Chemical Quality of Surface Waters and Sedimentation in the Saline River Basin Kansas

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ABSTRACT

This report gives the results of an investigation of the sediment and dissolved minerals that are transported by the Saline River and its tributaries.

The Saline River basin is in western and central Kansas; it is long and narrow and covers 3,420 square miles of rolling plains, which is broken in some places by escarpments and small areas of badlands. In the western part the uppermost bedrock consists predominantly of calcareous clastic sedimentary rocks of continental origin of Pliocene age and in most places is covered by eolian deposits of Pleistocene and Recent age. In the central part the exposed bedrock consists predominantly of calcareous marine sedimentary rocks of Late Cretaceous age. In the eastern part the exposed bedrock consists mainly of noncalcareous continental and littoral clastic sedimentary rocks of Early Cretaceous and Permian age. Fluvial deposits are in the valleys, and eolian materials are present over much of the uplands.

Average precipitation increases rather uniformly from about 18 inches per year in the west to almost 28 inches per year in the east. Runoff is not affected by irrigation nor regulated by large structures, but it is closely related to precipitation. Average runoff increases from less than 0.2 inch per year in the west to more than 1.5 inches per year in the east. Aquifers of the flood-plain and terrace deposits and of the Cretaceous Dakota Sandstone are the major sources of ground-water accretion to the streams.

In the upper reaches of the Saline River, the water is only slightly mineralized; during the period of record the specific conductance near Wakeeney never exceeded 750 micromhos per centimeter. In the lower reaches, however, the water is slightly mineralized during periods of high flow and is highly mineralized during periods of low flow; the specific conductance near Russell exceeded 1,500 micromhos per centimeter more than 80 percent of the time.

Near Russell, near Wilson, and at Tescott the water is of the calcium bicarbonate type when the specific conductance is less than about 1,000 micromhos per centimeter, but it is of the sodium chloride type when the specific conductance is more than about 1,500 micromhos per centimeter. The water is of the calcium bicarbonate, sodium bicarbonate, or sodium chloride type when the conductance is between 1,000 and 1,500 micromhos per centimeter.

Most of the increase in mineralization of the water is caused by inflow of highly mineralized ground water. The ground-water inflow was estimated to be 22 percent of the total streamflow at Tescott in 1948 and 60 percent in 1952. Mineralization increases and water quality deteriorates progressively downstream along nearly the entire Saline River, especially in the part of the area directly underlain by the Dakota Sandstone between the vicinities of Fairport and Wilson; sodium and chloride are the principal constituents

of water contributed by the Dakota. The total percentage of the salt in the Saline River that comes from oil-field brines is considered to be small.

The water in the upper Saline River is of good quality for domestic use except that it is hard; the water in the lower Saline River is of poor quality for domestic use because most of the time it is highly mineralized, is hard, and contains high concentrations of chloride and sulfate. In the upper reaches of the river, the water is of good quality for irrigation. In the lower reaches, if the water were impounded in a reservoir, it would be of good quality for irrigation during years of high flow and of very poor quality during years of low flow. The water in the lower reaches is of poor quality for industrial use because it is highly mineralized most of the time.

Relations of suspended-sediment discharge to water discharge were used with the long-term streamflow duration curves to compute the long-term average suspended-sediment discharges and concentrations at five locations. Sediment discharge is closely related to runoff. Sediment contributions from areas in the basin increased from 120 tons per square mile per year in the western part of the basin to 490 tons per square mile per year in the eastern part. The long-term averages of the suspended-sediment concentrations are influenced principally by the erodibility of the source material; they range from 2,600 to 4,600 ppm and are highest in the Paradise Creek basin, which is underlain by large areas of loess and the erodible Blue Hill Shale Member of the Carlile Shale.

Suspended sediment transported by the Saline River and its tributaries is mostly fine material; 63 to 76 percent is finer than 0.004 mm. In Paradise Creek and in Saline River near Russell, about 5 percent of the suspended sediment is sand; in Saline River near Wakeeney, Saline River at Tescott, and Wolf Creek, less than 1 percent of the suspended sediment is sand.

Large variations in the size of bed material at different points in the basin are due mainly to variations in the geologic source of the material. The bed material in the Saline River is much finer downstream from Sylvan Grove than upstream from Sylvan Grove, probably because of deposition of particles from suspension and because of addition of finer material from the banks and from tributaries.

Average unmeasured sediment discharges range from less than 1 percent of the total sediment discharge in Wolf Creek and in Saline River at Tescott to about 5 percent in Saline River near Wakeeney. Unmeasured sediment discharges of as much as 20 percent of the total sediment discharge were computed for individual days.

Probable specific weights of sediment deposits were computed by two methods. Computed specific weights based on the median particle size of the sediment ranged from 42 to 52 pounds per cubic foot for deposits that have not been compacted materially by overlying deposits or by alternate wetting and drying. Computed specific weights based on the percentage of material larger than 0.05 mm ranged from 52 to 73 pounds per cubic foot.

INTRODUCTION

The investigation of the chemical quality of surface waters and of the sedimentation in the Saline River drainage basin was made as part of the program of the Department of the Interior for the development of the Missouri River basin. The overall program includes plans for regulation and control of floodwaters, irrigation of agricultural land, production of hydroelectric power, pollution abatement, and propagation of fish and wildlife. Successful planning of economically feasible projects requires information both on the chemical quality of the water and on the sediments transported by the water; the purpose of this investigation is to obtain, present, and evaluate such information for the Saline River drainage basin.

This report summarizes the results of the investigation of chemical quality to September 1957 and of sedimentation to September 1959. It includes the results of some special studies of chemical quality in the 1958 and 1959 water years. Information is provided on the amounts, chemical character, and sources of the mineral constituents dissolved in the water; the amounts, particle-size distribution, and sources of the sediment transported by the water; and the probable specific weight the sediment would have if deposited in a reservoir.

The dissolved mineral constituents and sediment transported by the streams were derived mostly from the rocks and minerals that underlie the basin. They vary in amount and in character from one part of the basin to another. Variations are due partly to differences in geology and partly to differences in runoff characteristics; therefore, much of this report describes the geology and runoff characteristics of the basin and their relation to water quality and sedimentation.

PERSONNEL AND ACKNOWLEDGMENTS

This investigation was made under the successive supervision of P. C. Benedict, regional engineer, and D. M. Culbertson, district engineer, Lincoln, Nebr. E. R. Leeson, district engineer, Topeka, Kans., furnished unpublished streamflow records and results of flow-duration studies that were made in cooperation with the Kansas State Water Resources Board. L. W. Furness, hydraulic engineer, Topeka, Kans., contributed valuable data and interpretation of the runoff conditions in the basin. Two reports by W. H. Durum (1950, 1953) have been used as a basis for much of the discussion of chemical quality of water in this report.

PREVIOUS INVESTIGATIONS

During 1906–7 the U.S. Geological Survey (Parker, 1911, p. 204, 219–223) obtained comprehensive data on the turbidity and on the concentration of dissolved minerals in the Saline River near Sylvan Grove and some data for the Saline River and Salt Creek near Russell. From these data, Parker (1911, p. 220) concluded that the

Saline River is "one of the saltiest streams in the United States" and that the salt is derived from the saliferous shales of the Dakota Sandstone.

During March to November 1930 the Corps of Engineers, U.S. Army (U.S. Congress, 1934a, p. 215, 226, 227, 229; 1934b, p. 1053, 1076) obtained data on the monthly suspended-sediment discharge and on the particle-size distribution of bed material of the Saline River at Tescott. The Corps of Engineers concluded that the Saline River "transports the smallest amount of suspended sediment and has the lowest suspended-sediment concentration of any of the major streams in the Kansas River drainage area" (U.S. Congress, 1934a, p. 226). Data obtained in 1930 cannot be compared directly with data obtained after 1945 because of the differences in the methods of sampling, types of samplers, and procedures for computing monthly sediment discharges.

During 1940–46 the U.S. Bureau of Reclamation obtained data (unpublished) on the chemical quality of water in the Saline River and some of its tributaries. In July and August 1948 the U.S. Bureau of Reclamation (1950) made a sedimentation survey of Sheridan Lake on the upper Saline River.

DESCRIPTION OF THE DRAINAGE BASIN

The Saline River basin is in western and central Kansas, is about 200 miles long, and averages less than 25 miles in width. (See pl. 1.) The total drainage area is 3,420 square miles. Altitude ranges from 1,170 feet above sea level near Salina to about 3,470 feet at the western edge of the basin. The Saline River lies between the Solomon River on the north and the Smoky Hill River on the south. The headwaters are in Thomas County, and the confluence with the Smoky Hill River is near Salina.

Most of the tributaries are short and intermittent; some in the western part of the basin are ephemeral. Three principal tributaries—Paradise, Wolf, and Spillman Creeks—enter the Saline River from the northwest. The other principal tributary, Mulberry Creek, enters from the southwest.

Many of the largest towns in the vicinity are a short distance outside the basin; the largest is Salina, population 26,176, which is partly in the basin. The largest towns within the basin are Plainville, population 2,082, and Lincoln, population 1,636. (Population figures are from the 1950 published records of the Bureau of the Census.)

The basin is served by U.S. Highway 24 and State Route 18 from east to west and by six major north and south highways. Two lines of the Union Pacific Railroad serve the entire length of the basin, and lines of the Missouri Pacific Railroad and the Atchison, Topeka and Santa Fe Railway cross the extreme eastern part.

Agriculture and petroleum production are the principal industries of the basin. Agricultural land is divided about equally between cropland and pasture, and cattle are raised in all parts of the basin. Major oil fields are in Ellis, Russell, and Trego Counties; the important oil-producing centers are Ellis, Hays, Russell, and Ellsworth, just outside the basin on the south.

CLIMATE AND VEGETATION

The climate changes gradually through the length of the basin, mainly because of the small range in altitude and the nearly uniform latitude of the basin. The differences in climate, in conjunction with other factors, affect the amount of dissolved minerals and the sediment carried by the streams.

Average yearly temperatures are about 55°F throughout the basin, but the seasonal variations are large; temperatures of above 100°F and below 0°F occur nearly every year. The normal growing season ranges from about 155 days in the west to about 175 days in the east. The average date of last killing frost in the spring is April 25 in the east and April 30 in the west; the average date of the first killing frost in the fall is October 10 in the west and October 15 in the east.

Average precipitation increases rather uniformly from about 18 inches per year in the west to almost 28 inches per year near Salina and Lindsborg. Intense rainstorms are fairly common in the basin; 1- and 2-day rains of more than 5 inches have occurred at most of the Weather Bureau stations. Snowmelt normally contributes only a small part of the runoff.

The native vegetation of the basin is predominantly grass. The central part of the basin is described by Albertson and Weaver (1945) as being a typical mixed prairie region. The decrease in length and quantity of grass from east to west in the basin reflects the decrease in precipitation. Tall grasses—particularly bluestems, needlegrass, and bunchgrass—are dominant in the east, but they become mixed with short grasses in the central part of the basin. Blue grama and buffalograss are the dominant native grasses in the west, and even these maintain a lower density in the headwaters area.

GEOLOGY

Sedimentary strata, which range in age from Permian to Recent, crop out in the Saline River basin. In general, the bedrock geology can be separated into three major divisions: From the headwaters of the Saline to the vicinity of Sheridan Lake, the exposed bedrock is predominantly calcareous clastic sedimentary rocks of continental origin and of Pliocene age; from Sheridan Lake to the vicinity of Russell, the exposed bedrock consists largely of calcareous marine sedimentary rocks of Late Cretaceous age; and from Russell to a few miles west of Salina, the exposed bedrock is noncalcareous continental and littoral clastic sedimentary rocks of Early Cretaceous age. Relatively small outcrops of Permian rocks are in the extreme eastern part of the basin, and Quaternary deposits are scattered throughout the basin. Fluvial deposits are in the valleys, and eolian materials are present over much of the uplands. Bedrock geology and approximate extent of eolian materials (loess) are shown on plate 2.

A generalized stratigraphic column is shown in table 1. The geologic history of the rocks underlying the Saline River basin has been summarized by Frye (1945a, p. 22–31). The geology in specific parts of the Saline River basin has been discussed in detail by the following: Rubey and Bass, 1925; Bass, 1926; Plummer and Romary, 1942, 1947; Frye, Leonard, and Hibbard, 1943; Frye, 1945b; Frye and Swineford, 1946; Swineford, 1947; Runnels and Dubins, 1949; Swineford and Frye, 1951; Frye and Leonard, 1952; Prescott, 1955; Bayne, 1956; Frye, Leonard, and Swineford, 1956.

The Pliocene and Pleistocene history of the Saline River basin, which is strongly reflected in the present Saline River and its tributaries, has been discussed by Frye and Leonard (1952) and Frye, Leonard, and Swineford (1956).

TABLE 1.—*Generalized section of outcropping geologic formations (after Prescott, 1955)*

System	Series	Stratigraphic unit	Member	Thickness (feet)	Character
	Pleistocene and Recent	Alluvium		0–90	Sand, gravel, and silt in stream channels and underlying the flood plains. Along minor streams it is poorly sorted and contains a greater percentage of fine materials.
Quaternary		Dune sand		0–20	Fine to coarse wind-deposited sand.
		Terrace deposits (late Wisconsin)		0–55	Sand, gravel, silt, and clay derived principally from older alluvial deposits and from the Ogallala Formation. Deposits along tributary streams are generally poorly sorted and fine textured.

TABLE 1.—*Generalized section of outcropping geologic formations (after Prescott, 1955)*—Continued

System	Series	Stratigraphic unit		Member	Thickness (feet)	Character
Quaternary—Con.	Pleistocene	Sanborn Group	Bignell Loess		0-4	Light-tan silt that occurs in scattered localities.
			Peorian Loess		0-30	Light-tan to yellowish-gray silt that mantles the uplands in much of the area. In places is terminated upward by the Brady Soil of Schultz and Stout (1948).
			Loveland Formation		0-15	Massive tan to reddish-tan silt with thick soil of Sangamon age at top.
			Crete Formation		0-25	Sand and gravel with some silt and clay. Generally overlain by loess of the Loveland or Peoria.
		Meade Group	Sappa Formation		0-15	Silt, clay, and fine sand. Contains the Pearlette Ash Member. Occurs in only a few places.
			Grand Island Formation		0-15	Sand, gravel, silt, and clay. Occurs in only a few places.
Tertiary	Pliocene	Ogallala Formation			0-150	Sand, gravel, silt, and clay predominantly calcareous. May be consolidated or unconsolidated. Contains beds of limestone, caliche, and "quartzite."
		—Unconformity—				
Cretaceous	Upper	Niobrara Formation		Smoky Hill Chalk Member	100±	Chalk and chalky shale, blue gray, yellow, and tan. Contains a silicified zone and some bentonite.
				Fort Hays Limestone Member	50±	Chalk and chalky limestone with some thin beds of chalky shale. Light to dark gray.
		Carlile Shale		Codell Sandstone Member	250±	Sandstone, fine grained and silty. Locally may be represented by silty shale and thin sand laminae in shale.
				Blue Hill Shale Member		Clayey, gray-black to dark-gray noncalcareous shale.
				Fairport Chalky Shale Member		Gray to blue-gray calcareous shale.
		Greenhorn Limestone			90±	Gray chalky shale and chalky limestone.
		Graneros Shale			40±	Dark-gray noncalcareous shale.
	Lower	Dakota Sandstone			200±	Clay, shale, and siltstone with lenses of fine-grained sandstone.
		Kiowa Shale			50±	Fissile, light-gray, dark-gray, and black shale; contains thin limestone beds throughout. Locally, lenticular sandstones occur at any position within the shale; concretionary "ironstone" bands, quartzitic sandstone, and selenite crystals are also common.
Permian	Lower	Wellington Formation			100±	Chiefly gray, red, or brown silty shale with thin interbedded deposits of calcareous material.

PHYSICAL CHARACTERISTICS OF THE DRAINAGE

The Saline River drainage basin includes parts of three physiographic units as defined by Schoewe (1949). These units correspond roughly to a threefold division of the bedrock geology. The three units are, from west to east, the High Plains section, the Blue Hills of the Dissected High Plains section, and the Smoky Hills of the Dissected High Plains section. The entire drainage basin is included in the Great Plains physiographic province.

The part of the High Plains section that is in the Saline River basin extends from the headwaters of the main stream to about the western boundary of Ellis County. It consists of nearly flat to gently rolling uplands and broad shallow valleys. Maximum relief is about 250 feet. The regional slope of the upland surface is about 15 feet per mile to the east. The valleys of the Saline River and its tributaries are wide and shallow near the headwaters in Thomas County, but dissection of the uplands increases steadily to the east. The escarpment of the Fort Hays Limestone Member of the Niobrara Formation marks the eastern margin of the High Plains. A second escarpment, higher in altitude, is produced by the mortar beds of the Ogallala Formation. (See fig. 1.) As in much of the Saline River basin, the valleys show marked asymmetry. The south slopes are steeper and more strongly dissected than the north slopes; and the tributaries entering from the south are shorter, have steeper gradients, and are more numerous than the tributaries entering from the north.

The Blue Hills lie east of the High Plains. They are bounded on the west by the escarpment of the Fort Hays Limestone Member and on the east by the lowermost escarpment of the Greenhorn Limestone in the vicinity of Russell. The western escarpment is characterized by broad upland benches deeply incised by the main drainage channels. In the central part of the Blue Hills, gently rolling plains are characteristic where the bedrock is nonresistant shale, and flat uplands having steep rocky slopes are characteristic where the bedrock is limestone. The stream valleys are well incised (fig. 2), and relief is about 300 feet.

The eastern part of the Saline River basin is in the Smoky Hills. The Smoky Hills are bounded on the west by the Greenhorn Limestone escarpment and on the east by the valley of the Smoky Hill River in Saline County. The topography is controlled largely by the differential weathering of the Dakota Sandstone and consists of relatively broad alluvial valleys and scarped uplands. Resistant sandstone ledges and isolated hills and mounds are common. Local relief is as much as 300 feet.

FIGURE 1.—Uplands along small tributary north of Ellis. Mortar beds of the Ogallala Formation form the rimrock on the cliff to the left.

FIGURE 2.—Saline River near Russell. The cliff to the right exposes channel sandstone and clay strata of the Dakota Sandstone.

The Saline River is ephemeral from the headwaters to southeast Sheridan County and is intermittent eastward to the vicinity of the Trego-Ellis County line (fig. 3). The river is perennial for the rest of its length.

The channel of the Saline River is generally meandering over most of its length. Meanders are more numerous and more closely spaced downstream from Sylvan Grove than those farther west. The greatest width of the valley, which is a short distance upstream from the mouth, is about 3.5 miles. The meander belt reaches a maximum width of nearly 1.5 miles in the same area.

Constriction of the Saline River valley from 1.5 miles at Sylvan Grove to 0.5 mile near the Wilson station upstream and an associated very narrow meander belt are related in part to drainage history and in part to resistant channel sandstones of the Dakota Sandstone, which border the Saline River valley throughout Russell County. Downstream from Sylvan Grove the width of the valley is about 1.5 miles and is relatively constant as far as Beverly, except in the Lincoln area where resistant quartzite of the Dakota (Frye and Swineford, 1946) crops out. From Beverly to Tescott the valley width increases to 2.0 miles. On the flood plain in Saline County, meander scars having surfaces above the present channel suggest Recent degradation.

The width of the channel of the Saline River gradually increases downstream and reaches a maximum in the vicinity of Russell (fig. 4).

FIGURE 3.—Saline River north of Ellis. Sandy bed is characteristic of the river in this reach.

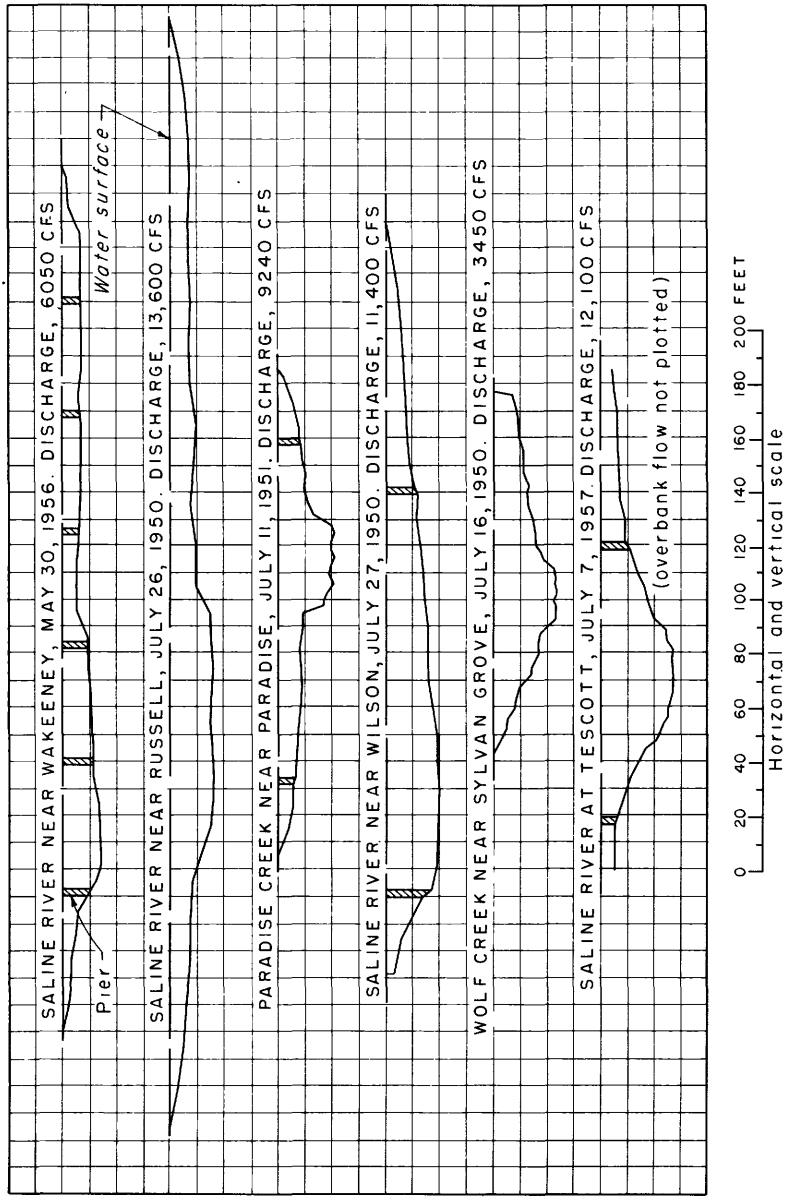

FIGURE 4.—Channel cross sections at gaging stations.

Near Sylvan Grove there is a marked change in channel shape: Five miles west of Sylvan Grove the channel is wide, is relatively shallow, and has low sandy banks; at Sylvan Grove the channel is narrow, is deep, and has high banks of fine material overgrown by vegetation (fig. 5).

The valleys of the major tributaries to the Saline River are similar to the valley of the main stream. The valley of Paradise Creek (fig. 6) increases irregularly in width from about 0.5 mile at the confluence with Eagle Creek to 0.8 mile at the mouth. The Wolf Creek valley is 0.6 mile wide at the junction with East Fork Wolf Creek and nearly 1 mile wide at the confluence with the Saline River. About 3 miles upstream from the confluence, a marked constriction of the Wolf Creek valley is caused by a lentil of carbonate-cemented sandstone of the Dakota, which forms cliffs nearly 50 feet high.

Drainage-basin areas, lengths, and relief ratios were computed for selected tributaries to the Saline River to compare these properties that influence erosion and deposition. (See table 2.) Relief ratio (Schumm, 1954, p. 22) is the ratio of the maximum relief in a basin to its longest dimension parallel to the principal drainage line (drainage-basin length). In general, relief ratio decreases as drainage-basin dimensions increase.

Maner (1958) has correlated relief ratio directly with sediment delivery rate in small basins of homogeneous lithology. Relations between relief ratio and sediment yield also have been determined by Schumm (1954, p. 23) and Hadley and Schumm (1956). A significant relationship between relief ratio and sediment yield cannot be derived without restriction of sediment data to parts of the basins underlain by relatively homogeneous lithologies. For the tributaries of the Saline River, sediment data are available for Paradise and Wolf Creeks; however, significant relationships cannot be developed because of the lack of lithologic homogeneity in these two tributary basins.

Drainage density, defined as the ratio of the total length of all channels to the drainage area, was calculated for Paradise and Wolf Creek basins as 3.6 and 3.9, respectively. Because of inadequate topographic coverage, these values are approximations. Drainage densities were also calculated for six small drainage basins in Saline County where reliable measurements could be made on recent U.S. Geological Survey 7½-minute quadrangles; the results suggest that the calculated densities for Wolf and Paradise Creeks might be about half the true densities. The mean of the drainage densities for the small basins in Saline County was plotted against the mean of their relief ratios; the position of the plotted point relative to

FIGURE 5.—Saline River at Sylvan Grove.

FIGURE 6.—Paradise Creek at the gaging station near Paradise. Flow is slightly above normal.

TABLE 2.—*Geomorphic properties for selected tributary basins in the Saline River drainage*

Stream	Drainage area (square miles)	Length of basin (miles)	Relief ratio
Mulberry Creek (upstream from confluence with Dry Creek)	278	24.2	0.0047
Wolf Creek	261	26.2	.0047
Paradise Creek	240	36.0	.0036
Spillman Creek	175	22.0	.0043
Dry Creek	152	23.0	.0032
Spring Creek (Saline County)	131	18.2	.0048
Mulberry Creek (upstream from confluence with Spring Creek)	126	19.5	.0056
North Fork Saline River	86	23.0	.0037
Bullfoot Creek	86	14.0	.0066
Elkhorn Creek	72	16.0	.0060
Salt Creek	58	10.8	.0086
East Fork Wolf Creek	55	14.5	.0073
Eagle Creek	49	15.0	.0057
Bacon Creek	47	13.9	.0063
Unnamed tributary south of Zurich	44	11.5	.0061
Table Rock Creek	43	12.0	.0049
Cedar Creek	36	9.3	.0078
Unnamed tributary north of Ellis	30	10.0	.0071
Hell Creek	26	7.5	.0101
Trego Creek	24	8.0	.0070

the positions of points for several other areas (Strahler, 1952) suggests some similarity of the small basins in Saline County to the Ozark Plateau. (See fig. 7.) However, available data indicate that sediment concentrations for the major streams in the Saline River basin are generally from 5 to 10 times higher than those for streams draining the Ozark Plateau. Evidently the primary factors influencing sediment yields are soil characteristics and land use.

Evidence of continuously changing drainage patterns can be seen at many places in the Saline River basin. Examination of aerial photographs for parts of Lincoln County reveals numerous meander scars, abandoned channels, and diversions, which indicate both natural and man-induced changes in the course of the main stream and its tributaries.

The gradients of the Saline River and its tributaries are shown on longitudinal profiles (pl. 3). From the headwaters to about mile 257, the altitudes shown on plate 3 were taken from a topographic map (contour interval, 20 ft) prepared by the Army Map Service; the distances were scaled from maps (scale 1:118,400) prepared by the U.S. Soil Conservation Service. From about mile 257 to mile 61, the altitudes and distances were derived from the topographic maps (scale 1:125,000; contour interval, 20 ft) prepared by the U.S. Geological Survey from 1890 to 1893. From mile 61 to the mouth, altitudes and distances were derived from topographic maps (scale 1:24,000; contour interval, 10 ft) prepared by the U.S. Geological Survey from 1955 to 1957.

Streams at grade, neither eroding nor depositing, are assumed to have a smooth parabolic longitudinal profile, which indicates a balance between discharge, slope, and sediment load throughout the watercourse. Wolman (1955, p. 47) has pointed out, however, that equilibrium between aggradation and degradation is not solely dependent on slope. If contributions of discharge and load to a river by its tributaries are nonuniform with respect to distance, the profile of a graded stream will not conform to a smooth concave curve. Also, marked changes in slope may indicate concentrated erosion or deposition. Depositional anomalies or increases in discharge are

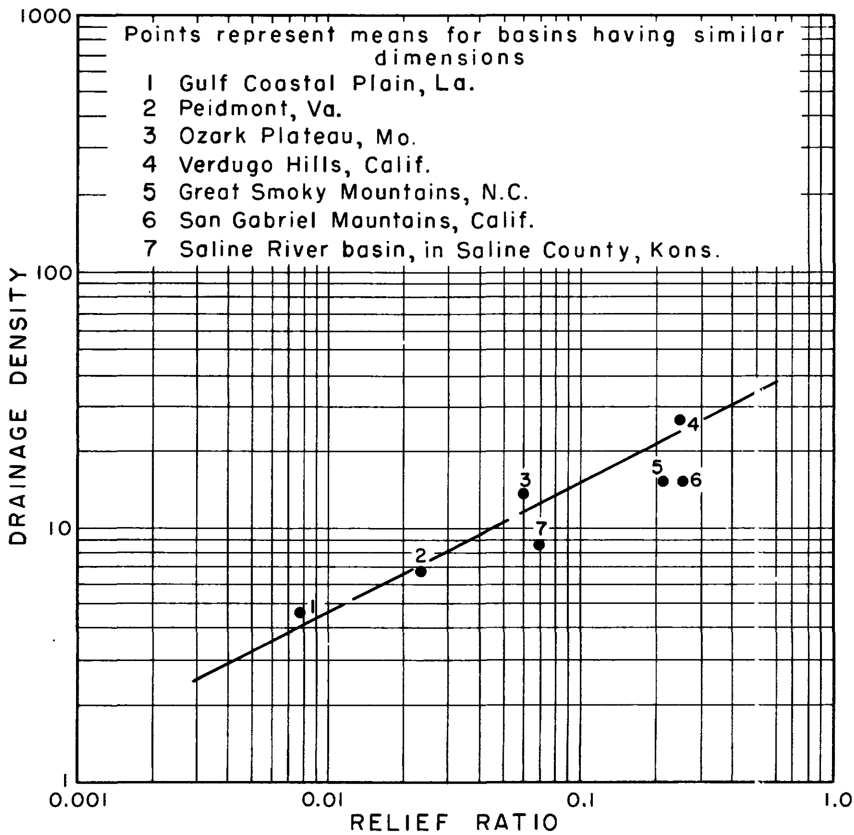

FIGURE 7.—Relation of drainage density to relief ratio. After Schumm (1954); data from Strahler (1952).

associated with a lessening of gradient, whereas underlying resistant areas or disproportionate increases in load are associated with convexities in the profile.

Because of inaccurate drainage representation on topographic maps west of Saline County, especially for the tributaries, the profiles shown on plate 3 may represent the valley profiles more than actual stream profiles. For example, the profiles of some of the smaller tributaries in the vicinity of Lincoln (about 80 to 110 miles upstream from mouth of Saline River) show in the lower courses slight convexities reflecting the presence of terraces that would not be shown on actual stream profiles.

The long profile of the Saline River itself actually approaches a smooth concave curve in overall aspect. However, the greater part of the profile can be readily divided into four parts on the basis of significant changes in average gradient. From mile 274 to mile 200 the average gradient is about 8 feet per mile, from mile 200 to mile 133 the average gradient is about 5 feet per mile, from mile 133 to mile 76 the average gradient is about 3 feet per mile, and downstream from mile 76 the average gradient is about 1.5 feet per mile.

The gradients are markedly less in the lower reaches than in the upper reaches of most of the larger tributaries (pl. 3). However, the gradient of Paradise Creek averages about 10 feet per mile throughout its length. The gradients of Mulberry Creek and its principal tributaries gradually decrease downstream and thus approach "ideal" concave profiles.

RUNOFF

The flow of the Saline River was measured as early as 1895 near Beverly and 1897 near Salina. Records of daily flow have been maintained for the gaging station at Tescott since 1919 and for five other gaging stations for 4 to 31 years. The periods of daily streamflow records for the gaging stations (pl. 1) are as follows:

Gaging stations	*Drainage area (square miles)*	*Period of record*
Paradise Creek: Near Paradise	212	April 1946 to September 1953
Wolf Creek: Near Sylvan Grove	261	October 1945 to September 1953
Saline River:		
Near Wakeeney	696	October 1955 to September 1959 [1]
Near Russell	1,502	October 1945 to September 1953
Near Wilson	1,900	May 1929 to September 1959 [1]
At Tescott	2,820	September 1919 to September 1959 [1]

[1] Station still in operation as of September 1961.

The Saline River is one of the few rivers in the Kansas River basin that is not yet regulated by reservoirs of appreciable size. The largest reservoir in the Saline River basin is Sheridan Lake, which has a contributing drainage area of 463 square miles and had a capacity of 793 acre-feet when it was built in 1935. The capacity was reduced to 436 acre-feet by 1948, owing mainly to sedimentation and partly to repairs that were made necessary by two failures of the dam (U.S. Bur. Reclamation, 1950). Numerous farm ponds and small reservoirs, having drainage areas of a few acres to about 3 square miles, have a regulating effect on the streams. The low flows at Tescott have been partly regulated by a low dam at Lincoln and, in the early years of the streamflow record, by mills at Shady Bend and Tescott. Streamflow in the basin is affected very little by irrigation. In 1950, less than 400 acres (estimated from U.S. Dept. Commerce, 1952) was irrigated from both surface and underground sources.

Because of the elongated shape of the basin and variable storm patterns, the resulting intensity of floods can be rather variable. The flood of July 1951, in progressing downstream, reached peaks of 8,860 cfs (cubic feet per second) near Russell and 17,800 cfs near Wilson and then increased to 61,400 cfs at Tescott. The flood of June 1957 increased from 13,000 cfs near Wakeeney to 24,300 cfs near Wilson and then decreased to 8,440 cfs at Tescott.

Runoff varies markedly, not only from year to year but also from place to place during the same year. Runoff in different parts of the basin for the 7-year period of concurrent record is shown in figure 8. Extremes of runoff occurred in 1951 and 1953, but the average runoff for the 7-year period is not likely to be representative of the average runoff for a much longer period. Therefore, long-term averages were determined from flow-duration curves that had been computed by correlating short-term records with regionally adjusted long-term (36-yr) records in the Saline River basin and in nearby basins. An explanation of the method is given by Furness (1959). These averages were used to determine the lines of equal runoff on plate 4. Each line represents the average depth of runoff in 1 year for the area in the vicinity. The average runoff increases from less than 0.2 inch in the west to more than 1.5 inches in the east.

Precipitation is the principal factor that influences the average runoff. Lines of equal annual precipitation for a 36-year period are shown on plate 4. The general progressive increase of rainfall from west to east is more uniform than that of runoff; however, the interrelation is significant even in this basin where rainfall is usually inadequate to satisfy the demands of evaporation and transpiration, and runoff is only the residual after these and other forces of nature have abstracted their requirements. The areal variations of runoff shown on plate 4 may not be fully or adequately delineated by the small number of records of streamflow that were available. Undoubtedly, records at additional sites would define additional variations resulting from the many controlling factors, such as vegetative cover, surface slope, soils, permeability of aquifers, and variable character of subsurface geology.

Although the major source of water for the Saline River and its tributaries is surface runoff, a significant contribution is made from

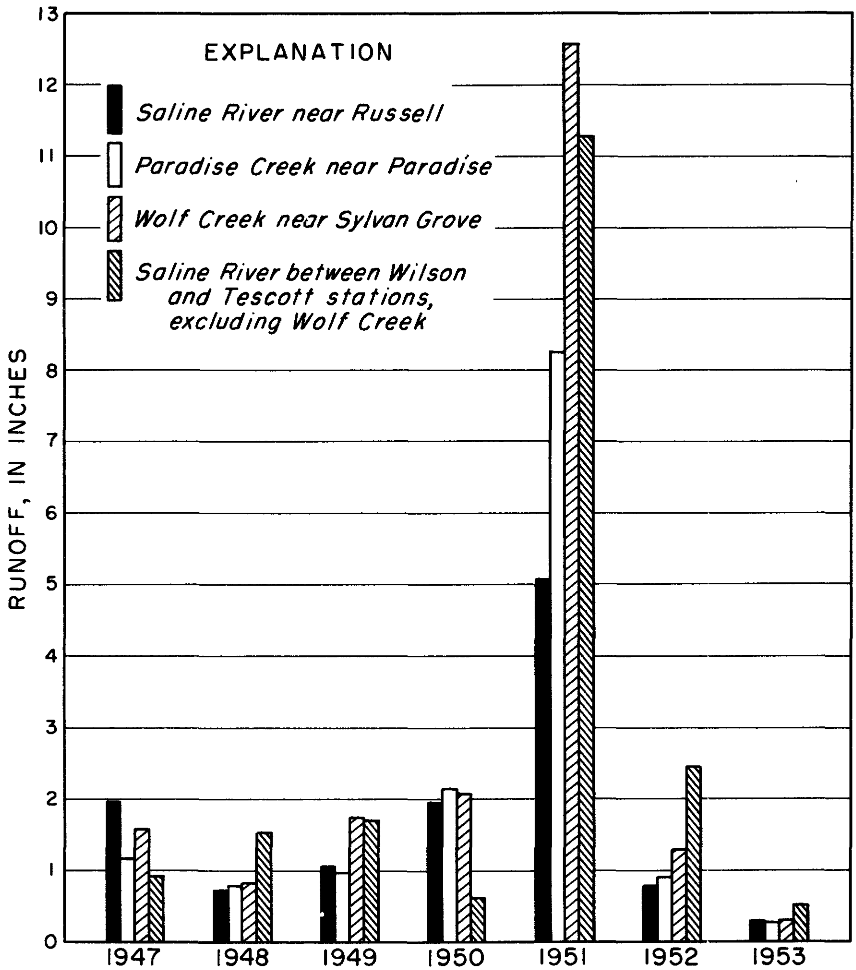

FIGURE 8.—Runoff in the Saline River basin, water years 1947–53.

the ground-water reservoir. During times of very low precipitation, as in the winter, the discharge of the Saline River is maintained principally by ground-water inflow.

In the westernmost part of the basin, the river channel is at a higher altitude than the water table. Thus, the stream receives all its discharge from overland runoff and contains flowing water only during and immediately after rains and during periods of snowmelt. In eastern Sheridan County the channel of the Saline River cuts below the normal level of the water table, and the stream receives discharge from the ground-water reservoir. During periods when the water table is low, the channel of the Saline River may be dry as far east as the Trego-Ellis County line.

Normally, the Ogallala Formation provides significant quantities of ground-water inflow to the Saline River, particularly in Sheridan County. Many springs occur near the contact of the Ogallala Formation and the underlying Smoky Hill Chalk Member of the Niobrara Formation. Water migrates freely through the highly permeable sediments constituting most of the Ogallala, but is prevented from further downward percolation by the relatively impermeable silicified sand of the lower part of the Ogallala and the chalk at the top of the Smoky Hill.

Sources of ground-water accretion throughout the basin and the major sources in the downstream areas are the deposits of the flood plains and terraces. Water entering these deposits from either precipitation or subsurface inflow from bedrock readily migrates into the channels of the Saline River and its major tributaries.

The Dakota Sandstone contributes a significant quantity of ground water through several aquifers. The principal aquifers are channel sandstones; other aquifers are thinner, more persistent sandstone and siltstone layers. Springs are common at the contacts between sandstone and impervious clay. Ground water in the Dakota is under artesian pressure, and a few wells drilled into its strata flow at the surface (Berry, 1952, p. 38). In most places water in the deepest strata is under the greatest pressure (Frye and Brazil, 1943, p. 56). The valleys of the Saline River and its tributaries near Russell (particularly Salt Creek, Cedar Creek, and Paradise Creek near its mouth) are areas of substantial ground-water discharge, because here strata of the Dakota emerge from beneath the Upper Cretaceous and Tertiary strata to the west.

The map of average runoff shows only a measure of the central tendency of streamflow. The magnitude and frequency of the high and low flows, which should be known for control and use of the available water, can best be shown by flow-duration curves Such

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curves, representative of a 36-year period for 6 stations in the Saline River basin, are shown in figure 9. The curve for Saline River at Tescott is based on available data for 1921–56 that were adjusted slightly to reflect regional streamflow characteristics. The curves for the other 5 stations were computed by correlating the available data for each station with regionally adjusted 36-year records for Tescott and for stations in nearby drainage basins. The methods of regionally adjusting and correlating streamflow data are explained by Furness (1959). The reliability of the curve for each station depends mainly on the length of record available; only 4 years of record was available for Saline River near Wakeeney.

The slope of a duration curve is an index of variability of flow; steep slopes indicate great variability, and low slopes indicate regularity of flow owing to storage of water in channels and in the ground-water reservoirs. Figure 9 shows that Paradise and Wolf Creeks are flashy streams and that, of the two, Wolf Creek has more sustained low flow, probably because of a greater contribution of ground water from the Dakota Sandstone. During medium and high flows the curves for the three main-stem stations downstream from Wakeeney are similar, but at very low flows the curves show that contributions from ground-water supplies are least at the Russell station and most sustained at the Wilson station.

The ratio of the flow that is equaled or exceeded 90 percent of the time to the flow that is equaled or exceeded 50 percent of the time is a relative index of dry-weather flow. As computed from the curves on figure 9, the ratio would be close to zero for the tributary stations on Paradise and Wolf Creeks and would be 0.13, 0.24, and 0.25, for the main-stem stations near Russell, near Wilson, and at Tescott, respectively.

CHEMICAL QUALITY OF THE WATER

All water from natural sources contains mineral constituents dissolved from the atmosphere and from the rocks and minerals of the earth's crust. For a given stream, the concentrations of these constituents vary constantly in response to such factors as changes in water discharge and differences in geology, and they may vary from one reach to another and even within the same reach from time to time. Also, the variation of the concentrations influences the economic utilization of a given water supply. Therefore, in this study, the relations of the concentrations to changes in water discharge, to differences in geology, and to utilization are discussed.

This study is based on chemical analyses of surface water from samples obtained daily at 5 sites, about monthly at 1 site, and infrequently at 29 sites and of ground water from 12 wells; the data were obtained by the U.S. Geological Survey during the period October 1945 to October 1958. Sampling sites are shown on plate 1.

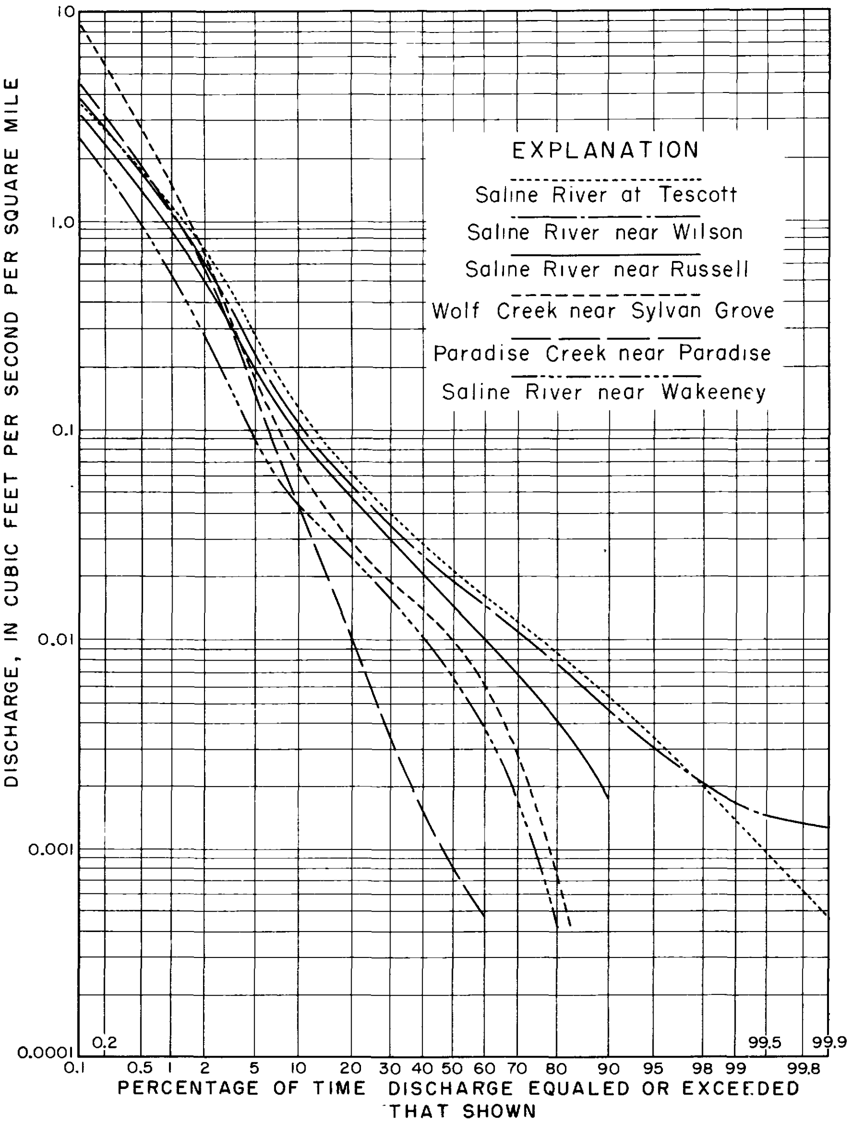

Figure 9.—Duration curves of daily mean discharges for water years 1921–56.

The sites where samples were obtained daily and the periods of record are as follows:

Saline River near Wakeeney	October 1955 to September 1957
Saline River near Russell	January 1946 to September 1949
Paradise Creek near Paradise	March 1947 to September 1949
Saline River near Wilson	February 1948 to September 1951
Saline River at Tescott	December 1949 to September 1953

Samples were obtained about monthly from Wolf Creek near Sylvan Grove from September 1946 to September 1949. Results of chemical analyses have been published in the annual series of U.S. Geological Survey water-supply papers entitled "Quality of Surface Waters of the United States." Records of daily specific conductance are on file in the district office of the U.S. Geological Survey in Lincoln, Nebr.

Salinity surveys provided data for eight sites on the Saline River in August 1948 and again in June 1949 and for a few sites on the Saline River and its tributaries in June 1949, May 1950, and August and October 1958.

Because the records are not concurrent for all the principal sampling sites, direct comparisons of water quality for a given time between two sites are not possible; however, because the stream regime did not change significantly during the 13 years, direct comparisons of the relations of water quality to water discharge and to geology are valid. The records for three of the principal sites include periods of very low and very high flows and, therefore, represent the probable extremes in water quality in the Saline River.

The records obtained near Wakeeney probably are adequate to define the long-term quality because the water quality remains relatively uniform at all ranges of water discharge. Near Russell, near Wilson, and at Tescott, the adequacy of records for defining long-term quality is uncertain; however, the water quality is closely dependent on water discharge. Comparison of flow-duration curves in figure 10 for the periods of record (2 to 4 yr) with curves for a long-term (36-yr) period gives some indication of the adequacy of the records. For the Saline River near Russell and for Paradise Creek, the duration curves for the periods of record are similar to those for the long-term period; the records probably are representative of the long-term water quality. For the Saline River near Wilson and at Tescott, the duration curves indicate that the periods of record were wetter than the long-term periods; the long-term averages of water quality probably are, therefore, even worse than the averages for the periods of record.

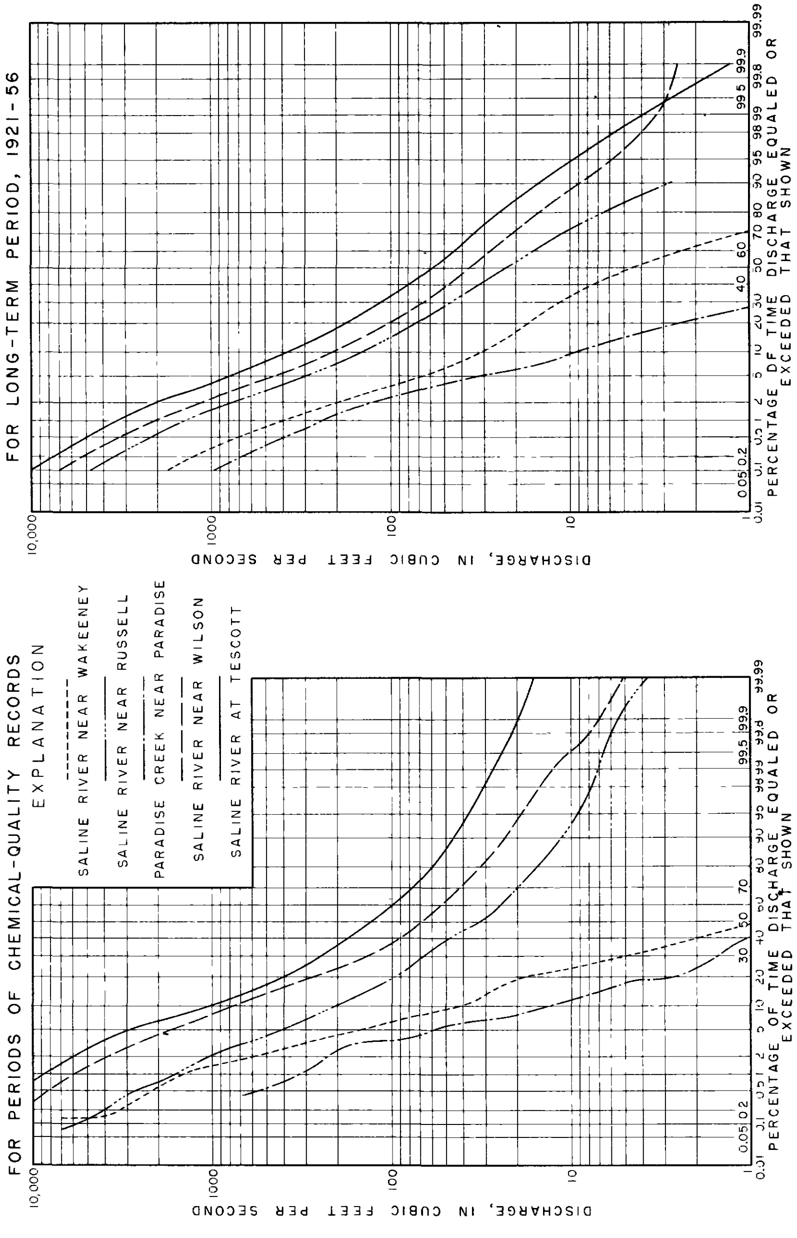

FIGURE 10.—Duration curves of daily mean discharges for streams in the Saline River basin.

CHEMICAL CHARACTERISTICS

All samples were analyzed in the laboratory of the U.S. Geological Survey at Lincoln, Nebr. The methods of analysis varied considerably over the 13-year period as new and improved methods continually replaced the old methods. The methods used are common to the field of water chemistry and were generally similar to those recommended by the American Public Health Association (1955). A complete chemical analysis of each daily sample was not practicable; therefore, analyses were made of composites of two or more daily samples. In general, only samples representing similar discharges and having similar degrees of mineralization were composited together, and the amount of water from each daily sample was proportional to the water discharged at the time of sampling.

The dissolved-solids concentration and specific conductance of water are closely related, and either can be used to express the degree of mineralization of water. Specific conductance is used in this report because it was determined for each sample collected, whereas dissolved-solids concentrations were determined only for composite samples and a few selected samples.

The analytical results are given in parts per million (ppm) in the tables and in equivalents per million in some of the illustrations. Conversion from parts per million to equivalents per million is made by multiplying by the following factors:

Cations	*Factor*	*Anions*	*Factor*
Calcium (Ca^{++})	0.04990	Carbonate (CO_3^{--})	0.03333
Magnesium (Mg^{++})	.08224	Bicarbonate (HCO_3^-)	.01639
Sodium (Na^+)	.04350	Sulfate (SO_4^{--})	.02082
Potassium (K^+)	.02558	Chloride (Cl^-)	.02820
		Fluoride (F^-)	.05263
		Nitrate (NO_3^-)	.01613

SALINE RIVER

CHEMICAL COMPOSITION

The relation of specific conductance to dissolved-solids content for water in the Saline River is shown in figure 11. The dissolved-solids content can be approximated by use of the graph or, because the graph is a straight line, by use of a conversion factor of 0.62.

Water in the Saline River is only slightly mineralized in the upper reaches, but it becomes increasingly more mineralized downstream to the general vicinity of Wilson. Then the mineralization of the water decreases somewhat between Wilson and Tescott. The rate of increase in mineralization is especially pronounced between the general vicinities of Fairport and Wilson. During periods of high flow the differences in mineralization from the upper reaches

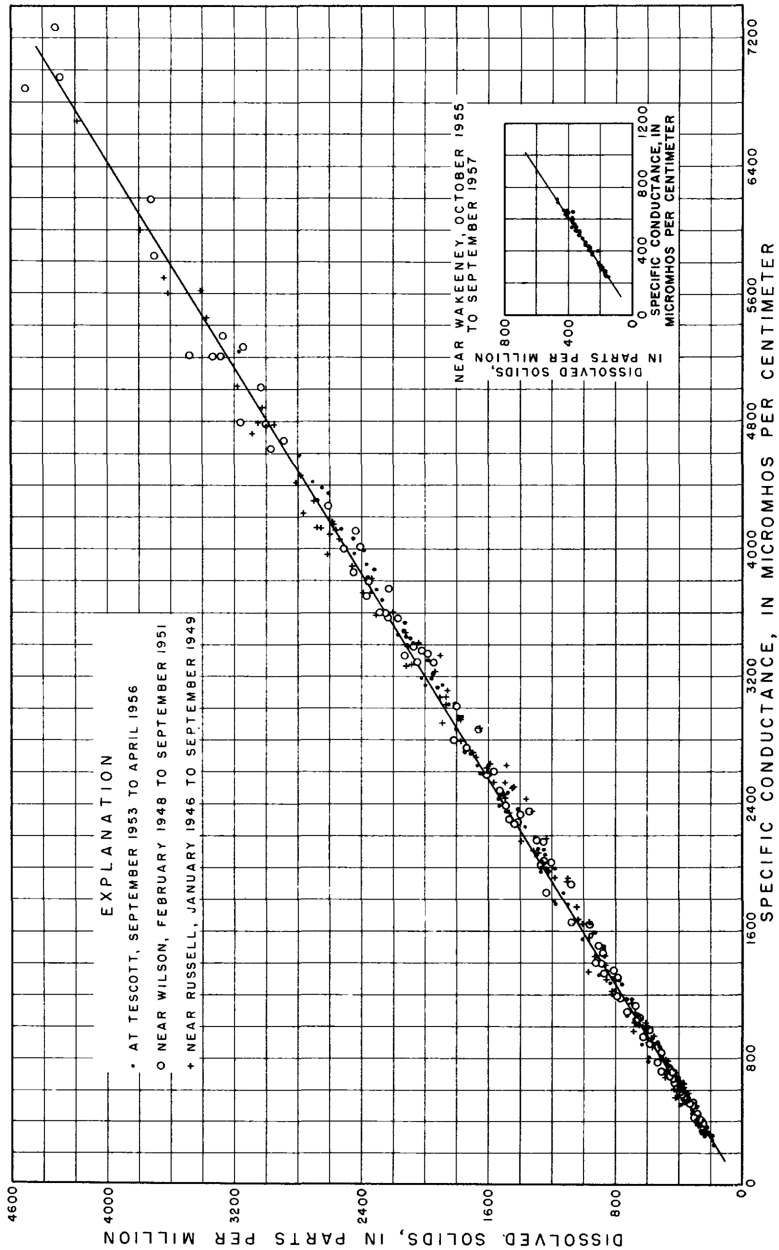

FIGURE 11.—Relation of specific conductance to dissolved-solids content for water in the Saline River.

of the Saline River to the lower reaches are slight; during periods of low flow the differences are large. The minimum observed daily specific conductances, representing periods of high flow, and the maximum observed daily specific conductances, representing periods of low flow, for four sites on the Saline River illustrate the differences in mineralization in the respective reaches of the river. The minimum and maximum specific conductances, in micromhos per centimeter, near Wakeeney were 205 and 726; near Russell, 203 and 11,000; near Wilson, 332 and 8,210; and at Tescott, 253 and 5,550.

Daily specific-conductance records at each of the four sites on the Saline River were used to prepare figure 12, which shows the percentage of time that the observed specific conductances exceeded given amounts for the periods shown. For the figure, the single specific-conductance measurement made each day was considered to be representative of the water for the entire day; for days when no measurement was made, the specific conductance was estimated.

Figure 12 indicates that near Wakeeney the water is only slightly mineralized at all times; the specific conductance never exceeded 750 micromhos per centimeter. Near Russell, Wilson, and Tescott, however, the water is highly mineralized most of the time; 70 percent of the time the specific conductance, in micromhos per centimeter, exceeded 2,100 near Russell, 2,650 near Wilson, and 2,300 at Tescott.

As the degree of mineralization of the streamflow varies, the concentrations of the individual dissolved-mineral constituents vary also. The relations of the concentrations of the principal constituents to specific conductance for the Saline River near Wakeeney and Russell are shown in figures 13 and 14. These relations are represented by the average curves based on the concentrations of all analyses for a given site.

Near Wakeeney the water is of the calcium bicarbonate type for all ranges in specific conductance. Increases in the specific conductance are accompanied by increases in the concentrations of each of the principal constituents except potassium. Near Russell (and also near Wilson and at Tescott) the water is of the calcium bicarbonate type when the specific conductance is less than about 1,000 micromhos per centimeter but is of the sodium chloride type when the specific conductance is greater than about 1,500 micromhos per centimeter. The water is of the calcium bicarbonate, sodium bicarbonate, or sodium chloride type when the specific conductance is between 1,000 and 1,500 micromhos per centimeter. Increases in

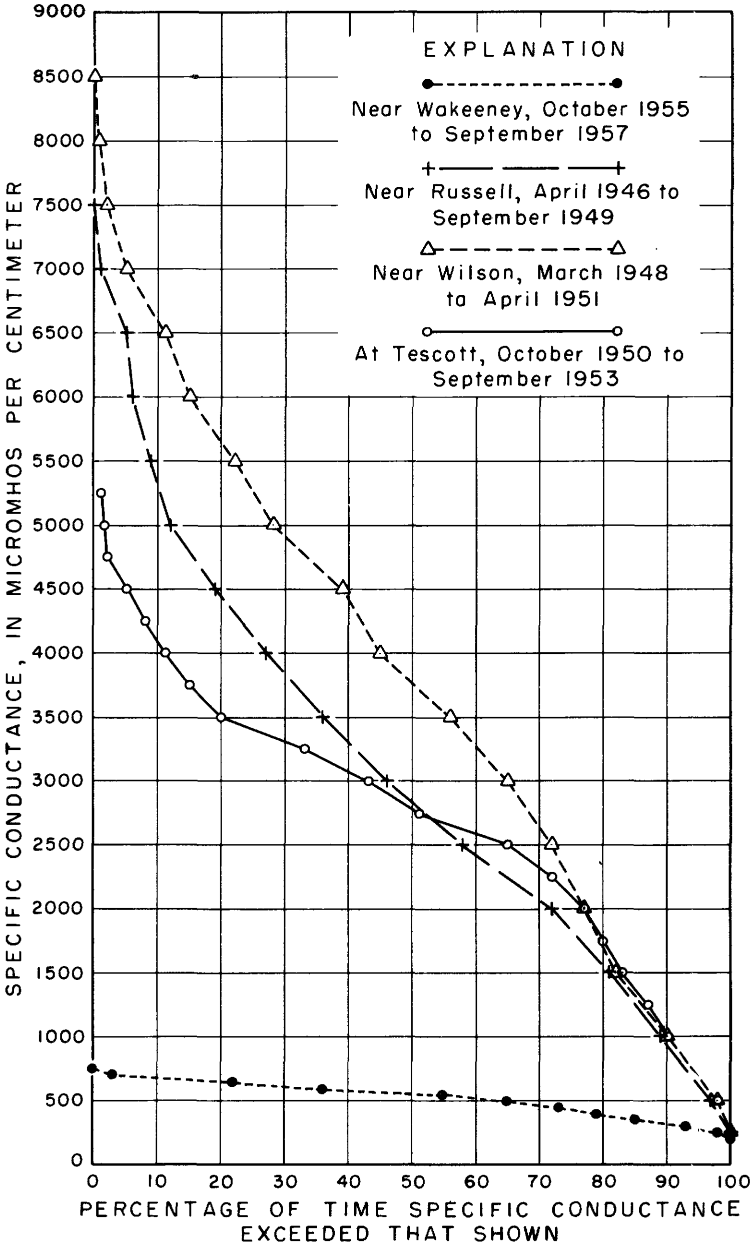

FIGURE 12.—Specific conductance-duration curves for the Saline River.

specific conductance near these downstream sites are accompanied by relatively large increases in concentrations of sodium, chloride, and sulfate and by relatively small increases in the other principal constituents.

The relations in figures 13 and 14 are based on date from at least 2 years of daily record and are well defined. These relations, when used with graphs in figure 12, provide a reasonably accurate method for

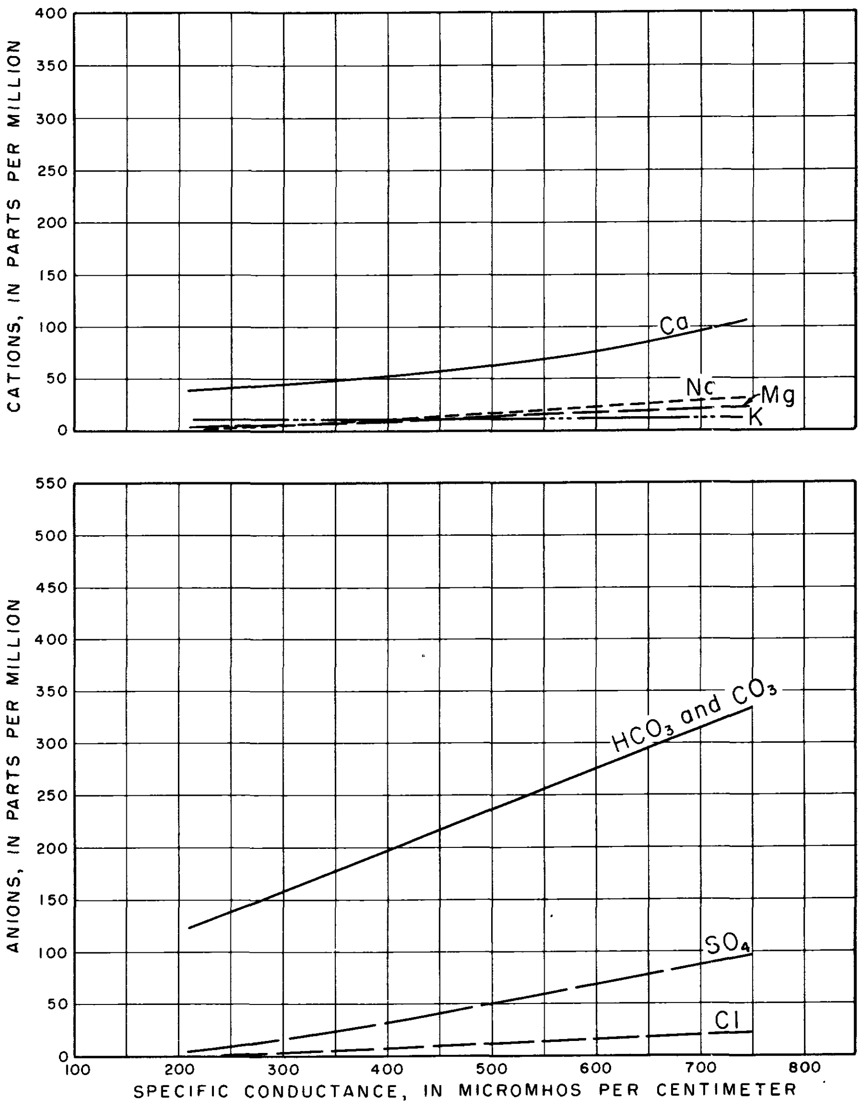

FIGURE 13.—Relation of the concentrations of the ions to specific conductance, Saline River near Wakeeney.

computing the percentage of time that the concentrations of the principal constituents exceeded given amounts. To illustrate the method, assume that the percentage of time the chloride concentrations exceeded 250 ppm near Russell is to be determined. Figure 14 shows that the chloride concentrations exceeded 250 ppm when the specific conductance exceeded about 1,500 micromhos per centimeter. Figure 12 shows that the specific conductance near

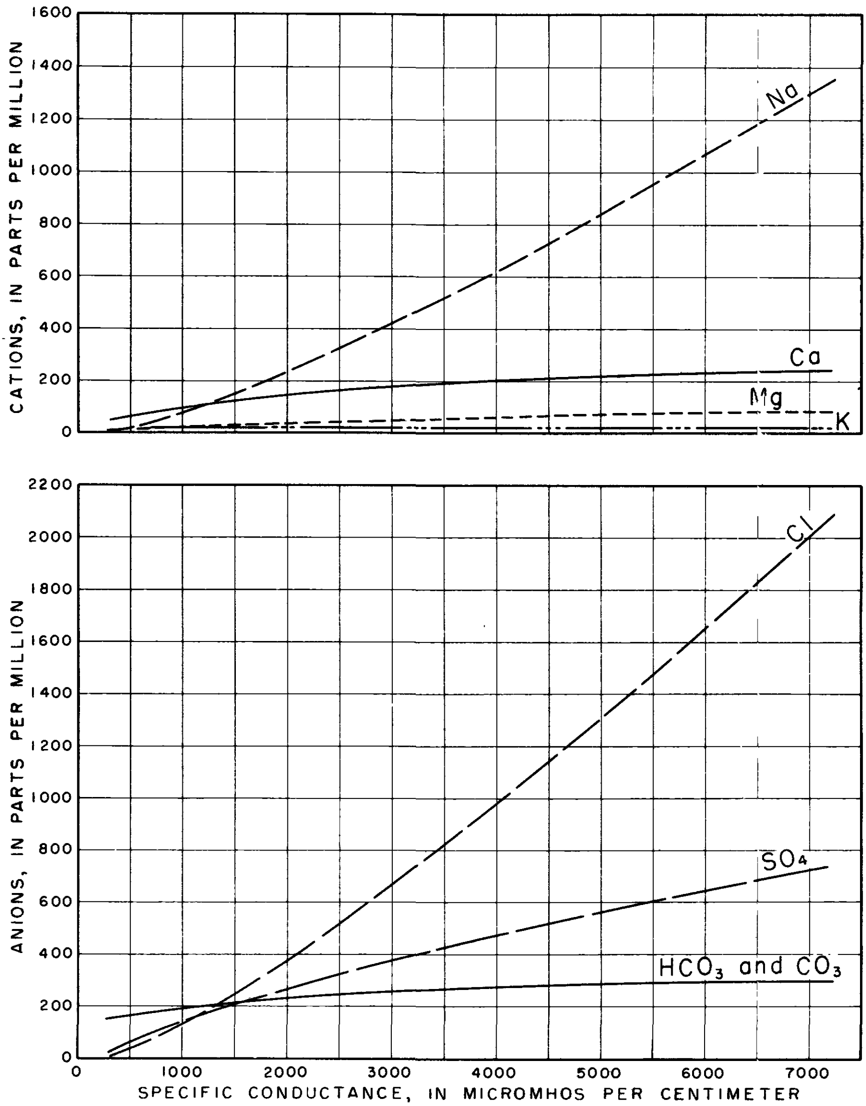

FIGURE 14.—Relation of the concentrations of the ions to specific conductance, Saline River near Russell.

Russell exceeded 1,500 micromhos per centimeter 82 percent of the time. It is concluded, therefore, that the chloride concentrations exceeded 250 ppm 82 percent of the time. Results of similar computations for the principal constituents in the water at the four daily sampling sites are given in table 3.

Concentrations of silica, iron, fluoride, nitrate, and boron were also determined. In Saline River water, however, these constituents, with the possible exception of silica, generally are present in small concentrations only and, therefore, are not included in table 3.

TABLE 3.—*Concentration-duration data for principal dissolved-mineral constituents of water from the Saline River*

Constituent	Percentage of time concentrations (ppm) exceeded—												
	5	10	25	50	100	150	200	250	300	400	500	750	1,000
Near Wakeeney													
Calcium (Ca)			100	83	2	0							
Magnesium (Mg)	91	72	0										
Sodium (Na)	91	77	23	0									
Potassium (K)	100	99	0										
Bicarbonate plus carbonate as HCO_3					100	94	75	57	18	0			
Sulfate (SO_4)	99	97	83	63	0								
Chloride (Cl)	87	72	0										
Near Russell													
Calcium (Ca)			100	99	87	65	25	0					
Magnesium (Mg)	98	94	79	44	0								
Sodium (Na)	100	99	97	93	86	81	75	69	61	48	38	17	8
Potassium (K)	94	85	0										
Bicarbonate plus carbonate as HCO_3					100	99	83	48	5	0			
Sulfate (SO_4)	100	99	99	98	93	87	82	74	63	42	21	0	
Chloride (Cl)	100	99	98	96	92	88	84	81	77	70	60	41	27
Near Wilson													
Calcium (Ca)				99	87	67							
Magnesium (Mg)	97	92	79	52	0								
Sodium (Na)		99	97	95	90	84	81	78	75	69	61	41	22
Potassium (K)	96	91	0										
Bicarbonate plus carbonate as HCO_3						100	92	78	43	0			
Sulfate (SO_4)		100	99	97	93	88	81	77	72	56	33	0	
Chloride (Cl)		100	99	96	92	88	85	82	80	76	72	60	44
At Tescott													
Calcium (Ca)			100	99	88	20	0						
Magnesium (Mg)	98	93	78	6	0								
Sodium (Na)		100	98	96	90	86	81	78	73	51	33	6	0
Potassium (K)	100	8	0										
Bicarbonate plus carbonate as HCO_3							89	60	2	0			
Sulfate (SO_4)		100	99	98	94	90	85	79	69	18	1	0	
Chloride (Cl)	100	99	98	97	93	89	86	83	80	75	65	23	7

The chemical composition of the water in the Saline River has been summarized in table 4. Shown for each of the four sites are the maximum and minimum observed concentrations or other measurements and the average chemical analyses calculated by the time-weighted and discharge-weighted methods. The discharge-weighted average was calculated directly from the laboratory analyses and the discharge data. The time-weighted average was calculated indirectly from the average specific conductance for the year and from the curves in figures 13 and 14 and similar curves for Wilson and Tescott. Table 4 shows that the time-weighted average differs significantly from the discharge-weighted average for the same years.

The concentrations of silica in the river water are similar for all sites and are usually about 20 ppm, but because the total mineralization near Wakeeney is much lower than that at the sites downstream, the proportion of silica to other constituents is higher. Likewise, concentrations of iron are similar for all sites. The reported weighted-average concentrations of iron may be lower than the actual concentrations in the river because part of the iron may have precipitated between the time of collection and the time of analysis.

Fluoride and nitrate concentrations in the river water are low at all times. The maximum observed fluoride concentration was 1.4 ppm near Wilson, and the maximum nitrate concentration was 23 ppm at Tescott. The maximum observed concentration of boron was 1.3 ppm near Wilson, but the concentration of boron was less than 0.5 ppm nearly all the time. Concentrations of boron are several times greater downstream from Wakeeney than at Wakeeney, but the difference may simply reflect the differences in the degree of mineralization at Wakeeney and at the downstream sites.

Miscellaneous chemical-quality data, some of which were obtained concurrently at several sites, are given in table 5. These data indicate that the increase in mineralization of the water from Wakeeney to Wilson is gradual rather than abrupt.

Disposal of oil-field brines has been a problem since 1923, when the first oil well in the Saline River basin was developed near Fairport (Frye and Brazil, 1943). In general, brines have been disposed of in so-called evaporation ponds, in shallow disposal wells drilled into sandstone of Cretaceous age, or in deep disposal wells drilled into porous rocks of Pennsylvanian age or older. From the evaporation ponds, much of the brine has percolated to the groundwater reservoir and has seeped, or will eventually seep, into streams of the basin; also, much of it has been washed by surface runoff directly into streams.

TABLE 4.—*Summary of the chemical composition of water from the Saline River*

[Results in parts per million except as indicated]

Type of data	Period represented	Mean discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption-ratio	Specific conductance (micromhos per cm)	pH
Near Wakeeney																							
Maximum observed	1955–57	------	61	0.29	107	26	26	21	340	91	21	0.7	7.1	0.17	475	0.65	1,210	334	60	17	0.7	[1] 726	8.6
Minimum observed			15	.00	35	2.6	1.5	8.1	132	3.5	.0	.2	.2	.03	148	.20	--------	104	0	2	.1	[1] 205	7.4
Time-weighted average	1955–56	13.3	-----	------	60	10	14	10	220	41	10	----	----	----	283	.38	--------	191	11	13	.4	457	----
Discharge-weighted average			22	.03	47	4.7	5.0	10	167	19	1.2	.4	1.0	.07	201	.27	11.0	137	0	7	.2	315	----
Time-weighted average	1956–57	98.8	-----	------	60	10	14	10	220	41	10	----	----	----	286	.39	--------	191	11	13	.4	461	----
Discharge-weighted average			20	.03	48	5.6	4.2	12	[2] 168	17	2.1	.4	5.4	.06	202	.27	53.9	143	5	5	.2	316	----
Near Russell																							
Maximum observed	1946–49	------	52	0.50	242	91	1,290	33	350	745	1,920	0.7	10	0.71	4,430	6.02	2,470	978	725	84	23	[1] 11,000	8.5
Minimum observed			8.3	.00	45	5.0	<11	1.2	124	8.0	10	.1	.0	.00	208	.28	71	135	5	12	.3	[1] 203	7.3
Discharge-weighted average [3]	1945–46	41.3	-----	.08	155	38	497		238	346	757	.5	2.3	----	1,960	2.67	219	544	349	66	9.3	3,150	----
Time-weighted average	1946–47	218	-----	------	165	45	350	11	245	340	560	----	----	----	1,640	2.23	--------	597	396	56	6.2	2,640	----
Discharge-weighted average			-----	.08	99	18	124		[2] 190	158	186	.4	2.6	----	706	.96	416	321	165	46	3.0	1,170	----
Time-weighted average	1947–48	78.6	-----	------	190	55	550	10	265	440	875	----	----	----	2,270	3.09	--------	701	484	63	9.0	3,660	----
Discharge-weighted average			45	.02	103	21	174	12	[2] 192	171	277	.5	1.7	.15	904	1.23	193	344	187	51	4.1	1,380	----
Time-weighted average	1948–49	118	-----	------	155	40	305	10	235	310	490	----	----	----	1,480	2.01	--------	551	358	54	5.7	2,390	----
Discharge-weighted average [3]			23	.07	88	17	119	9.8	[2] 183	140	202	.3	2.2	.21	702	.95	245	290	140	46	3.0	1,170	----

Near Wilson																							
Maximum observed	1948–51	------	48	0.30	209	95	1,340	17	439	716	2,020	1.4	9.1	1.3	4,520	6.15	5,200	814	570	78	21	[1] 8,210	8.5
Minimum observed			8.0	.00	51	2.5	18	5.5	150	18	19	.2	.0	.02	250	.34	183	145	0	19	.6	[1] 332	7.3
Time-weighted average	1948–49	148	----	----	162	51	655	11	295	435	950	----	----	----	2,430	3.30	----	614	372	69	11	3,920	----
Discharge-weighted average [3]			23	.08	94	22	221	9.0	[2] 211	179	328	.4	3.3	.20	1,000	1.36	400	325	152	59	5.3	1,630	----
Time-weighted average	1949–50	302	----	----	160	50	630	11	290	425	910	----	----	----	2,360	3.21	----	605	367	69	11	3,800	----
Discharge-weighted average			21	.07	77	13	131	9.6	195	111	184	.4	1.8	.32	656	.89	535	246	86	52	3.6	1,050	----
At Tescott																							
Maximum observed	1950–53	------	34	0.40	192	59	912	12	414	515	1,310	0.7	23	0.46	3,180	4.32	8,920	656	383	76	17	[1] 5,550	8.3
Minimum observed			12	.01	42	3.3	7.8	5.8	131	9.0	7.0	.1	.2	.01	170	.23	157	120	0	11	.3	[1] 253	7.2
Discharge-weighted average [3]	1949–50	372	20	.05	74	13	129	9.2	201	107	179	.4	2.3	----	642	.87	645	238	73	53	3.6	1,050	----
Time-weighted average	1950–51	1,590	----	----	130	29	293	10	236	282	416	----	----	----	1,350	1.84	----	444	250	58	6.0	2,170	----
Discharge-weighted average			18	.04	74	8.9	62	7.5	181	93	85	.4	4.6	.10	448	.61	1,920	221	73	37	1.8	699	----
Time-weighted average	1951–52	275	----	----	138	32	365	10	250	320	517	----	----	----	1,590	2.16	----	476	271	62	7.3	2,570	----
Discharge-weighted average			----	----	153	30	271	----	[2] 294	324	373	----	12	.19	1,380	1.88	1,020	505	264	53	5.2	2,160	----
Time-weighted average	1952–53	80.6	----	----	150	40	530	9	270	385	740	----	----	----	2,110	2.87	----	539	318	68	9.9	3,400	----
Discharge-weighted average			----	----	128	37	453	----	279	343	622	----	5.5	.22	1,790	2.43	390	472	243	67	9.1	2,940	----

[1] Daily measurement.
[2] Includes carbonate as bicarbonate.
[3] Includes estimated data.

TABLE 5.—*Miscellaneous chemical analyses of water from the Saline River*

[Results in parts per million except as indicated]

Date of collection	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption-ratio	Specific conductance (micromhos per cm)	pH
South Fork, near Oakley																						
Aug. 12, 1948	(1)	14	0.00	26	5.2	8.8		120	0	4.0	2.0	------	------	------	104	0.14	86	0	18	0.4	210	7.8
June 21, 1949	(1)	16	.02	28	2.6	6.7		107	0	4.8	.5	0.1	2.1	0.11	128	.17	81	0	15	.3	192	7.1
Near Grainfield																						
Aug. 12, 1948	[2] 7	13	0.00	54	11	29		248	0	24	11	------	------	------	222	0.30	180	0	26	0.9	468	7.8
June 21, 1949	6.1	34	.02	76	18	39		312	16	40	15	0.6	2.7	------	412	.56	264	0	24	1.0	641	8.1
Near Wakeeney																						
Aug. 12, 1948	264	14	0.02	27	6.0	7.5	2.0	112	0	11	1.7	0.4	3.6	------	101	0.14	92	0	15	0.3	215	7.8
June 21, 1949	76.6	19	.02	53	6.8	15		192	0	23	6.0	.1	4.2	------	242	.33	161	4	18	.5	388	7.2
Near Ellis																						
Oct. 14, 1958	[2] 15	------	------	------	------	45	------	221	0	249	66	------	------	------	694	0.94	419	238	18	1.0	972	7.8
Near Plainville																						
Aug. 12, 1948	80.9	24	0.02	88	14	27	4.4	206	0	118	41	0.4	2.4	------	496	0.67	277	108	17	0.7	670	8.0
June 21, 1949	119	26	.02	86	13	22		217	0	108	16	.4	2.1	0.08	414	.56	268	90	15	.6	606	8.0
Oct. 14, 1958	[2] 21	------	------	------	------	53	------	225	0	239	87	------	------	------	728	.99	434	249	21	1.1	1,050	7.7

Near Codell																					
Oct. 14, 1958	[2] 30	------	------	------	------	96	------	220	0	282	207	------	------	------	1,030	1.40	540	360	27	1.8	1,460	7.7
Near Fairport																					
Aug. 13, 1948	73.8	23	0.02	126	23	105	5.2	224	0	168	188	0.4	6.7	------	876	1.19	409	225	35	2.3	1,230	7.9
June 22, 1949	144	22	.02	104	17	46		214	0	138	77	.4	1.9	------	602	.82	330	155	24	1.1	870	7.3
Near Russell																					
Aug. 13, 1948	78.8	19	0.02	104	26	245	9.6	192	0	234	360	0.4	0.8	------	1,100	1.50	366	209	58	5.6	1,880	8.0
June 22, 1949	131	22	.02	113	20	108		222	0	178	161	.4	4.2	------	824	1.12	365	183	39	2.5	1,220	7.8
Near Wilson																					
Aug. 11, 1948	97.7	20	0.02	117	35	407	4.4	210	0	274	636	0.4	0.0	------	1,600	2.18	436	264	67	8.5	2,840	8.0
June 22, 1949	223	21	.02	111	20	135		223	0	184	194	.4	4.4	0.14	866	1.18	360	177	45	3.1	1,330	7.1
Aug. 13, 1958	106	18	.04	122	36	414	13	237	0	336	600	.6	6.0	.28	1,690	2.30	452	258	66	8.5	2,760	7.7
At Trescott																					
Aug. 11, 1948	162	17	0.02	93	16	181	10	206	4	137	275	0.4	3.1	------	950	1.29	298	123	56	4.5	1,480	8.3
June 22, 1949	503	18	.02	74	12	57		172	0	100	77	.4	3.8	------	478	.65	234	93	35	1.6	758	7.7

[1] Almost no flow.
[2] Estimated.

The Section of Oil-Field Waste Disposal, Division of Sanitation of the Kansas State Board of Health, is responsible for safeguarding the water supplies of the State from contamination by oil-field brines and since 1958 has had authority to enforce proper disposal methods. As of December 1959, records of the Section of Oil-Field Waste Disposal indicate that of the 523,507 barrels of brine produced daily in the Saline River basin, 99.9 percent is returned underground to prevent and abate contamination.

The high concentrations of sodium and chloride in water from the Saline River might be interpreted as resulting from oil-field brine contamination. However, these high concentrations probably do not result from oil-field-brine contamination because they generally are accompanied by high concentrations of sulfate, and the oil-field brines have low concentrations of sulfate (Jeffords, 1948, p. 4). The total percentage of salt in the Saline River that now comes from oil-field brines is considered to be small.

RELATION OF CHEMICAL COMPOSITION TO WATER DISCHARGE

The concentrations of dissolved minerals in most streams vary inversely with the water discharges. The amount of mineral material dissolved by water is dependent on the solubility of the mineral material, on the length of time the water is in contact with the material, and on the consolidation and stability of the material. The concentrations are low during periods of high discharge because most of the flow is surface runoff that has had little time for contact with mineral material. However, the concentrations are high during periods of low discharge because most of the flow is from ground water that has had close contact with the mineral material for a long time.

The relations of the chemical composition to water discharge for the Saline River near Wakeeney and Russell are shown in figures 15 and 16. The curves are based on averages of the concentrations, in equivalents per million, of the individual analyses for the periods of record. The curves for Wilson and Tescott are not shown, but they are similar to those for Russell except that the discharges are generally higher.

Near Wakeeney the water is predominantly of the calcium bicarbonate type at all ranges of water discharge. As the water discharge increases, the percentages of calcium and bicarbonate increase (although total mineralization decreases), and the percentages of

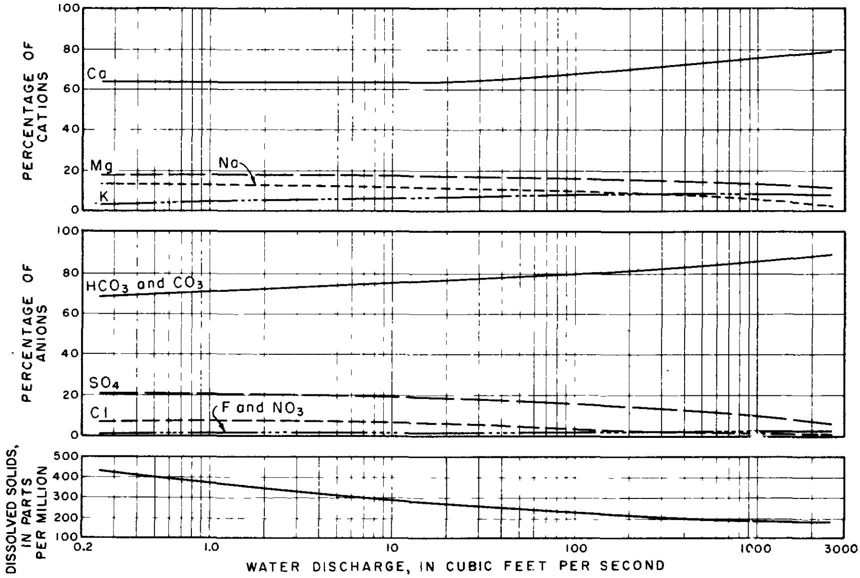

FIGURE 15.—Relations of dissolved solids and percentages of ions to water discharge, Saline River near Wakeeney.

magnesium, sodium, sulfate, and chloride decrease. Near Russell, Wilson, and at Tescott the water is predominantly of the sodium chloride type at low flow and of the calcium bicarbonate type at high flow. The transition in water type is gradual. The discharges at which the transition occurs become progressively higher in a downstream direction. Near Russell, calcium and bicarbonate become the predominant ions when the discharge exceeds about 300 cfs; near Wilson, when the discharge exceeds about 600 cfs; and at Tescott, when the discharge exceeds about 1,000 cfs.

The percentages of magnesium remain relatively uniform at all water discharges, but they are higher in the less mineralized waters of the upstream reaches of the river than in the waters of the downstream reaches. The percentages of sulfate are similar at low flows for the entire Saline River. Near Wakeeney, however, the percentages of sulfate decrease gradually as the water discharge increases; whereas near Russell, Wilson, and Tescott, they increase from low to medium flows and decrease from medium to high flows. The percentages of potassium and of fluoride plus nitrate increase slightly as the water discharges increase.

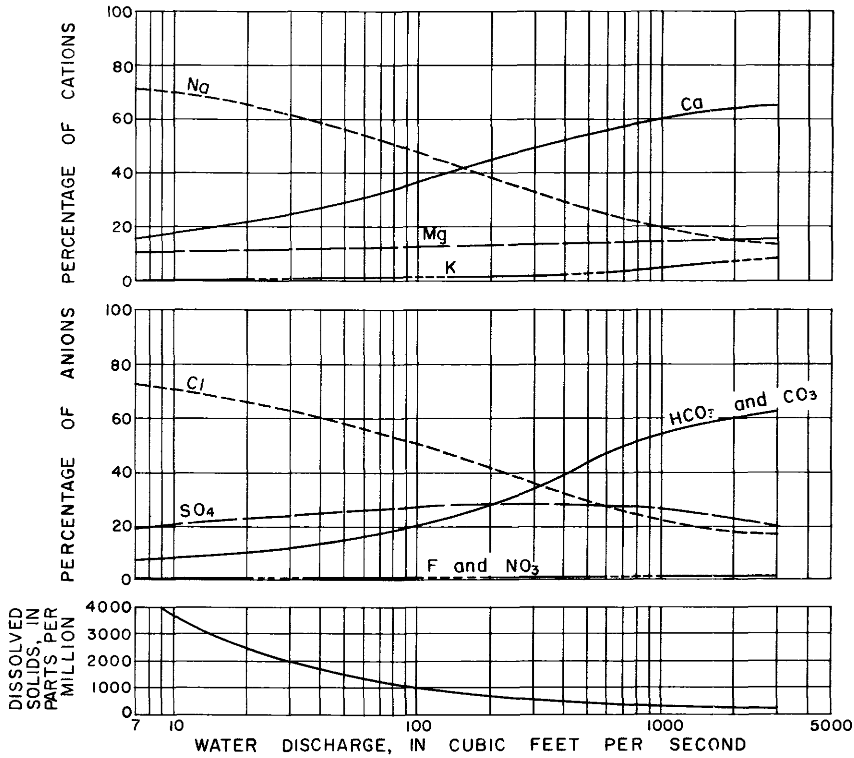

FIGURE 16.—Relations of dissolved solids and percentages of ions to water discharge, Saline River near Russell.

Samples of ground water were obtained from 12 wells, most of which were within a quarter of a mile of the river and near sites where samples of surface water were obtained (pl. 1). Results of the chemical analyses of the samples are given in table 6. In the upper part of the basin, water from the alluvium adjacent to the stream is similar in type to the surface water nearby. In the lower part of the basin, some of the water from the alluvium is very highly mineralized and is similar in type to the surface water at low stages, and some is only moderately mineralized and is similar in type to the surface water at high stages. Water from a well near Tescott (SW¼SW¼ sec. 15, T. 12 S., R. 5 W.) was much more highly mineralized in June 1949 than it was in August 1948; the increase may be the result of differing proportions of water from the Dakota Sandstone and from the alluvium at the two times.

TABLE 6.—*Chemical analyses of ground water from selected wells*

[Results in parts per million except as indicated]

Location	Depth of well (feet)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption-ratio	Specific conductance (micromhos per cm)	pH
Near Grainfield:																				
NW¼NW¼ sec. 27, T. 10 S., R. 28 W.	15	Aug. 12, 1948	39	------	47	17	14	222	14	16	------	0.2	--------	272	187	5	14	0.4	408	7.9
SE¼SE¼ sec. 30, T. 10 S., R. 28 W.	80	June 21, 1949	36	0.02	70	20	31	296	46	20	0.7	5.0	--------	388	257	14	21	.8	605	7.7
Near Wakeeney:																				
SW¼SE¼ sec. 9, T. 11 S., R. 23 W.	25	Aug. 12, 1948	34	------	164	28	36	322	252	55	------	6.0	--------	818	524	260	13	.7	1,100	7.7
		June 21, 1949	34	.47	165	28	50	334	258	60	.3	8.6	--------	826	527	253	17	.9	1,140	7.4
Near Plainville:																				
SW¼SW¼ sec. 11, T. 11 S., R. 18 W.	32	Aug. 12, 1948	49	------	240	71	116	474	652	55	------	7.5	1,430	1,520	891	503	22	1.7	1,870	7.8
		June 21, 1949	46	1.2	242	56	112	378	648	53	.3	21	1,370	1,460	835	525	23	1.7	1,770	7.6
SE¼NE¼ sec. 24, T. 11 S., R. 18 W.	------	Aug. 12, 1948	36	------	182	37	65	380	388	14	------	3.5	--------	978	606	294	19	1.2	1,230	7.6
		June 21, 1949	32	.04	179	35	65	337	412	12	.7	9.7	--------	972	591	315	19	1.2	1,250	7.2
Near Russell:																				
NW¼SE¼ sec. 35, T. 12 S., R. 14 W.	28	Aug. 13, 1948	21	------	102	9.0	34	300	33	8.5	------	100	--------	486	292	46	20	.9	777	7.5
		June 22, 1949	18	1.2	116	6.9	33	290	33	29	.3	95	--------	498	318	80	19	.8	758	7.2
Near Wilson:																				
NW¼SE¼ sec. 10, T. 13 S., R. 11 W.	36	do	22	.38	129	25	83	359	132	72	.6	89	--------	772	425	131	30	1.8	1,150	7.4
Near Tescott:																				
SW¼SW¼ sec. 15, T. 12 S., R. 5 W.	57	Aug. 11, 1948	29	------	414	108	238	500	180	990	------	3.8	2,210	2,630	1,480	1,070	26	2.7	3,970	7.2
		June 22, 1949	21	56	676	214	379	434	488	1,790	.0	2.9	3,790	4,260	2,570	2,210	24	3.3	5,980	6.7
NW¼SE¼ sec. 16, T. 12 S., R. 5 W.																				
Well 1	45-50	Aug. 11, 1948	42	------	110	32	66	388	132	86	------	1.7	--------	700	406	88	26	1.4	1,220	7.8
Well 2	------	June 22, 1949	38	4.8	116	15	47	396	86	28	.1	.1	--------	544	351	26	23	1.1	820	7.5
NE¼NE¼ sec. 21, T. 12 S., R. 5 W.																				
Well 1	45-50	Aug. 11, 1948	40	------	116	13	34	412	35	30	------	.2	--------	464	343	5	18	.8	780	7.5
Well 2	42	June 22, 1949	31	.07	122	14	68	[1] 373	116	41	.3	30	--------	622	362	56	29	1.6	910	8.3

[1] Includes equivalent of 17 ppm of carbonate (CO_3).

TRIBUTARIES TO THE SALINE RIVER

Some chemical-quality data were obtained for most of the tributaries to the Saline River. Only one or two analyses were made for most of the tributaries; they represent the quality of the water at low discharges and are given in table 7. Several selected analyses that represent the quality of the water at various discharges for Wolf Creek near Sylvan Grove and a summary of the chemical composition of the water from Paradise Creek near Paradise are given in tables 8 and 9, respectively.

Data for Wolf Creek were obtained about 3 miles upstream from the confluence with the Saline River. In the lower reaches of Wolf Creek at least, the water is similar in composition to that in the lower reaches of the Saline itself. The water is highly mineralized at low discharges (specific conductance of 7,490 micromhos per cm at 0.6 cfs) and is of the sodium chloride sulfate type. It is only slightly mineralized at medium and high discharges (289 micromhos per cm at 131 cfs and 290 micromhos per cm at 3,880 cfs) and is of the calcium bicarbonate type. Most of each year the water discharge is below about 5 cfs, and the specific conductance of the water probably is more than about 2,500 micromhos per centimeter. The water is usually very hard, and concentrations of silica, iron, fluoride, nitrate, and boron are low.

Data obtained daily for Paradise Creek show that near Paradise and upstream the water is relatively low in mineralization and is of the calcium sulfate or calcium bicarbonate type at all discharges. Concentrations of chloride are low or moderate.

Data from the salinity survey on May 28, 1949, indicate that at low discharges the quality of the water downstream from Paradise deteriorates rapidly (table 7). The specific conductance, in micromhos per centimeter, was 860 near Paradise, 1,230 a mile downstream, 2,030 about 5 miles downstream, and 2,310 near the confluence with the Saline River.

RELATION OF CHEMICAL COMPOSITION TO GEOLOGY

Water begins dissolving atmospheric gases, among which is carbon dioxide, and minute particles of dust as it condenses in the atmosphere. When the slightly mineralized rainwater strikes the ground, it begins to dissolve the rocks and minerals with which it comes into contact.

The presence of carbon dioxide enhances the ability of the water to dissolve some of the minerals in the earth's crust. Carbonates of iron, calcium, and magnesium, for example, nearly insoluble in water alone, are readily soluble in water charged with carbon dioxide. If the water comes into contact principally with relatively insoluble igneous rocks, a small amount of mineral material is dissolved. If, however, the water comes into contact principally with relatively soluble sedimentary rocks, a large amount of mineral material is dissolved.

Chemical analyses of selected low-flow samples of surface waters in the Saline River basin have been represented diagrammatically (Stiff, 1951) on plate 2 to show relations between the chemical composition and the bedrock. The shape of the diagrams indicates the relative concentrations of the principal constituents in the water, and the size of the diagrams indicates roughly the relative degrees of mineralization of the water.

During periods of high flow, calcium and bicarbonate predominate in the water from nearly all areas; although the bedrock differs from place to place, the principal soluble constituent of the rocks at or near the surface is calcium carbonate. Even in areas where bedrock is relatively noncalcareous, calcium carbonate probably is the principal soluble constituent because leaching has removed other more readily soluble material.

For long periods during each year the streamflow in the Saline River is low and is principally from ground water. Because the influent ground water so seriously deteriorates the quality of the water in the lower part of the basin, the proportion of the flow at Tescott that is ground-water accretion was estimated from hydrographs of the ground-water component of the streamflow and of the total streamflow (pl. 5). The method used was for the most part that of Wisler and Brater (1951, p. 29–31). The following assumptions were necessary: The surface runoff from any rain is carried out of the immediate area within a few days; during fair weather and during periods of continuous below-freezing temperatures, nearly all the streamflow is derived from ground water; during periods of rising stage, the inflow of ground water to the stream is nearly halted; and just after the peak stage, the inflow is sharply accelerated and then gradually reverts to the normal amount. The hydrograph of the ground-water component during each period of high runoff was so drawn as to represent the average of the decreased discharge during the period of rising stage and the increased discharge after the peak stage.

TABLE 7.—*Miscellaneous chemical analyses of water from tributaries to the Saline River*

[Results in parts per million except as indicated]

Site	Date of collection	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption-ratio	Specific conductance (micromhos per cm)	pH
North Fork Saline River near Oakley	*1948* Aug. 12	([1])	12	0.00	10	2.7	5.5		44	8.8	2.0				67	0.09	36	0	25	0.4	78	7.1
Do	*1949* June 21	([1])	20	.02	16	1.3	9.2		60	6.4	3.0	0.2	5.9		108	.15	46	0	31	.6	136	7.7
North Fork Saline River near Wakeeney	*1958* Aug. 13	0.1	23	.04	60	11	12	14	155	94	12	.5	.7	0.16	308	.42	196	69	11	.4	462	7.7
Salt Creek near Russell	do	3.3	8.7	.04	243	94	1,510	20	373	914	2,180	1.1	8.0	.62	5,270	7.17	995	689	76	21	8,300	8.1
Paradise Creek: Near Natoma	*1949* May 28										28				575	.78					838	
Above confluence with Eagle Creek	do										20				736	1.00					977	
Eagle Creek at Paradise	*1958* Aug. 13	.42	16	.04	109	20	43	8.1	200	233	32	.5	15	.13	592	.81	354	190	20	1.0	832	7.8
Paradise Creek: Near Paradise, at gaging station	*1949* May 28	[2] 1.6									19				640	.87					860	
1 mile below gaging station	do										108				874	1.19					1,230	
About 5 miles below gaging station	do										322				1,310	1.78					2,030	
Near confluence with Saline River	do										403				1,490	2.03					2,310	
Do	June 22	[2] 7	20	.02	96	21	167		247	240	166	.1	2.1	.11	884	1.20	326	123	53	4.0	1,360	8.0
Cedar Creek near Bunker Hill	*1958* Aug. 13	2.5	16	.04	163	16	78	5.4	218	337	76	.5	22	.20	841	1.14	474	295	26	1.6	1,180	7.7
Unnamed Creek, 2 miles west of Sylvan Grove	*1950* May 5	[3] <1.5					5.8		139	1.0	.5		4.9	.50	166	.23	107	0	10	.2	237	7.6

West Twin Creek near Sylvan Grove	May 2	1.0	17	.02	124	21	77		279	230	66	.6	.8	.20	698	.95	396	167	30	1.7	1,020	7.9
East Twin Creek near Sylvan Grove	do	<1.0	13	.02	94	16	56		284	143	28	.4	1.5	.20	514	.70	301	68	29	1.4	758	7.9
Unnamed Creek, 1.5 miles west of Vesper	May 5	[3]<1.0	------	------	------	------	6.0		145	1.0	.6	------	4.5	.50	158	.21	112	0	10	.2	247	7.6
Spillman Creek above Bacon Creek near Ash Grove	*1958* Aug. 13	.24	15	.04	123	15	50	7.7	246	212	35	.4	14	.13	609	.83	370	168	22	1.1	886	7.7
Spillman Creek near Lincoln	*1950* May 2	1.0	9.1	.02	101	19	165		361	138	174	.6	2.4	.20	808	1.10	330	34	52	5.4	1,300	7.7
Do	May 5	[3]190	------	------	------	------	14		186	18	4.0	------	1.8	.30	222	.30	148	0	17	.5	324	7.5
Lost Creek near Lincoln	May 2	1.0	18	.02	105	9.5	57		211	150	42	------	45	.06	548	.75	301	128	29	1.4	791	7.5
Spring Creek near Lincoln	do	<1.0	6.2	.02	102	15	59		222	200	37	.4	.8	.20	540	.73	316	134	29	1.4	803	7.9
Bullfoot Creek near Lincoln	May 5	[3]<1.5	------	------	------	------	140		260	156	140	------	2.4	.50	700	.95	271	58	53	3.7	1,120	7.8
Beaver Creek near Lincoln	do	[3]<1.0	------	------	------	------	131		312	279	39	------	4.3	.50	778	1.06	321	65	47	3.2	1,080	7.8
Elkhorn Creek near Lincoln	May 2	<1.0	4.8	.02	128	24	87		218	345	49	.4	.7	.20	780	1.06	418	239	31	1.9	1,080	8.0
Twelve Mile Creek near Shady Bend	May 5	[3]<1.0	------	------	------	------	88		286	170	21	------	1.9	.30	534	.73	251	16	43	2.4	796	7.7
Table Rock Creek near Beverly	May 2	<1.0	21	.02	125	33	162		[4]426	235	142	.6	4.6	.20	970	1.32	448	99	44	3.3	1,440	8.3

[1] Almost no flow.
[2] Daily mean discharge.
[3] Estimated.
[4] Includes equivalent of 18 ppm of carbonate (CO_3).

TABLE 8.—*Selected analyses of water from Wolf Creek near Sylvan Grove*

[Results in parts per million except as indicated]

Date of collection	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption-ratio	Specific conductance (micromhos per cm)	pH
Oct. 2, 1948	0.6	6.5	0.01	91	89	1,540	9.6	222	776	2,000	0.4	2.0	0.62	4,630	6.30	593	411	85	27	7,490	8.0
June 2, 1949	4.3	19	.02	100	33	459		272	288	608	.1	2.0	------	1,650	2.24	385	162	72	10	2,810	6.9
June 7	131	16	.02	45	3.6	6.7		144	8.0	10	.4	.9	------	186	.25	128	10	10	.3	289	7.0
July 16, 1950	3,880	15	.10	45	1.8	14		148	17	5.0	.3	2.9	.10	194	.26	120	0	20	.5	290	8.0

TABLE 9.—*Summary of the chemical composition of water from Paradise Creek near Paradise*

[Results in parts per million except as indicated]

Type of data	Period represented	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption-ratio	Specific conductance (micromhos per cm)	pH
Maximum observed	1947–48	-----	28	0.50	254	38	107	27	300	588	166	0.5	12	0.30	1,050	1.43	574	745	549	55	3.5	1,360	8.9
Minimum observed	1947–48	-----	7.0	.00	40	1.2	2.8	.4	136	23	.0	.1	0	.03	182	.25	0	124	0	2	.1	266	7.0
Discharge-weighted average [1]	1947	29.1	13	.10	111	15	19	5.8	192	196	17	.3	3.7	------	497	.68	39.0	338	181	11	.4	699	----
Do. [2]	1947–48	12.2	24	.05	53	4.4	10	3.2	153	44	3.1	.2	2.2	------	255	.35	8.40	150	25	13	.4	338	----

[1] Represents 74 percent of runoff for water year October 1946 to September 1947.
[2] Includes estimates for unsampled periods. Represents 100 percent of runoff for water year October 1947 to September 1948.

The ground-water inflow in the Saline River at Tescott was estimated for the 1948 water year, a year when the total flow was near the long-term (36-yr) average, and for the 1952 water year, a year following 2 years of much greater than normal precipitation and streamflow. For 1948 the ground-water inflow (represented by the broken line on pl. 5) was about 22 percent of the total flow, and for 1952 (not shown in the report) it was about 60 percent of the total. Obviously, the ground-water inflow in the Saline River at Tescott is always a significant part of the total flow and varies in percentage from year to year, partly in response to differences in the pattern and amount of stream discharge for a given year and partly in response to the antecedent hydrologic conditions, particularly the altitude and configuration of the water table in the basin.

QUATERNARY SYSTEM

Deposits of Pleistocene and Recent age overlie the Ogallala Formation in most of the western part of the basin and overlie older rock units in some places in the eastern part.

Valley fills and terrace deposits of Pleistocene and Recent age are present in flood-plain, terrace, and upland positions. They consist of fluvial material and range from silt and sandy clay to gravel (Frye and Leonard, 1952). A thin layer of volcanic ash is also present locally. The composition of the gravels varies locally from predominantly quartz and granitic pebbles to material derived largely from Cretaceous bedrock. In many places the sand and gravel are cemented by carbonate into lenticular masses of conglomerate.

The approximate extent and thickness of loess deposits in the basin are shown on plate 2. The extent of the loess increases from small patches in the uplands in the eastern part of the basin to a thick blanket in the western part. The loess is uniform, fossiliferous, and calcareous (Frye and Leonard, 1952). The silt fraction, which is the predominant material, is composed mainly of quartz, feldspars, carbonate particles, and mica (mostly muscovite). The clay fraction is made up of illite and montmorillonite in varying proportions. Except for lower alkali and higher water content (Swineford and Frye, 1951), the overall composition of the loess is closely similar to granite. One unit is characteristically red because of finely disseminated iron oxide. The loess deposits also include at least two well-developed paleosols, which in places have caliche zones containing large carbonate concretions.

Because the loess of Pleistocene and Recent age and the soils developed on the loess are mainly calcareous, they supply much of the calcium bicarbonate that is in the overland flow and, especially in the western part of the basin, in the ground water. In much of the basin, zones of calcium carbonate accumulation lie within 5 feet of the land surface; they are nearer the surface in the western part of the basin than in the eastern part because of differences in leaching that result from differences in average precipitation. The zones of accumulation are exposed on many steep slopes and in gullies and headcuts.

The effects of the alluvium and terrace deposits on composition of the surface water probably are slight in most of the basin because the relative quantities of alluvium and terrace deposits generally are small (pl. 2) and because quartz, which is only slightly soluble, is the dominant mineral constituent. These deposits are probably well leached in most places; where they are not, the effects on composition of surface water probably are similar to those of the bedrock in the area because the alluvial deposits contain much material derived locally from the bedrock.

TERTIARY SYSTEM

The Tertiary System is represented in the basin by the Ogallala Formation of Pliocene age, which unconformably overlies progressively older strata from west to east. The Ogallala consists of predominantly clastic sediments resulting from continental deposition; considerable variation in lithology is common (Frye, 1945a, p. 66; Bayne, 1956, p. 25). Thus, its effects on the chemical composition of water in the basin cannot be generalized. Sand, most commonly arkosic, is the dominant constituent of the formation. Particles of crystalline rock are common in the sand; coarser material, particularly if boulders are present, is of local origin and is principally chalk or shale from the underlying Cretaceous strata (Frye and Swineford, 1946, p. 48). The Ogallala also contains bentonite clay, volcanic ash, and a small amount of sandy or silty limestone.

Exposure of the Ogallala and the chemical quality of associated waters are affected by the degree of cementation of constituent materials in the formation and by the amount of Pleistocene cover. Two types of cement are present in the Ogallala—calcium carbonate and silica. Carbonate predominates as a cement, but it also is present as nodules, stringers, and individual particles throughout the formation. Where clastic rocks are well indurated by carbonate cement, they form resistant ledges, commonly called mortar beds, which may persist for some distance. Calcium bicarbonate, which predominates in water from areas underlain by the Ogallala, is not only derived from the abundant calcite cement in the Tertiary deposits but in part from the overlying loess deposits. Silica is present as finely disseminated opaline or chalcedonic cement throughout the Ogallala, but it is especially concentrated in the so-called quartzite of the Ogallala. This quartzite, which has been described in detail by Frye and Swineford (1946), is notable for the presence of small amounts of ferrous iron as well as siliceous cement. The relatively high silica content of waters associated with the Ogallala is probably due not only to the greater solubility of amorphous or cryptocrystalline silica cement but also to the presence of volcanic glass in the thin, but persistent, ash layers within the formation and in the overlying Pleistocene deposits. The volcanic ash layers may also be a significant source of boron, fluoride, and potassium.

Water from areas underlain by the Ogallala Formation is represented by diagrams for the South Fork and North Fork Saline Rivers near Oakley and the Saline River near Grainfield (pl. 2). In the upper Saline River, the flow is maintained almost entirely by direct precipitation and surface runoff and is, therefore, of low mineralization. Near Grainfield the channel intercepts the water table in the Tertiary deposits, and the dissolved-solids content increases significantly.

CRETACEOUS SYSTEM

The general effects of the Niobrara Formation on composition of river water can be studied best from data for the North Fork Saline River near Wakeeney and to a smaller degree from data for the Saline River near Wakeeney. The water from areas underlain by the upper part of the Niobrara is similar to the water from areas underlain by the Ogallala but contains considerably more sulfate. (See pl. 2.) Most of the calcium bicarbonate probably is derived from the highly erodible and soluble chalk and calcareous shale of the Smoky Hill Chalk Member of the Niobrara, which is exposed on steep slopes along the valleys of the Saline and North Fork Saline Rivers. Sulfate is derived from the oxidation of the pyrite cores of abundant flat, circular limonitic concretions in the Smoky Hill. The water in the North Fork Saline River is in direct contact with the sulfurous concretions for a considerable distance where the channel cuts to bedrock, and the stream probably is recharged at times by ground water from numerous fracture zones in the Smoky Hill. Silica is derived from the uppermost layers of the Smoky Hill, which has undergone local silicification (Frye and Leonard, 1949, p. 30; Prescott, 1955, p. 47; Bayne, 1956, p. 22).

A further source of calcium bicarbonate in the Saline River is the Fort Hays Limestone Member of the Niobrara Formation, which is well exposed in prominent bluffs along the valley of the main stream. The Fort Hays consists of massively bedded chalk or chalky limestone averaging about 95 percent of calcium carbonate and composed of foraminiferal shells in a fine-grained calcite matrix (Runnels and Dubins, 1949).

The effects of the Codell Sandstone Member of the Carlile Shale on the chemical composition of the water probably are slight. The amount of material dissolved from this member by surface runoff is small because the outcrop area of the member is small; however, the streams derive some ground water from this member. The Codell consists of very fine grained clayey sandstone, which grades downward into sandy shale. Some of the sandstone is loosely cemented by soluble calcium carbonate, and the clayey material may bring about some alkali fixation.

The increases in dissolved solids, especially sulfate, in the Saline River between Wakeeney and Codell may be attributed for the most part to the effects of the Blue Hill Shale Member of the Carlile Shale. The Blue Hill is a very fissile blue-gray shale containing numerous ferruginous and (or) calcareous concretions. A concretionary ironstone layer persists near the base of the member. Data for Paradise Creek near Paradise and Eagle Creek at Paradise indicate that the water draining the area directly underlain by the Blue Hill is of the calcium bicarbonate or calcium sulfate type. Sulfate is derived from gypsum and pyrite; gypsum crystals are abundant in the Blue Hill, especially in the lower part. Salt has also been noted (Rubey and Bass, 1925, p. 35).

Calcium bicarbonate undoubtedly is contributed to the Saline River basin drainage by the Fairport Chalky Shale Member of the Carlile Shale; the contributions are represented in the data for Cedar Creek near Bunker Hill and Spillman Creek near Ash Grove.

Underlying the Carlile Shale is another source of calcium bicarbonate, the Greenhorn Limestone. The Greenhorn consists of interbedded calcareous shale and thin chalk or dark crystalline limestone. The limestone beds of the lower part of the Greenhorn are composed largely of fossil material and contain traces of petroliferous (Landes, 1930, p. 29) and phosphatic material (Rubey and Bass, 1925, p. 47). At the top of the Greenhorn is the resistant "fencepost limestone," a slightly sandy hard chalk bed containing some iron oxide. The Greenhorn Limestone contains very little water; however, much calcium carbonate is contributed to the streams by surface runoff that has been in contact with the limestone scattered over much of the upland area in the lower part of the basin.

The Graneros Shale exposures, though widely scattered, are present in relatively narrow bands. The shale most likely affects the chemical composition of the water in much of the lower part of the basin; however, no data are available to show the influence. The Graneros consists of fissile dark blue-gray clay shale, sandy or silty shale, and some locally interbedded iron-stained sandstone. A thin bed of ironstone persists at the base. The Graneros Shale is noncalcareous except for a few layers of sandy limestone and calcareous concretions near the top. Selenite crystals, pyrite, and melanterite (iron sulphate) commonly are abundant; thus, sulfate is expected to be the major constituent contributed to water by the Graneros. Small amounts of boron and fluoride may be derived from thin layers of bentonite.

The Dakota Sandstone is the principal contributor of dissolved minerals in the basin, especially during low-flow periods. Springs issuing from the Dakota empty directly into the lower reaches of the Saline River and many of its principal tributaries. Generally, the water from the Dakota is highly mineralized and is characterized by high concentrations of sodium and chloride.

The Dakota is a very complex stratigraphic unit consisting of irregularly bedded gray shale; tan sandy or silty shale; thin-bedded fine-grained clayey sandstone and siltstone; varicolored kaolinitic clay layers; lignite; and relatively coarse-grained lenticular channel sandstone (Plummer and Romary, 1942; 1947). The dominant clay mineral throughout the Dakota is kaolinite. Iron is present as hematite, limonite, siderite, or, where associated with lignite or calcite cement, as pyrite. Persistent zones of concretionary hematite "shot" are in several strata. Some selenite is associated with the clay and shale, and a few scattered calcareous concretions are present locally.

Cementation in sandstone of the Dakota has been discussed in detail by Swineford (1947). The channel sandstone typically contains ferruginous cement; however, some calcium carbonate cementation gives rise to irregularly shaped masses of indurated clastic rocks, and some large lenticular sandstone bodies in southern Lincoln County contain dolomitic calcite cement.

Such wide variations in the composition of the Dakota result in similar variations in the chemical composition of associated waters. This fact is most readily apparent from the variability in the quality of water from wells penetrating the Dakota west of its outcrop area in the Saline River basin. (See analyses in Frye and Brazil, 1943.) The effects of the Dakota on the chemical composition of surface water can be seen readily from diagrams (pl. 2) for Salt Creek near Russell, Wolf Creek near Sylvan Grove, and the Saline River near Russell, Wilson, and at Tescott.

The contributions of dissolved constituents to the streams probably are most significant where beds of coarse channel sandstone, the principal aquifer within the Dakota, emerge from beneath younger strata to the west. The distribution of these beds in Russell County has been determined by Rubey and Bass (1925, p. 57–62). Contributions of dissolved minerals from the Dakota are probably not so great in downstream areas of the basin because of more extensive leaching and smaller source areas for ground-water recharge.

The sodium chloride from the Dakota is probably derived mostly from sand and silt, and the calcium sulfate from clay and shale. The source of the sodium chloride in water from the Dakota is very finely disseminated salt, probably resulting from deposition of the sand and silt in a deltaic tidal marsh environment.

No chemical analyses were made of water from streams that might be significantly affected by the Kiowa Shale. Because the Kiowa is poorly exposed, it probably contributes only small amounts of dissolved mineral material. However, some sulfate may be derived from the plentiful gypsum in the shale.

PERMIAN SYSTEM

Much of the Wellington Formation is mantled with thick deposits of alluvium, as much as 90 feet in some parts of Saline County (Latta, 1949, p. 35); therefore, the composition of the water in the streams probably is influenced principally by the alluvium rather than by the Wellington.

RELATION OF CHEMICAL QUALITY TO USE

The quality requirements of water for different uses are variable; therefore, the water is classified for use according to different criteria. For most uses, water that is only slightly mineralized is preferred, and the suitability of the water decreases as the mineralization increases.

DOMESTIC USE

The dissolved-mineral constituents of most importance to domestic users are calcium, magnesium, iron, manganese, chloride, fluoride, sulfate, and nitrate. Calcium and magnesium in water cause hardness, which impairs the quality of the water because of the curd that forms when soap is added and because of the scale that is deposited in pipes and in water heaters and boilers. Magnesium in high concentrations, especially if associated with sulfate, may act as a laxative. Iron and manganese, even when present in low concentrations, stain laundry and porcelain fixtures, and they can be tasted when present in concentrations higher than about 0.5 ppm (California Inst. Technology, 1952, p. 276). High concentrations of chloride cause water to taste salty and may cause physiological injury to people suffering from certain heart or kidney ailments. However, some investigators believe that concentrations as high as 1,000 ppm are harmless (California Inst. Technology, 1952, p. 209). Fluoride in drinking water may cause teeth to become mottled. However, a small amount of fluoride in water consumed by children apparently aids in sound tooth development and lessens the incidence of dental caries (Am. Water Works Assoc., 1950, p. 56). High concentrations of sulfate in drinking water may cause a laxative effect; however, many persons develop a tolerance to the sulfate through continued use of the water. Nitrate is the end product in the oxidation of organic nitrogen compounds; therefore, higher-than-normal concentrations of nitrate may indicate the presence of pollution associated with the decomposition of organic wastes and, in drinking water, may cause the development of cyanosis in infants (Maxcy, 1950).

No specific standards for hardness have been established, but the following gradations generally are recognized:

Hardness as $CaCO_3$ *(ppm)*	*Rating*	*Suitability*
Less than 60	Soft	Suitable for many uses without further softening.
60–120	Moderately hard	Usable except in some industrial applications.
121–200	Hard	Softening required by laundries and some other industries.
More than 200	Very hard	Requires softening for many uses.

The U.S. Public Health Service in 1914 established standards for the quality of water used in interstate traffic under their jurisdiction. The standards tend to be conservative because they are designed for the protection of people easily affected by changes in water. They were revised in 1946 (U.S. Public Health Service, 1946) and were adopted by the American Water Works Association as standards for all public supplies. The standards pertaining to some of the mineral constituents are as follows:

Constituent	*Maximum concentration (ppm)*
Iron plus manganese (Fe+Mn)	0.3
Magnesium (Mg)	125
Sulfate (SO_4)	250
Chloride (Cl)	250
Fluoride (F)	1.5
Nitrate (NO_3)	[1] 44
Dissolved solids	[2] 500

[1] Maxcy, 1950. Not a Public Health Service recommendation.
[2] 1,000 ppm permitted if no other water is available.

The water in the Saline River is hard or very hard. The minimum hardness measured was 104 ppm near Wakeeney, and a hardness of as much as 978 ppm was measured near Russell. (See table 4.) Hardness-duration data are shown in table 10. These data were determined in the same way as those shown in table 3.

TABLE 10.—*Hardness-duration data for the Saline River*

Percentages of time	Hardness as $CaCO_3$ exceeded for given percentages of time (ppm)			
	Near Wakeeney	Near Russell	Near Wilson	At Tescott
10	310	850	780	580
20	300	780	740	550
30	270	730	700	530
40	250	660	670	510
50	240	610	610	490
60	220	560	570	480
70	190	480	510	450
80	160	400	390	390
90	140	280	270	290
100	90	130	130	120

The concentrations of dissolved solids were well within the suggested limits of 500 ppm near Wakeeney. However, the concentrations were much above the maximum limit of 1,000 ppm most of the time at the downstream sites.

Concentrations of magnesium, fluoride, and nitrate are well below their respective limits, and the concentrations of iron plus manganese probably are within the limit most of the time. However, chloride and sulfate concentrations are considerably in excess of their limits most of the time. (See table 3.) The water in the upper Saline River is of good quality for domestic use except that it is hard; the water in the lower Saline River is of poor quality for domestic use most of the time because it is highly mineralized, is hard, and contains high concentrations of chloride and sulfate.

Water in most of the tributaries to the Saline River probably is of good quality for domestic use. The quality of the water in most of the tributaries is better at medium and high discharges than at the low discharges represented in table 7. The water in the downstream reaches of Paradise and Salt Creeks is of poor quality for domestic use.

IRRIGATION

Generally, water for irrigation should be of such quality that it will not adversely affect the productivity of the land to which it is applied. Investigators have suggested methods for classifying irrigation water so that its long-term effect on soil productivity can be forecast (Wilcox, 1948; Scofield, 1936; Eaton, 1950; U.S. Salinity Laboratory Staff, 1954). All methods of classifying water are arbitrary to a certain degree. The method of classification used in this report was proposed by the U.S. Salinity Laboratory Staff (1954).

Certain properties are of principal importance in determining the quality of water for irrigation. These properties are the total concentration of the dissolved salts, the relative proportion of sodium to calcium and magnesium, the concentration of boron or other elements that may be toxic, and for some water the concentration of bicarbonate as compared with the concentrations of calcium and magnesium.

High concentrations of dissolved salts in irrigation water may cause a buildup of salts in the soil solution and may make the soil saline. The tendency of irrigation water to cause a high buildup of salts in the soil is called the salinity hazard of the water. The specific conductance of the water is used as an index of the salinity hazard.

High concentrations of sodium relative to the concentrations of calcium and magnesium in irrigation water can adversely affect soil structure. Cations in the soil solution become fixed on the surface of fine soil particles; calcium and magnesium tend to flocculate the particles, whereas sodium tends to deflocculate them. The adverse effect on soil structure caused by high sodium concentrations in the irrigation water is called the sodium hazard of the water. An index used for predicting the sodium hazard of a water is the sodium-adsorption-ratio (SAR), which is defined by the equation

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

where Na^+, Ca^{++}, and Mg^{++} are in equivalents per million (U.S. Salinity Laboratory Staff, 1954).

The salinity hazard and sodium hazard of the water may be evaluated by use of a diagram by the U.S. Salinity Laboratory Staff (1954). (See fig. 17.) Interpretation of the diagram is as follows:

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

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

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

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

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

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

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

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

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

Water from the Saline River has been classified for irrigation (fig. 17). Near Wakeeney the classification of the water was the same for both years although the annual average water discharge varied considerably (table 4). Near Russell, near Wilson, and at Tescott the classification varied as the annual average discharge varied.

Boron is essential to the normal growth of all plants; however, if present in excessive concentrations, it may be highly toxic to some

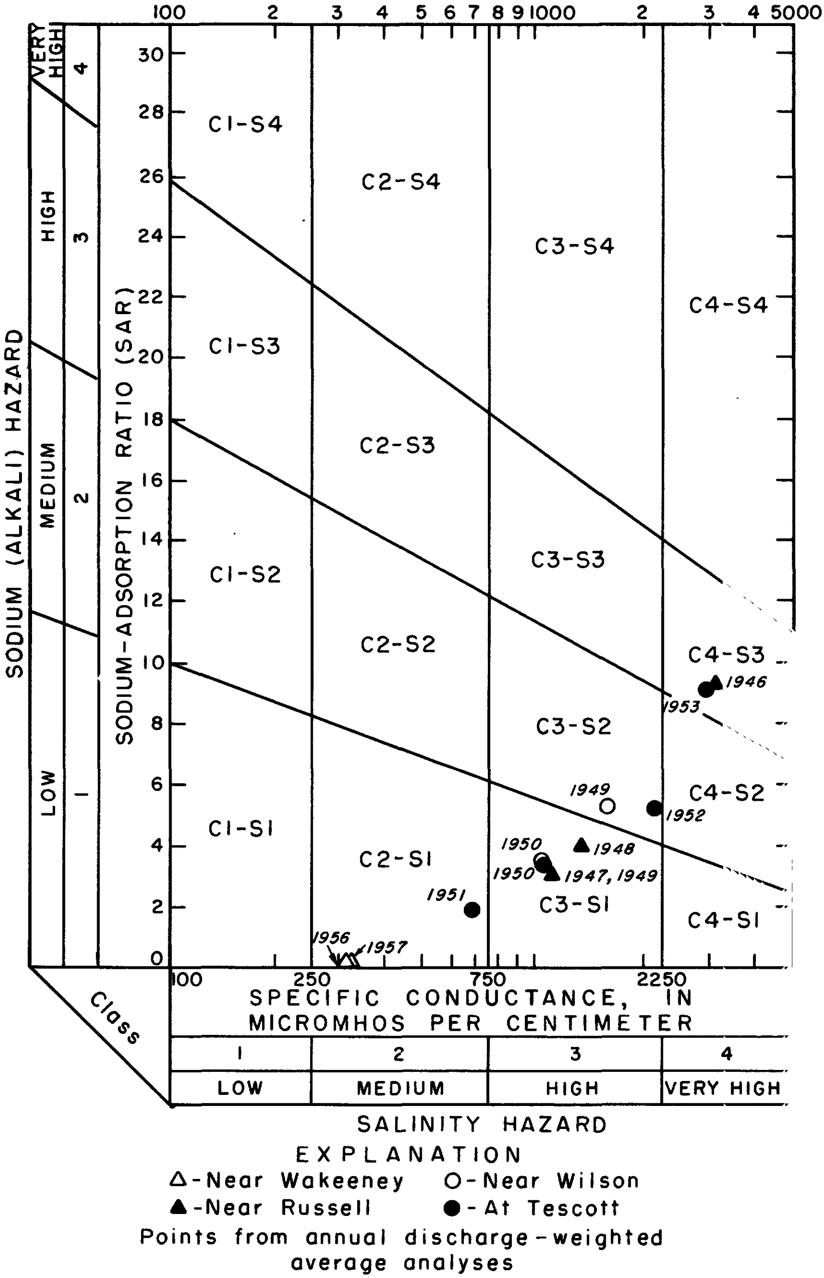

FIGURE 17.—Classification of water for irrigation, Saline River. Diagram from U.S. Salinity Laboratory Staff, 1954.

species (Wilcox, 1955, p. 6). The concentrations of boron in the water of the Saline River are probably sufficiently high to satisfy the boron requirements for most crop plants and sufficiently low to be nontoxic even to boron-sensitive crops.

High concentrations of bicarbonate in irrigation water may cause calcium and magnesium to precipitate in the soil as carbonate salts. Precipitation of calcium and magnesium results in an increase in the proportionate amount of sodium in the water; the increase may have the same effect on the soil as if the sodium hazard of the irrigation water had been high and may cause an increase in the pH of the soil. Water in the Saline River generally contains less bicarbonate, as equivalents per million, than calcium and magnesium; therefore, the water is probably safe for use.

INDUSTRY

Water for industry is used principally as an ingredient with other raw materials, as a buoyant medium, for cleaning, for heating, or for cooling. The quality requirements of water used for cleaning, heating, or cooling are probably similar for each type of industry, but the requirements of water used as an ingredient with other raw materials or as a buoyant medium differ considerably from one industry to another.

Industries requiring water of a definite chemical quality usually have their own facilities for treating water. Water suitable for domestic use is also suitable for most industrial uses or can be treated at a reasonable cost so that it will be suitable.

> One characteristic * * * is of primary importance for all industries, namely, that the concentrations of the various constituents of the water remain relatively constant. That the water is originally of poor quality for a particular industrial use is probably not as important, once a process is started and the difficulties created by the presence of undesirable constituents in water are eliminated, as having the quality remain constant. Short-time variations in concentrations of substances in the process water require continued attention and added expense (California Inst. Technology, 1952, p. 127).

Water from the upper Saline River and many of the tributaries is of suitable quality for many industrial uses; however, the quantities of water available are small and undependable. Water in the lower Saline River is of poor quality for most industrial uses most of the time, principally because of the high degree of mineralization but also because the quality of the water changes drastically from time to time.

FLUVIAL SEDIMENT

All streams contain sediment derived from the rocks and soils of the drainage area. The sediment is transported either as bed load or as suspended load, and for a given stream the discharge and particle-size distribution of the sediment vary in response to such factors as changes in water discharge and differences in geology and soils. The magnitude and variations of the sediment discharge and particle-size distribution influence the economic development or control of a given water supply. Therefore, in this study, the relations of sediment discharge and particle-size distribution to changes in water discharge, to differences in geology and soils, and to the space that the sediment would occupy in reservoirs are discussed.

The sediment investigations by the Geological Survey were started in May 1946 with the study of suspended-sediment transport on the Saline River near Russell. Since that time, continuous records of suspended-sediment concentration and discharge have been obtained at 4 sites for periods of 3½ to about 5½ years. Periodic and infrequent records were obtained at 2 sites for periods of 2 years. Sampling sites are shown on plate 1, and periods of record are shown in the following table:

Site	*Type of record*	*Period of record*
Saline River near Wakeeney	Continuous	October 1955 to September 1959
Saline River near Russell	do	May 1946 to September 1951
Paradise Creek near Paradise	do	March 1947 to September 1951
Saline River near Wilson	Infrequent	February 1948 to January 1950
Wolf Creek near Sylvan Grove	Continuous	April 1947 to September 1950
Saline River at Tescott	Periodic	June 1957 to June 1959
	Continuous	July 1959 to September 1959 [1]

[1] Data still being obtained as of September 1960.

The continuous records were generally adequate to define the suspended-sediment discharge for each day and the total suspended-sediment discharge for each month and year during the period, and the particle-size distributions of suspended sediment were defined for a wide range of concentrations and discharges. The data for Saline River near Wilson were not used in this report because the measurements were insufficient to define the relation of suspended-sediment discharge to water discharge and because no particle-size analyses were made. Suspended-sediment records are published in the annual series of the U.S. Geological Survey Water-Supply Papers entitled "Quality of Surface Waters of the United States."

Each site where continuous records were obtained was located at a streamflow gaging station and was equipped with a U.S. D-43 sampler suspended from a cable on a reel that was affixed to the bridge railing. Samples were usually obtained by local residents each day except during times of rapidly changing discharge, when samples were obtained several times a day. These samples, collected at a single vertical, were generally representative of the average concentration in the cross section determined from measurements made by Geological Survey personnel at three to five verticals across the streams. At the sites where periodic and infrequent records were obtained, measurements were made by Survey personnel at 3 to about 20 verticals.

Bed material was sampled at many points in the basin in 1953, 1957, and 1958 with a core sampler, which obtains samples about 2 inches in diameter and from 4 to 6 inches in length. Bed material was sampled at Tescott in 1957 with a U.S. BM-54 sampler, which obtains samples about 4 inches wide and 3 inches deep.

All suspended-sediment samples were analyzed for concentration, and many samples were analyzed for particle size. Concentrations were determined by weighing the sample, removing the water by decantation and evaporation, weighing the dry sediment, and computing the ratio of weight of sediment to weight of sample; the results are expressed in parts per million.

Particle sizes of suspended sediment and bed material were determined by several methods. The sieve method measures the size of particles directly, but the results are influenced by the shape of the particles. The pipet, bottom-withdrawal-tube, and visual-accumulation-tube methods measure particle diameters indirectly by determining the fall velocity of the particles in water, but the results are influenced by the shape and density of the particles. The results are expressed as particle diameters by using the same relationship of fall velocity to diameter as that found for spheres having a specific gravity of 2.65 (Inter-Agency Comm. Water Resources, 1958). Fall velocities were determined in native water, in distilled water with mechanical dispersion, and in distilled water with chemical and mechanical dispersion. The use of distilled water with a chemical dispersing agent prevents the formation of aggregates of small particles; if aggregates were allowed to form, they would fall with higher velocities than the individual particles, and an apparently coarser particle-size distribution would result.

For the continuous records, concentrations were plotted with respect to time, and an average curve was drawn. From the curve the mean concentration was determined for each day except for days of rapidly changing concentration. The mean concentration was multiplied by the mean water discharge for the day and by a units conversion factor to obtain the suspended-sediment discharge in tons per day. For days of rapidly changing concentration and discharge, the suspended-sediment discharges for small increments of time were computed and summed to obtain the suspended-sediment discharge for the day.

For the periodic and infrequent records, each suspended-sediment concentration was multiplied by the concurrent water discharge and by the units conversion factor to obtain the instantaneous suspended-sediment discharge in tons per day.

SUSPENDED-SEDIMENT DISCHARGE

The type of suspended-sediment sampler used in this investigation collects the water-sediment mixture in a zone from the water surface to about 0.4 foot above the bed. Therefore, the measured suspended-sediment discharge is only a part of the total sediment discharge and does not include the bedload nor part of the suspended sediment below the lowest point sampled. The unmeasured part of the total sediment discharge can be negligible or substantial; the amount depends mainly on the stream velocity, particle size of bed material, and channel geometry.

The discharge of suspended sediment from different areas in the basin is dependent mainly on the amount of runoff from the areas and also on the erodibility of the rocks and soils, on the steepness of the land and channel slopes, and on the intensity and amount of precipitation. The effects of such factors as temperature, vegetal cover, and land use have not been evaluated quantitatively in the present report, either because these factors are nearly uniform through the basin or because their effects are obscured by other factors.

Generally, suspended-sediment discharge is highly variable with respect to time. However, if a long period of record is available, the average suspended-sediment discharge for that period will be representative of average conditions and will be useful in planning future water-resources development and, when computed as sediment discharge per unit of drainage area, can be used as an indicator of the erosional rates of different areas.

For the Saline River basin, only relatively short periods of record of sediment discharges were available; therefore, in order to determine long-term averages, the sediment discharges were correlated with the water discharges for which the long-term averages and frequency distributions were known. (See duration curves, fig. 9.) A typical example of the correlation between sediment discharge and water discharge is shown in figure 18.

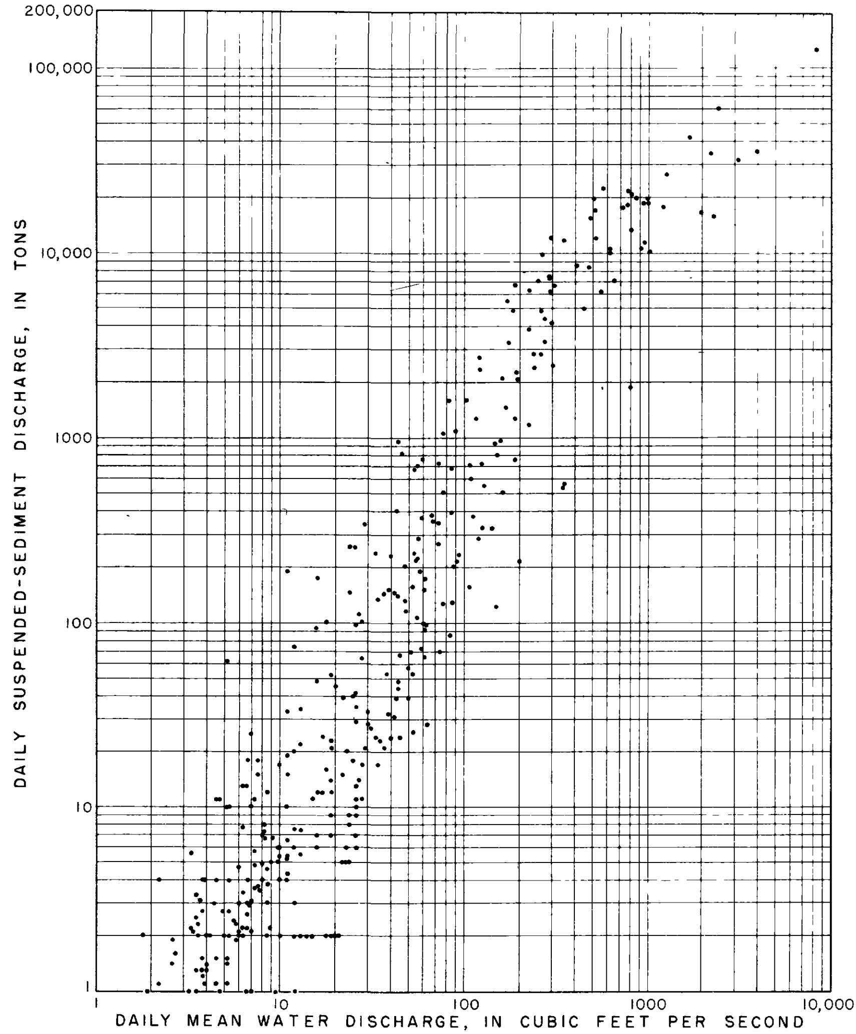

FIGURE 18.—Relation of suspended-sediment discharge to water discharge, Paradise Creek near Paradise, April 9, 1947, to September 30, 1951.

The long-term averages of suspended-sediment discharges were computed as follows: (1) Graphs such as figure 18 were divided into ranges of water discharge, the arithmetic average of the plots in each range was computed, and points representing the averages were plotted on figure 19. Curves that best fit the average points were drawn. (2) The water discharges that were equaled or exceeded during selected percentages of time were computed from figure 9, and sediment discharges corresponding to these water discharges were taken from figure 19. (See table 11 for Paradise

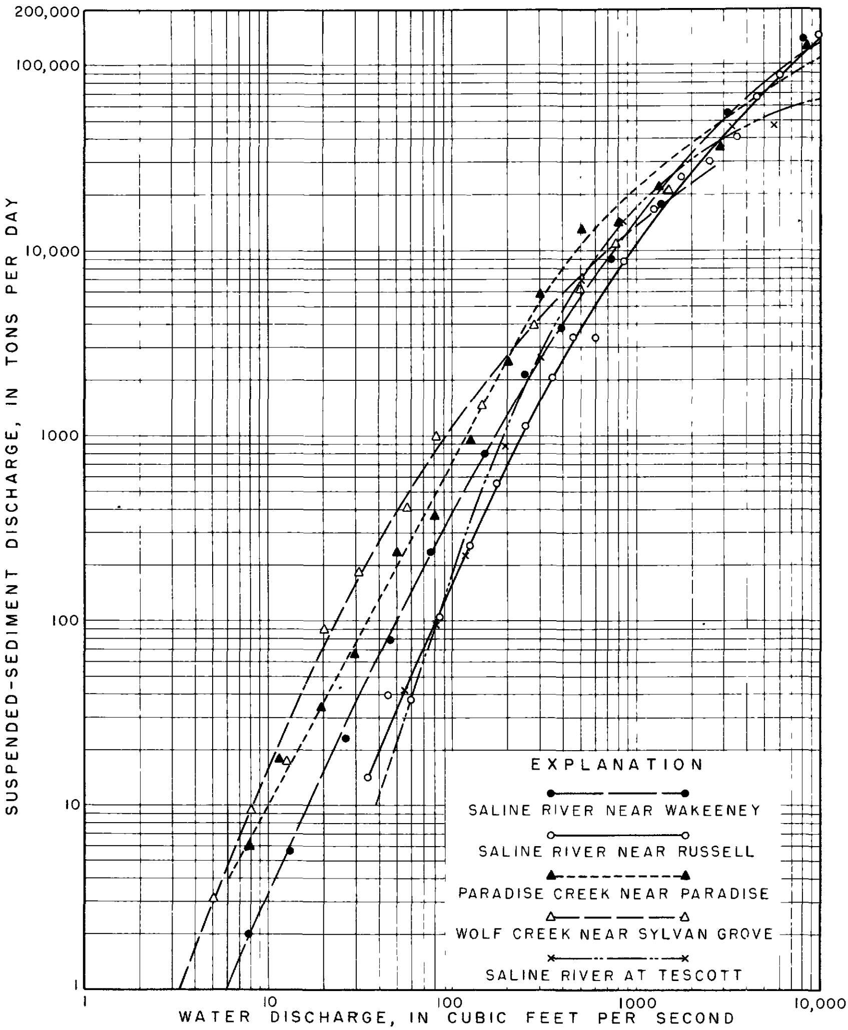

FIGURE 19.—Average relations of suspended-sediment discharge to water discharge.

Creek near Paradise.) The average sediment discharge for each interval between successive percentages of time was computed as the average of the sediment discharges at the limits of each time interval. Each average sediment discharge was multiplied by the length of each respective time interval (expressed as a percentage of the total time); these products were summed and divided by 100 to give the long-term average in tons per day.

TABLE 11.—*Computation of long-term average suspended-sediment discharge, Paradise Creek near Paradise*

Percentage of time	Water discharge equaled or exceeded [1] (cfs)	Suspended-sediment discharge [2] (tons per day)	Interval between succeeding percentages of time	Average suspended-sediment discharge for time interval (tons per day)	Sediment discharge multiplied by time interval
0	[3] 8,350	101,000	0.1	61,000	6,100
.1	960	21,000	.1	18,000	1,800
.2	680	15,000	.1	13,200	1,320
.3	530	11,400	.2	9,500	1,900
.5	380	7,600	.2	6,400	1,280
.7	295	5,200	.3	4,450	1,340
1.0	240	3,700	.4	2,950	1,180
1.4	180	2,200	.6	1,700	1,020
2.0	130	1,200	1.0	800	800
3	73	400	2	243	486
5	32	86	2	52	104
7	14	18	3	13.5	40
10	9.5	9	5	5.5	28
15	4.2	2	5	1.5	8
20	2.2	1	10	.5	5
30	.75	[4] 0	10	0	0
40	.33	[4] 0	10	0	0
50	.18	[4] 0	10	0	0
60	.10	[4] 0	40	0	0
100	0	0	-----------	-----------	-----------
Total			100	-----------	17,411

Average suspended-sediment discharge:

Tons per day	174
Tons per year	63,600
Tons per square mile per year	300

[1] Computed from fig. 9.
[2] From fig. 19.
[3] Maximum daily discharge.
[4] Estimated.

Some assumptions are made in this computation of average suspended-sediment discharge. One is that the duration curves of water discharges for the 36-year period 1921–56 are about the same as those for any other period of about 36 years. Another assumption is that the average relationships of suspended-sediment discharge to water discharge for the periods of sediment records are the same as those for other periods. The validity of both assumptions would be affected by changes in vegetal cover and land use, possible climatic cycles, construction of numerous small detention dams, and such conservation practices as contouring and terracing. In spite of these possible changes, the computed average suspended-sediment discharges are probably fairly representative of past discharges and can be used for predictions of future average sediment discharges.

The sedimentation survey of Sheridan County State Lake (U.S. Bur. Reclamation, 1950) provides a determination of sediment accumulation in the lake for an effective sedimentation period of 10.8 years ending in June 1948. The inflow of sediment computed by using an estimated trap efficiency of 80 percent was 55,000 tons per year. This amount includes the sediment that was transported as bedload.

Table 12 summarizes the results of the sediment discharge computations. Average suspended-sediment discharges were not computed for the Wilson station because sediment measurements were insufficient to establish the relationship between sediment discharge and water discharge.

TABLE 12.—*Long-term average sediment discharges and concentrations at measuring points*

Location	Suspended sediment		
	Discharge		Discharge-weighted average concentration (ppm)
	Tons per day	Tons per year	
Inflow to Sheridan Lake	[1] 150	[1] 55, 000	[1] 4, 100
Saline River near Wakeeney	200	73, 000	3, 000
Saline River near Russell	670	240, 000	2, 800
Paradise Creek near Paradise	170	62, 000	4, 600
Wolf Creek near Sylvan Grove	230	85, 000	3, 600
Saline River at Tescott	2, 200	800, 000	3, 600

[1] Includes sediment discharged as bedload.

Sediment discharges near Wakeeney are affected by accumulation of sediment in Sheridan Lake. Because of changes in the height of the dam, periods of no storage, and changes in reservoir capacity owing to sediment accumulation, effects of Sheridan Lake on sediment discharges downstream are difficult to evaluate. The trap efficiency of Sheridan Lake during the period of sediment record for Wakeeney was estimated to be 50 percent; it was smaller than the trap efficiency during the period covered by the sedimentation survey because the storage capacity of the lake had been reduced by deposited sediment.

Table 13 shows computed average sediment contributions from six different areas in the basin; a close relation is evident between average sediment discharge in tons per square mile per year and average runoff. The differences in discharge-weighted average concentrations may be caused principally by differences in erodibility of the source material.

In the drainage area upstream from Wakeeney the major sources of suspended sediment are the Pleistocene and Recent loess deposits. The abundance, fineness, and unconsolidated nature of these deposits account for suspended-sediment concentrations that are fairly high in this area, even though slopes are not steep.

TABLE 13.—*Long-term average sediment contributions from areas in the Saline River basin*

Area	Drainage area (square miles)	Average runoff (inches per year)	Suspended sediment		
			Tons per year	Tons per square mile per year	Discharge-weighted average concentration (parts per million)
Upstream from Sheridan Lake	463	[1] 0.4	[2] 55,000	[2] 120	[2] 4,100
Between Sheridan Lane and Wakeeney	233	.7	[3] 46,000	200	3,900
Between Wakeeney and Russell	806	1.1	170,000	210	2,600
Paradise Creek drainage	212	.9	62,000	290	4,600
Wolf Creek drainage	261	1.2	85,000	330	3,600
Between Russell and Tescott, excluding Paradise and Wolf Creek drainage areas	845	1.6	410,000	490	4,200

[1] From pl. 4.
[2] Includes sediment discharged as bedload.
[3] The difference between the suspended-sediment discharge near Wakeeney and the estimated sediment outflow from Sheridan Lake.

In the drainage area between Wakeeney and Russell the major sources of suspended sediment are the Pleistocene deposits on the uplands and the Recent alluvial and colluvial deposits in the valley. Minor sources are the shaly beds of the Smoky Hill Chalk Member of the Niobrara Formation, where exposed in badland slopes, and the easily disintegrated Blue Hill Shale Member of the Carlile Shale. Concentrations are lower in this area than those upstream because the loess deposits are less abundant and because much of the exposed bedrock, particularly the Fort Hays Limestone Member of the Niobrara Formation, is resistant to erosion.

In the area drained by Paradise Creek the major sources of suspended sediment are the Pleistocene and Recent loess deposits and the Blue Hill Shale Member of the Carlile Shale. Of the six areas, the Paradise Creek area has the highest concentration because the abundant loess and the Blue Hill Shale Member of the Carlile Shale are highly erodible.

The major sources of suspended sediment in the area drained by Wolf Creek are the same as those in the area drained by Paradise Creek; however, the mean concentration for the Wolf Creek area is lower because the loess and Blue Hill Shale Member are present only in the upper part of the area, where they are not subject to so much dissection and concentrated runoff. Also, the Wolf Creek area has more vegetal cover, and a larger percentage of the area is underlain by the more resistant Greenhorn Limestone and Dakota Sandstone.

Between Russell and Tescott the major sources of suspended sediment are the valley alluvium and terrace deposits. Other sources are the fine-grained strata of the Greenhorn Limestone and the Graneros Shale; fine-grained strata of the Dakota Sandstone contribute some sediment, especially from dissected "badland" slopes in Russell County. Concentrations are relatively high in this area, mainly because of the abundance of fine-grained material in the valley alluvium and terrace deposits.

PARTICLE SIZE OF SUSPENDED SEDIMENT

The particle-size distribution of suspended sediment in a stream varies with concentration, rate of flow, length of time after rain, major source of sediment, season of the year, and many other factors. However, the particle-size distribution for a particular site can be characterized by the weighted-average percent-finer values, in which the weighting factor is the suspended-sediment discharge. These weighted averages represent the size composition that the sediment would have if all the suspended-sediment discharge for several years were collected in one place and thoroughly mixed.

If the percent-finer values are correlated with the suspended-sediment discharge, then the weighted-average percent-finer values are the only values that will accurately represent the size composition of the total suspended-sediment discharge. However, if there is no correlation, a simple unweighted average of the percent-finer values will be as representative as the weighted average. Percent-finer values for suspended sediment in the Saline River basin were tested for correlation with suspended-sediment discharge. For most sampling stations and most particle sizes, no correlation was found. Correlation was found for the 0.004-mm size at the Paradise and Russell stations, and the weighted averages were computed for that size at those locations. The weighted averages were the same as the unweighted averages; therefore, unweighted averages were used for all sizes and all sampling stations. Only the 0.004-, 0.016-, and 0.062-mm sizes were used (except at the Tescott station where the 0.002-mm size was used) because many of the samples were not analyzed for the other sizes. In order to keep the data consistent, only the analyses in distilled water with chemical and mechanical dispersion were used in the computations. Results of the computations are shown graphically in figure 20.

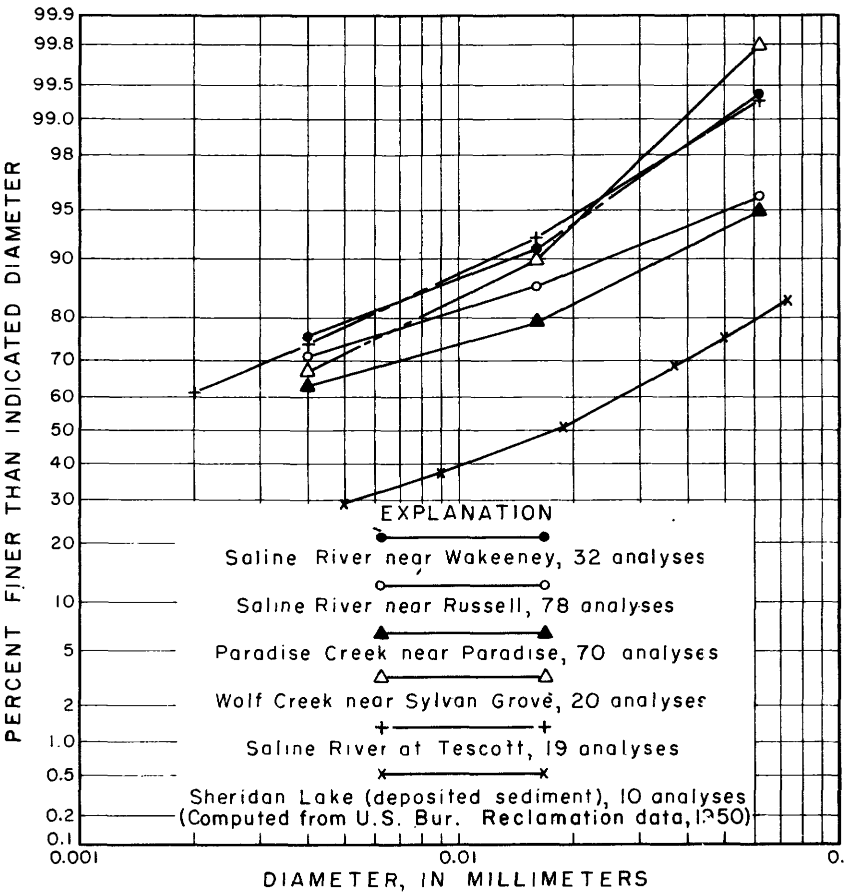

FIGURE 20.—Average particle-size distributions of suspended and deposited sediment analyzed in a dispersed state.

In Paradise Creek and the Saline River near Russell, about 5 percent of the suspended sediment is sand (coarser than 0.062 mm); whereas in Wolf Creek and the Saline River near Wakeeney and at Tescott, less than 1 percent of the suspended sediment is sand. These differences partly reflect the differences of the amount of sand in the valley alluvium. Suspended sediment at all the measuring sites has high percentages of clay (63 to 76 percent finer than 0.004 mm). The deposited sediment in Sheridan Lake is coarser than the suspended sediment at the five other sites, partly because its source was different, partly because it includes large particles that were transported as bedload, and partly because it does not include the finest part of the suspended sediment, which passed through the spillway.

Some of the suspended-sediment samples were divided into two parts for analyses—one in distilled water and one in native water. The size distribution from the analysis in native water was coarser than that in distilled water because the smallest particles flocculated. Because of turbulence, sediment particles in flowing streams probably remain partly dispersed; but after entering a reservoir in which the turbulence is less, the particles may flocculate. Little is known about flocculation in streams or reservoirs; so the effects of flocculation on the location, specific weight, and rate of compaction of sediment deposits cannot be evaluated. However, one effect of flocculation would very likely be to increase trap efficiency; that is, to increase the proportion of the total sediment that is retained in the reservoir.

From the few samples that were analyzed in both native and distilled water, no systematic differences were observed between degree of flocculation of the sediment at the different stations.

BED MATERIAL

Samples of the streambed material were collected at 19 locations in the basin (pl. 1) and were analyzed for particle size (table 14). Some of the samples were examined for mineralogic composition to aid in determining the geologic source.

The bed material in the vicinity of Oakley is derived principally from the Pleistocene and Recent loess deposits and is, therefore, very fine. An increase in size near Grainfield may be due to the presence of material from some of the coarse strata of the Ogallala Formation, and a further increase near Wakeeney may be due to the presence of large indurated fragments from siliceous clastic rocks of the lower part of the Ogallala Formation and silicified chalk of the upper part of the Niobrara Formation. Near Plainville the size of the bed material has decreased, probably because streams such as the unnamed tributary near Zurich have contributed much fine and medium sand from the Codell Sandstone Member of the Carlile Shale. Near Russell the size of the bed material has increased; large cobbles (not shown by the analyses) of Greenhorn Limestone and cemented Dakota Sandstone are abundant in the bed.

From the Wilson station to about 4 miles west of Sylvan Grove, medium and coarse sand derived from channel sandstone of the Dakota is abundant. Near Sylvan Grove the streambed and banks undergo a radical change in about 20 river miles. The bed changes from predominantly medium and coarse sand to mostly silt and some fine sand. The channel changes from wide and shallow to narrow and deep and from gently sloping sandy banks to steep well-vegetated banks composed mainly of silt. Accompanying the changes are a decrease in gradient and marked increases in valley width and degree of meandering. Likewise, the soils in the valley change from fine sand and sandy loam to silt loam.

Addition of silt and fine sand, solution of cementing materials, and progressive sorting probably are the major factors in the change of bed-material size near Sylvan Grove. The silt and fine sand are derived from soils, streambanks, and fine-grained strata of the Dakota Sandstone. The sediment in Wolf Creek is too fine to be a major contributor at Sylvan Grove where the percentage of silt has not increased gently, but it could be a factor east of Sylvan Grove where the percentage of silt has made a large increase. Particles of cemented sandstone derived from the Dakota in Russell County are broken down by solution of carbonate and ferruginous cement in the course of transport. Limestone particles are reduced in size by abrasion and by solution. Progressive sorting occurs where a decrease in gradient is accompanied by a relatively small increase in discharge; some of the suspended load settles to the bottom and becomes part of the bedload. Probably the amount of sand contributed to the river by the Dakota is less near Sylvan Grove than between Russell and Wilson because the calcite-cemented sandstone prevalent in Lincoln County is generally more resistant to erosion than the iron-cemented channel sandstone predominant in the Dakota of Russell County.

From 4 miles east of Sylvan Grove to the mouth, the bed-material size remains substantially constant.

TABLE 14.—*Particle-size analyses of bed material*

[Method of analysis: S, sieve; V, visual accumulation tube]

Date	Number of sampling points	Bed material: Percent finer than indicated size, in millimeters										Method of analysis	Remarks
		0.062	0.125	0.250	0.50	1.0	2.0	4.0	8.0	16.0	32.0		
Saline River near Oakley													
1953													
June 29	1	88	89	91	94	97	98	100				S	
Saline River near Grainfield													
1953													Distance (feet) from left bank:
June 29	1	0	1	3	51	83	94	98	100			S	5.
	1		0	7	49	73	86	94	97	100		S	10.
	1		0	5	50	78	90	95	99	100		S	15.
	1		0	5	48	80	91	95	99	100		S	20.
	1		0	4	28	66	90	95	99	100		S	25.
	1	1	1	10	60	87	95	98	99	100		S	30.
	1		0	14	66	86	92	97	98	100		S	35.
	1	0	1	9	42	71	86	94	98	100		S	40.
	1	0	1	8	45	70	85	94	98	100		S	45.
	1		0	6	39	67	86	96	97	100		S	50.
	1	0	1	8	53	85	95	98	99	100		S	55.
Average, 11 sampling points			0	7	48	77	90	96	98	100		S	

TABLE 14.—*Particle-size analyses of bed material*—Continued

Date	Number of sampling points	Bed material: Percent finer than indicated size, in millimeters										Method of analysis	Remarks
		0.062	0.125	0.250	0.50	1.0	2.0	4.0	8.0	16.0	32.0		
Saline River near Wakeeney													
1958													Distance (feet) from left bank:
June 26	1	5	5	6	19	50	72	83	91	100		S	5.
	1	7	7	8	14	36	61	79	89	100		S	10.
	1	3	4	4	12	30	59	80	94	100		S	15.
	1	3	4	5	15	45	75	93	100			S	20.
	1	1	2	3	21	61	90	98	100			S	25.
	1	7	8	11	21	57	85	97	100			S	30.
Average, 6 sampling points		4	5	6	17	46	74	88	96	100		S	
Unnamed tributary near Zurich													
1958													
May 9	1	8	10	25	76	95	99	99	99	100		SV	
	1	1	1	9	60	94	97	98	100			SV	
Average, 2 sampling points		4	6	17	68	94	98	98	100			SV;	
Saline River near Plainville													
1958													Distance (feet) from left bank:
June 26	1		0	4	32	70	88	96	98	100		S	10.
	1	0	1	22	67	90	97	100				S	15.
	1	0	1	7	56	91	98	100				S	20.
	1		0	14	58	92	99	100				S	25.
	1		0	8	63	96	100					S	30.
	1	0	1	6	62	95	100					S	35.
Average, 6 sampling points			0	10	56	89	97	99	100			S	

Saline River near Codell

1958 May 9	1	1	1	1	12	32	48	70	88	95	98	SV	

Saline River near Russell

1958 June 25	1	7	8	13	19	51	80	88	91	100	--------	S	Distance (feet) from left bank: 5.
	1	9	11	15	23	51	77	93	96	100	--------	S	10.
	1	6	6	10	30	57	71	80	86	100	--------	S	15.
	1	1	2	5	19	51	71	83	89	100	--------	S	20.
	1	2	2	10	26	47	62	72	87	100	--------	S	25.
	1	2	2	6	24	49	60	68	78	100	--------	S	30.
	1	2	2	13	54	90	100	--------	--------	--------	--------	S	35.
	1	1	2	15	34	57	70	76	84	100	--------	S	40.
	1	1	2	8	27	50	61	70	78	100	--------	S	45.
	1	2	2	11	38	66	83	93	98	100	--------	S	50.
	1	9	11	25	49	69	77	83	88	100	--------	S	55.
	1	6	7	18	47	77	87	92	95	100	--------	S	60.
	1	4	5	10	25	55	72	82	90	100	--------	S	65.
	1	6	8	15	31	49	61	75	90	100	--------	S	70.
	1	3	5	14	35	55	64	77	87	100	--------	S	75.
	1	2	2	8	55	94	99	100	--------	--------	--------	S	80.
Average, 16 sampling points		4	5	12	34	60	75	83	90	100	--------	S	

Paradise Creek at Codell

1958 May 9	1	24	28	38	52	69	73	78	81	88	100	SV	

Paradise Creek 1 mile downstream from Paradise

1958 May 8	1	1	1	1	14	65	86	98	100	--------	--------	SV	
	1	81	92	96	98	100	--------	--------	--------	--------	--------	V	

TABLE 14.—*Particle-size analyses of bed material*—Continued

Date	Number of sampling points	Bed material: Percent finer than indicated size, in millimeters										Method of analysis	Remarks
		0.062	0.125	0.250	0.50	1.0	2.0	4.0	8.0	16.0	32.0		
Paradise Creek near Paradise													
1957													
Dec. 11	1	1	1	1	16	45	57	70	85	97	100	SV	Many flat particles as much as 6 in. not sampled.
Saline River near Wilson													
1958													
May 7	1	--------	0	10	73	92	94	98	99	100	--------	SV	Near center of flow. Sand 4 in. deep. Left half of channel scoured to bedrock.
	1	--------	0	8	57	90	95	98	100	--------	--------	SV	Right ⅓ of flow. Sand 6-8 in. deep.
	1	1	1	8	38	72	84	92	97	98	100	SV	Near right edge of water. Sand 10-12 in. deep.
	1	1	1	9	50	79	88	94	98	99	100	SV	On right bank near water.
Average, 4 sampling points		--------	0	9	54	83	90	96	98	99	100	SV	
Saline River 4 miles west of Sylvan Grove													
1958													
May 8	1	10	15	22	36	50	63	76	89	100	--------	SV	Near left bank.
	1	3	4	12	48	79	86	92	96	99	100	SV	Left ⅓ of flow.
	1	1	1	4	44	82	92	97	99	100	--------	SV	Near center of flow.
	1	1	1	19	47	80	92	98	100	--------	--------	SV	Right ⅓ of flow.
	1	2	4	29	86	99	100	--------	--------	--------	--------	SV	Near right bank.
Average, 5 sampling points		3	5	17	52	78	87	93	97	100	--------	SV	
Wolf Creek near Lucas													
1958													
May 10	1	40	47	53	61	73	75	79	85	94	100	SV	Upstream side of bridge.

Wolf Creek near Sylvan Grove													
1958 May 8	1	95	99	100	--------	--------	--------	--------	--------	--------	--------	V	
Saline River at Sylvan Grove													
1958 May 10	1	5	5	13	56	85	93	99	100	--------	--------	SV	
	1	33	42	58	85	94	95	95	98	100	--------	SV	
	1	4	5	28	95	100	--------	--------	--------	--------	--------	SV	
	1	6	10	42	83	89	94	99	100	--------	--------	SV	
Average, 4 sampling points		12	16	35	80	92	96	98	100	--------	--------	SV	
Saline River 4 miles east of Sylvan Grove													
1958 July 1	1	61	88	96	98	99	100	--------	--------	--------	--------	S	
Saline River at Tescott													
1957 June 28	1	84	88	95	97	98	100	--------	--------	--------	--------	SV	Sta. 50.
	1	38	45	58	68	76	84	88	100	--------	--------	SV	Sta. 90. No samples could be obtained at stas. 70 and 80.
	1	74	83	95	98	99	100	--------	--------	--------	--------	SV	Sta. 105.
Average, 3 sampling points		65	72	83	88	91	95	96	100	--------	--------	SV	
July 10	1	--------	--------	0	63	98	100	--------	--------	--------	--------	SV	Sta. 85.
Mulberry Creek near Brookville													
1958 May 7	1	32	35	60	97	100	--------	--------	--------	--------	--------	V	Center of flow.
Mulberry Creek near Glendale													
1958 May 8	1	4	4	11	56	73	78	86	94	100	--------	SV	Center of flow.

The bed of Paradise Creek is mainly coarse sand and gravel derived from the Niobrara Formation and Carlile Shale. The largest particles are chalk, dominantly slumped from the lower Fort Hays Limestone Member of the Niobrara. The bed of Wolf Creek near Lucas has a high percentage of silt, but it includes pebbles, probably reworked from terrace deposits, that are as much as 32 mm in diameter; however, the bed near Sylvan Grove is composed of silt and very fine sand.

Further studies are needed to determine the exact magnitude of the changes in size of bed material and the quantitative effects of the different factors that produce the changes. The Saline River is an excellent location for such studies because of the large changes of bed-material size in relatively short distances. Such further studies would involve detailed sampling and analysis of bed material and suspended sediment, measurement of stream gradients, sampling and analysis of material in tributaries and streambanks, and detailed studies of the exposed bedrock in and near the stream valley.

UNMEASURED SEDIMENT DISCHARGE

The concentration of suspended sediment in most streams varies in a vertical direction; the minimum concentration is at or near the surface, and the maximum concentration is at the bed. Concentrations of particles finer than sand are nearly uniform throughout the depth, but sand and coarser particles have much greater concentrations near the bed than near the surface except in extremely turbulent streams. The lower 3 to 5 inches of the stream (called the unsampled zone) cannot be sampled by suspended-sediment samplers currently in use; therefore, the concentration of a depth-integrated sample is generally less than the mean concentration in the entire depth.

The discharge that is computed by multiplying the concentration determined from depth-integrated samples by the water discharge for the entire depth and by an appropriate units conversion factor is called the measured suspended-sediment discharge. However, because the water discharge is for the entire depth, the measured suspended-sediment discharge includes part of the suspended-sediment discharge in the unsampled zone. All sediment discharge not computed as measured suspended-sediment discharge is called unmeasured sediment discharge and consists of sediment rolling or sliding on the bed, sediment moving in short skips or leaps near the bed, and part of the suspended sediment in the unsampled zone. Nearly all the material finer than sand, because of its uniform vertical distribution, is included in the measured suspended-sediment discharge; therefore, the unmeasured sediment discharge is composed mostly of sand or coarser particles. In sand-bed streams, unmeasured sediment discharge is a fairly large part of the total sediment discharge unless the stream is deep, velocities are low, or discharges of sediment finer than sand are so high that the unmeasured sediment discharge is small in relation to the total.

Table 15 shows the unmeasured sediment discharges that were computed by two methods and also shows some corresponding hydraulic measurements. The first computational method was presented by Colby (1957) and is called the Colby method in the table. The method requires measurements of only the width, mean depth, mean velocity, and the concentration of suspended sand. The second method of computation was presented by Colby and Hembree (1955) and is called the modified Einstein method. This method requires measurements of width, mean depth, mean velocity, temperature, suspended-sediment discharge, and particle-size analyses of bed material and suspended sediment.

Absence of results of modified Einstein computations in table 15 is due to inadequate data or to hydraulic conditions such that the method was not applicable.

For Saline River near Wakeeney, unmeasured sediment discharges ranging from 0.1 to 8.6 percent of the total sediment discharge were computed. The average unmeasured sediment discharge is probably about 5 percent of the total. For Saline River near Russell and Paradise Creek near Paradise the unmeasured sediment discharges were from 1.2 to 20 percent of the total. Because percentages are low when the discharges are high, the low percentages should have more weight and the average is probably about 3 percent. For Saline River at Tescott and Wolf Creek near Sylvan Grove, unmeasured sediment discharges are generally less than 1 percent of the total because only small amounts of sand are present in the beds.

The following are average total sediment discharges for a 36-year period, computed by adding the estimated average unmeasured sediment discharges to the suspended-sediment discharges shown in table 12.

Location	*Average total sediment discharge (tons per year)*
Saline River near Wakeeney	77,000
Saline River near Russell	250,000
Paradise Creek near Paradise	64,000
Wolf Creek near Sylvan Grove	85,000
Saline River at Tescott	800,000

TABLE 15.—*Computations of unmeasured sediment discharge*

Date	Water discharge (cfs)	Mean velocity (fps)	Mean depth (ft)	Measured suspended-sediment discharge (tons per day)	Unmeasured sediment discharge (tons per day)		Unmeasured sediment discharge (percent of computed total)	
					Colby method	Modified Einstein method	Colby method	Modified Einstein method
Saline River near Wakeeney								
1956								
May 30	7,080	2.75	7.24	224,000	234	----------	0.1	----------
30	957	3.67	2.47	18,500	1,740	----------	8.6	----------
31	268	3.08	1.53	2,180	130	----------	5.6	----------
June 2	31	1.57	.51	69	4.5	----------	6.1	----------
July 5	54	1.77	.82	265	6.7	----------	2.5	----------
7	127	1.70	1.55	552	8.4	----------	1.5	----------
Saline River near Russell								
1949								
June 2	95	1.57	0.79	176	43	33	20	16
Oct. 10	1,070	2.76	4.88	19,600	620	820	3.1	4.0
1950								
June 29	677	2.68	2.76	35,800	430	----------	1.2	----------
July 7	104	2.09	.90	536	69	125	11	19
26	13,600	3.98	9.13	253,000	7,700	----------	3.0	----------
Aug. 8	2,300	3.85	4.89	36,600	2,000	----------	5.2	----------
1951								
June 24	9,600	2.84	6.78	124,000	3,200	1,600	2.5	1.3
Saline River at Tescott								
1957								
June 19	2,870	3.01	11.0	36,800	99	----------	0.3	----------
Paradise Creek near Paradise								
1949								
June 8	414	3.49	4.11	7,240	860	1,700	11	19
10	72	2.30	1.34	222	41	44	16	16
1950								
May 9	3,770	3.61	6.62	103,000	3,500	8,800	3.3	7.9
July 4	345	3.20	3.60	20,300	270	----------	1.3	----------
1951								
May 23	907	3.92	6.18	7,840	450	----------	5.4	----------
June 21	1,720	3.83	7.95	25,000	720	----------	2.8	----------
July 11	9,220	5.77	9.41	119,000	8,900	19,000	7.0	14
Wolf Creek near Sylvan Grove								
1949								
June 9	2,680	2.10	11.8	23,900	640	----------	2.6	----------
Oct. 10	1,230	2.34	9.30	24,200	240	----------	1.0	----------
1950								
May 29	520	2.67	6.84	9,650	22	----------	.2	----------
July 16	3,400	2.27	13.5	81,000	52	----------	.06	----------
16	3,760	2.24	14.2	78,100	53	----------	.07	----------
17	1,280	1.84	13.0	23,200	11	----------	.05	----------
27	970	2.40	7.71	20,800	29	----------	.1	----------

SPECIFIC WEIGHT OF DEPOSITED SEDIMENT

According to Hembree and others (1952, p. 35, 37),

The specific weight of sediment deposits depends upon the type of material in transport, primary particle size, effect of change in concentration of the mineral constituents in solution, degree of sorting, and amount of consolidation.

* * * * * * *

If all sediment particles have about the same specific gravity, the specific weight of sediment deposits depends upon the porosity of the deposit. * * * Deposits of silts and clays have greater porosity and smaller specific weight than deposits of larger particles partly because the range in size may be greater in the coarser deposits.

* * * * * * *

The determination of an average figure for the specific weight of a deposit that might be formed from the sediment in transport is necessary to ascertain the space the sediment will occupy in a reservoir. * * *

Most methods of computations of the probable specific weight of deposited sediment require a knowledge of the particle size of the sediment that is to be deposited. Average particle-size distributions of the measured suspended sediment have been computed. (See p. 66 and fig. 20.) The particle size of the deposited sediment would be affected by the addition of coarse material transported as bedload and by the removal of fine material that would not be trapped in a reservoir. The size distributions in the following table were computed by combining the average particle sizes of measured suspended sediment with the particle size (assumed to be all sand) of the unmeasured sediment discharge.

Average particle-size distributions of total sediment discharge

Location	Percentage of sediment		
	Clay (<0.004 mm)	Silt (0.004–0.062 mm)	Sand (0.062–2.0 mm)
Saline River near Wakeeney	72	22	6
Saline River near Russell	69	24	7
Paradise Creek near Paradise	61	31	8
Wolf Creek near Sylvan Grove	67	33	0
Saline River at Tescott	74	25	1

Not all the sediment entering a reservoir is trapped; the percentage that is trapped depends on many factors, such as the particle size, velocity of flow through the reservoir, flocculation, density currents, and location of spillways and outlets.

The sediment trapped in a reservoir has a coarser size distribution than the sediment entering the reservoir because some of the fine material is discharged and the coarse material remains.

The following table shows size distributions that the deposited sediment would have if the trap efficiencies were assumed to be 50 percent for clay, 90 percent for silt, and 100 percent for sand. (Small reservoirs would be likely to have trap efficiencies of these magnitudes.)

Average particle-size distributions of deposited sediment

Location	Percentage of sediment		
	Clay (<0.004 mm)	Silt (0.004–0.062 mm)	Sand (0.062–2.0 mm)
Saline River near Wakeeney	58	32	10
Saline River near Russell	55	34	11
Paradise Creek near Paradise	46	42	12
Wolf Creek near Sylvan Grove	53	47	0
Saline River at Tescott	61	37	2

Hembree and others (1952, p. 39) have presented a relation of specific weight of deposited sediment to the median particle size of the sediment. The data used by Hembree and his colleagues are for samples collected near the surface of submerged sediment deposits; therefore, specific weights computed from this relation are representative of relatively new deposits that have not been compacted materially by overlying deposits nor by alternate wetting and drying. This relation was used to compute the probable specific weights for the sediment discharge at the five stations for which particle-size analyses are available. In reservoirs that trap nearly all the total sediment discharge, the median particle sizes for the 5 stations would be from 0.001 to 0.002 mm and the specific weights would be from 42 to 46 pounds per cubic foot. In reservoirs having relatively low trap efficiencies (50 percent for clay, 90 percent for silt, and 100 percent for sand), the median particle sizes would be from about 0.003 to 0.005 mm and the specific weights would be from 48 to 52 pounds per cubic foot.

Lane and Koelzer (1943, p. 37) have presented a relation of specific weight of deposited sediment to the percentage of material larger than 0.05 mm in diameter. The data on which this relation was based were predominantly for samples collected near the surface of either submerged or exposed deposits. In reservoirs that trap nearly all the total sediment discharge, the percentages of material larger than 0.05 mm would be from 7 to 10 for Wakeeney, Russell, and Paradise Creek, less than 1 for Wolf Creek, and about 1 for Tescott. According to the relation, the specific weights would be from 66 to 69 pounds per cubic foot for Wakeeney, Russell, and Paradise Creek, about 52 pounds per cubic foot for Wolf Creek, and about 56 pounds per cubic foot for Tescott. In reservoirs having relatively low trap efficiencies, the percentages of material larger than 0.05 mm would be from 12 to 14 for Wakeeney, Russell, and Paradise Creek, less than 1 for Wolf Creek, and 3 for Tescott. Specific weights would be from 71 to 73 pounds per cubic foot for Wakeeney, Russell, and Paradise Creek, about 52 pounds per cubic foot for Wolf Creek, and about 62 pounds per cubic foot for Tescott.

Sediment deposits in Sheridan Lake had specific weights ranging from 49.5 pounds per cubic foot for a fine-grained deposit near the dam to 95.7 pounds per cubic foot for a coarse-grained deposit near the head of the lake and averaging 66.5 pounds per cubic foot (U.S. Bur. Reclamation, 1950, p. 8, 10).

CONCLUSIONS

The Saline River basin is underlain by calcareous and noncalcareous sedimentary rocks, which range in age from Permian to Tertiary, and by unconsolidated eolian and fluvial deposits of Pleistocene and Recent age. These rocks directly affect the chemical quality and the sediment of the streams.

Streamflow in the basin is affected very little by impoundage or by irrigation. Average runoff for 1921–56 increased from less than 0.2 inch per year in the west to more than 1.5 inches per year in the east. Differences in average runoff result mainly from differences in average precipitation, which ranges from 18 inches per year in the west to almost 28 inches per year in the east. Dry-weather flow is well sustained where ground water is contributed to the streams by aquifers of alluvium and Dakota Sandstone.

Water in Saline River near Wakeeney is only slightly mineralized and is of the calcium bicarbonate type at all ranges of water discharge. During the period of record the specific conductance of the water near Wakeeney never exceeded 750 micromhos per centimeter.

Near Russell, near Wilson, and at Tescott the water is only slightly mineralized and of the calcium bicarbonate type during periods of high water discharge, but it is highly mineralized and principally of the sodium chloride type during periods of low water discharge. High chloride concentrations are associated with high mineralization and generally poor quality of water; chloride concentrations were more than 500 ppm 60 percent of the time near

Russell, 72 percent of the time near Wilson, and 65 percent of the time at Tescott. Concentrations of iron, fluoride, nitrate, and boron were nearly always low.

The water in the lower reaches of Wolf Creek is similar in chemical composition to the water in the lower reaches of the Saline River. It is highly mineralized, is very hard, and contains principally sodium, chloride, and sulfate at low water discharge; but it is only slightly mineralized and contains principally calcium and bicarbonate at high water discharge.

The water in Paradise Creek near Paradise and upstream is only slightly mineralized and contains principally calcium, sulfate, and bicarbonate at all water discharges. However, downstream from Paradise the mineralization increases significantly; data obtained at low discharge showed an increase of specific conductance from 860 micromhos per centimeter near Paradise to 2,310 micromhos per centimeter near the confluence with the Saline River.

As of 1959, 99.9 percent of the oil-field brine produced in the basin was being returned underground to prevent pollution of fresh water supplies. The total percentage of the salt in the Saline River that comes from oil-field brines is considered to be small.

In most of the Saline River basin the water is of the calcium bicarbonate type during periods of high flow when the water is mainly from overland runoff. However, the chemical characteristics of the water are significantly affected by bedrock geology during periods of low flow when the water is mainly ground-water inflow. The amount of ground-water inflow varies from year to year. During 1948—a year when the total flow was near the long-term (36-yr) average—ground-water inflow was estimated to be 22 percent of the total flow at Tescott, and during 1952—a year following 2 years of much greater-than-normal precipitation and streamflow—it was estimated to be 60 percent.

The effects of alluvium on the chemical characteristics of the water probably are slight in most of the basin because the quantity of alluvium generally is small. Water from areas underlain by the Ogallala Formation generally is slightly mineralized, relatively highly siliceous, and of the calcium bicarbonate type. Water from areas directly underlain by the Niobrara Formation is also slightly mineralized and of the calcium bicarbonate type; however, it contains considerably more sulfate than water from the areas underlain directly by the Ogallala.

The effects of the Codell Sandstone Member of the Carlile Shale on the chemical characteristics of streamflow are probably slight.

The Blue Hill Shale Member contributes principally calcium, sulfate, and carbonate to the water, and the Fairport Chalky Shale Member contributes principally calcium and carbonate.

The Greenhorn Limestone contains very little water; however, the limestone is scattered over much of the uplands in the lower part of the basin and probably contributes much calcium carbonate to overland runoff. The Graneros Shale probably contributes principally sulfate to the surface waters.

The Dakota Sandstone is the principal contributor of dissolved minerals in the basin, especially during low-flow periods. The water from the Dakota is highly mineralized and contains principally sodium and chloride.

The water in the upper Saline River is of good quality for domestic use, except that it is hard; the water in the lower Saline River is of poor quality for domestic use because most of the time it is highly mineralized, is hard, and contains high concentrations of chloride and sulfate. Except in the downstream reaches of Paradise and Salt Creeks, the water in the tributaries generally is of good quality for domestic use.

Near Wakeeney the water in the Saline River is of good quality for irrigation; it has a medium salinity hazard and a low sodium hazard. Near Russell, near Wilson, and at Tescott the water has a high salinity hazard and a low sodium hazard during years of medium to high water discharge and a very high salinity hazard and a high sodium hazard during years of low water discharge. Throughout the river, concentrations of boron probably are sufficiently high to satisfy the boron requirements for most crop plants and sufficiently low to be nontoxic even to boron-sensitive crops. Because concentrations of calcium and magnesium exceed the concentrations of bicarbonate, adverse soil conditions resulting from excessive bicarbonate concentrations are not likely to develop.

Water in the upper Saline River and in many of the tributaries is of suitable quality for many industrial uses. Water in the lower Saline River generally is of poor quality for most industrial uses, principally because of the high degree of mineralization and also because of drastic changes in the quality of the water from time to time.

Suspended-sediment discharge is closely related to runoff. The average annual sediment contributions from areas in the basin increased from 120 tons per square mile in the western part of the basin to 490 tons per square mile in the eastern part. Long-term averages of the suspended-sediment concentrations range from 2,600 to 4,600 ppm; they are highest in Paradise Creek basin, where the sediment is contributed by extensive deposits of loess and by beds of the Blue Hill Shale Member.

Suspended sediment at all the sampling sites is mostly clay; it averages 63 to 76 percent finer than 0.004 mm. An average of about 5 percent of the suspended sediment in Paradise Creek and in Saline River near Russell is sand. Almost none of the suspended sediment in Wolf Creek, in Saline River near Wakeeney, and in Saline River at Tescott is sand. Deposited sediment in Sheridan Lake is coarser than the suspended sediment at any of the sampling sites because its source was different, because it includes bedload, and because it does not include the fine sediment that passed through the spillway.

Particle sizes of bed material range from silt to large cobbles, mainly because of variations in the source material. The bed material in the headwaters area, near Oakley, is very fine because it is derived from loess. The bed material is coarser near Grainfield and near Wakeeney than it is near Oakley because of material from coarse strata of the lower part of the Ogallala Formation and because of large fragments from the upper part of the Niobrara Formation. Between Wakeeney and Wilson, increases in the size of bed material are due to the addition of particles of Greenhorn Limestone and cemented Dakota Sandstone, and decreases in the size of bed material are due to the addition of fine and medium sand from the Codell Sandstone Member of the Carlile Shale and medium and coarse sand from the channel sandstone of the Dakota.

A pronounced decrease in bed-material size near Sylvan Grove is accompanied by a decrease in stream gradient, an increase in degree of meandering, and pronounced changes in bank material, bank vegetation, and valley soils. The major factors causing this decrease in bed-material size probably are the addition of silt and fine sand, solution of cement, and progressive sorting. Further studies are needed to determine the exact magnitude of the changes in bed-material size and the quantitative effects of the different factors that produce the changes.

Unmeasured sediment discharges at different times and places in the basin range from less than 1 to about 20 percent of the total sediment discharge. The average unmeasured sediment discharges are about 5 percent for Saline River near Wakeeney, 3 percent for Saline River near Russell and for Paradise Creek near Paradise, and less than 1 percent for Wolf Creek near Sylvan Grove and for Saline River at Tescott.

Sediment discharged at the sampling sites if deposited in reservoirs would have specific weights that were computed as 42 to 52 pounds per cubic foot by a method based on the median size of the sediment and as 52 to 73 pounds per cubic foot by a method based on the percentage of coarse sediment. The specific weights computed for the finest sediment and for reservoirs having high trap efficiencies were lower than the specific weights computed for the coarser sediment and for reservoirs having low trap efficiencies.

GLOSSARY

Bedload is sediment that moves along in virtually continuous contact with the streambed and that bounces along the bed in short skips or leaps.

Discharge-weighted average represents approximately the chemical character of the water if all the water passing a point in the stream during a period were impounded in a reservoir and mixed. It is calculated by dividing the sum of the products of water discharge and concentration of individual analyses by the sum of the water discharges for the period that the analyses represent.

Equivalent per million (epm) is a unit for expressing the concentration of chemical constitutents in terms of the relative combining power of the electrically charged particles, or ions, in solution. In chemical reactions, 1 epm of a cation reacts with exactly 1 epm of an anion.

Flocculation is formation of aggregates by coalescence of small particles that are subjected to certain physicochemical conditions.

Fluvial sediment is sediment transported by, suspended in, or deposited from water.

Ion is an electrically charged particle, atom, molecule, or radical in which the charge is due to the gain or loss of one or more electrons. The ion is, accordingly, negative (anion) or positive (cation) in electrical sign. Most mineral material when dissolved in water disintegrates to ions.

Particle-size classification is the classification recommended by the American Geophysical Union Subcommittee on sediment terminology (Lane and others, 1947, p. 937). According to this classification, clay-size particles have diameters between 0.0002 and 0.004 mm, silt-size particles have diameters between 0.004 and 0.062 mm, and sand-size particles have diameters between 0.062 and 2.0 mm.

Part per million (ppm) is a unit for expressing the concentration of chemical constituents or sediment. The number of parts per million of chemical constituents is computed as one million times the ratio of the weight of constituents to the weight of the solution. The number of parts per million of sediment is computed as one million times the ratio of the weight of sediment to the weight of the water-sediment mixture.

Percent sodium is the ratio, expressed in percentage, of sodium to the sum of the positively charged ions (calcium, magnesium, sodium, and potassium)—all ions in equivalents per million.

Runoff is the unregulated discharge of water in surface streams. It is expressed in units of volume per unit of time (for example, acre-feet per year) or in units of depth that would be occupied by the water discharged in a given time if the water were spread uniformly over the drainage area (for example, inches per year).

Sediment is fragmental material that originates mostly from rocks and that is transported by, suspended in, or deposited from water or air or is accumulated in beds by other natural agencies.

Sediment discharge is the rate at which dry weight of sediment passes a section of a stream or conduit or is the quantity of sediment, as measured by dry weight or by volume, that is discharged in a given time.

Sediment sample is a quantity of water-sediment mixture that is collected to represent the average concentration of suspended sediment, the average particle-size distribution of suspended or deposited sediment, or the specific weight of deposited sediment.

Specific conductance of water is a measure of the ability of the water to conduct an electrical current and is expressed in micromhos per centimeter at 25°C. (For brevity, the units are referred to as micromhos per centimeter.) It varies with the concentrations and types of ions in solution and can, therefore, be used to estimate the degree of mineralization of the water.

Specific weight of a sediment deposit is the weight of solids per unit volume of deposit in place.

Suspended sediment is sediment that moves in suspension in water and that is maintained in suspension either by the upward components of turbulent currents or as a colloid.

Time-weighted average represents approximately the chemical character of the water diverted from a stream during a period if the quantity of water diverted were constant during the period and if the water were mixed subsequent to diversion.

Trap efficiency is the ratio, expressed as a percentage, of the weight of sediment retained in a reservoir to the weight of sediment entering the reservoir.

Type of water designates the character of the water with respect to its dissolved mineral composition. It indicates the anion and cation present in the highest concentrations in equivalents per million.

Vertical is a line extending vertically from the surface to the bed of a stream. It is a location at which sediment samples are obtained or other hydraulic measurements are made.

Water discharge is the rate at which water passes a section of a stream or conduit or is the quantity of water that is discharged in a given time. It includes the sediment and dissolved solids that are contained in the water.

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SAMPLING SITES AND STREAMFLOW GAGING STATIONS IN THE SALINE RIVER BASIN, KANSAS

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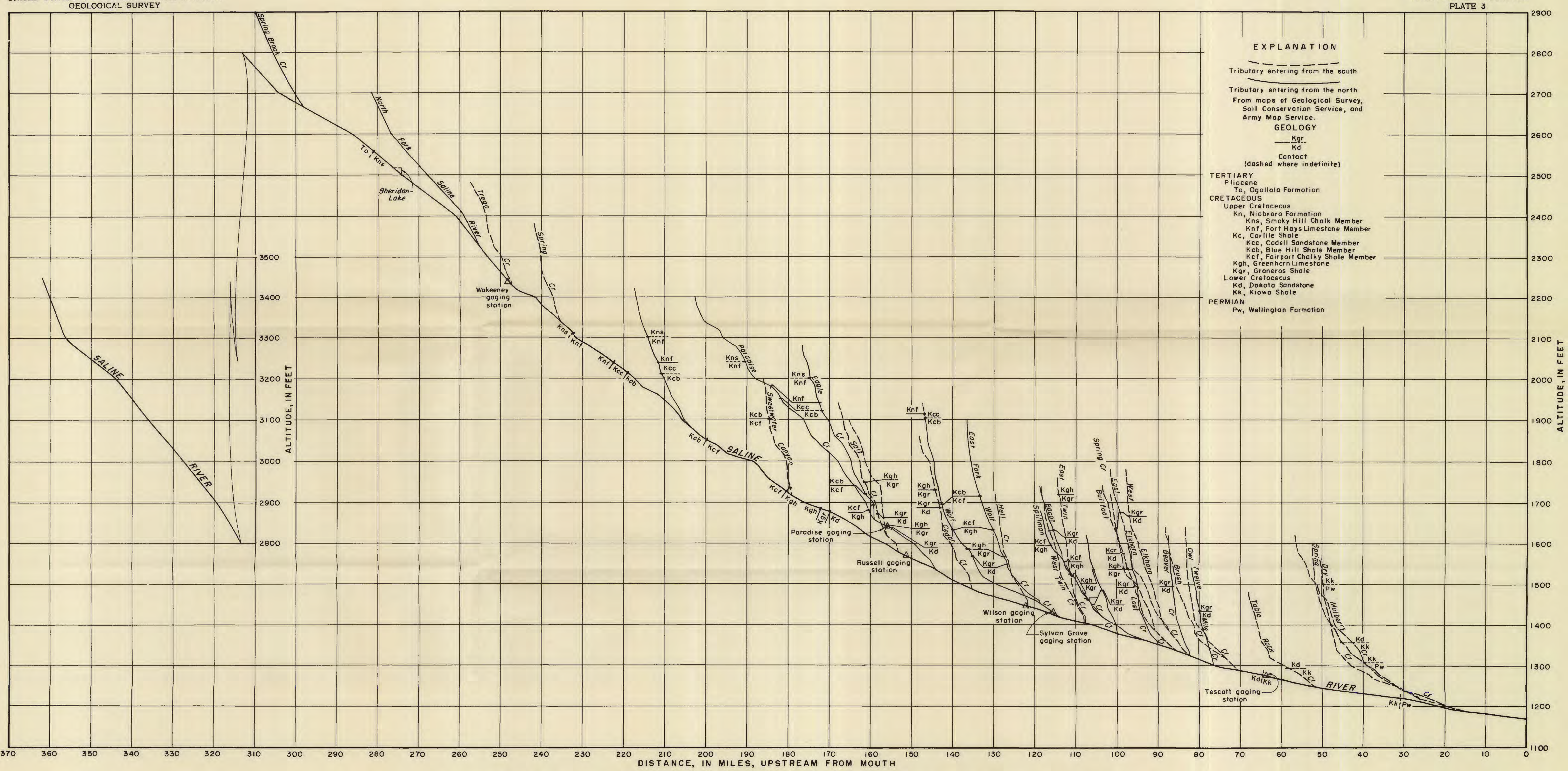
MAP OF SALINE RIVER BASIN, KANSAS, SHOWING GENERALIZED GEOLOGY AND CHEMICAL COMPOSITION OF SURFACE WATERS



LONGITUDINAL PROFILES OF STREAMS, SALINE RIVER BASIN, KANSAS

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EXPLANATION

▲ Streamflow gaging station

⊕ Long-term precipitation station from which lines of equal precipitation were derived

—·—·— Boundary of drainage area

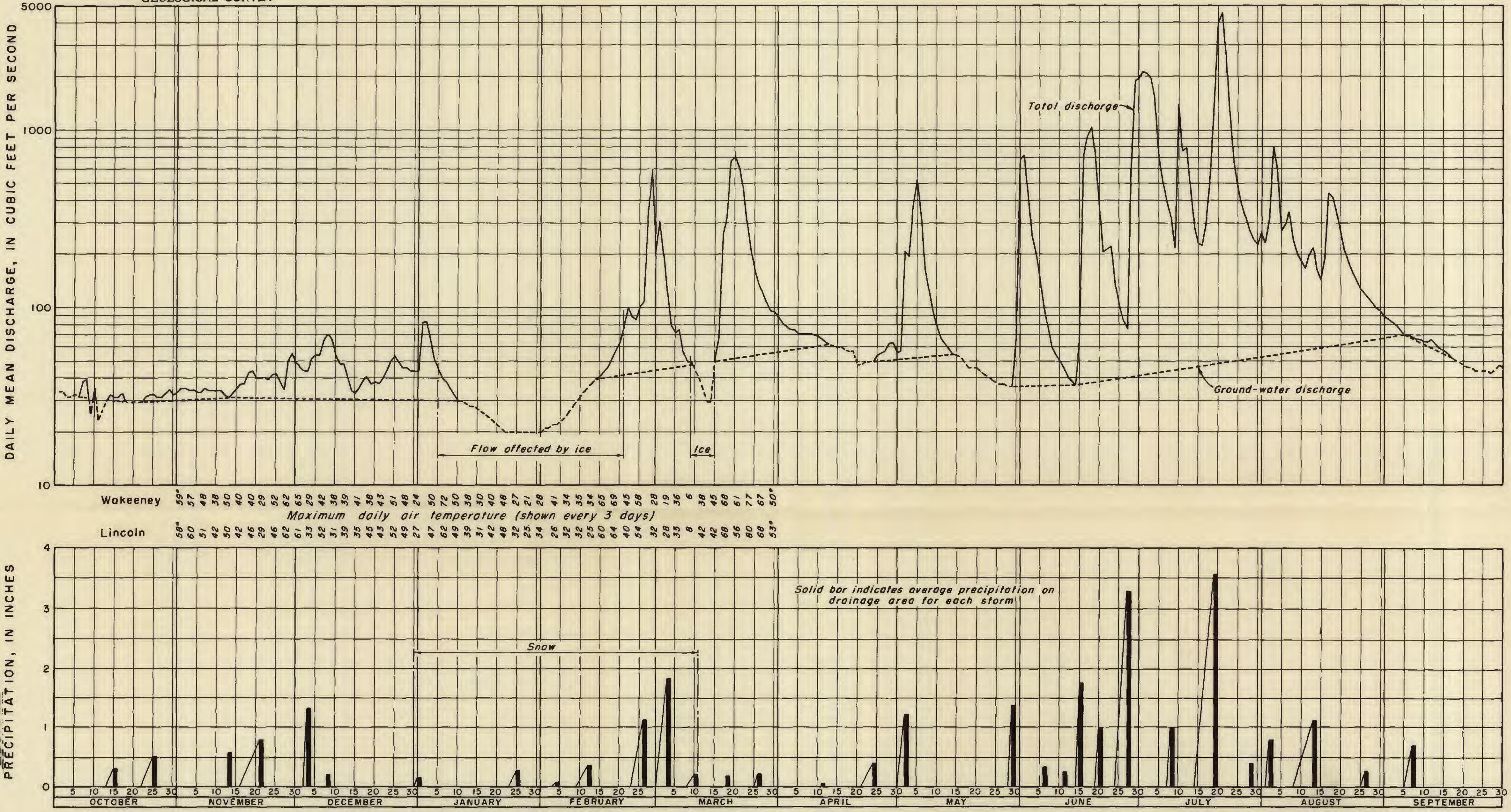
inches,

- - -1.5- - - Lines of equal annual runoff, in inches, Oct. 1, 1920, to Sept. 30, 1956. Interval 0.2 inch and 0.5 inch

——22—— Lines of equal annual precipitation, in inches, Jan. 1, 1921, to Dec. 31, 1956. Interval 2 inches

PRECIPITATION AND RUNOFF IN THE SALINE RIVER BASIN, KANSAS

690-419 O - 64 (In pocket)



HYDROGRAPH FOR SALINE RIVER AT TESCOTT, KANSAS, OCTOBER 1947 TO SEPTEMBER 1948

690-419 O - 64 (In pocket)