

Previous studies have determined that brine upwelling from the underlying Permian formations enters the alluvium and mixes with freshwater, and then discharges to the river (Layton and Berry, 1973). The study was conducted to determine if brine moves upward into alluvium in localized or over large areas.

The eastern part of the study area focuses only on the South Fork Ninnescah River and extends from westernmost Kingman County, to just beyond the U.S. Geological Survey streamflow-gaging station on the South Fork Ninnescah River near Murdock in eastern Kingman County. In the eastern part of the study area, only streamflow and surface-water quality were studied.

Purpose and Scope

This report (1) describes the location and extent of saline ground-water discharge to the South Fork Ninnescah River; (2) identifies the source(s) of the saline water and brine; (3) defines the movement and mixing of fresh and saline waters, and brine; and (4) considers the potential of selected measures that might be taken to alleviate or reduce the salinity problem.

A network of 160 observation and monitoring wells was established for this study (fig. 2). Observation wells (82) were used to measure ground-water levels only and included wells specifically installed for observation, abandoned or active irrigation wells, stock-watering, and oil-field water-supply wells. Monitoring wells (78) were used to obtain measurements of water levels and to collect

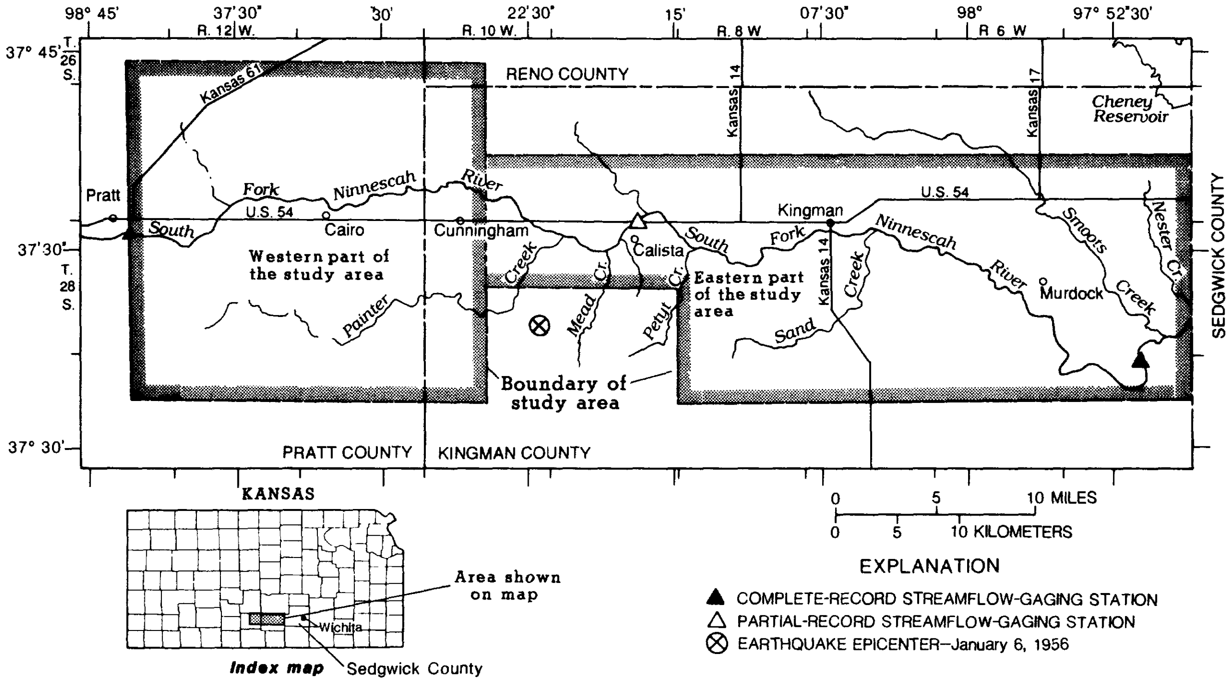
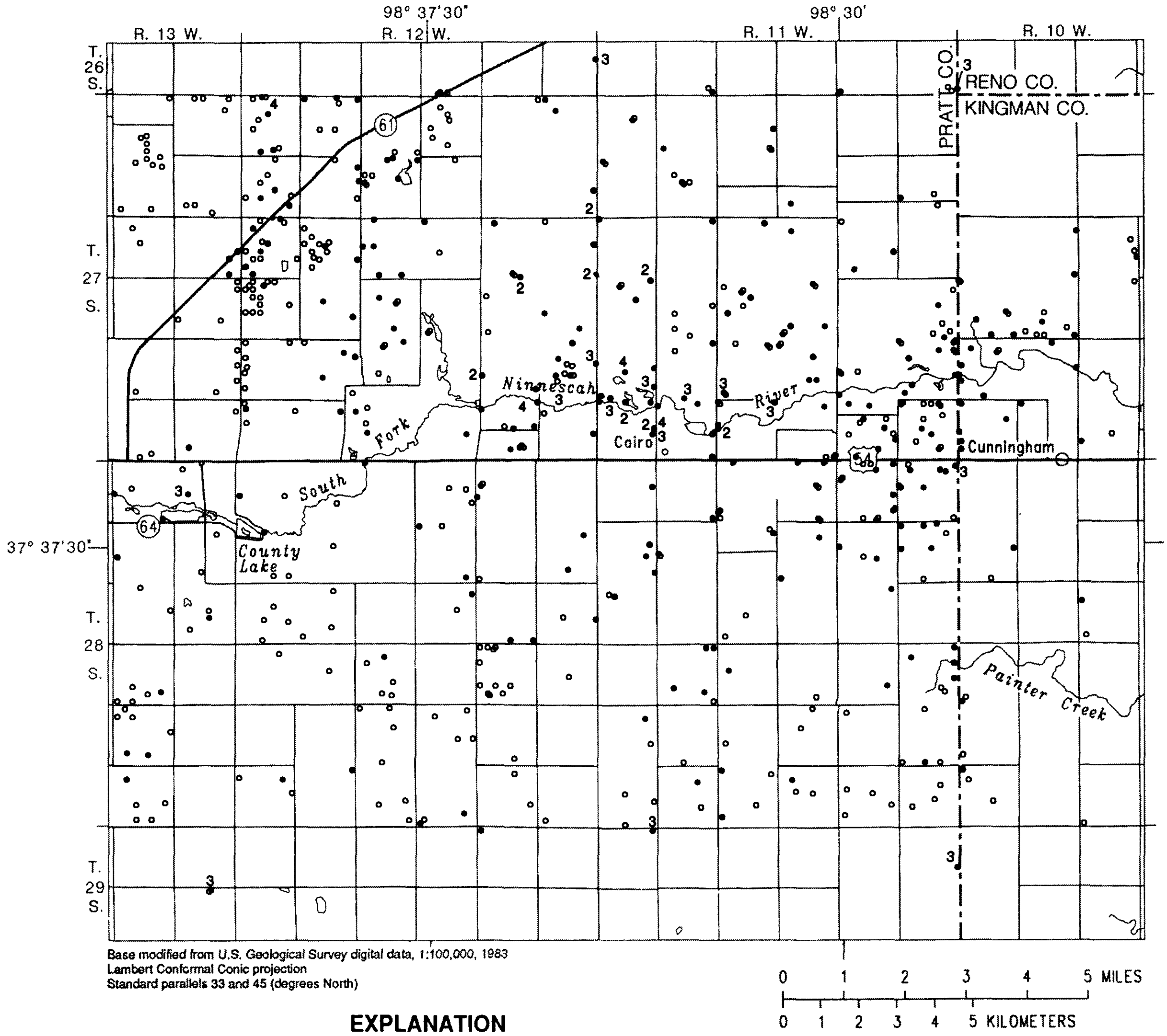


Figure 1. Location of study area.



EXPLANATION

•3 OBSERVATION OR MONITORING WELL--Number indicates more than one well at that location.

∘ OIL-OR-GAS WELL OR TEST HOLE

Figure 2. Location of observation or monitoring wells and oil-or-gas wells and test holes from which data were collected or used.

water samples for chemical analysis and included wells specifically installed for monitoring. Water levels were measured with a steel tape to the nearest 0.01 foot. Ninety-three samples of ground water were collected from the monitoring wells and analyzed for specific conductance, chloride, and 14 for fluid density at the U.S. Geological Survey laboratory in Lawrence, Kansas, according to methods discussed in Fishman and Friedman (1989). Gamma-ray logs were obtained from monitoring wells installed by the U.S. Bureau of Reclamation and the U.S. Geological Survey. Geophysical logs from 213 oil-or-gas wells and test holes also were used in the study (fig. 2).

Water samples were collected from the South Fork Ninnescah River, selected springs, ponds, and marshes and analyzed only for specific conductance and chloride. Salinity-seepage (gain-loss) surveys were made on the river, and electromagnetic terrain surveys were conducted in the area.

Data obtained during this investigation are published in U.S. Geological Survey Open-File Report 91-186, "Geohydrologic data for the South Fork Ninnescah River Valley and adjacent plains in Pratt and Kingman Counties, south-central Kansas" by J.B. Gillespie, G.D. Hargadine, N.C. Myers, and D.A. Hargadine (1991). Lithologic logs of wells drilled by the U.S. Bureau of Reclamation and specific-conductance values and chloride concentrations in samples collected from selected monitoring wells are included in "Supplemental Information" at the end of this report (tables 3 and 4).

Previous Studies

General studies of the geology, ground water, and quality of ground and surface water of Kansas include "Pleistocene Geology of Kansas" by Frye and Leonard (1952) and "The Geologic History of Kansas" by Merriam (1963).

The geology and ground-water resources in Kingman County were studied by Lane (1960). Layton and Berry (1973) conducted studies in Pratt County on the saline-water contamination in the South Fork Ninnescah River Valley near Cairo. Fader and Stullken (1978) studied the geohydrology of the Great Bend Prairie, south-central Kansas. Nonpoint mineral intrusion into Kansas surface water, which includes the South Fork Ninnescah River in Kingman and Pratt Counties, was identified by Hargadine and Luehring (1978) and Hargadine and others (1979). Other related reports are listed in the "Selected References."

Acknowledgments

The authors appreciate the cooperation of the landowners, oil-field operators, and county and State highway officials who contributed or gave permission for data collected. Special thanks are given to Jack Grier and Bruce Davidson for access to their property containing salt marshes; Sharon Falk and personnel of the Big Bend Groundwater Management District No. 5 for consultation and data; Northern Natural Gas Company for permitting access to their record files and water wells; D.O. Whittemore of the Kansas Geological Survey for sharing his valuable knowledge of the water chemistry of the area and use of chemical analysis of water samples from wells installed by the Kansas Geological Survey; and W.S. Alberg, consulting geologist, for sharing his detailed knowledge of the oil industry and local geology. Special acknowledgment is given to Shirley Shadix and the drill crew of the U.S. Bureau of Reclamation for installing monitoring wells at 15 sites in the study area under the Bureau's Technical Assistance to the States Program.

Well and Sampling-Site Numbering System

The system of numbering wells and sampling sites in this report is based on a modified U.S. Bureau of Land Management system of land subdivision. The first number indicates the township, generally south (S) of the Kansas-Nebraska State line; the second indicates the range west (W) or east (E) of the sixth principal meridian; and the third indicates the section in which the well or sampling site 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; the third, the quarter-quarter-quarter section or 10-acre tract; and in some cases, the fourth, the quarter-quarter-quarter-quarter section or 2.5-acre tract. The 160-acre, 40-acre, 10-acre, and 2.5-acre tracts are designated A, B, C, and D in a counterclockwise direction beginning in the northeast quadrant of the section. Where there is more than one well or sampling site in a 2.5-acre or 10-acre tract, consecutive numbers are added, beginning with 2, in the order in which the well or site is inventoried. For example, 27S-11W-31ADDD2 indicates the second well or sampling site inventoried in the southeast quarter of the southeast quarter of the southeast quarter of the northeast quarter of sec. 31, T. 27 S., R. 11 W. (fig. 3).

GEOLOGIC SETTING

The South Fork Ninnescah River Valley and the adjacent gently rolling plains in eastern Pratt and westernmost Kingman Counties are

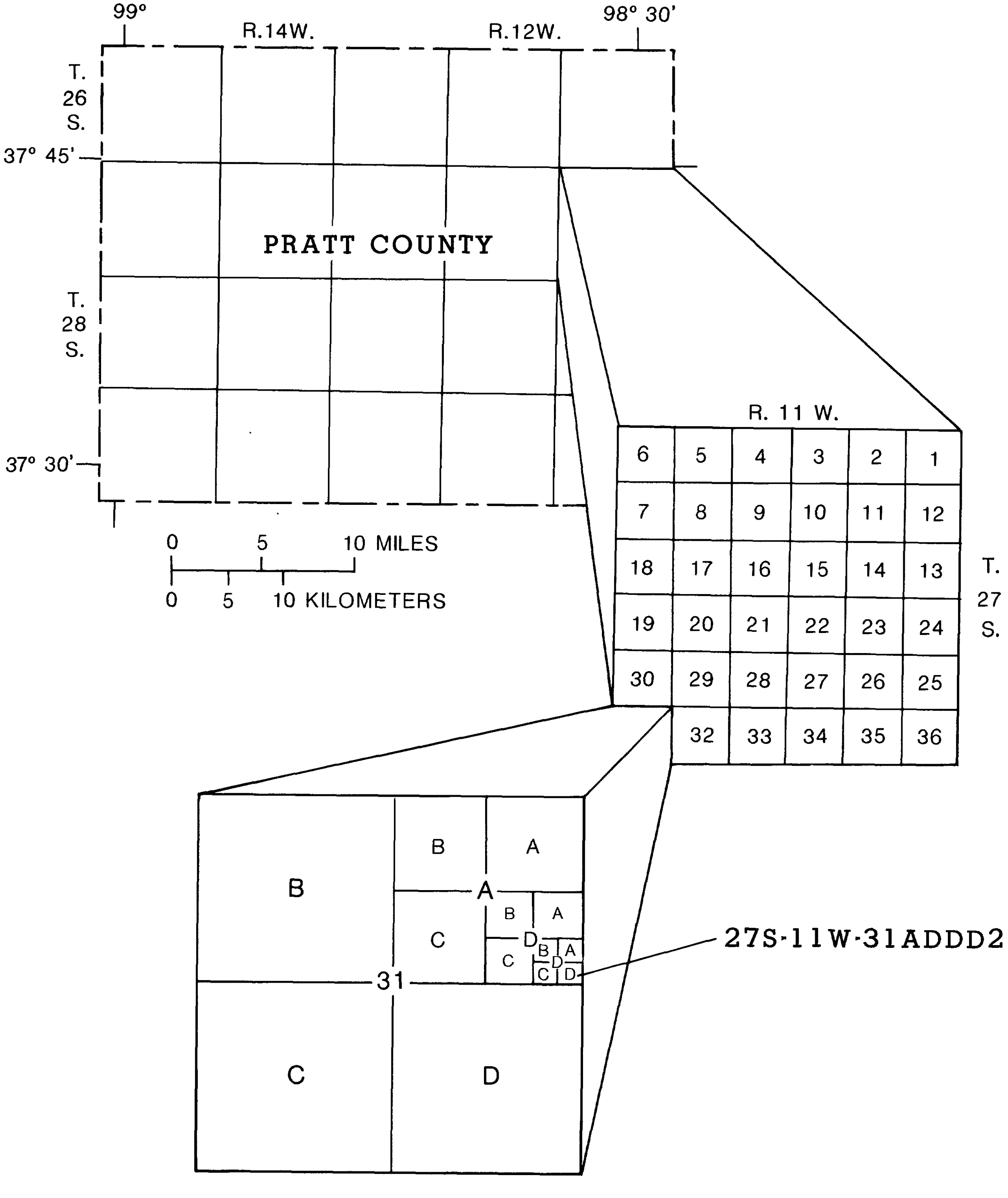


Figure 3. Well and sampling-site numbering system.

underlain by unconsolidated Pleistocene alluvial and eolian deposits overlying consolidated Permian rocks. The geologic units included in this study, in ascending order, are the Wellington Formation, Ninnescah Shale, Stone Corral Formation, Harper Sandstone, and Salt Plain Formation of Permian age, and undifferentiated Pleistocene alluvium. The stratigraphic relation of these units (fig. 4) is correlated with the upper part of a gamma-ray log of an oil-and-gas test hole at 27S-12W-25DBBD.

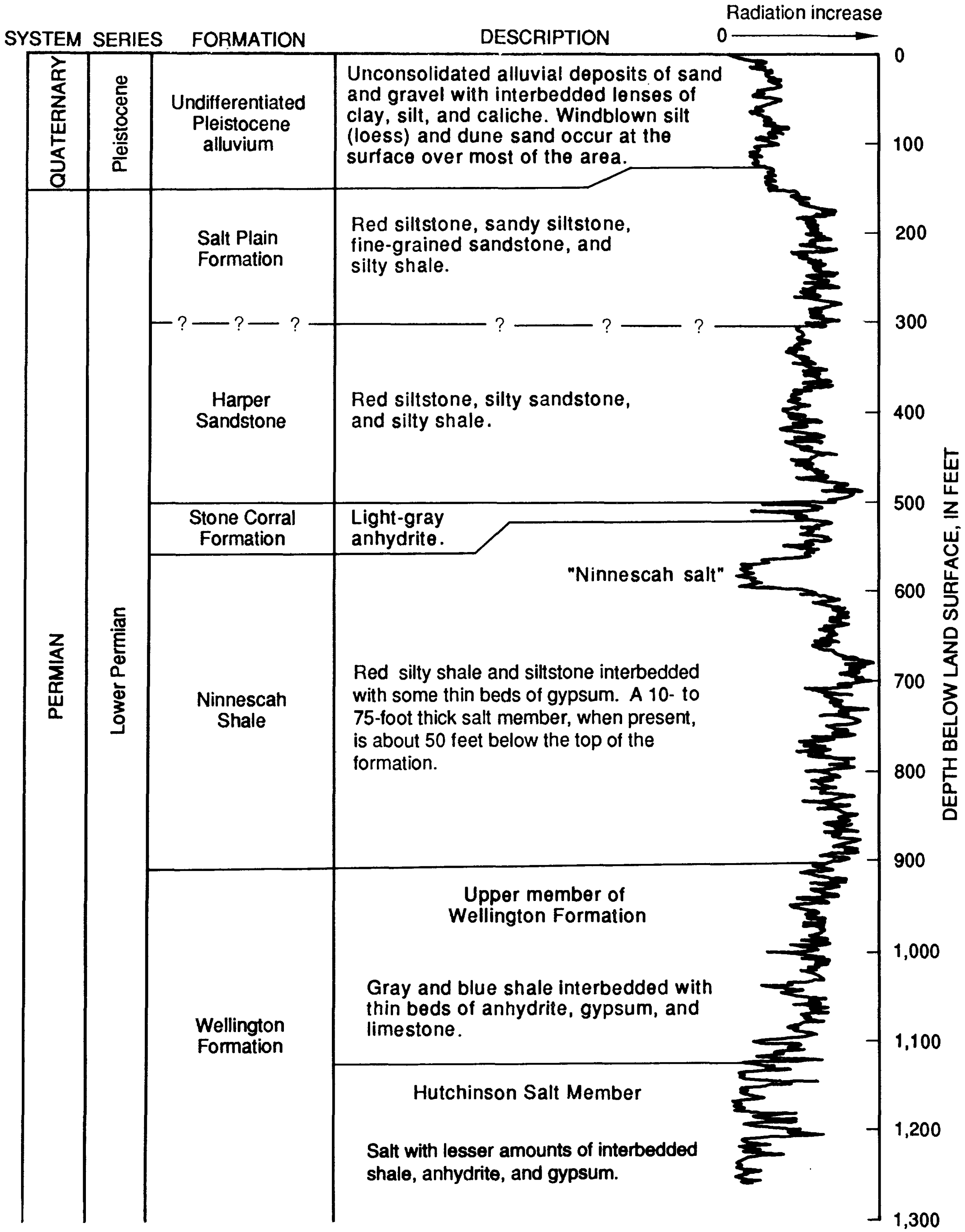


Figure 4. Upper part of gamma-ray log of oil-and-gas test hole at 27S-12W-25DBBD showing stratigraphic relation of geologic units discussed in this report.

The major geologic structure in the area is the post-Mississippian and pre-Permian Pratt Anticline (fig. 5), a southern extension of the Central Kansas Uplift (Merriam, 1963). The Cunningham Anticline is a minor structure just to the southeast of the Pratt Anticline. The eastern flank of the Pratt Anticline underlies the western part of the study area. The Cunningham Anticline underlies the eastern part. Post-Mississippian and pre-Permian faults are associated with these structures. Most of these faults trend northeasterly, parallel to the two main structures in the area (Merriam, 1963, and W.S. Alberg, consulting geologist, written commun., 1991) (fig. 5). These faults exhibit vertical displacement in the Precambrian and lower Paleozoic rocks but are not known to reach the land surface. The Permian rocks dip gently

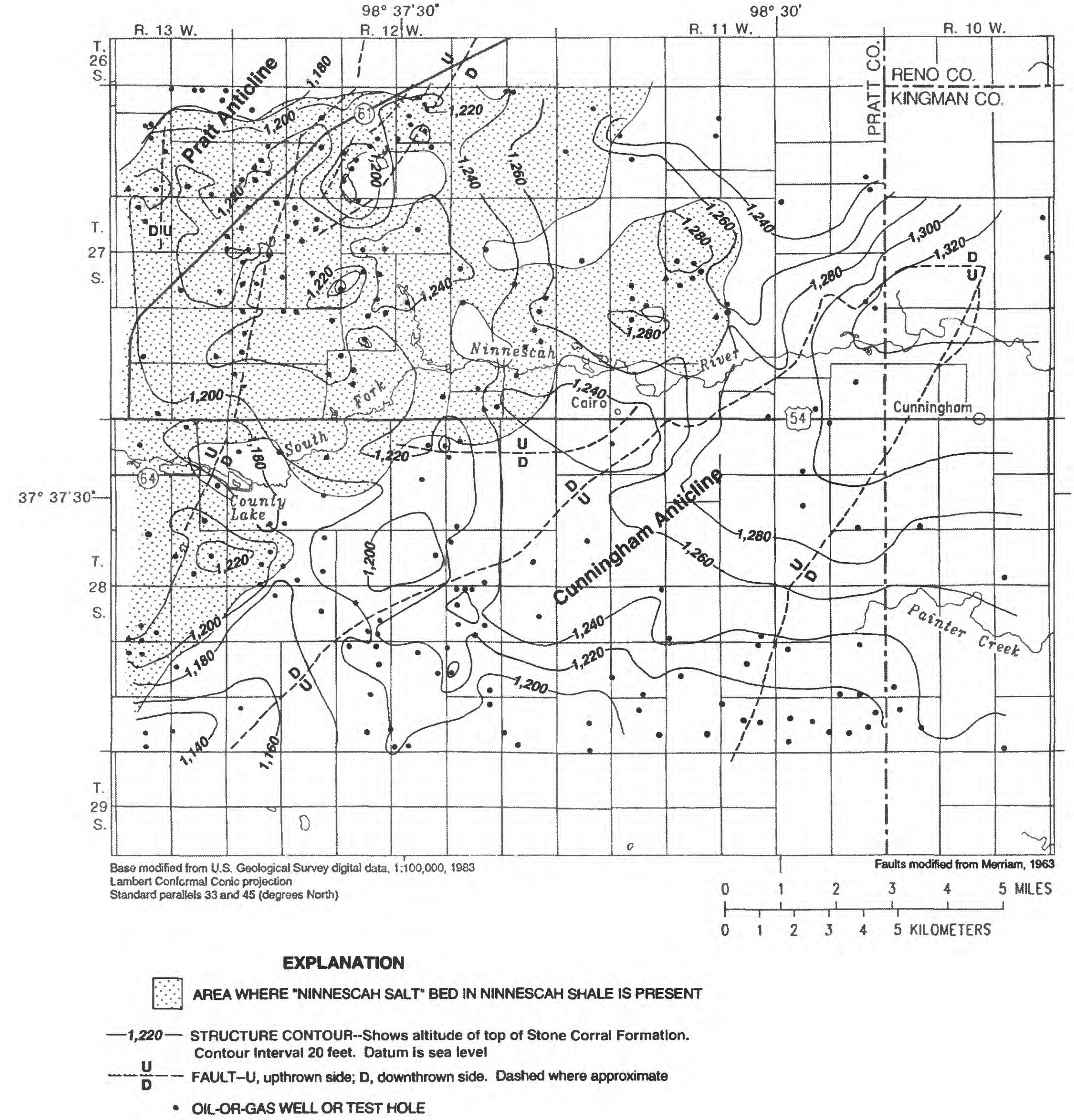


Figure 5. Configuration and altitude of top of Stone Corral Formation and location of geologic structures and pre-Permian faults in western part of study area.

to the west, and the minor structure on top of the Stone Corral Formation (fig. 5) is the result of post-depositional deformation (Merriam, 1963). An earthquake of a magnitude of 4.4 on the Richter scale occurred on January 6, 1956; the epicenter was located 7 mi southeast of Cunningham at 28S-9W-30BDDA (Gordon, 1988) (fig. 1), in Kingman County. The post-Stone Corral deformation and slight movement along the deeper fault zones during post-Permian to recent times probably have caused fracturing in the friable Permian siltstone, sandstone, and shale.

Permian System

Each of the following geologic units underlie the entire study area. All of the geologic units described in the following sections, except the Wellington Formation, are also known as Permian "red beds" because of their distinctive brick-red color.

Wellington Formation

The middle member of the Wellington Formation is the Hutchinson Salt Member, which is predominantly salt (halite) interbedded with lesser amounts of gray shale, anhydrite, and gypsum. The salt is locally up to 400 to 500 ft thick. The upper member of the Wellington Formation consists of about 200 ft of gray shale interbedded with gypsum, anhydrite, and limestone, with predominantly gray shale near the top. Some varicolored gray and maroon shale also is found in the upper member.

Ninnescah Shale

The Ninnescah Shale overlies the Wellington Formation. This shale is the oldest Permian "red bed" unit that underlies the area. It is composed of alternating beds of red silty shale and siltstone interbedded with some thin beds of gypsum. Maximum thickness is about 400 ft. In the northwestern part of the study area, the Ninnescah Shale contains the "Ninnescah salt," a salt bed located about 50 ft below the top of the formation that ranges from 0 to about 70 ft in thickness (fig. 6). The lateral extent of the "Ninnescah salt" has been altered by dissolution, probably caused by deep circulation of ground water through porous zones and fractures in the overlying formations. Oil-field and exploration drillers report that lost circulation or loss of fluid is a common occurrence while drilling through the salt bed. During oil exploration in the 1930's, drillers reported that drill bits and cable tools dropped as much as 50 ft in salt cavities. The location of oil-or-gas wells or test holes in which lost circulation occurred from 1984 to 1990 (W.S. Alberg, consulting geologist, written commun., 1991) is shown in figure 6.

Analysis of geophysical logs indicates deformation subsidence and possible collapse of the overlying Stone Corral Formation into the cavities in the "Ninnescah salt," (fig. 7). To further substantiate evidence of subsidence, a plot of the thickness of the interval between the Stone Corral Formation and the Hutchinson Salt Member was compared to the thickness of the "Ninnescah salt" (fig. 8). The plot indicates a smaller thickness where the salt bed is not present due to dissolution and subsequent subsidence. Localized subsidence or collapse probably has fractured the overlying formations.

Stone Corral Formation

The top of the Stone Corral Formation ranges from about 1,140 to 1,320 ft above sea level in the western part of the study area (fig. 5). The Stone Corral Formation is about 20 to 30 ft thick in this area and is composed of two light-gray anhydrite beds separated by a thin shale.

Harper Sandstone

The Harper Sandstone, a red siltstone, silty sandstone, and silty shale, attains a maximum thickness of about 250 ft. Light gray-green streaks and spots are a common attribute of the unit. The Harper Sandstone is divided into two members, the Chikaskia Sandstone Member overlain by the Kingman Sandstone Member. These members are addressed as a single unit in this report.

Salt Plain Formation

The Salt Plain Formation consists of red siltstone, sandy siltstone, fine-grained sandstone, and silty shale. Light gray-green streaks and spots are also a common characteristic of the Salt Plain Formation. The Salt Plain Formation forms the top of the bedrock surface and

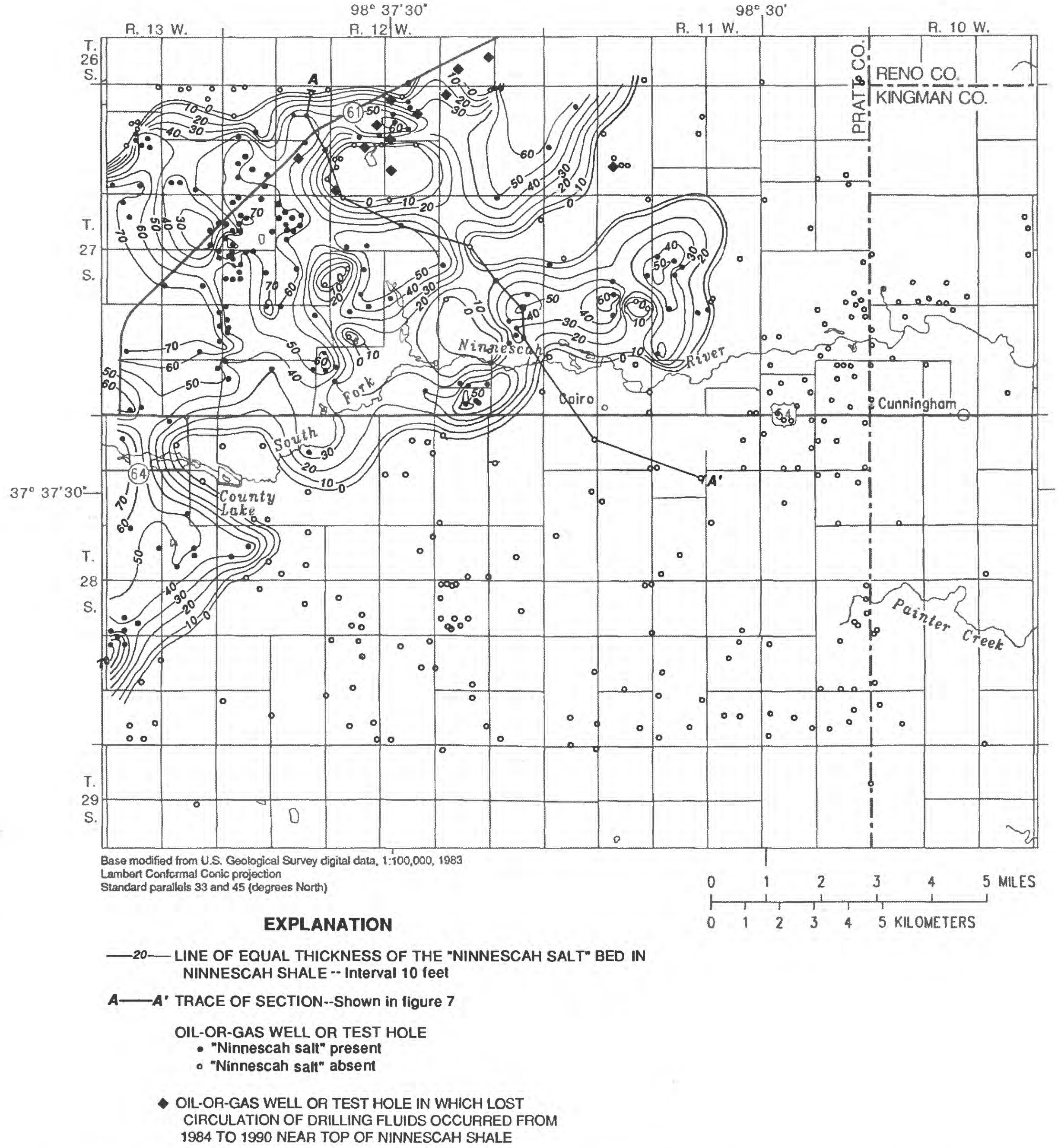


Figure 6. Thickness of "Ninnescah salt" bed in Ninnescah Shale in western part of study area.

underlies the alluvium in the western part of the study area (fig. 9).

Quaternary System

Undifferentiated Pleistocene alluvium overlies the Permian bedrock in the study area. The alluvium (fluvial and eolian deposits) may be as much as 215 ft thick in the adjacent plains but ranges from about 65 to 130 ft in thickness in the South Fork Ninnescah Valley. Earlier geologic work has referenced stratigraphic units of the fluvial and eolian materials (Layton and Berry, 1973). These units, in ascending order are the: Holdredge, Fullerton, Grand Island, Sappa, Crete, and Loveland Formations. Differentiation of the age of unconsolidated alluvial deposits in the study area generally is difficult. For the purposes of this investigation,

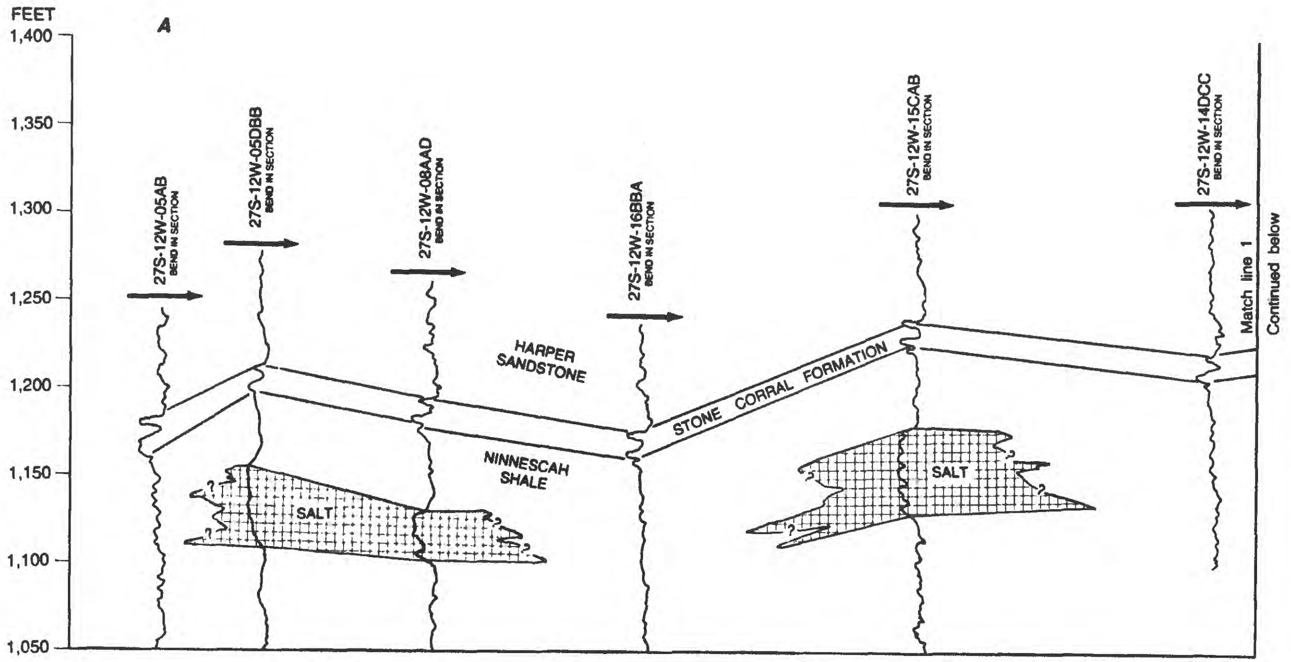


Figure 7. Geologic section showing upper part of Ninnescah Shale, Stone Corral Formation, and lower part of Harper Sandstone. Trace of section shown in figure 6.

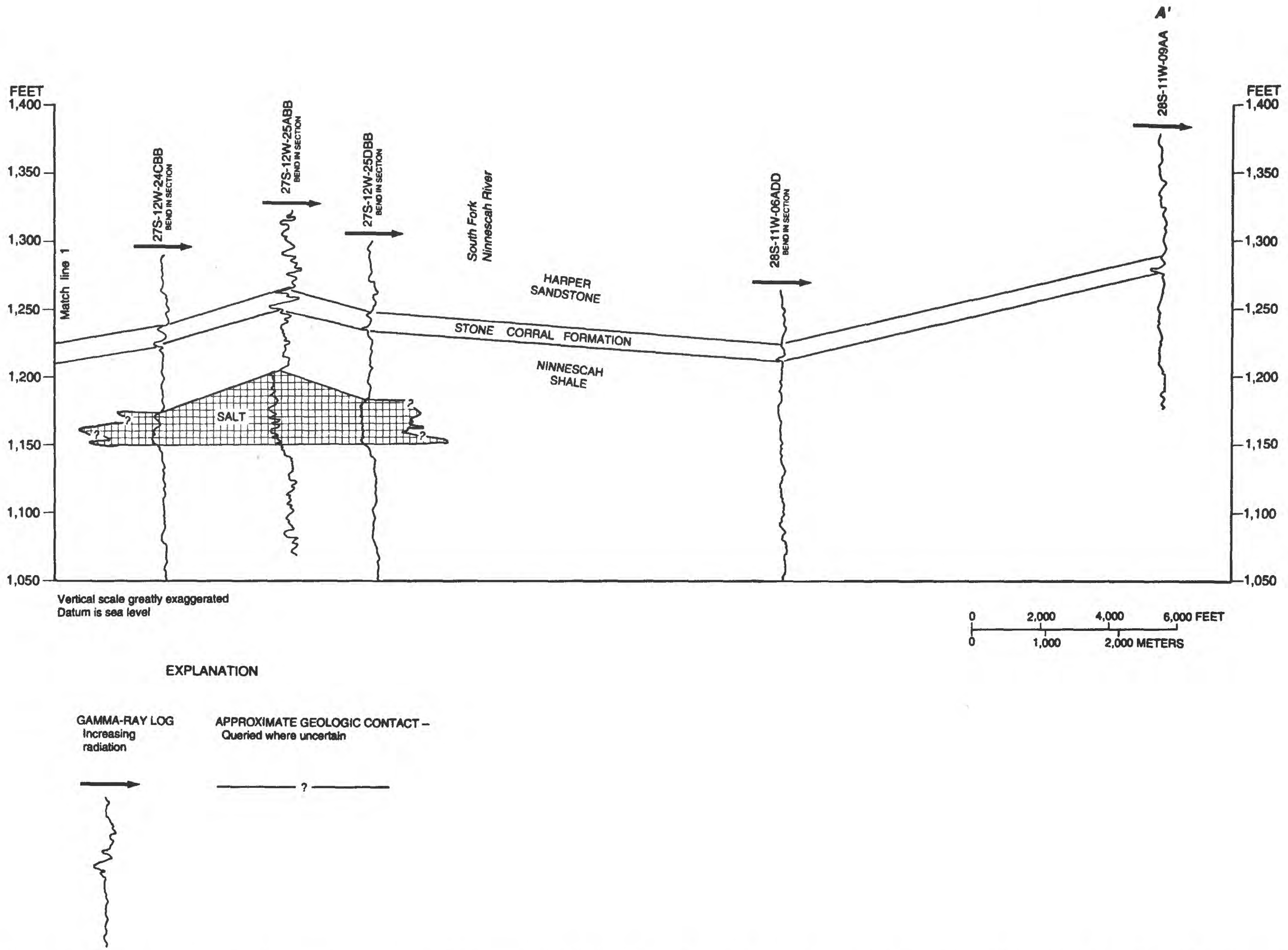


Figure 7. Geologic section showing upper part of Ninnescah Shale, Stone Corral Formation, and lower part of Harper Sandstone--Continued. Trace of section shown in figure 6.

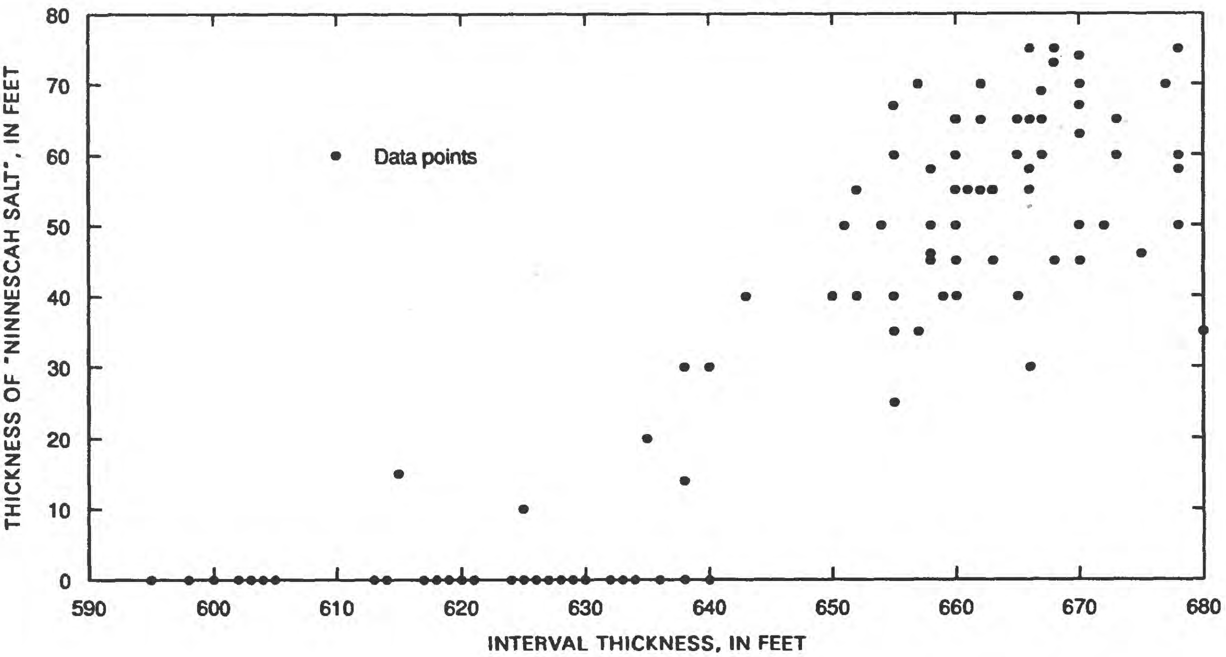


Figure 8. Plot of interval thickness between Stone Corral Formation and Hutchinson Salt Member compared to thickness of "Ninnescah salt."

the alluvium is divided into lower, middle, and upper units. The lithology and gamma-ray logs of the alluvium are shown in two cross sections in figure 10.

The lower alluvium consists mainly of medium-to-coarse sand, gravel, with some silt. The gravel is composed mostly of quartz and feldspar, and near the bottom the alluvium commonly contains pebbles of ironstone. The thickness ranges from about 20 to 30 ft.

The middle alluvium generally consists of discontinuous tan-gray clay, silty clay, silt, and silty sand deposits. The thickness is variable and ranges from 0 to 30 ft. It is possible that this layer may have been breached by localized collapse structures that were created when the overlying Permian rocks and alluvium collapsed into the dissolution cavities in the "Ninnescah salt."

The upper alluvium consists mainly of medium-to-coarse sand, gravel composed mostly of quartz and feldspar, with some silt, clay, and caliche lenses. Upper alluvium thickness ranges from 30 to 120 ft. Eolian deposits and soil ranging from a few inches to several feet in thickness blanket the surface. The eolian deposits may be fine-grained loess but are primarily stabilized sand dunes.

HYDROLOGIC SYSTEM

Surface Water

The South Fork Ninnescah Valley extends eastward from the gently rolling plains of the Great Bend Prairie in the western part of the study area to the Permian bedrock in most of the eastern part. In the western part of the study area, the flood plain is about 0.7 mi wide and is about 100 ft below the surrounding plains. The gradients of the valley and the river are about 11 and 8 ft/mi, respectively. Precipitation near Pratt totals about 24 in/yr (National Oceanic and Atmospheric Administration, 1983-90).

The South Fork Ninnescah River is a gaining stream through the entire area or reach. Naturally occurring saline ground water is discharged to the river near Cairo in Pratt County (Layton and Berry, 1973). Parker (1911) reported that chloride concentrations of the river water at Pratt were 30 mg/L and at Kingman were 289 mg/L. This increase in chloride concentrations was attributed to inflow from abandoned salt works near Kingman. The

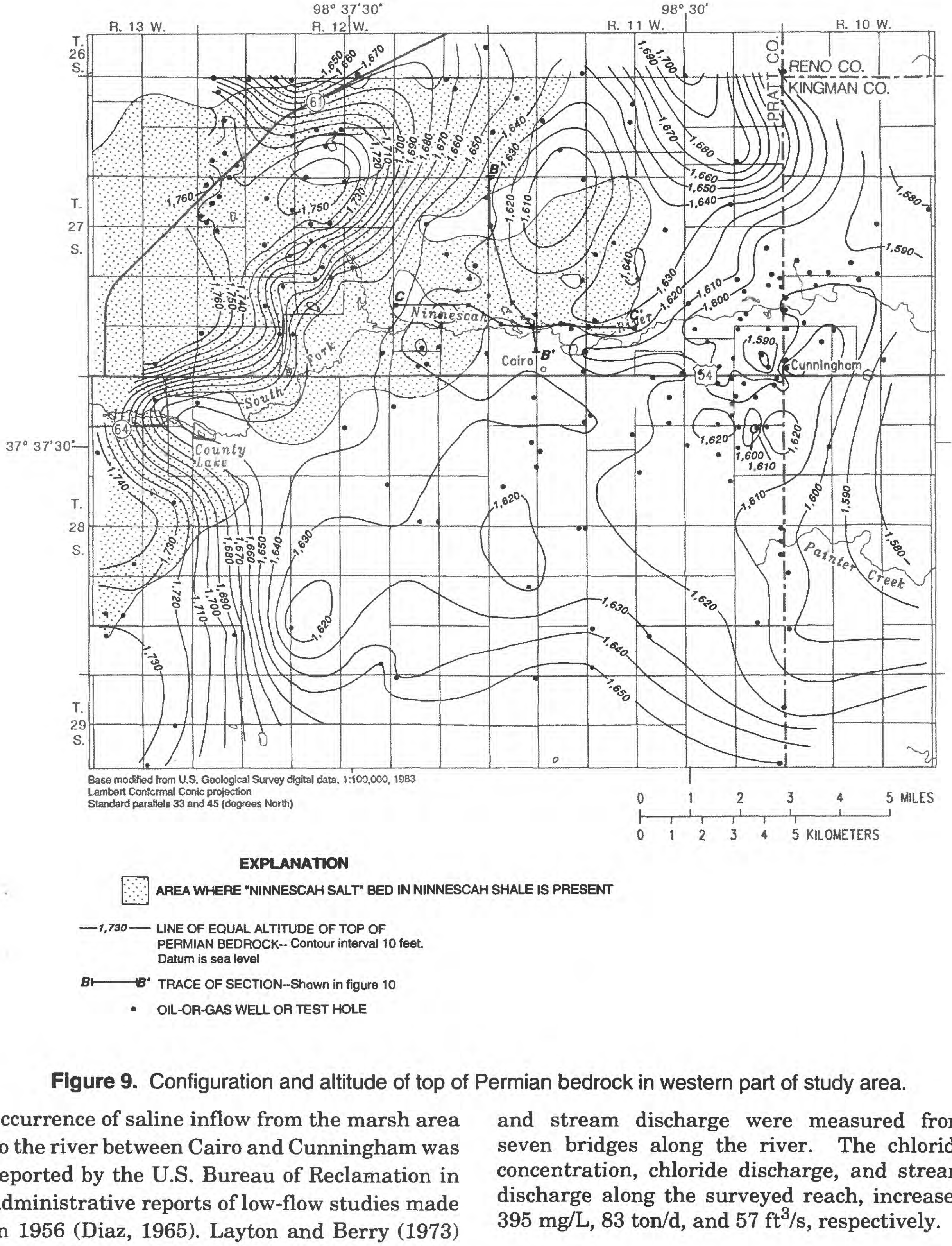


Figure 9. Configuration and altitude of top of Permian bedrock in western part of study area.

occurrence of saline inflow from the marsh area to the river between Cairo and Cunningham was reported by the U.S. Bureau of Reclamation in administrative reports of low-flow studies made in 1956 (Diaz, 1965). Layton and Berry (1973) report that in April 1963 a salinity-seepage survey was conducted from the county bridge at 28S-12W-07BADA near Pratt to the Pratt-Kingman County line. Chloride concentrations and stream discharge were measured from seven bridges along the river. The chloride concentration, chloride discharge, and stream discharge along the surveyed reach, increased 395 mg/L, 83 ton/d, and 57 ft^3/s, respectively.

Streamflow

Three U.S. Geological Survey streamflow-gaging stations are located in the study area

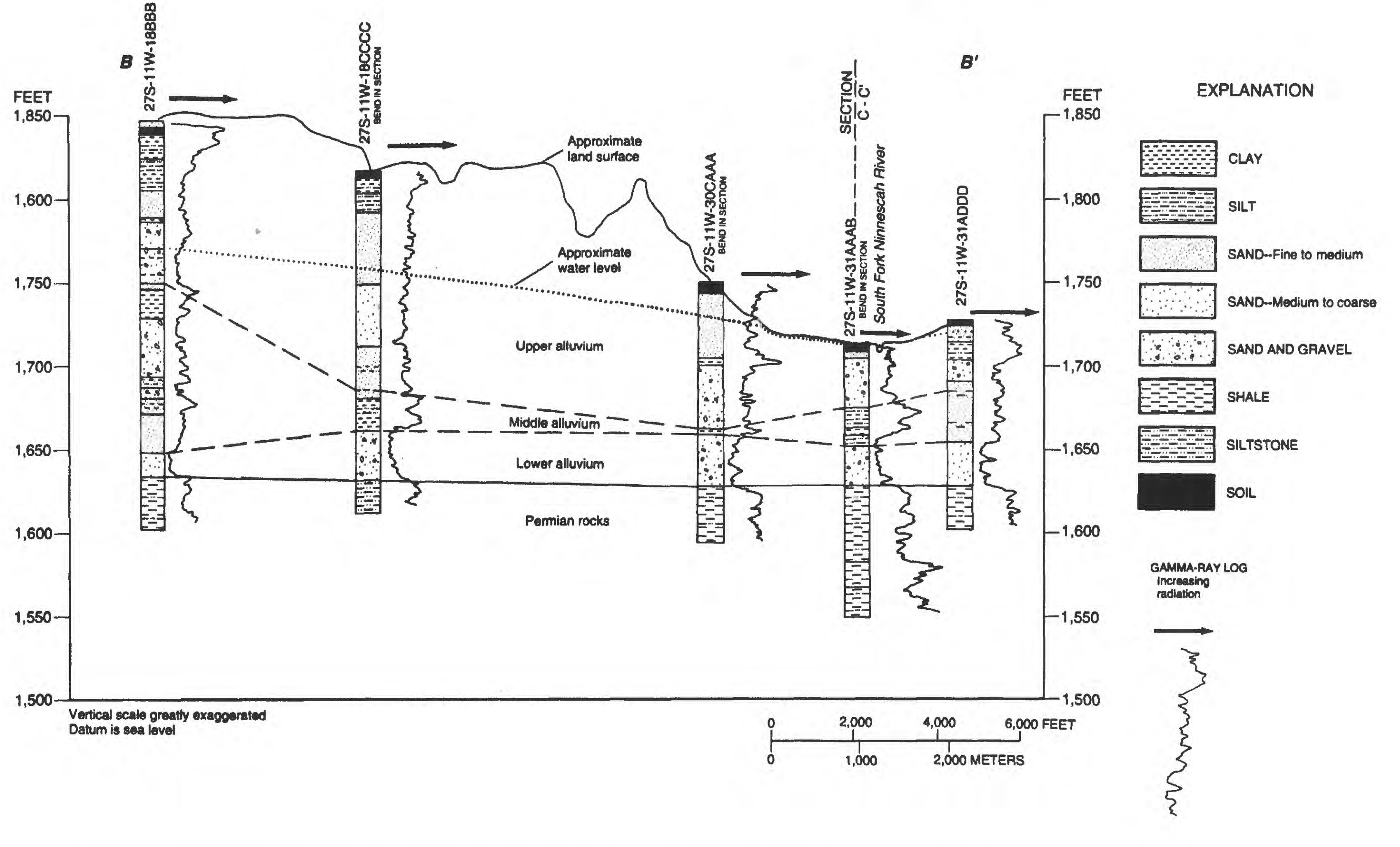


Figure 10. Geohydrologic sections showing lithology of alluvium and Permian bedrock. Trace of sections shown in figure 9.

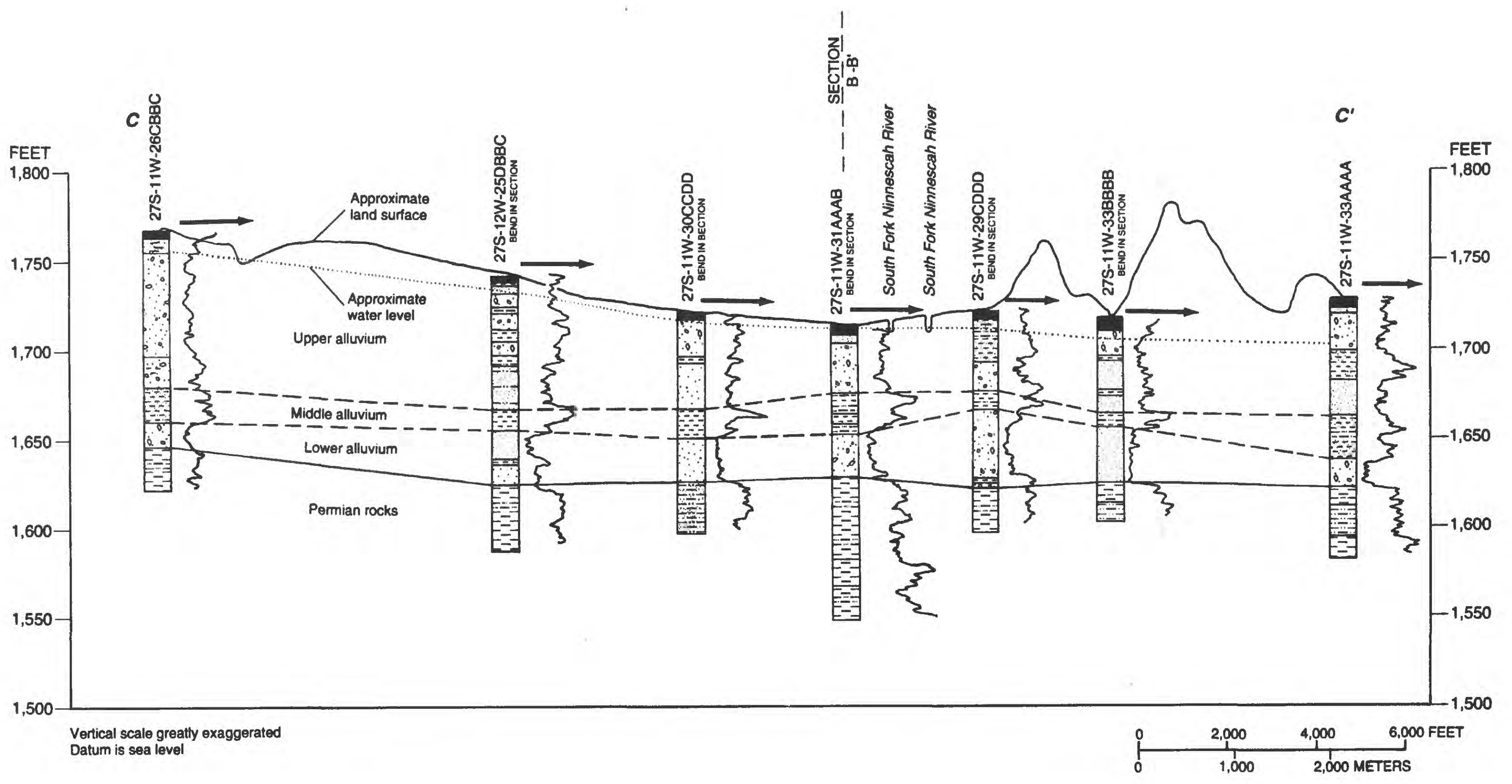


Figure 10. Geohydrologic sections showing lithology of alluvium and Permian bedrock--Continued. Trace of sections shown in figure 9.

(fig. 1). Continuous records of stage recorded at two stations are used to compute daily mean discharges by applying the daily mean stages to the stage-discharge curves or tables. The South Fork Ninnescah River near Pratt gaging station (station no. 07144910) in the western part of the study area has a contributing drainage area of approximately 117 mi^2. The station has 9 years of record, and the average discharge is 16.4 ft^3/s or 11,880 acre-ft/yr. The South Fork Ninnescah River near Murdock gaging station (station no. 07145200) in the eastern part of the study area has a contributing drainage area of approximately 540 mi^2. This station has 34 years of record, and the average discharge for the last 9 years is 222 ft^3/s or 161,000 acre-ft/yr. There is about a 14-fold increase in streamflow between the two stations. A low-flow partial-record station, South Fork Ninnescah River near Calista (station no. 07145130) in the eastern part of the study area has 21 years of record (fig. 1). Base flow in the South Fork Ninnescah River consists mainly of ground-water discharge from the alluvial aquifer.

Salinity-Seepage Surveys

Two salinity-seepage surveys and one salinity survey were made from November 1988 to November 1989 during periods of nearly stable base flow and no measurable contribution from precipitation. The sites and their distance upstream from the streamflow-gaging station on the South Fork Ninnescah River near Murdock are shown in figure 11.

A salinity-seepage survey was conducted at 10 bridges over the South Fork Ninnescah River on November 2, 1988, from the gaging station at Pratt to the Pratt-Kingman County line (fig. 12). Chloride concentration, chloride discharge, and stream discharge, increased 350 mg/L, 82 ton/d, and 67.4 ft^3/s, respectively, from river mile 69.6 to river mile 50.5. These salinity-seepage survey results were similar to the results of a salinity-seepage survey that was conducted in 1963 (Layton and Berry, 1973). In this reach, the stream discharge uniformly increased from 11.2 ft^3/s at the gaging station to 78.6 ft^3/s at the county line. There was a substantial increase in the chloride concentration (240 mg/L) and chloride discharge (36.2 ton/d) between river mile 58.2 and 57.1.

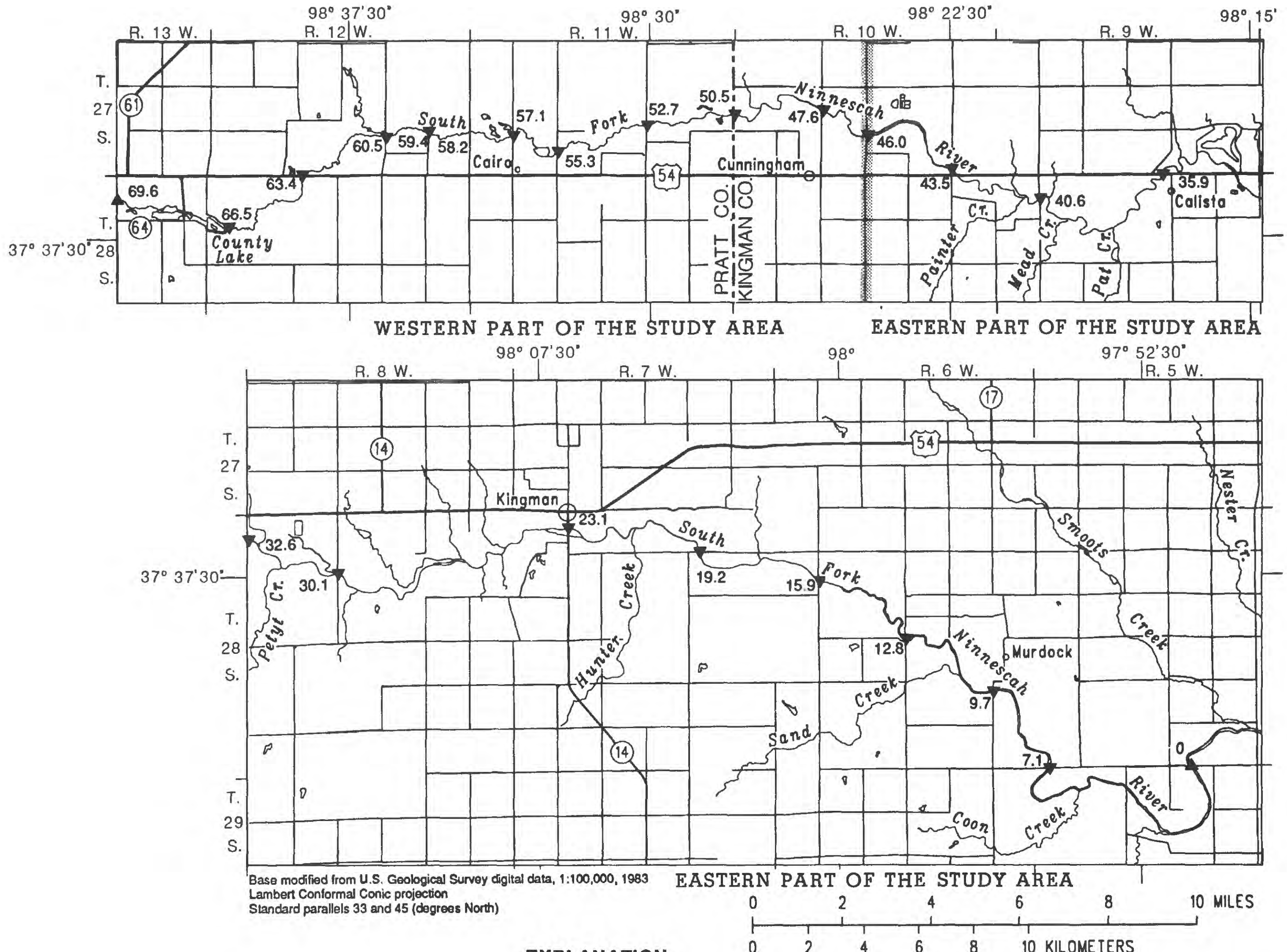
A salinity survey was conducted in January 18, 1989, at 23 bridges between the two complete-record streamflow-gaging stations on the South Fork Ninnescah River (fig. 13). The chloride concentrations gradually increased downstream from river mile 69.6 (the gaging station at Pratt) to river mile 58.2 (near Cairo) then sharply increased to river mile 57.1. Increases in concentrations continued to river mile 52.7, then decreased gradually to just west of Kingman, where the South Fork Ninnescah Valley has been cut by downward erosion into the Permian bedrock and the river gains from ground-water discharge only from a narrower alluvial aquifer. Upstream of this reach the river gains discharge from the alluvial aquifer, which underlies the entire river valley and adjacent plains.

On November 1-2, 1989, a salinity-seepage survey was conducted at nine bridges between the two streamflow-gaging stations on the South Fork Ninnescah River (fig. 13). Chloride concentrations were similar to the values measured during the January 1989 salinity survey. The chloride- and stream-discharge curves show a uniform increase from the gaging station at Pratt to river mile 47.6. In this reach, the slopes decrease as the alluvial aquifer adjacent to the river valley becomes very thin, and therefore, less ground water discharges to the river. The chloride-concentration curve increases from Pratt to river mile 52.7, 2 mi west of the Pratt-Kingman County line. In this reach, the slope begins to decline, which probably indicates little saline ground-water discharge from the Permian rocks through the alluvium to the river from this point to the gaging station near Murdock.

During the salinity-seepage surveys of January and November 1989, chloride concentrations at Kingman were 285 and 290 mg/L, respectively. Parker (1911) reported a similar chloride concentration in the South Fork Ninnescah River at Kingman (289 mg/L).

Chloride Distribution

From 1963 to 1988, measurements of chloride concentration and stream discharge were made at a miscellaneous partial-record streamflow-gaging station on the South Fork Ninnescah River near Calista in Kingman County (fig. 1). In general, chloride concentrations and discharges have been relatively stable



EXPLANATION

30.1 ▼ SALINITY- AND SEEPAGE-MEASUREMENT SITE--Number is river miles upstream from streamflow-gaging station on South Fork Ninnescah River near Murdock as shown in figure 1

▲ STREAMFLOW-GAGING STATION

Figure 11. Salinity- and seepage-measurement sites on South Fork Ninnescah River from Pratt to near Murdock streamflow-gaging stations.

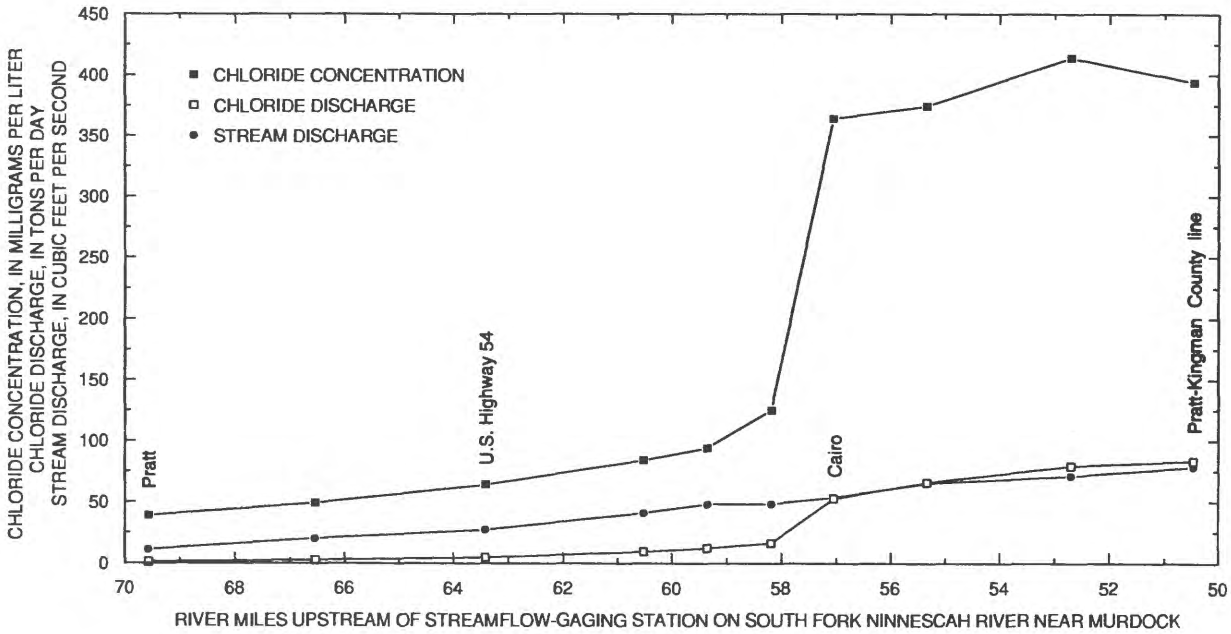


Figure 12. Chloride concentrations, chloride discharges, and stream discharges for South Fork Ninnescah River from Pratt to Pratt-Kingman County line, November 2, 1988.

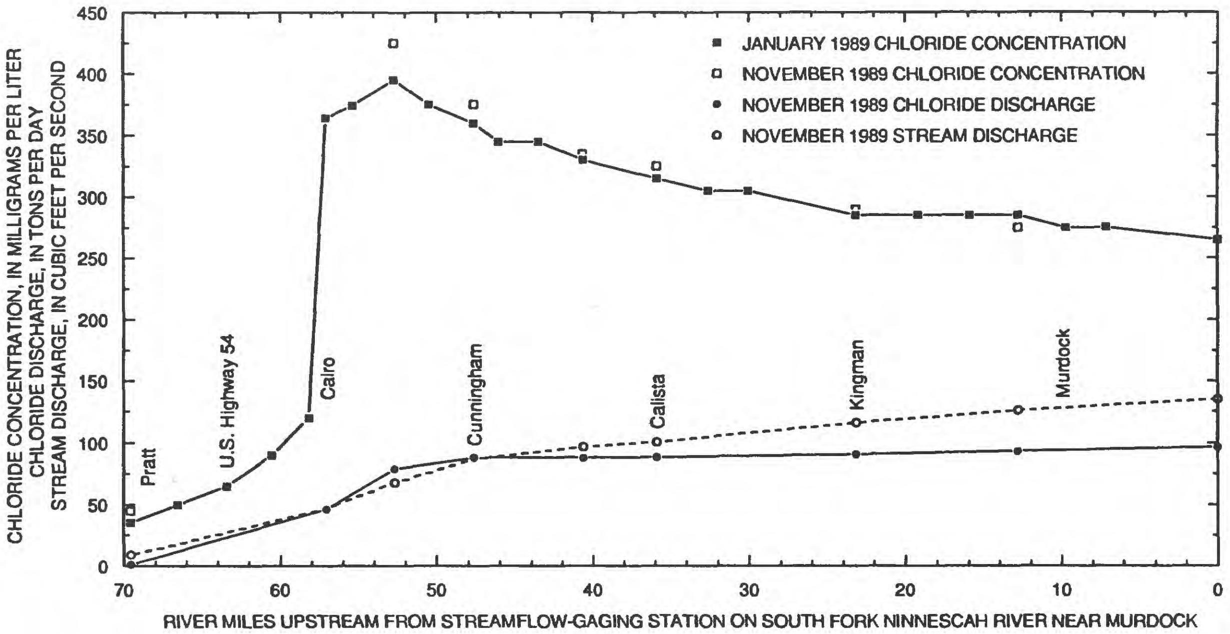


Figure 13. Chloride concentrations, chloride discharges, and stream discharges for South Fork Ninnescah River from Pratt to near Murdock, January 18 and November 1-2, 1989.

for approximately 26 years (fig. 14). Chloride concentrations near Calista are equal to or exceed 250 mg/L, 97 percent of the time (Hargadine and others, 1979). Hargadine and others (1979) also report that chloride concentrations at the streamflow-gaging station near Murdock are equal to or exceed 250 mg/L, 75 percent of the time.

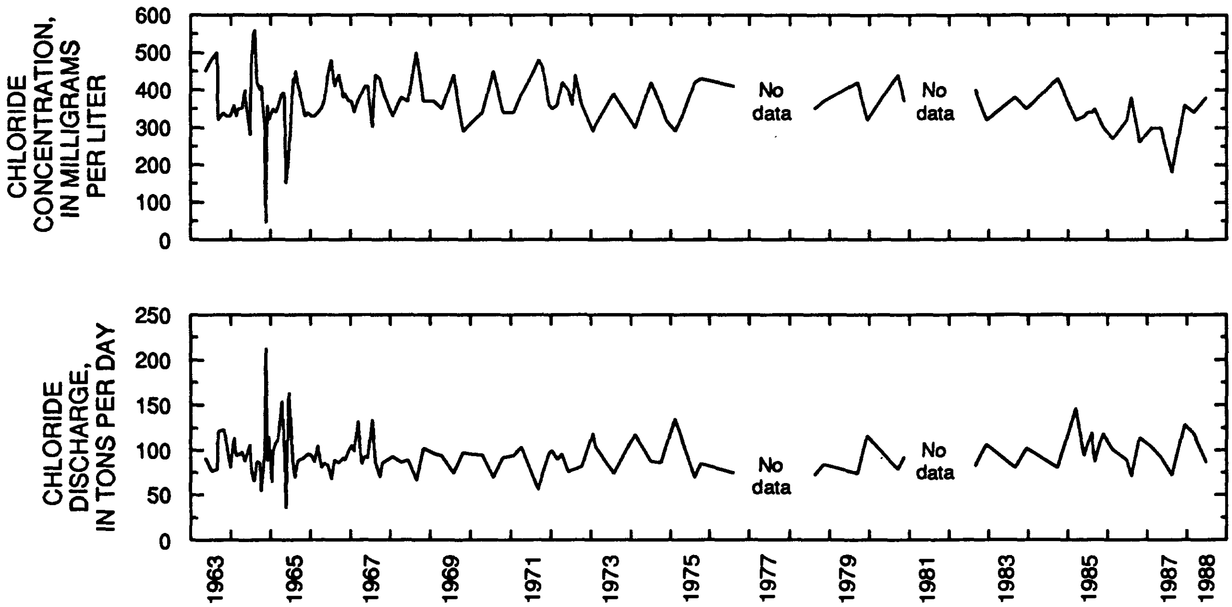


Figure 14. Chloride concentrations and chloride discharges for South Fork Ninnescah River near Calista, 1963-88.

Surface-water samples were collected from small tributaries, ponds, marshes, springs, and the river in the South Fork Ninnescah Valley during 1988-89 (fig. 15). Chloride concentrations ranged from 24 mg/L in a marsh on the north side of the river near Cunningham to 10,800 mg/L in the south fork of what is locally known as Grier's marsh (27S-11W-31AAA) just north of the river near Cairo. The larger chloride concentrations were in the major area of saline ground-water discharge to the river near Cairo. Chloride concentrations in samples collected in the river north of Cairo at 27S-11W-32BBBC were 620 mg/L near the left bank and 180 mg/L in the center of the river, indicating that the saline ground water was entering the river from the north side.

Ground Water

The ground-water system consists of two principal aquifers--the alluvial aquifer and the underlying Permian formations. The ground-water flow in both aquifers is toward the South Fork Ninnescah River, the major ground-water discharge area for the southern part of the Great Bend Prairie. The alluvial aquifer is recharged by percolation of precipitation.

Eighteen U.S. Geological Survey ground-water monitoring sites and one Big Bend Groundwater Management District No. 5 (GMD5) site were chosen for periodic ground-water-level measurements to compare the vertical distribution of fluid-potential levels (the actual water level in a well without any corrections for water density) and water quality in both the alluvial aquifer and Permian rocks. Fluid-potential levels were used because of the variable density of the water in the Permian and alluvial aquifers. Water levels of the denser water (saline water and brine) are lower than comparable levels of freshwater. The density of the water in the monitoring wells ranged from 1.000 to 1.037 grams per cubic centimeter. Nine of the 18 monitoring sites were completed as nested well sites. Monitoring wells are constructed of three 2-in. diameter polyvinyl-chloride pipe (shallow, medium, and deep), with 10-ft screens. Nested wells are located about 5 ft apart. Three sites had two monitoring well nests. The deepest well at 27S-11W-31AAAB3 was completed 80 ft into the Permian rocks, a second well was completed at the bottom of the lower alluvial aquifer just above the Permian bedrock, and a third well was completed near the bottom of the upper alluvial aquifer. A total of 51 wells were installed in the western part of the study area.

Data from eight additional ground-water monitoring sites in GMD5 were used in the ground-water- quality network (fig. 16). Nests of

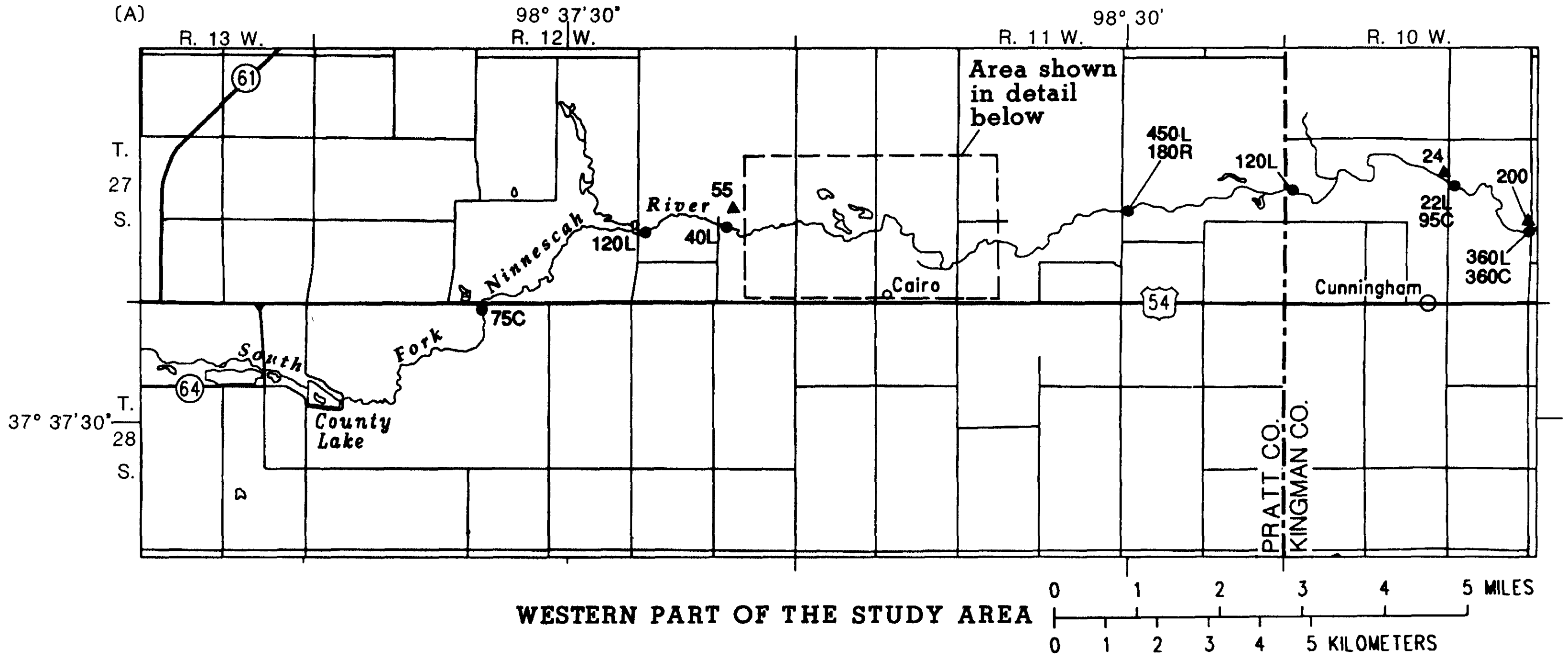
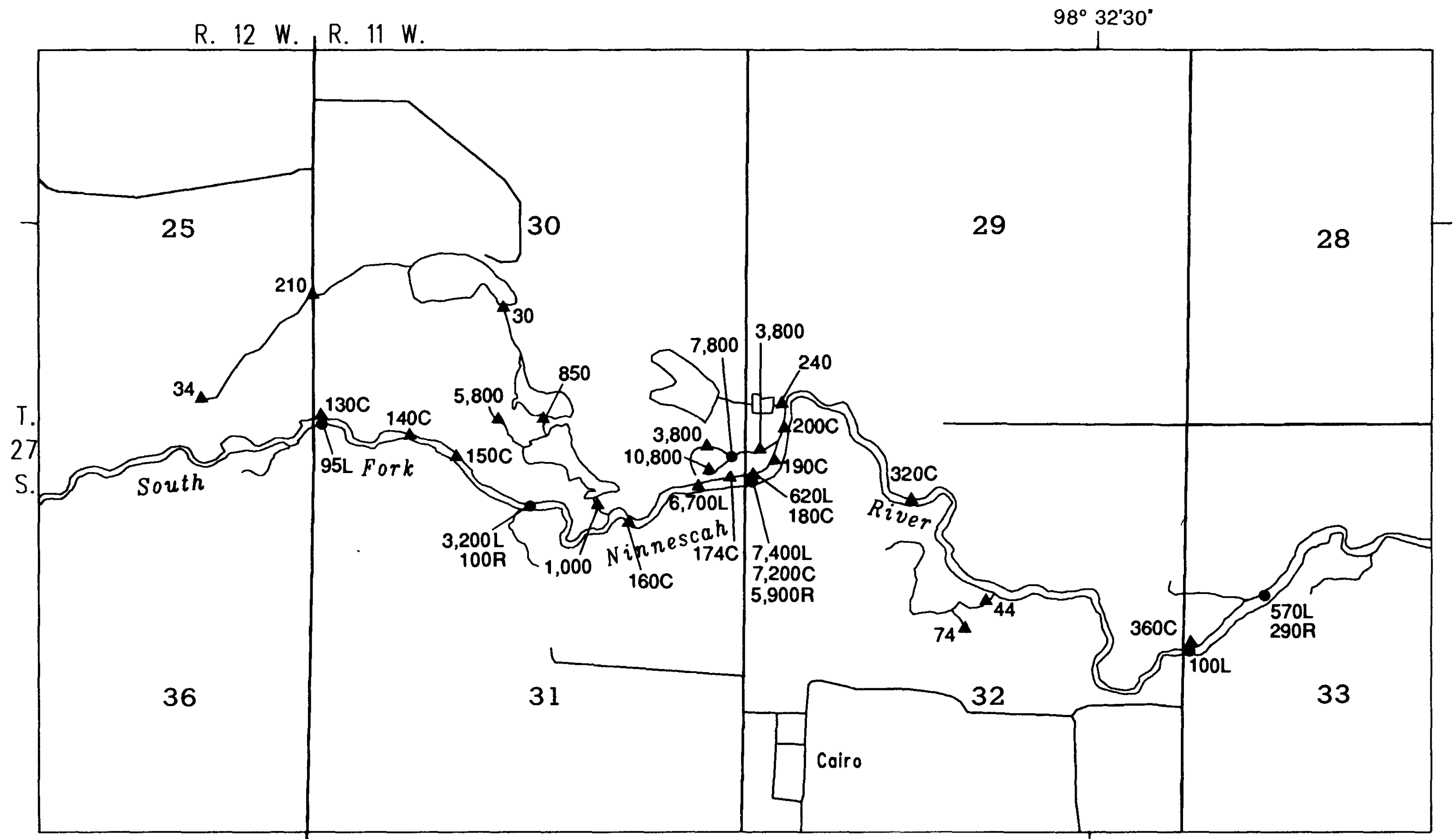


Figure 15. Chloride concentrations from water samples collected from small tributaries, ponds, marshes, springs, river, and beneath streambed in South Fork Ninnescah Valley, 1988-89.



Base modified from U.S. Geological Survey digital data, 1:100,000, 1983
Lambert Conformal Conic projection
Standard parallels 33 and 45 (degrees North)

EXPLANATION

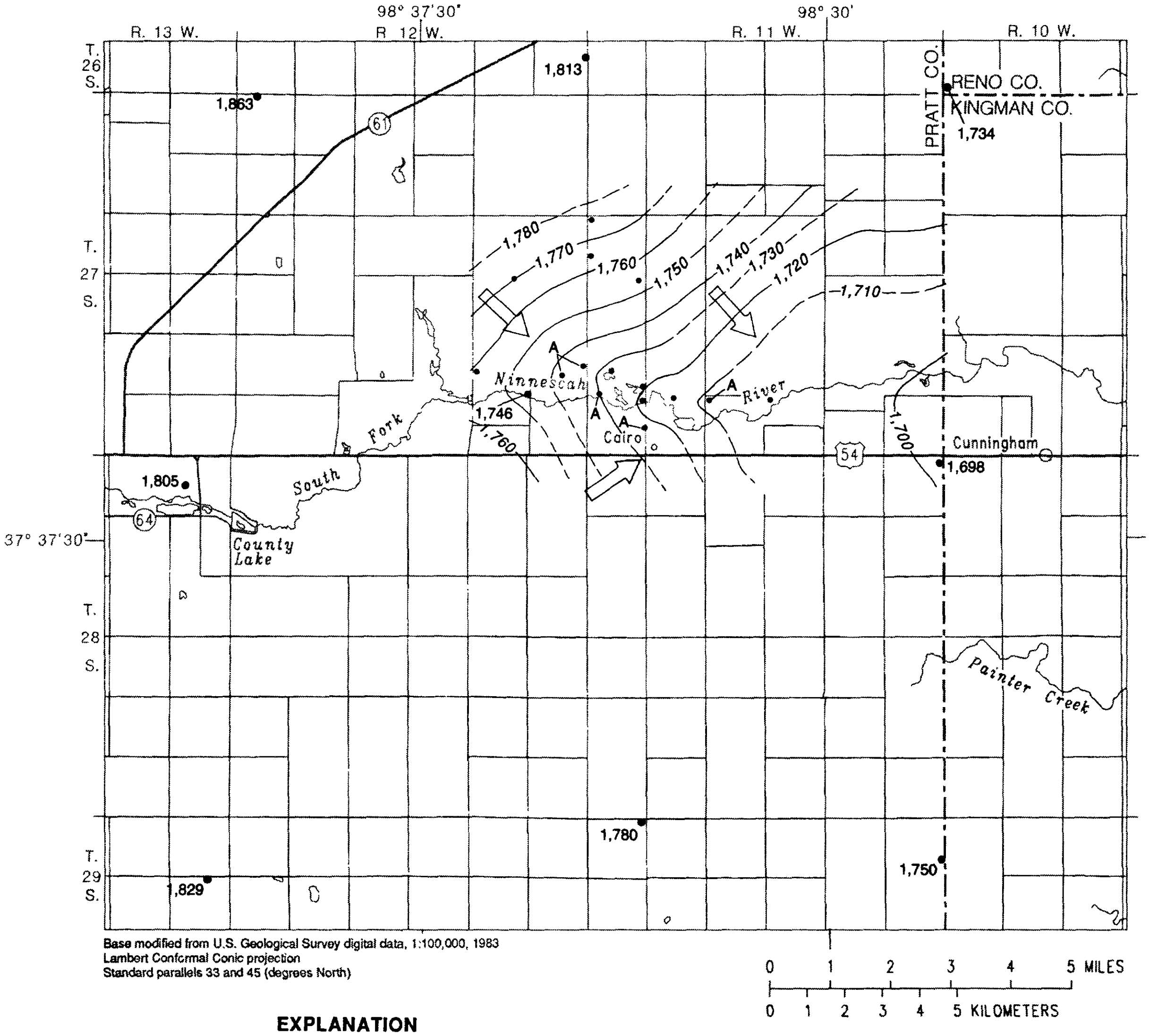
140C▲ SURFACE-WATER SAMPLE--Collected from small tributaries, pond, marsh, spring, or South Fork Ninnescah River

3,200 L / 100R ● GROUND-WATER SAMPLE--Collected from upper alluvial aquifer 3 feet beneath streambed

36 SECTION NUMBER

Numbers indicate chloride concentration, in milligrams per liter. Letter after a number indicates location of water sample in or beneath streambed; L, near left bank; C, center; and R, near right bank

Figure 15. Chloride concentrations from water samples collected from small tributaries, ponds, marshes, springs, river, and beneath streambed in South Fork Ninnescah Valley, 1988-89--Continued.



EXPLANATION

—1,780— LINE OF EQUAL FLUID-POTENTIAL LEVEL--Shows altitude of fluid level in Permian rocks, winter 1990. Dashed where approximate. Interval 10 feet. Datum is sea level

(arrow) APPROXIMATE DIRECTION OF GROUND-WATER FLOW

• U.S. BUREAU OF RECLAMATION-U.S. GEOLOGICAL SURVEY GROUND-WATER MONITORING SITE

1,829 GROUND-WATER MANAGEMENT DISTRICT NO. 5 GROUND-WATER MONITORING WELL--Number indicates altitude of fluid level in lower alluvial aquifer not corrected for variable density, in feet. Datum is sea level

A AQUIFER-TEST DATA AVAILABLE

Figure 16. Altitude of fluid-potential levels in Permian rocks in western part of study area, winter 1990.

wells at GMD5 sites were installed by the rotary-drilling method. Wells at each site consisted of a 5-in. diameter, polyvinyl-chloride casing with a 5-ft screen.

Ground-water-level data also were collected from 15 wells from the statewide observation-well network, 20 irrigation wells, and 52 oil-field water-supply wells. All of these wells were completed in the alluvial aquifer. Some of these ground-water samples were analyzed for specific conductance and chloride (Gillespie and others, 1991).

Alluvial Aquifer

Aquifer Characteristics

The configuration of the fluid-potential level surface in the lower alluvial aquifer is shown in figure 17. Fluid-potential levels were used because of variable-density water in the lower alluvial aquifer. The density of the water in the monitoring wells ranged from 1.000 to 1.019 grams per cubic centimeter. Lines of equal fluid-potential level for the entire western part of the study area were not drawn because of insufficient data. The configuration of fluid-potential surface in the upper alluvial aquifer in the western part of the study area is shown in figure 18. None of the water levels are affected by density except the water in well 27S-11W-31AAAC2, which has a density of 1.012 grams per cubic centimeter. Ground-water flow in the lower and upper alluvial aquifer is from the northern, southern, and western boundaries toward the river (figs. 17 and 18). Saturated thickness of the alluvial aquifer ranges from 62 ft in the river valley at the Pratt-Kingman County line to 170 ft in the plains near the northwest corner of the western part of the study area (fig. 19).

Layton and Berry (1973) determined the transmissivity and storage coefficient of the alluvial aquifer at two irrigation wells by aquifer-test analysis (table 1). These irrigation wells were located at 27S-13W-21ACA1 and 28S-13W-26DCB1 in the western part of the study area. Aquifer-test analyses of these wells also included data from two nearby observation wells. Layton and Berry (1973) postulated that had the aquifer tests continued for a longer period, the storage coefficients may have been in the range from 0.10 to 0.15 due to delayed drainage. The hydraulic conductivity was calculated for these two irrigation wells for this study (table 1). The transmissivity and hydraulic conductivity also were calculated from drawdown data from two irrigation wells south of the river in the western part of the study area (wells 28S-11W-10A and 28S-11W-32A, table 1). The aquifer-test data were analyzed using the straight-line method, also called the modified nonequilibrium method (Jacob and Lohman, 1952). Aquifer characteristics from all four irrigation wells are assumed to represent the upper and lower alluvial aquifer because the irrigation wells tested were screened in both parts of the aquifer, and lithologies penetrated by the four wells are similar.

Chloride Distribution in the Alluvial Aquifer

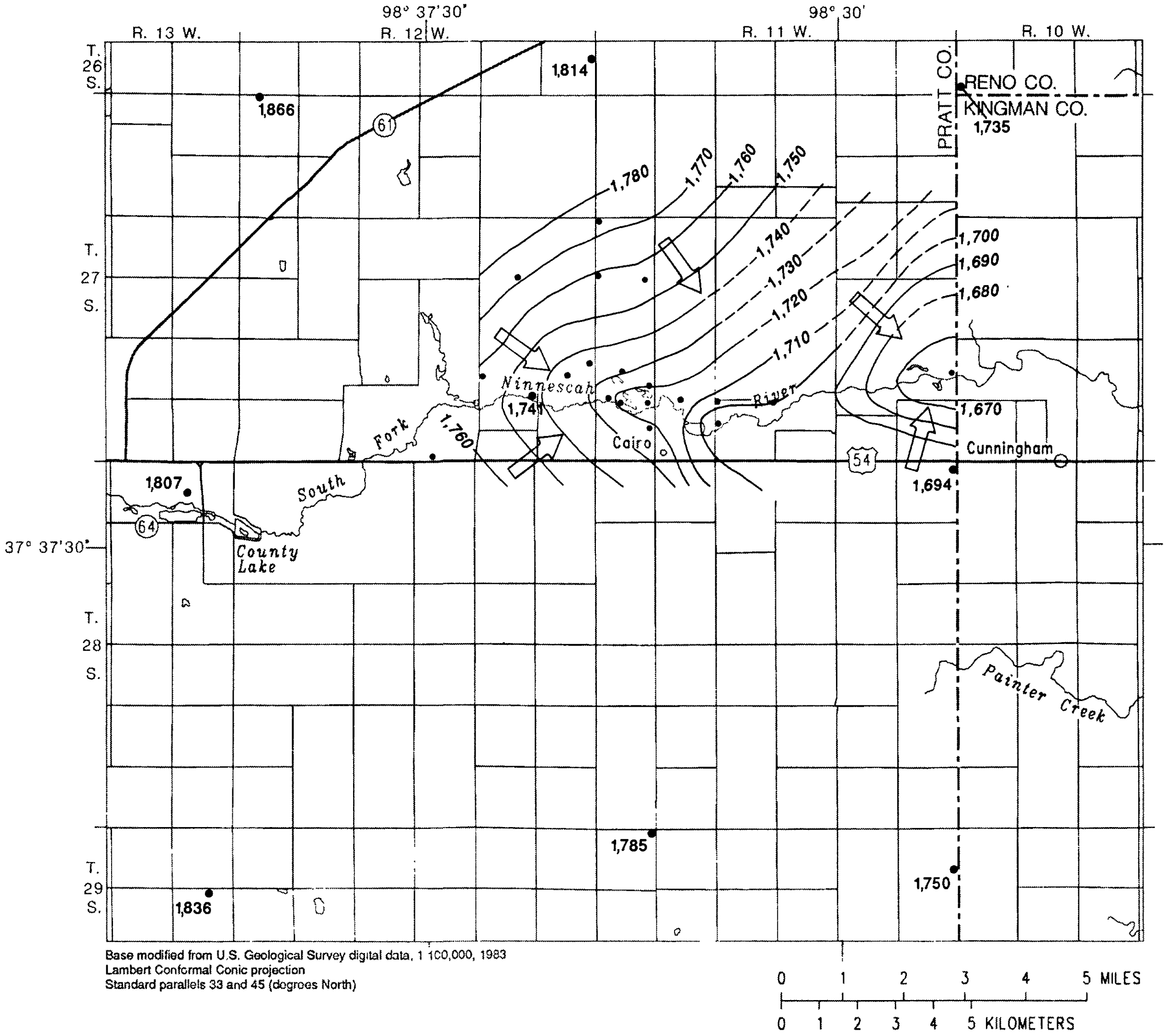
The chloride distribution in the upper alluvial aquifer is shown in figure 20A. Chloride concentrations ranged from 4 mg/L in wells 27S-11W-30ADDD and 27S-11W-32AACD to 11,300 mg/L in well 27S-11W-31AAAC2 just on the north side of the river north of Cairo. The chloride distribution in the lower alluvial aquifer is shown in figure 20B. The chloride concentrations ranged from 14 mg/L in well 29S-11W-01DADA2 near the southeast corner of the study area to 16,800 mg/L in well 27S-12W-06BABA2 near the northwest corner of the area. In general, the larger chloride concentrations were identified in the areas where saline ground water discharges to the river and overlie the area where salt is present or is near the edge of the salt in the Ninnescah Shale. Chloride concentrations in a section approximately perpendicular to the river in the area of saline ground-water discharge are shown in figure 21.

Water samples also were collected from the upper alluvial aquifer from 0.5-in.-diameter drive points 3 ft beneath below the streambed of the South Fork Ninnescah River (fig. 15). Chloride concentrations from these samples ranged from 22 mg/L near the left bank of the river north of Cunningham to 7,400 mg/L near the left bank of the river north of Cairo. Samples were collected from different locations beneath the river at the sampling site in the major areas of saline ground-water discharge. At 27S-11W-31BADD northwest of Cairo, the chloride concentration beneath the river near the left bank was 3,200 mg/L and near the right bank, 100 mg/L. In general, saline ground water discharges near the left bank and freshwater near the right bank in the predominant area of saline ground-water discharge.

Permian Rocks

Aquifer Characteristics

The configuration of the fluid-potential surface in the Permian rocks in the western part



EXPLANATION

—*1,700*— LINE OF EQUAL FLUID-POTENTIAL LEVEL--Shows altitude of fluid level in lower alluvial aquifer not corrected for variable density. Dashed where approximate. Interval 10 feet. Datum is sea level.

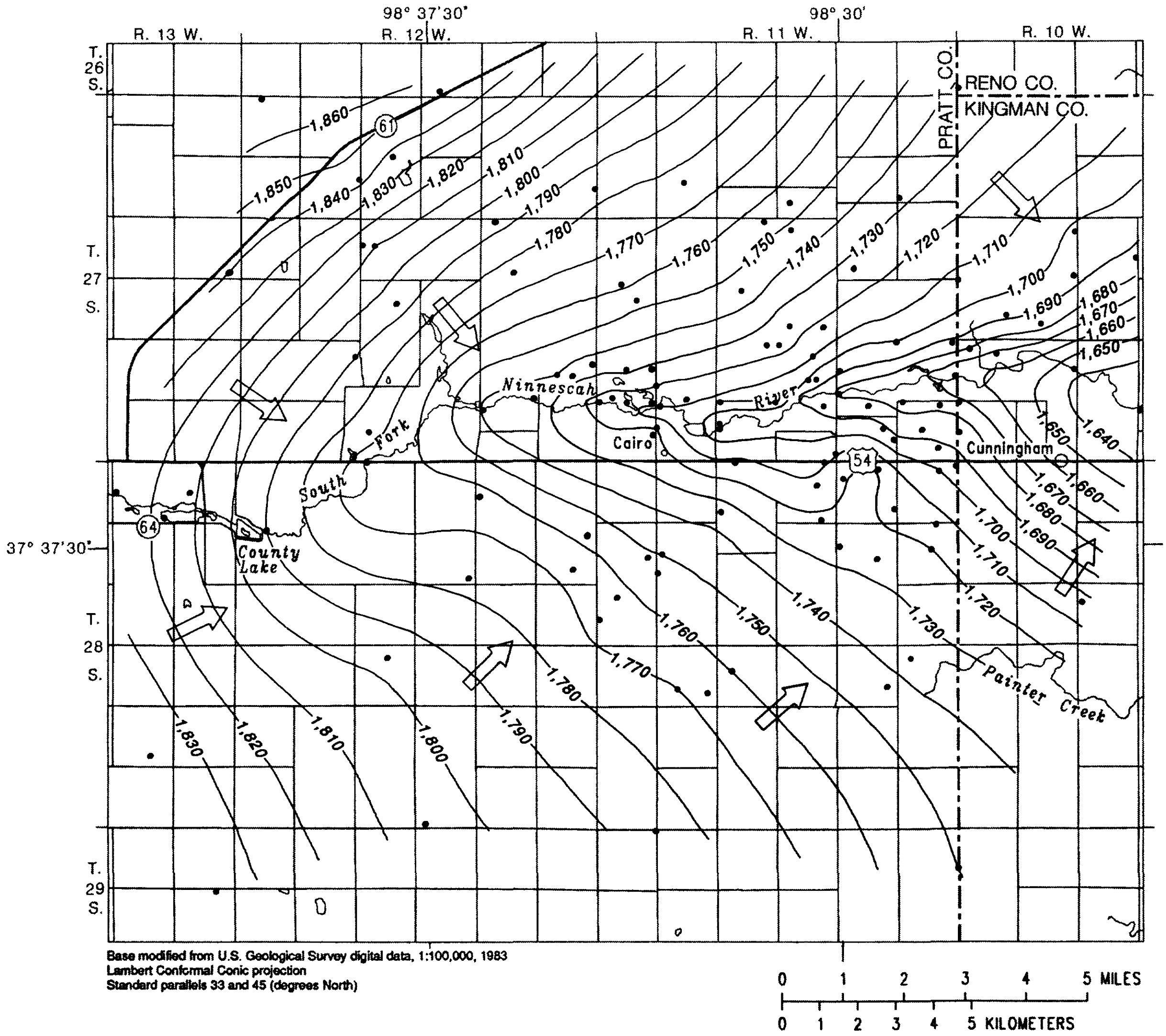
⇨ APPROXIMATE DIRECTION OF GROUND-WATER FLOW

• U.S. BUREAU OF RECLAMATION-U.S. GEOLOGICAL SURVEY GROUND-WATER MONITORING SITE

1,836• GROUNDWATER MANAGEMENT DISTRICT NO. 5 GROUND-WATER MONITORING WELL--Number indicates altitude of fluid level in lower alluvial aquifer not corrected for variable density, in feet. Datum is sea level.

Figure 17. Altitude of fluid-potential levels in lower alluvial aquifer in western part of the study area, winter 1990.

of the study area, as determined from measurements in the winter of 1990, is shown in figure 16. Lines of equal fluid level for the entire area were not drawn because of insufficient data. In the western part of the study area, ground-water flow in the Permian rocks is from the northern, southern, and, western boundaries toward the river, approximately perpendicular to the lines of equal fluid-potential level (fig. 16). Near the river, flow lines in the Permian rocks bend upward toward the South Fork Ninnescah River (fig. 21). The only



EXPLANATION

——1,820—— FLUID-POTENTIAL CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Contour interval 10 feet. Datum is sea level

⇨ APPROXIMATE DIRECTION OF GROUND-WATER FLOW

• MONITORING WELL

Figure 18. Altitude of fluid-potential surface in upper alluvial aquifer in western part of study area, winter 1990.

fluid-potential level data available from the Permian rocks are from wells that are completed in the top of the rocks. No fluid-potential level data were available from deeper within the Salt Plain Formation or the underlying Permian formations.

The hydraulic conductivity of the Permian rocks was determined from aquifer tests utilizing recovery or slug-test analyses in five of the U.S. Bureau of Reclamation-U.S. Geological Survey monitoring wells (table 2 and fig. 16). Recovery analysis for a constant drawdown test, as described by Jacob and Lohman (1952), was used on a flowing artesian well that flowed for 4 hours at constant discharge of 0.39 gal/min. Slug-test data were analyzed from four wells using a method described by Cooper and others (1967). The five hydraulic-conductivity values

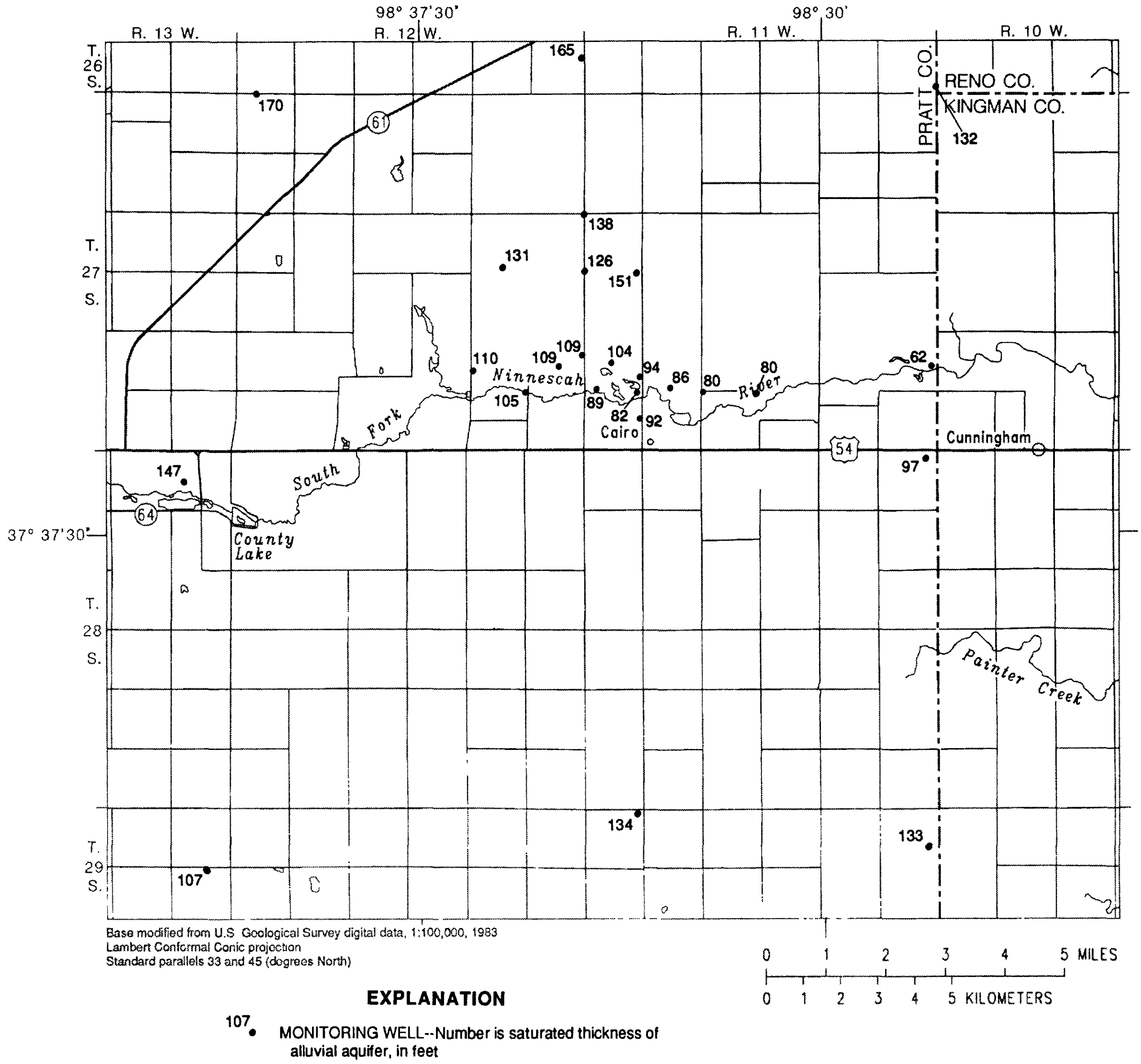


Figure 19. Saturated thickness of alluvial aquifer determined at selected wells in western part of study area, winter 1990.

averaged 0.5 ft/d and ranged from 0.2 to 0.7 ft/d (table 2). Locally, the hydraulic conductivity could be greater because of fracturing and possible brecciated zones due to collapse of the Permian formations into the salt-bed cavities in the Ninnescah Shale.

Chloride Distribution in Permian Rocks

Chloride distribution in the top of the Permian rocks is shown in figure 20C. Chloride concentrations ranged from 31 mg/L in well 29S-13W-12ABBA in the west-southwest part of the study area to 32,700 mg/L in well 27S-12W-35AAAA next to the South Fork Ninnescah River near the area where the major chloride-concentration increase in river water begins. In general, as with alluvial chloride distribution, the larger chloride concentrations are in the major area where saline ground water discharges to the river and overlie the area where salt is present or are near the edge of the salt in the Ninnescah Shale. Chloride concentrations in a section approximately perpendicular to the river in the area of saline ground-water discharge are shown in figure 21.

Table 1. *Results of aquifer tests in alluvial aquifer in eastern Pratt County, Kansas*

Well number (fig. 2)	Transmissivity (feet squared per day)	Hydraulic conductivity (feet per day)	Storage coefficient	Remarks
27S-13W-21ACA1	21,000	155	0.001	Data from Layton and Berry (1973)
28S-11W-10A	21,000	200	([1])	
28S-11W-32A	26,000	200	([1])	
28S-13W-26DCB1	21,000	200	0.002	Data from Layton and Berry (1973)
Average[2]	22,000	190		

[1]Storage coefficients calculated from drawdown data from a pumped well generally are not reliable.
[2]Rounded to two significant figures.

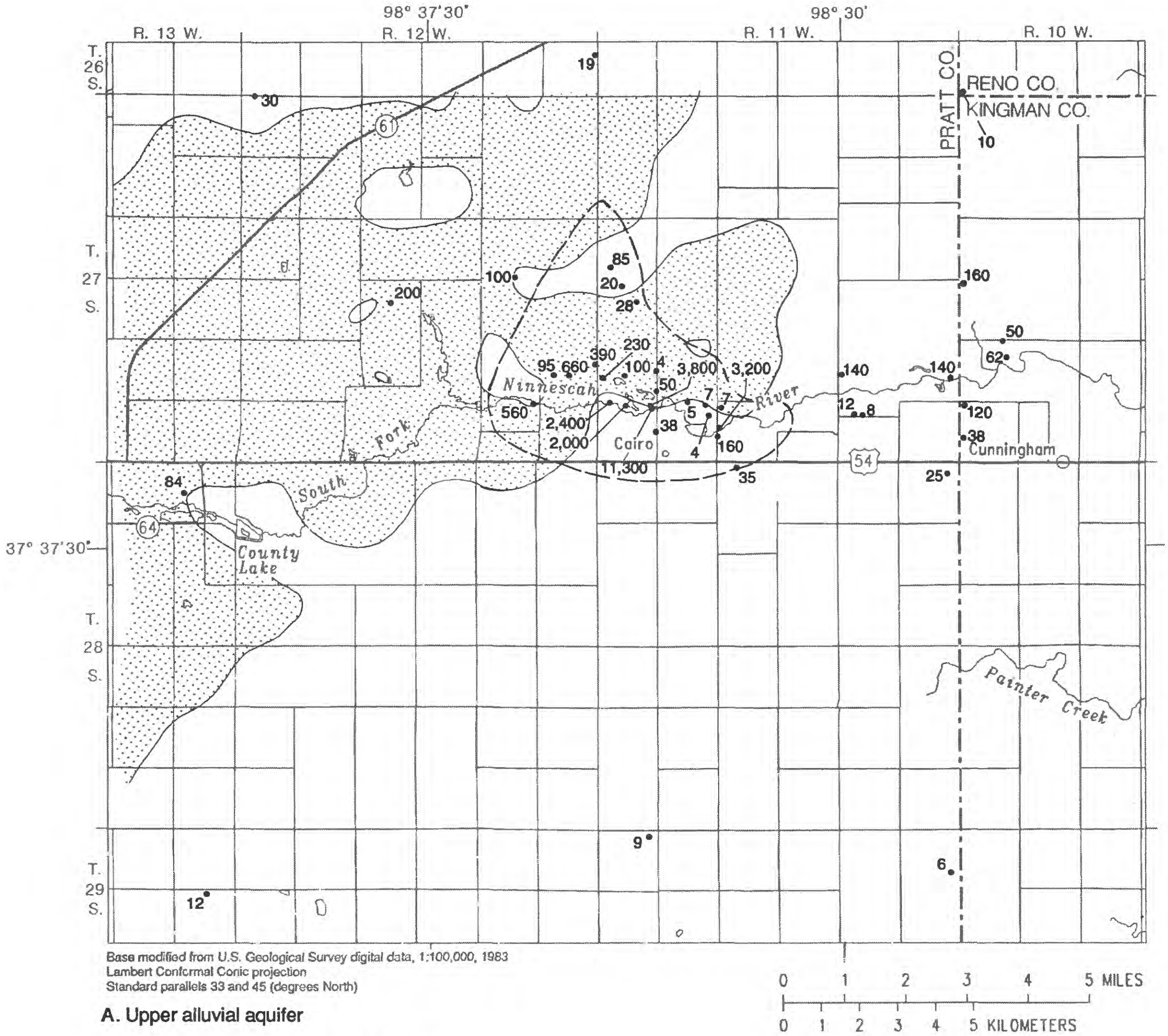
Areas of Saline Ground Water Identified By Electromagnetic Terrain Survey

Electromagnetic terrain surveys were used to delineate areas of saline ground water and to measure the apparent terrain conductivity of the combined soil, rock, and interstitial water from the land surface to the depth of exploration of the instrument. The electromagnetic instrument used in this study was an EM-34-3[1] manufactured by Geonics Ltd., Ontario, Canada, and is briefly described by Grady (1989). For a more detailed explanation of the instrument and its operation, the reader is referred to the manufacturer's series of technical notes (McNeill, 1980a, b).

Fourteen electromagnetic terrain surveys were conducted to help delineate the areas of alluvial saline ground water in the South Fork Ninnescah River Valley (fig. 22A). Eleven of these electromagnetic terrain survey traverses were perpendicular to the river and are presented in figure 23 in downstream order. Each graph shows three curves depicting a series of apparent terrain-conductivity measurements taken every 131 ft along the traverse in respect to the distance north or south of the river. The curves represent exploration depths of 25, 50, and 99 ft. In general, the graphs show that the apparent terrain conductivity, thus the salinity of the ground water, increases with depth in the river valley (fig. 20). However, in segments of traverses 6 and 9 north of the river, the apparent terrain-conductivity values in the shallower exploration depths are as great or greater than at the deeper depth. This indicates that the salinity of the ground water at these two locations is approximately the same vertically and probably reflects upward vertical movement of ground water. At these two locations, surface-water samples from small streams in the marsh area contained chloride concentrations of 5,800 to 10,800 mg/L, respectively (fig. 15). The variability of the apparent terrain-conductivity in traverse 14 northwest of Cunningham may be the result of past leakage of oil-field brine from surface disposal pits, leaky disposal wells, or broken pipelines (Robert Maxedon, local landowner, oral commun., 1989).

An electromagnetic terrain survey was conducted along a 6-mi reach in the South Fork Ninnescah River from the county bridge at 27S-11W-31BBBB to the county bridge at 27S-11W-27DDDA (fig. 22). The EM-34-3 was mounted on floats with a 33-ft intercoil spacing and in the horizontal dipole mode. Apparent conductivity measurements were made every 50 ft as the electromagnetic terrain-conductivity meter was floated down the river, which averaged about 1 ft in depth. The conductivity measurements were made near the left bank or north edge of the river because most of the saline ground-water discharge enters the river from the north. Relatively large conductivity values would reflect relatively large salinity in the ground water beneath the riverbed. Figure 22B shows that saline ground water is entering the river in intermittent reaches along the river rather than along the entire reach as previously assumed. The largest apparent

[1]The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.



A. Upper alluvial aquifer

EXPLANATION

AREA WHERE "NINNESCAH SALT" BED IN NINNESCAH SHALE IS PRESENT

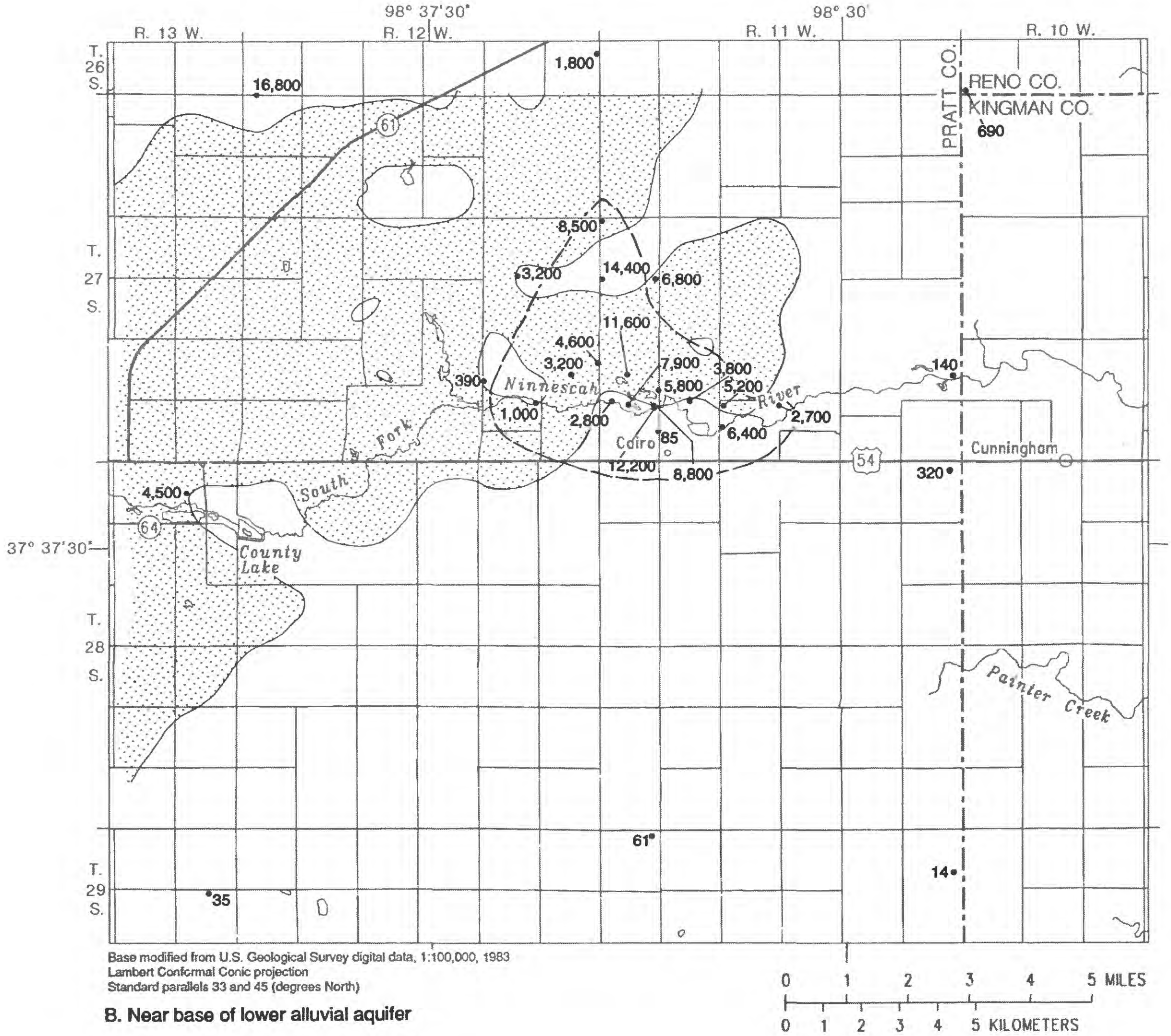
— — FLUID-POTENTIAL LEVEL BOUNDARY--Approximate boundary of area where fluid levels in wells in Permian rocks are higher than fluids in lower alluvial aquifer (corrected for variable density)

25• MONITORING WELL--Number is chloride concentration, in milligrams per liter

Figure 20. Chloride concentrations in water samples collected from wells completed (A) in upper alluvial aquifer, (B) near base of lower alluvial aquifer, and (C) in top of Permian rocks in western part of study area.

conductivity, at county bridge at 27S-11W-32BBBC north of Cairo (fig. 22, map reference letter C), coincides with the greatest increase in chloride concentration in the South Fork Ninnescah River as determined by seepage- salinity surveys.

The source of the saline ground-water discharge to the South Fork Ninnescah River is brine discharge from the Permian rocks to the alluvial aquifer, which then discharges to the river (fig. 24 A-E). The chloride discharge to the river in the 5-mi reach of saline ground-water discharge is about 63 ton/d, based on the November 2, 1988, salinity-seepage survey. If it is assumed that the water in the Permian rocks has a chloride concentration of approximately 33,000 mg/L (fig. 20C), the mean daily briny



EXPLANATION

AREA WHERE "NINNESCAH SALT" BED IN NINNESCAH SHALE IS PRESENT

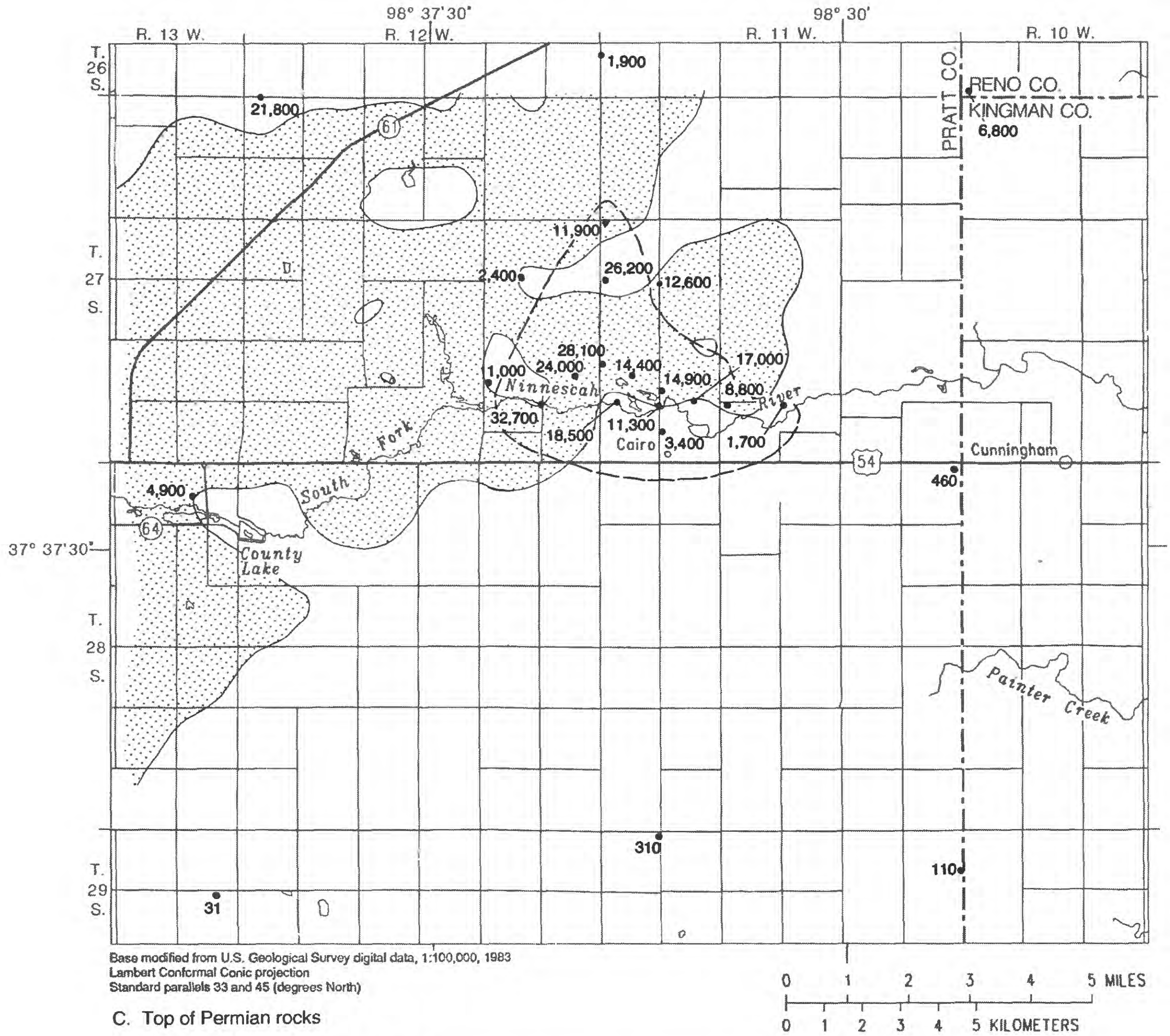
FLUID-POTENTIAL LEVEL BOUNDARY--Approximate boundary of area where fluid levels in wells in Permian rocks are higher than fluids in lower alluvial aquifer (corrected for variable density)

320 MONITORING WELL--Number is chloride concentration, in milligrams per liter

Figure 20. *Chloride concentrations in water samples collected from wells completed (A) in upper alluvial aquifer, (B) near base of lower alluvial aquifer, and (C) in top of Permian rocks in western part of study area--Continued.*

ground-water discharge from the Permian rocks to the alluvial aquifer may be estimated by the equation:

$$\text{Discharge (cubic feet per second)} = \frac{\text{chloride discharge (tons per day)}}{0.0027\,(\text{conversion factor}) \times \text{chloride concentration (milligrams per liter)}}. \quad (1)$$



C. Top of Permian rocks

EXPLANATION

AREA WHERE "NINNESCAH SALT" BED IN NINNESCAH SHALE IS PRESENT

FLUID-POTENTIAL LEVEL BOUNDARY--Approximate boundary of area where fluid levels in wells in Permian rocks are higher than fluids in lower alluvial aquifer (corrected for variable density)

460 MONITORING WELL--Number is chloride concentration, in milligrams per liter

Figure 20. Chloride concentrations in water samples collected from wells completed (A) in upper alluvial aquifer, (B) near base of lower alluvial aquifer, and (C) in top of Permian rocks in western part of study area--Continued.

Thus, the rate of briny ground-water discharge would be about 0.7 ft^3/s or 300 gal/min. The total ground-water discharge from the Permian rocks to the alluvial aquifer cannot be estimated.

The base-flow increase of the river from Pratt to the Pratt-Kingman County line of 67 ft^3/s is estimated to be the approximate ground-water discharge from the alluvial aquifer (fig. 12). Therefore, the briny ground-water discharge comprises approximately 1 percent of the discharge to the river.

FLOW AND MIXING OF FRESH AND SALINE WATER

Saline ground water discharges to the river near the center of the western part of the study

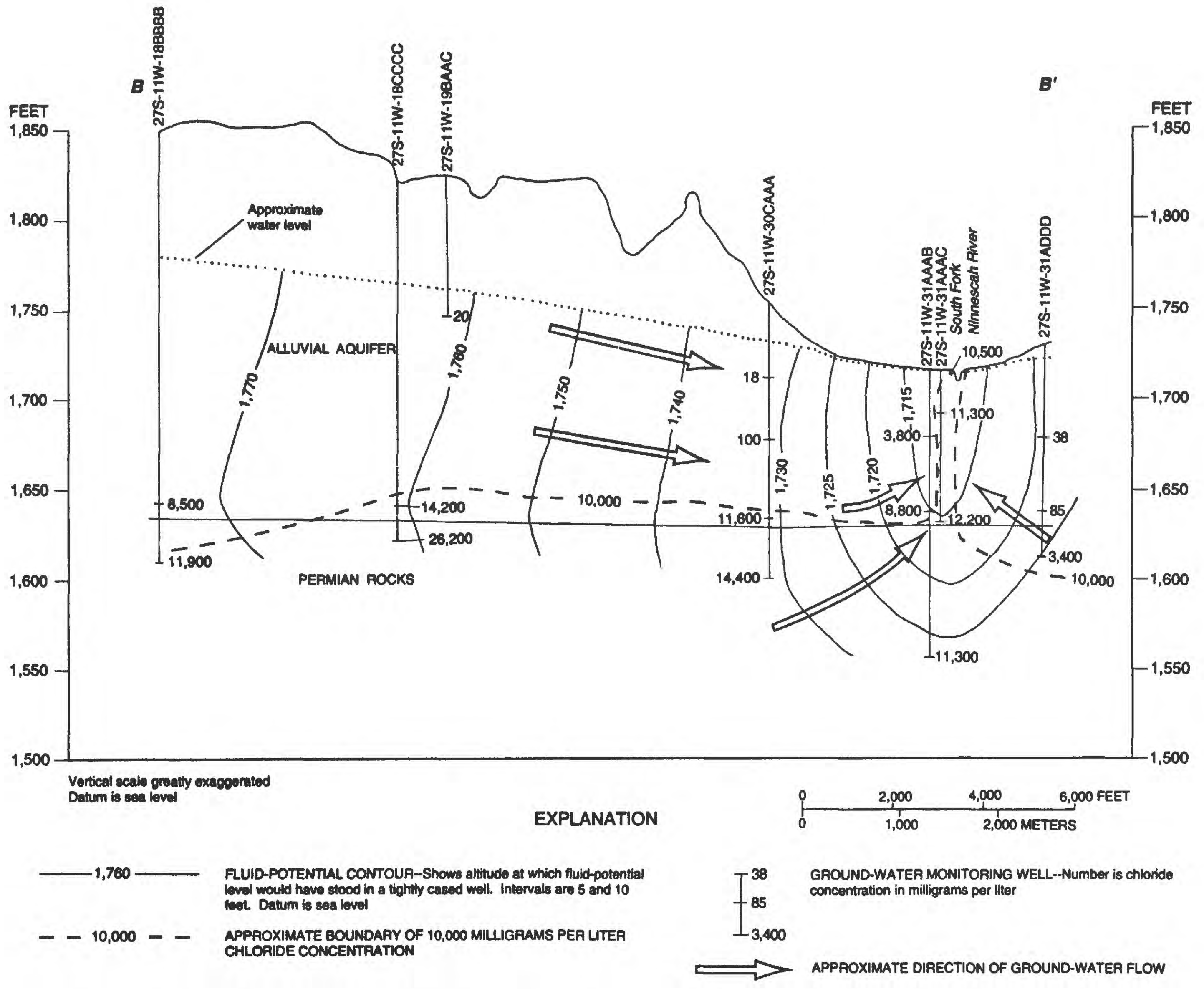


Figure 21. Lines of equal fluid potential and chloride concentrations in alluvial aquifer and in top of Permain rocks, winter 1990. Trace of section shown in figure 9.

Table 2. *Results of recovery and slug tests in Permian rocks in eastern Pratt County, Kansas*

Well number (fig. 16)	Hydraulic conductivity (feet per day)	Type of test
27S-11W-30CCDD	0.7	Recovery
27S-11W-31ADDD	.2	Slug
27S-11W-33BBBB	.7	Slug
27S-12W-25ADDA	.5	Slug
27S-12W-25DBBC	.4	Slug
Average	.5	

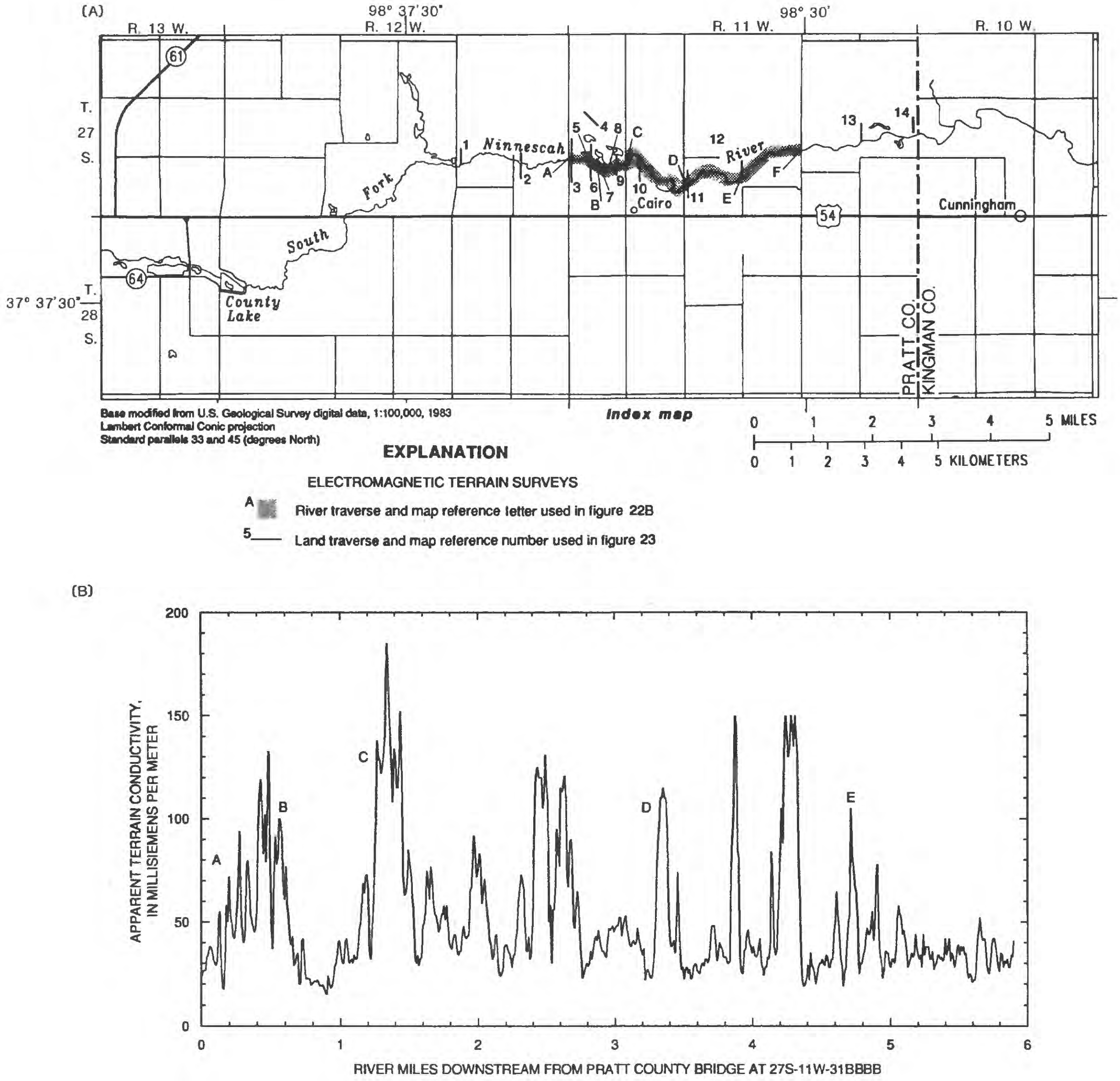


Figure 22. (A) Location of traverses and (B) apparent terrain conductivity for South Fork Ninnescah River electromagnetic survey traverse, 1989.

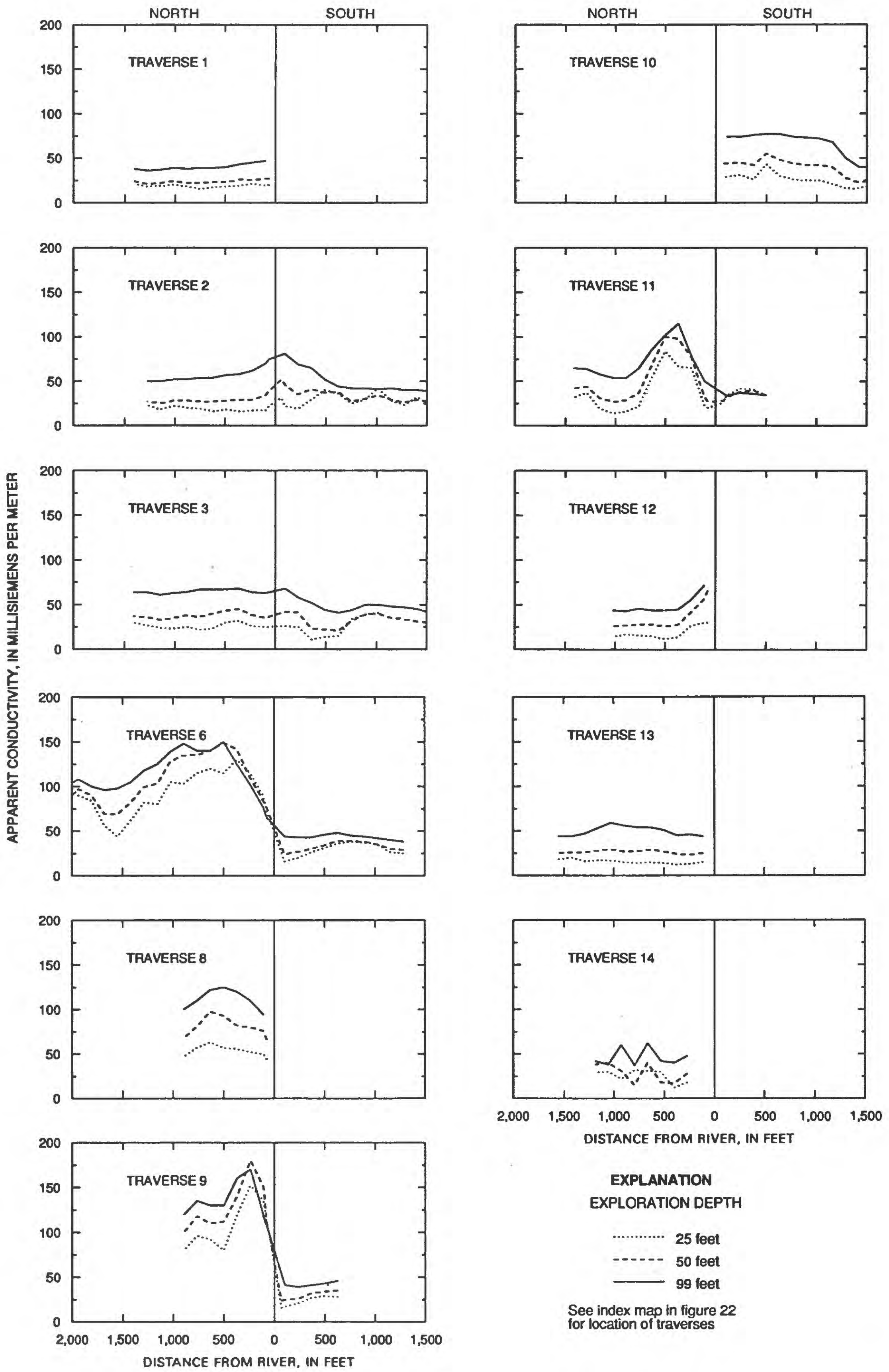
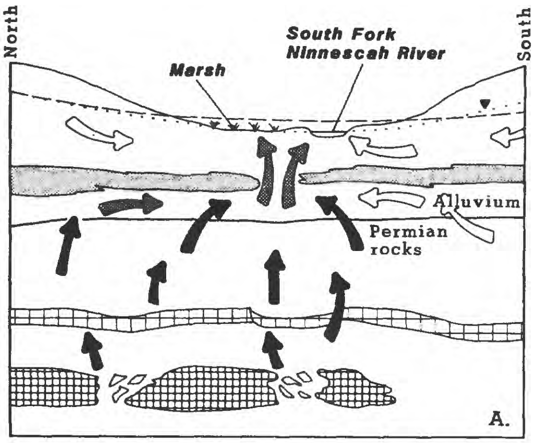
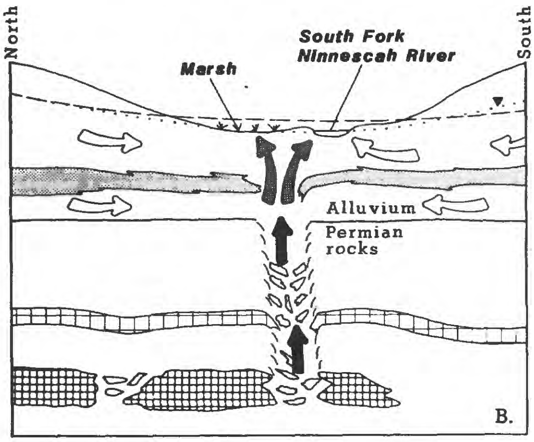


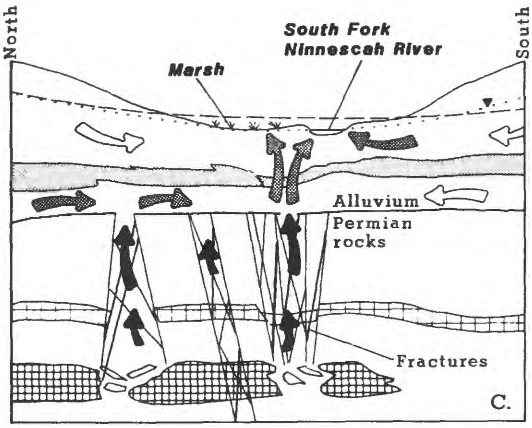
Figure 23. Apparent terrain conductivity along electromagnetic survey traverses perpendicular to South Fork Ninnescah River, 1989.



A. Brine flows upward through the Permian rocks from the salt-dissolution zone through the granular interstices of the siltstone and fine sandstone to the alluvium. The brine enters the alluvium in a localized area near the river, mixes with freshwater, moves upward as saline ground water through an opening between discontinuous clay or silt layers of the middle alluvium, and discharges to the river or marsh.

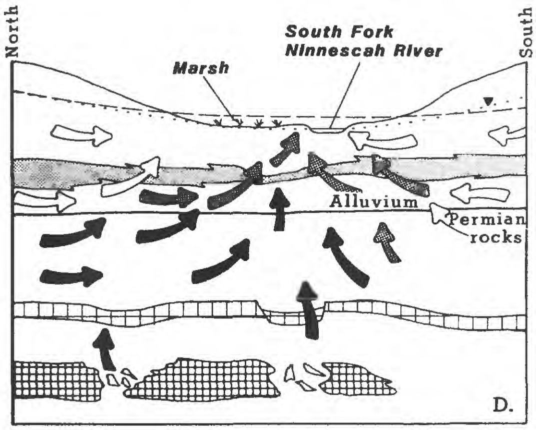


B. Brine flows upward from the salt-dissolution zone through the brecciated rubble caused by the collapse of the overlying beds into a cavity in the salt bed. The collapse also has opened a breach in the middle alluvium. The brine mixes with freshwater in the localized area of this collapse structure, and saline water flows through the breach and discharges to the river or marsh.

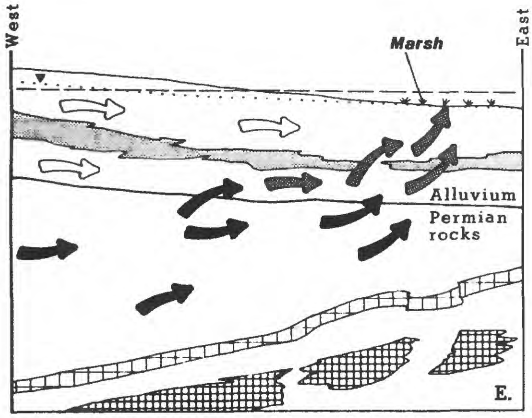


C. Brine flows upward from the salt-dissolution zone through fractures in the Permian rocks caused by slight movements along pre-Permian faults underlying the area. Brine mixes with freshwater in the alluvium and flows upward as saline ground water through the middle alluvium and discharges to the river or marsh. The area in which brine flows into the alluvium could be localized near the river or the area could extend away from the river.

Figure 24. Hypotheses for the discharge of saline ground water to South Fork Ninnescah River.



D. Brine flows upward from the salt-dissolution zone through the granular interstices of the siltstone and fine sandstone to the alluvium. The brine enters the alluvium in a large area extending away from the river, mixes with freshwater, moves through lower alluvial aquifer as saline ground water toward the river, then flows upward through the middle alluvium, and discharges to the river or marsh.



E. The brine source is not the salt-dissolution zone in the Ninnescah Shale directly underlying the river or area as in the other hypotheses. The source is brine in the Salt Plain Formation that flows downgradient from the west of the study area and enters the alluvium, mixes with freshwater, and flows upward as saline ground water through the middle alluvium, and discharges to the river or marsh.

NOT TO SCALE

EXPLANATION

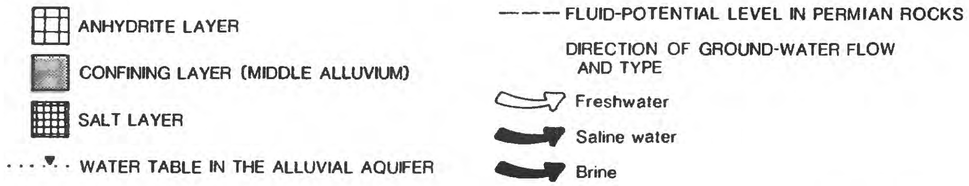


Figure 24. Hypotheses for the discharge of saline ground water to South Fork Ninnescah River--Continued.

area and is the main emphasis of this report. Five hypotheses on how the saline ground water discharges to the South Fork Ninnescah River in a relative localized area are shown and described in figure 24. All or any combination of these hypotheses could be active in the localized area.

The following ground-water discussion is restricted to the western part of the study area, focusing in and near the South Fork Ninnescah River Valley in the vicinity of Cairo. This area is the major area of saline ground-water discharge to the river.

Hydrographs representing 8 years of fluid-potential level data from eight ground-water monitoring wells in Big Bend Ground-water Management District No. 5 are shown in figure 25. These data indicate that fluid-potential levels in the alluvial aquifer near the northern, southern, and western boundaries of

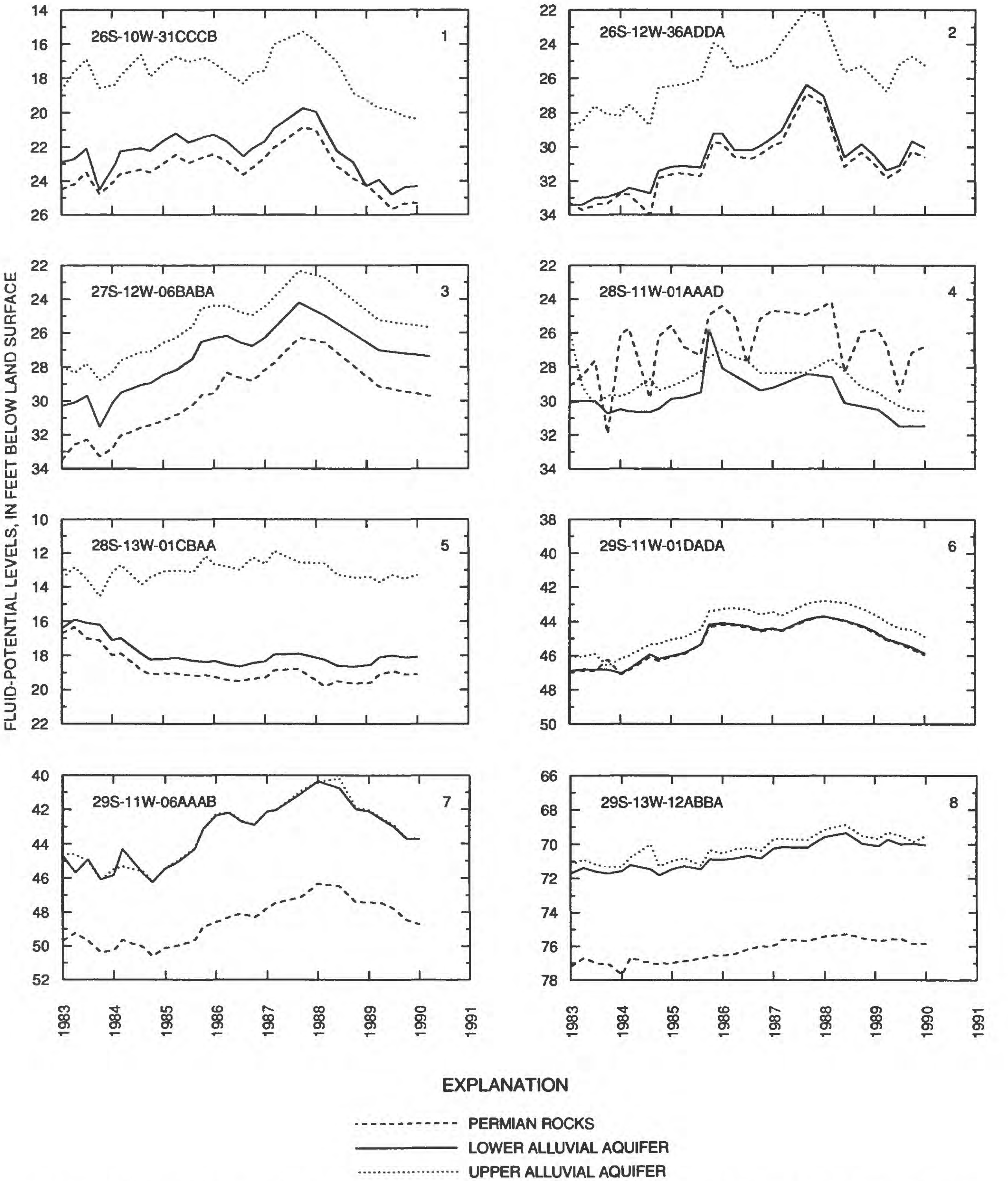


Figure 25. Fluid-potential levels at selected Groundwater Management District No. 5 ground-water monitoring wells for lower and upper alluvial aquifer and Permian rocks, 1983-90 (wells located in figures 16 and 17).

the western part of the study area are higher than the Permian-rock fluid-potential levels. Fluid-potential levels in the Permian-rock aquifer well 28S-11W-01AAAD near the eastern boundary of the western part of the study area are higher than the alluvial-aquifer fluid-potential levels. Also, the hydrographs at each site show hydraulic connection among aquifers as they respond similarly to the stresses on the ground-water system (similar fluid-potential level fluctuations). The fluid-potential level in the upper alluvial-aquifer monitoring well 28S-13W-01CBAA is affected by an adjacent stock pond.

Winter 1990 data from the U.S. Bureau of Reclamation-U.S. Geological Survey ground-water monitoring sites show that the fluid-potential levels in the Permian rocks were higher than the alluvial-aquifer fluid-potential levels in the major area where saline ground water is discharged to the South Fork Ninnescah River. The differences between the fluid-potential levels and water levels corrected and noncorrected for variable density in wells in the lower alluvial aquifer and Permian rocks are shown in figure 26. There are 10 wells in the outlined areas in which the fluid-potential levels in the Permian rocks were higher than fluid-potential levels in the lower alluvial aquifer when not corrected for variable density. Three of these wells near the river had fluid-potential levels higher than the land surface. Because both the alluvial aquifer and the Permian rocks contained ground water of variable density, a hydrostatic method (Jorgensen and others, 1982) was used to determine if different hydrostatic conditions exist between the two units. If hydrostatic conditions do not exist flow results. After correction for variable density, 13 wells (outlined area in figs. 20 and 26) had fluid-potential levels in the Permian rocks higher than fluid-potential levels in the lower alluvial aquifer. Therefore, corrections for density result in an even greater indication of flow between the two units. In general, chloride concentrations in the monitoring wells in the lower alluvial aquifer and Permian rocks were larger within these outlined areas (fig. 20).

Most of the ground-water movement from the ground-water divides north and south of the river valley is downgradient through the alluvial aquifer to the river. Fluid-potential levels suggest that, in general, a small component of ground water moves from the alluvial aquifer into the Permian rocks in these areas to the north, south, and also the west where the alluvial-aquifer fluid-potential levels are higher than the fluid-potential levels in the Permian rocks. Deep downward movement of this relatively fresh ground water, through fractures, may be the source of the ground water that is causing the dissolution of the salt bed in the Ninnescah Shale. The larger chloride concentrations within the outlined area also indicate that ground water is moving upward from the Permian rocks to the alluvial aquifer and into the South Fork Ninnescah River.

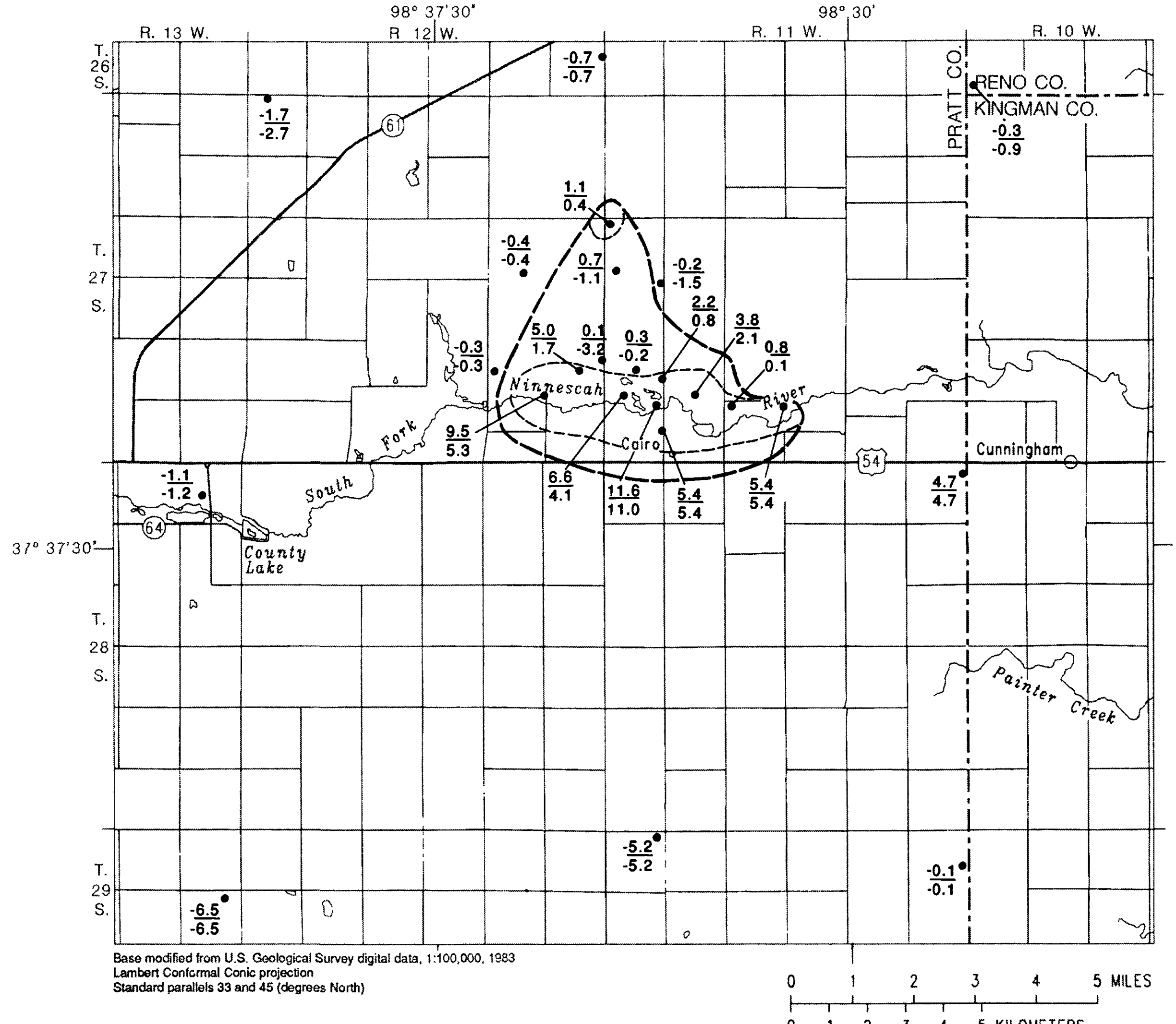
ALTERNATIVES FOR POTENTIAL ALLEVIATION OR CONTROL OF SALINE GROUND-WATER DISCHARGE

Several alternative methods for reduction of natural saline ground-water discharge have been suggested by the Kansas Water Office (Hargadine and others, 1979). The following alternative methods were considered:

(1) Construction of dams, diversion canals, storage reservoirs, and pump systems for the collection, storage, suppression, transmittal, and disposal of brines.

(2) Interception of brine flow by pumping of relief wells: The use of relief wells may reduce the natural saline ground-water discharge to the South Fork Ninnescah River. The relief wells, screened in the Permian rocks beneath and near the river valley in the area of maximum saline ground-water discharge to the river, might effectively decrease saline ground-water discharge to the river. In this area, fluid-potential levels in the Permian rocks are higher than fluid-potential levels in the alluvial aquifer (fig. 26). To decrease the saline ground-water discharge to the alluvium and ultimately to the river, proper well spacing and pumping rates would have to be established to lower fluid-potential levels in the Permian rocks to levels below the levels in the alluvial aquifer. Brine could be disposed by injection into deeper formations, by storage in evaporation reservoirs, or by desalinization.

(3) Diversion of fresh surface water and in-channel saline-water storage: Fresh surface water in the South Fork Ninnescah River upstream from the saline ground-water discharge area could be diverted through a canal to bypass the saline ground-water discharge area. However, the stream discharge at this point is only about one-third of the increase in



EXPLANATION

——— FLUID-POTENTIAL LEVEL BOUNDARY--Approximate boundary of area where fluid-potential levels in wells in Permian rocks are higher than fluid-potential levels in lower alluvial aquifer. Corrected for variable density

– – – FLUID-POTENTIAL LEVEL BOUNDARY--Approximate boundary of area where fluid-potential levels in wells in Permian rocks are higher than fluid-potential levels in lower alluvial aquifer. Not corrected for variable density

-6.5 / -6.5 • MONITORING WELL--Upper number is difference, in feet, between fluid-potential levels in a well in the Permian rocks and lower alluvial aquifer that have been corrected for variable density; Lower number is difference, in feet, that has not been corrected for variable density (positive number = fluid-potential level in Permian rocks is higher than fluid-potential level in lower alluvial aquifer; negative number = fluid-potential level in lower alluvial aquifer is higher than fluid-potential level in Permian rocks)

Figure 26. Difference between fluid-potential levels in monitoring wells in lower alluvial aquifer and Permian rocks in western part of study area, winter 1990.

streamflow from saline ground-water discharge. The channel of the South Fork Ninnescah River is about 10 ft deep and 100 ft wide. Therefore, a series of dams in the river channel may not create enough reservoir volume or hydrostatic head to contain the saline-water, in-channel storage.

(4) Reduction of brine flow by hydrostatic pressure: The brine flow from the Permian rocks

may be reduced by applying hydrostatic pressure to the saline ground-water discharge area. The fluid-potential levels in the Permian rocks are about 9 ft above the valley floor and about 20 ft above the river level. However, a dam high enough to create a reservoir to reduce the upward brine inflow to the alluvium would have to inundate most of the valley. Hydrostatic pressure may eventually cause the brine to move downgradient and flow under the dam and then into the river.

(5) Dilution is used in some areas of Kansas to improve the water quality in rivers. The drainage area in the South Fork Ninnescah River Basin above the primary saline ground-water discharge area would have a small surface-water yield, and there is no available dam site for surface-water storage.

(6) Reduction of recharge to subsurface salt beds: Reduction of recharge to the subsurface salt beds may reduce the dissolution of the salt and may decrease brine production. However, the recharge area to Permian rocks and the salt beds in the Ninnescah Shale covers an extensive area. The Permian bedrock is overlain completely by the alluvial aquifer; thus recharge occurs in any area where the fluid-potential levels are higher in the alluvial aquifer than in the Permian rocks.

SUMMARY

Planning officials and water managers of Sedgwick County and the Wichita metropolitan area are concerned about future water supplies. Saline water entering the South Fork Ninnescah River affects municipal, industrial, and irrigation water supplies. The South Fork Ninnescah River may serve as a potential source of water supply if the chloride content of the river could be reduced. To study saline ground-water discharge, a cooperative investigation of the South Fork Ninnescah River in Pratt and Kingman Counties was undertaken from July 1988 through June 1991. Chloride concentrations in the South Fork Ninnescah River near Murdock exceed 250 mg/L, 75 percent of the time. Most of the saline water is discharged from the alluvial aquifer into the South Fork Ninnescah River near Cairo in eastern Pratt County. During a stable period of base flow in November 1988, the stream discharge increased from 11 to 79 ft^3/s, and the chloride concentration increased from 39 to 394 mg/L, between Pratt and the Pratt-Kingman County line.

Saline water in the alluvial aquifer results from mixing of freshwater in the alluvial aquifer with brine from the underlying Permian rocks (in ascending order: the Ninnescah Shale, Stone Corral Formation, Harper Sandstone, and Salt Plain Formation). The brine source may originate from the dissolution of the salt bed in the Ninnescah Shale, about 600 ft below land surface. Subsidence and collapse into salt-dissolution cavities may cause fracturing in the overlying Permian siltstone, fine sandstone, shale, and dolomite. Slight movement along pre-Permian faults in the area also has created fracturing. Brine moves upward through the Permian rocks and discharges into the alluvial aquifer. The brine discharge to the alluvium is estimated to be about 0.7 ft^3/s or 300 gal/min. In the major area of saline ground-water discharge to the river in a 5-mi reach near Cairo, fluid-potential levels in the Permian rocks are higher than fluid-potential levels in the lower alluvial aquifer. In general, within this area of higher fluid-potential levels in the Permian rocks, the ground water in the lower alluvial aquifer and Permian rocks is saline. South of the South Fork Ninnescah River, ground water in the lower alluvial aquifer generally is fresh, and the ground water in the Permian rocks is fresh or slightly saline.

Electromagnetic terrain surveys in the area indicated that saline ground water is entering the river along the 5-mi reach at intermittent points rather than along the entire reach as previously assumed. Electromagnetic terrain surveys also indicated local areas of relatively large chloride concentrations in the alluvial aquifer north of the river in this same area.

Ground water flows from the ground-water divides to the north and south downgradient to the South Fork Ninnescah River. Most of the water moves downgradient through the alluvial aquifer; however, a small component flows through the Permian rocks and discharges saline water to the alluvial aquifer and thence into the river. The average hydraulic conductivity of the Permian siltstone and alluvium is about 0.5 and 190 ft/d, respectively.

Several methods for reducing the saline ground-water discharge to the South Fork Ninnescah River have been suggested. The most effective of these methods appears to be interception of brine flow in the Permian rocks by pumping of relief wells. Brine could be disposed by injection into deeper formations, by storage in evaporation reservoirs, or by desalinization.

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SUPPLEMENTAL INFORMATION

Table 3. *Lithologic logs of monitoring wells drilled by U.S. Bureau of Reclamation*

[All altitudes are referenced to sea level and are reported to the nearest foot. Depth is reported in feet below land surface. Location of wells shown in figure 2]

27S-11W-18BBBB.--Drilled June 2, 1989.
Altitude of land surface, 1,847 feet.

	Thickness, in feet	*Depth, in feet*
Sand, tan, fine	3	3
Soil, gray-brown, tough	3	6
Clay, brown, silty, iron stains, somewhat sandy	16	22
Silty tan, clayey	18	40
Sand, fine, grading to sand and gravel, coarse	18	58
Clay, tan	1	59
Sand and gravel, orange, arkosic, and quartzose clay stringers in lower part	36	95
Sand, tan, fine	4	99
Clay, tan, silty-sandy, soft	18	117
Sand and gravel, orange, quartzose and arkosic, some ironstone	35	152
Clay, white-tan, sandy, soft	6	158
Sand and gravel, arkosic, quartzose, with clay lenses	7	165
Sand, tan, clay bound	9	174
Sand, tan, fine	24	198
Sand, tan, equigranular, with abundant ironstone	14	212
Shale, red, silty-sandy, with some siltstone-sandstone; contains some gray-green streaks and spots	32	244

27S-11W-18CCCC.--Drilled May 1989.
Altitude of land surface, 1,818 feet.

	Thickness, in feet	*Depth, in feet*
Soil, clay, dark-brown, silty	3	3
Clay, light gray-green, silty	9	12
Silt and fine sand, orange	12	24
Sand, tan, fine-to-coarse, arkosic, with some small gravel	43	67
Sand, orange, medium-to-coarse, with some small gravel	37	104
Sand, tan, fine-to-medium, with clay layers	31	135
Clay, white, light-gray, silty, and fine sand	19	154
Sand, orange, medium-to-coarse, with some gravel, arkosic and quartzose; contains abundant ironstone	30	184
Siltstone and sandstone, red, shaly	20	204

Table 3. *Lithologic logs of monitoring wells drilled by U.S. Bureau of Reclamation*--Continued

27S-11W-19AAAB.--Drilled May 21, 1989.
Altitude of land surface, 1,812 feet.

	Thickness, in feet	*Depth, in feet*
Soil, dark-brown, silty	7	7
Clay, brown, silty and sandy	16	23
Sand, with clay layers, tan, some clay-bound sand, caliche zone at 35-36 feet	27	50
Sand, brown, fine-coarse	13	63
Clay, tan, sandy	2	65
Sand, tan, medium-to-coarse	10	75
Sand and gravel, coarse	17	92
Sand, tan, medium-to-coarse	43	135
Sand, tan, fine-to-medium, silty	45	180
Sand and gravel, orange, arkosic, quartzose; abundant ironstone below 200 feet	27	207
Clay, red and white, silty	3	210
Shale, red, silty-sandy	35	245

27S-11W-29CDDD.--Drilled June 7, 1989.
Altitude of land surface, 1,722 feet.

	Thickness, in feet	*Depth, in feet*
Soil, brown, very sandy	4	4
Clay, gray, silty, sandy, few sand layers	24	28
Sand and gravel, orange, with quartzose and arkosic	17	45
Clay, tan, silty, tough	10	55
Sand and gravel, orange, with abundant dark-brown ironstone	39	94
Clay, tan, with caliche, tough, some cemented	3	97
Ironstone gravel, dark-brown, equigranular	2	99
Shale, red, sandy-silty, with some sandstone-siltstone; contains gray-green streaks and spots	26	125

27S-11W-30CAAA.--Drilled April 28, 1989.
Altitude of land surface, 1,750 feet.

	Thickness, in feet	*Depth, in feet*
Soil, tan, brown, sandy	5	5
Sand, fine, tan, grading to sand and gravel, arkosic and quartzose, tan-pink	39	44
Clay, tan, silty	4	48
Sand and gravel, pink, quartzose and arkosic	39	87
Clay, tan	3	90

Table 3. *Lithologic logs of monitoring wells drilled by U.S. Bureau of Reclamation*--Continued

27S-11W-30CAAA.--Continued

	Thickness, in feet	*Depth, in feet*
Sand and gravel, quartzose and arkosic, tan-pink; lots of ironstone, gravel below 110 feet	31	121
Shale, silty and sandy, red, weathered in upper part of grading to sandstone-siltstone, with a few thin gray-green streaks in lower part	34	155

27S-11W-30CCDD.--Drilled May 26, 1989
Altitude of land surface, 1,721 feet.

	Thickness, in feet	*Depth, in feet*
Soil, dark-brown, sandy, silty	3	3
Sand and gravel, orange, medium-to-coarse, arkosic quartzose (pea size)	22	25
Clay, tan, silty	3	28
Sand, fine-to-coarse, some gravel, orange, arkosic	26	54
Clay, tan, silty	16	70
Sand, tan, medium-to-coarse, ironstone in lower part	24	94
Siltstone-sandstone, red, with some gray-green streaks	30	124

27S-11W-30DDAA.--Drilled April 26, 1989.
Altitude of land surface, 1,736 feet.

	Thickness, in feet	*Depth, in feet*
Soil, clayey, with gray-tan sand	2	2
Sand and gravel, tan, composed of quartz, feldspar, and brown limestone	10	12
Clay, tan, stiff	7	19
Sand, tan, fine, clayey	7	26
Sand and gravel, tan	4	30
Clay, tan, sandy	4	34
Sand, tan, fine, clayey	3	37
Clay, tan, sandy	3	40
Sand and gravel, tan, quartzose and arkose	27	67
Clay, tan, sandy	6	73
Sand and gravel, fine-to-coarse, composed mostly of quartz, feldspar, and ironstone	36	109
Shale, red, silty	26	135

Table 3. *Lithologic logs of monitoring wells drilled by U.S. Bureau of Reclamation*--Continued

27S-11W-31AAAB.--Drilled May 11, 1989.
Altitude of land surface, 1,714 feet.

	Thickness, in feet	*Depth, in feet*
Soil, tan, very sandy; sand, orange, fine	4	4
Sand, orange, fine	4	8
Sand and gravel, orange, coarse, arkosic and quartzose	29	37
Silt, light-tan, clayey, grading to tan-yellow; clay, slick	12	49
Clay, tan, sticky	5	54
Silt and fine sand, tan, clayey	6	60
Sand and gravel, orange, arkosic and quartzose, with abundant ironstone gravel	24	84
Shale, red, silty, and sandy, weathered to a pink clay in upper 3 to 4 feet; contains a few gray-green streaks and specks	46	130
Shale, red, silty and sandy, clayey; contains a few gray-green streaks and specks	15	145
Shale, red, silty and sandy, not as much clay as above; contains a few gray-green streaks and specks	19	164

27S-11W-31ADDD.--Drilled May 29, 1989.
Altitude of land surface, 1,728 feet.

	Thickness, in feet	*Depth, in feet*
Soil, dark-brown, sandy and silty	3	3
Sand, light-brown, silty	9	12
Clay, gray, silty	12	24
Sand and gravel, orange, medium-to-coarse, quartzose and arkosic	12	36
Sand, tan, fine-to-medium, with silt	37	73
Sand, tan, medium-to-coarse, with abundant ironstone	26	99
Shale, red, silty, and siltstone, red	25	124

27S-11W-33AAAA.--Drilled May 5, 1989.
Altitude of land surface, 1,728 feet.

	Thickness, in feet	*Depth, in feet*
Soil, red-brown, very sandy	4	4
Sand, red-brown, clayey, with a few large gravels	3	7
Sand and gravel, orange, arkosic and quartzose	20	27
Clay, tan-white, tough, with sandy layers and a caliche layer at about 39-40 feet	18	45
Sand, tan, fine, little clayey	20	65
Clay, tan, sandy and silty (mixes in drilling mud)	24	89

Table 3. *Lithologic logs of monitoring wells drilled by U.S. Bureau of Reclamation*--Continued

27S-11W-33AAAA.--Continued

	Thickness, in feet	*Depth, in feet*
Sand and gravel, arkosic and quartzose, with lots of ironstone gravel	16	105
Shale, silty, sandy, red, weathered in upper part	10	115
Sandstone-siltstone, red, firm dry pieces; contains gray-green streaks and specks, becoming shaly in lower part	30	145

27S-11W-33BBBB.--Drilled May 3, 1989.
Altitude of land surface, 1,718 feet.

	Thickness, in feet	*Depth, in feet*
Soil, tan-red brown, sandy	6	6
Sand and gravel, orange, arkosic and quartzose, some coarse	14	20
Clay, tan, soft	2	22
Sandy, orange, fine-to-medium	18	40
Clay, tan, soft	3	43
Sand, orange, fine-to-medium (lots of fine sand)	10	53
Clay, tan, silty, firm	8	61
Sand, orange, fine-to-medium, arkosic and quartzose abundant ironstone in lower part	31	92
Shale, silty and clayey, tan on top 2-3 feet, red below (weathered on top)	11	103
Siltstone-sandstone, mostly red, with some gray-green streaks and specks	11	114

27S-12W-14DCDC.--Drilled May 31, 1989.
Altitude of land surface, 1,822 feet.

	Thickness, in feet	*Depth, in feet*
Soil, brown, very sandy	3	3
Silt, tan, clayey	7	10
Clay, light tan-white, silty, with abundant caliche	22	32
Sand and gravel, orange, quartzose and arkosic	8	40
Clay, tan, light-tan, silty (mixes in drilling mud)	12	52
Caliche, white	3	55
Clay, tan, light-tan, silty	5	60
Silt and fine sand, tan	7	67
Sand, tan, fine	11	78
Sand and gravel, orange, with lots of ironstone	6	84
Sand, tan, fine	10	94
Sand and gravel, quartzose and arkosic, with some light-brown-colored ironstone, finer in lower part	48	142
Clay, tan, firm	3	145

Table 3. *Lithologic logs of monitoring wells drilled by U.S. Bureau of Reclamation*--Continued

27S-12W-14DCDC.--Continued

	Thickness, in feet	*Depth, in feet*
Sand, tan, fine, clayey	12	157
Clay, light-tan to white	8	165
Sand and gravel, arkosic and quartzose, with lots of ironstone gravel	17	182
Shale, red, silty, sandy, with gray-green streaks and spots	16	198
Sandstone, siltstone, red, with gray-green streaks and spots	12	210
Shale, red, silty-sandy, with gray-green streaks and spots	4	214

27S-12W-25ADDA.--Drilled May 1, 1989.
Altitude of land surface, 1,748 feet.

	Thickness, in feet	*Depth, in feet*
Soil, brown, very sandy	5	5
Sand, tan, fine	4	9
Sand and gravel, arkosic, orange	6	15
Clay, red-brown, sandy	2	17
Sand and gravel, tan to orange, arkosic and quartzose	5	22
Clay, tan, sticky, some black clay, with sandy stringers below 36 feet	33	55
Sand and gravel, pink, arkosic and quartzose	16	17
Silt, tan, clayey	10	81
Sand and gravel, orange, quartzose and arkosic, clay bound above 100 feet, grading to clean sand and gravel, with lots of pieces of ironstone below that point	40	121
Sandstone, red, few shaly layers; contains few thin gray-green streaks and spots	26	147

27S-12W-25 DBBC.--Drilled June 5, 1989.
Altitude of land surface, 1,743 feet.

	Thickness, in feet	*Depth, in feet*
Soil, tan-brown, sandy	3	3
Clay, tan, silty and sandy	3	6
Sand, tan, fine	4	10
Sand and gravel, orange, arkosic and quartzose	8	18
Silt, gray, soft	3	21
Sand and gravel, orange, arkosic and quartzose	9	30
Clay, black, mucky, soft	7	37
Sand and gravel, coarse, arkosic and quartzose	8	45
Clay, black, mucky soft	6	51
Sand, fine, tan, with silt	23	74
Clay, tan, tough	13	87

Table 3. *Lithologic logs of monitoring wells drilled by U.S. Bureau of Reclamation*--Continued

27S-12W-25 DBBC.--Continued

	Thickness, in feet	*Depth, in feet*
Sand, orange, fine-to-medium, arkosic, quartzose; contains lots of ironstone	16	103
Clay, tan, silty, tough	3	106
Sand, orange, arkosic and quartzose, with lots of ironstone	12	118
Shale, red, silty, sandy, with gray-green streaks and specks; below 135 feet, not much sample return, thus could be grading to sandstone, siltstone	37	155

27S-12W-26CBBC.--Drilled May 8, 1989.
Altitude of land surface, 1,767 feet.

	Thickness, in feet	*Depth, in feet*
Soil, tan, brown, sandy	3	3
Sand, red-brown clayey, some large gravel	8	11
Sand and gravel, orange, arkosic and quartzose, fine-to-medium, some coarse; contains some pieces of light-brown-colored ironstone; below 70 feet, some clay layers in sand and gravel	76	87
Clay, tan, sandy, some tough gray clay	18	105
Sand and gravel, orange, with 3-4 feet of cemented morter bed above the shale	15	120
Shale, red, silty, sandy, grading to sandstone, siltstone, shaly; contains some gray-green streaks and spots, weathered in upper part	24	144

Table 4. *Specific conductance and chloride concentrations in samples collected from monitoring and selected water wells completed in the alluvial aquifer and Permian rocks, 1982-89*

[--, indicates no information]

Well number	Date collected (month-day-year)	Depth of well (feet)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Chloride concentration (milligrams per liter)
Wells completed in upper alluvial aquifer (fig. 20A)				
26S-10W-31CCCB3	10-30-84	71	451	10
26S-12W-36ADDA3	10-30-84	85	418	19
27S-10W-19BBBB	--	--	--	160
27S-10W-19DCCD	04-20-89	111	580	50
27S-10W-30ABDC	04-20-89	--	550	62
27S-10W-31BBBB	04-20-89	90	800	120
27S-10W-31CBBB	04-20-89	95	480	38
27S-11W-18CCAA	07-18-89	--	723	85
27S-11W-19ACAC	05-03-89	146	544	28
27S-11W-19BAAC	05-03-89	112	533	20
27S-11W-25DAAD2	10-19-89	30	912	140
27S-11W-26BCBB	--	--	--	140
27S-11W-29CDDD3	10-11-89	41	422	5
27S-11W-30ADDD	03-02-89	--	375	4
27S-11W-30CAAA3	10-04-89	78	834	100
27S-11W-30CAAA4	10-04-89	40	405	18
27S-11W-30CBBD	05-10-89	--	1,040	230
27S-11W-30CCDD3	10-11-89	--	7,770	2,400
27S-11W-30DDAA3	10-04-89	66	550	50
27S-11W-31AAAB4	10-18-89	37	11,900	3,800
27S-11W-31AAAC2	10-18-89	29	32,000	11,300
27S-11W-31ADDD3	10-04-89	56	526	38
27S-11W-31BAAA2	03-01-90	39	6,630	2,000
27S-11W-32AABB	05-03-89	--	421	7
27S-11W-32AACD	06-23-89	--	402	4
27S-11W-32DAAA	05-04-89	--	916	160
27S-11W-33BBBB3	10-11-89	52	421	7
27S-11W-33BCCB2	03-08-90	29	10,600	3,200
27S-11W-35BACD	03-02-90	--	431	8
27S-11W-35BADC	03-02-90	--	461	12
27S-12W-06BABA3	10-30-84	90	495	30
27S-12W-14DCCB	05-03-89	--	624	100

Table 4. *Specific conductance and chloride concentrations in samples collected from monitoring and selected water wells completed in the alluvial aquifer and Permian rocks, 1982-89*--Continued

Well number	Date collected (month-day-year)	Depth of well (feet)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Chloride concentration (milligrams per liter)
Wells completed in upper alluvial aquifer (fig. 20A)--Continued				
27S-12W-21ACCA	05-03-89	--	1,140	200
27S-12W-25ADDA3	10-04-89	70	1,625	390
27S-12W-25CABC	04-20-89	92	590	95
27S-12W-25DBBC3	10-06-89	70	2,560	660
27S-12W-35AAAA3	11-23-82	51	2,270	560
28S-11W-01AAAD3	10-26-84	57	552	25
28S-11W-04BABB	04-05-89	--	514	35
28S-13W-01CBAA3	10-26-84	103	660	84
29S-11W-01DADA3	10-24-84	85	462	6
29S-11W-06AAAB3	10-24-84	78	470	9
29S-13W-12ABBA3	10-24-84	82	425	12
Wells completed near base of alluvial aquifer (fig. 20B)				
26S-10W-31CCCB2	03-08-83	155	2,670	690
26S-12W-36ADDA2	03-07-83	192	6,620	1,800
27S-11W-18BBBB2	06-06-89	212	25,200	8,500
27S-11W-18CCCC2	05-25-89	183	37,800	14,200
27S-11W-19AAAB2	05-25-89	205	18,400	6,800
27S-11W-25DAAD	10-19-89	64	855	140
27S-11W-29CDDD2	10-03-89	92	11,800	3,800
27S-11W-30CAAA2	10-04-89	120	32,100	11,600
27S-11W-30CCDD2	06-05-89	93	8,890	2,800
27S-11W-30DDAA2	05-02-89	108	17,000	5,800
27S-11W-31AAAB3	10-18-89	84	26,200	8,800
27S-11W-31AAAC	10-17-89	98	34,000	12,200
27S-11W-31ADDD2	06-06-89	97	529	85
27S-11W-31BAAA	03-01-90	91	22,700	7,900
27S-11W-33AAAA2	05-08-89	105	9,080	2,700
27S-11W-33BBBB2	05-04-89	90	15,400	5,200
27S-11W-33BCCB	03-08-90	--	18,900	6,400
27S-12W-06BABA2	03-07-83	196	46,600	16,800
27S-12W-14DCDC2	06-06-89	182	9,180	3,200
27S-12W-25DBBC2	05-05-89	118	10,300	3,200
27S-12W-26CBBC2	05-10-89	120	1,730	390

Table 4. *Specific conductance and chloride concentrations in samples collected from monitoring and selected water wells completed in the alluvial aquifer and Permian rocks, 1982-89*--Continued

Well number	Date collected (month-day-year)	Depth of well (feet)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Chloride concentration (milligrams per liter)
Wells completed near base of alluvial aquifer (fig. 20B)--Continued				
27S-12W-35AAAA2	11-23-82	89	3,830	1,100
28S-11W-01AAAD2	12-14-82	116	1,400	320
28S-13W-01CBAA2	04-26-83	157	14,200	4,500
29S-11W-01DADA2	12-09-82	150	477	14
29S-11W-06AAAB2	12-12-82	164	610	61
29S-13W-12ABBA2	04-26-83	158	470	35
Wells completed in top of Permian aquifer (fig. 20C)				
26S-10W-31CCCB	12-23-82	173	21,400	6,800
26S-12W-36ADDA	03-07-83	209	6,910	1,900
27S-11W-18BBBB	06-06-89	244	33,900	11,900
27S-11W-18CCCC	05-25-89	203	62,200	26,200
27S-11W-19AAAB	05-25-89	235	33,800	12,600
27S-11W-29CDDD	10-03-89	125	45,600	17,000
27S-11W-30CAAA	05-03-89	154	39,900	14,400
27S-11W-30CCDD	05-30-89	124	50,100	18,500
27S-11W-30DDAA	05-02-89	127	39,800	14,900
27S-11W-31AAAB2	10-18-89	133	33,300	11,300
27S-11W-31ADDD	06-06-89	124	12,600	3,400
27S-11W-33AAAA	05-08-89	143	7,130	1,700
27S-11W-33BBBB	05-04-89	111	25,100	8,800
27S-12W-06BABA	05-26-83	215	56,800	21,800
27S-12W-14DCDC	06-06-89	214	7,890	2,400
27S-12W-25ADDA	05-04-89	147	75,800	28,100
27S-12W-25DBBC	06-06-89	155	83,100	24,000
27S-12W-26CBBC	05-10-89	144	3,830	1,000
27S-12W-35AAAA	11-23-82	116	84,800	32,700
28S-11W-01AAAD	05-15-84	135	2,100	460
28S-13W-01CBAA	05-26-83	178	15,500	4,900
29S-11W-01DADA	07-15-86	192	810	110
29S-11W-06AAAB	07-07-86	195	1,460	310
29S-13W-12ABBA	11-12-84	188	510	31

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