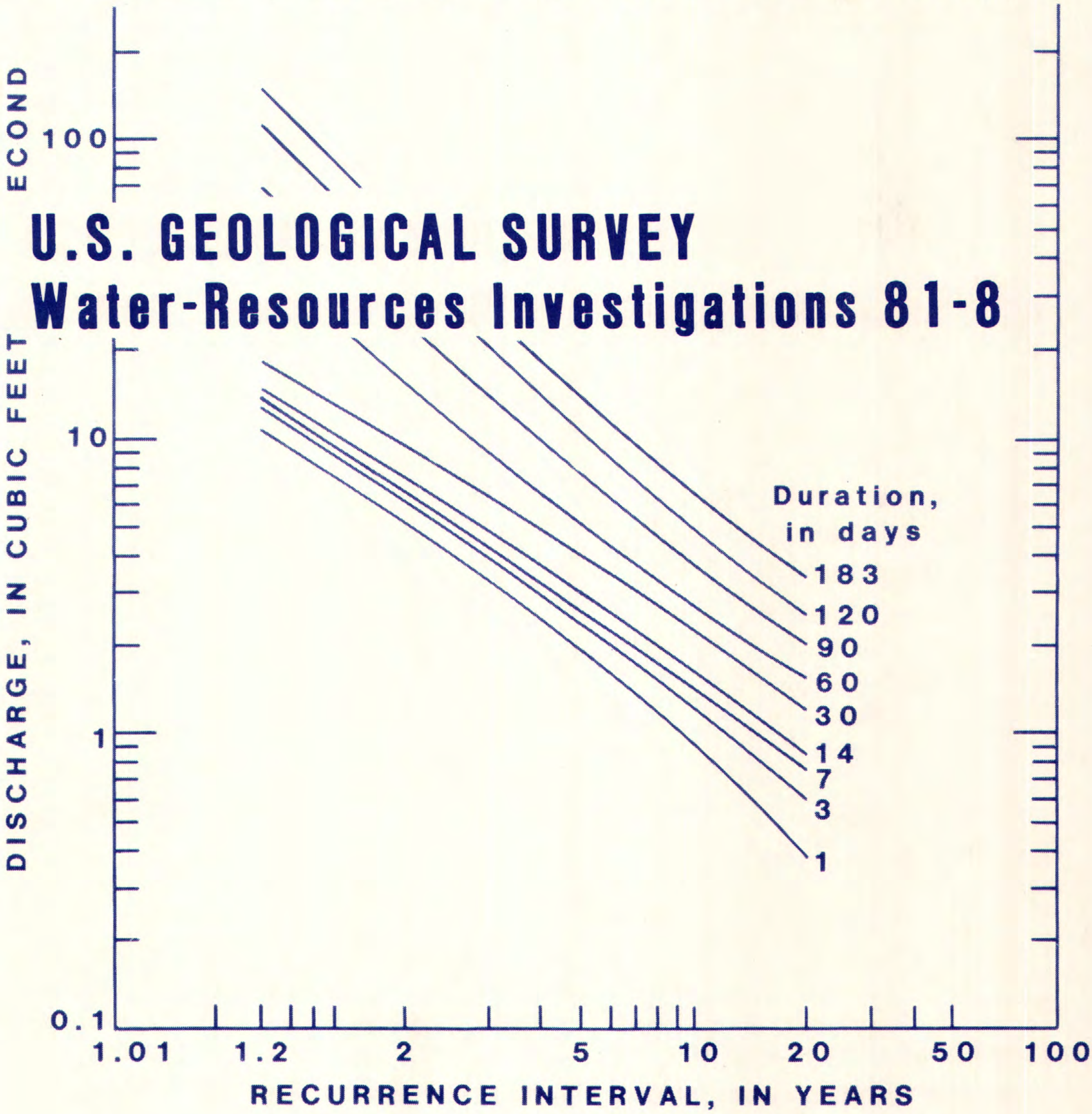
SELECTED HYDROLOGIC RELATIONSHIPS FOR SOLDIER CREEK, NORTHEASTERN KANSAS

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations 81-8



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Hydrologic data from Soldier Creek basin were compared with relations from statewide data. The quantity and quality of streamflow were affected mostly by soils, slopes, and land use. Average annual precipitation during the study (1964-76) was 35.12 inches, or 2.3 percent greater than the long-term (1929-76) average. The average streamflow in Soldier Creek at Topeka, Kansas, was 23 percent greater than the long-term average.

In general, frequency curves of annual peak discharges compared poorly with curves from statewide relations due to the absence of extremely low peaks during the short period. A comparison of low-flow frequency for drainage areas of more than 100 square miles indicated that reasonable results will not be obtained for estimates of 7-day and 30-day average annual minimum discharges by linear extrapolation to basins of less than 100 square miles. Comparison of flow-duration curves confirms the extrapolation for basins of less than 100 square miles, although the percentage duration of mean flow is variable.

Water surveys showed that calcium, bicarbonate, and sulfate were the predominant ions and dissolved solids were derived mostly from limestones and shales. Suspended sediment at gaged sites ranged from 9.94 to 848 tons per day; yield per unit area increased significantly between sites due to changes in hillside slopes and land use.

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By William J. Carswell, Jr.

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 81-8

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Lawrence, Kansas
1981

UNITED STATES DEPARTMENT OF THE INTERIOR

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SELECTED HYDROLOGIC RELATIONSHIPS

FOR SOLDIER CREEK, NORTHEASTERN KANSAS

By

W. J. Carswell, Jr.

ABSTRACT

Soldier Creek basin is a long, narrow area encompassing about 290 square miles almost directly north of Topeka, Kansas. The analyses of selected hydrologic data from the area are compared to statewide relations.

The basin is in the Dissected Till Plains and Attenuated Drift Border sections of the Central Lowlands physiographic province. Geologic formations in Geologic formations in the area consist principally of glacial till, limestone, and shale. The resulting soils and hillside slopes associated with these materials, along with agricultural development, significantly affect the quantity and quality of streamflow in different parts of the basin.

Based on records from a nearby National Weather Service precipitation gage, average annual precipitation in the basin during 1964-76 was 35.12 inches. The average during 1964-76 was 2.3 percent greater than the average of 34.32 inches during 1929-76.

Streamflow at the Topeka streamflow-gaging station during 1965-76 was 23 percent greater than the long-term average. Much of this increase is a result of an extremely wet year (1973) when the yearly average was 3.8 times the long-term average. Increases in average discharge per square mile at the Circleville and St. Clere streamflow- gaging stations are attributed to basin characteristics, such as average hillside slope, soil type and depth, and terracing.

Frequency curves of annual peak discharges were strongly affected by the period of record. In general, flood-frequency curves developed from recorded data compared poorly with frequency curves calculated from statewide relations. The difference results from the absence of extremely low peaks in the period of record.

The applicability of statewide low-flow frequency curves developed for basins draining more than 100 square miles was tested using observed-discharge data in Soldier Creek basin. The comparison indicated that reasonable results will not be obtained for estimates of 7- and 30-day average annual minimum discharges by linear extrapolation to basins with drainage areas less than 100 square miles.

Comparison of the flow-duration curves with curves developed from statewide relations seemed to confirm the extrapolation of the statewide relations to basins smaller than 100 square miles. The data did indicate, however, that percentage duration of mean flow might vary with drainage-area size for basins smaller than 100 square miles.

Two seepage-salinity investigations in the basin provided data on the chemical quality of the water in the main stem and its principal tributaries. Predominant ions in the water were calcium, bicarbonate, and sulfate. Dissolved solids in the water of Soldier Creek are derived from solution of limestones and shales in the basin.

Average suspended-sediment discharge ranged from 9.94 at the Goff station to 848 tons per day at the Topeka station. A significant increase in sediment yield per unit area occurs between the Soldier and Circleville stations. The increase was attributed to changes in average hillside slope and land-use practices. The average clay content of the suspended sediment ranged from 41 to 59 percent and average silt content ranged from 37 to 57 percent. Average sand content ranged from negligible to 13 percent. The percentage of unmeasured sediment discharge to total sediment discharge ranged from 0.2 to 14.

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INTRODUCTION

A network of hydrologic data-collection sites was established in the Soldier Creek basin during the spring of 1964 by the U.S. Geological Survey in cooperation with the Kansas Water Resources Board. The basic network was designed primarily to obtain detailed rainfall and runoff data. Subsequently, the network was expanded to obtain data on chemical quality, sediment, and ground water for defining the general hydrologic system. The basic network consisted of 7 continuous-record streamflow-gaging stations and 56 recording and nonrecording rainfall gages located within and adjacent to the basin (Carswell, 1978a; 1978b). The remainder of the network consisted of sites for intermittent sampling of water quality (chemical quality and sediment) and observation wells for recording ground-water levels. A comprehensive compilation of the hydrologic data is available to users in computer-readable form on a nine-channel magnetic tape (Carswell, 1978c).

This report summarizes and analyzes the products of the data-collection network in order to describe the hydrology in the Soldier Creek basin and evaluates the results of various methods used to estimate streamflow characteristics. Existing methods that were developed for use in Kansas generally are based on data from drainage basins larger than 100 square miles. Soldier

Creek basin, where five of the seven streamflow-gaging stations have drainage areas of less than 100 square miles, provides an opportunity to study streamflow characteristics of small drainage areas. This study provides valuable information even though the results cannot be conclusive because of the relatively short periods of streamflow record and limited range of physical and climatic characteristics within the basin.

The information and data analyses contained in the report provide useful information on the hydrology of small drainage basins. In addition, it provides a hydrologic framework for detailed modeling studies that are possible by using the extensive data available on magnetic tape. Data analyses and descriptions in this report include: (1) Point-rainfall frequency; (2) streamflow characteristics, such as mean discharge, flood frequency, low- and high-flow frequency, and flow duration related to selected basin characteristics; (3) water quality, including chemical quality, suspended sediment, bed and bank material; and (4) water levels in the alluvium.

DESCRIPTION OF BASIN

General

The Soldier Creek basin extends almost directly north of Topeka, as shown in figure 1, encompassing an area of about 290 square miles in northeastern Kansas. The Soldier Creek valley is about 48 miles long and ranges in width from about 0.5 mile in the upstream reaches to about 2 miles near the confluence with the Kansas River valley. The downstream reach of the Soldier Creek flows in the valley of the Kansas River for about 10 miles.

Climate in the area is characterized by warm to hot summers, cold winters, moderate surface winds, and average annual precipitation of about 35 inches. Warm, moist air from the Gulf of Mexico is the primary source of moisture for the precipitation in the basin. Approximately 70 percent of the annual precipitation occurs during the growing season, April through September, with June having the maximum monthly average.

The geologic formations that crop out in the area range in age from Pennsylvanian to Quaternary. The Pennsylvanian and Permian rocks, which consist principally of shale and limestone, underlie the basin and dip gently northwestward. Much of the bedrock is mantled by glacial deposits of Pleistocene age. Alluvial sand, gravel, silt, and clay of Pleistocene to Holocene age, which are the principal sources of ground water, underlie the valleys of Soldier Creek and its major tributaries. For additional information concerning the geology and ground-water resources of the basin and surrounding area, the reader is directed to Walters (1953) and Ward (1974).

Topography in the area is undulating with relief commonly greater than 100 feet. Soils on most of the uplands are heavy textured and relatively impermeable. Land use in the basin is almost exclusively agricultural with 54 percent cropland, 38 percent pasture, 8 percent forested area and other uses.

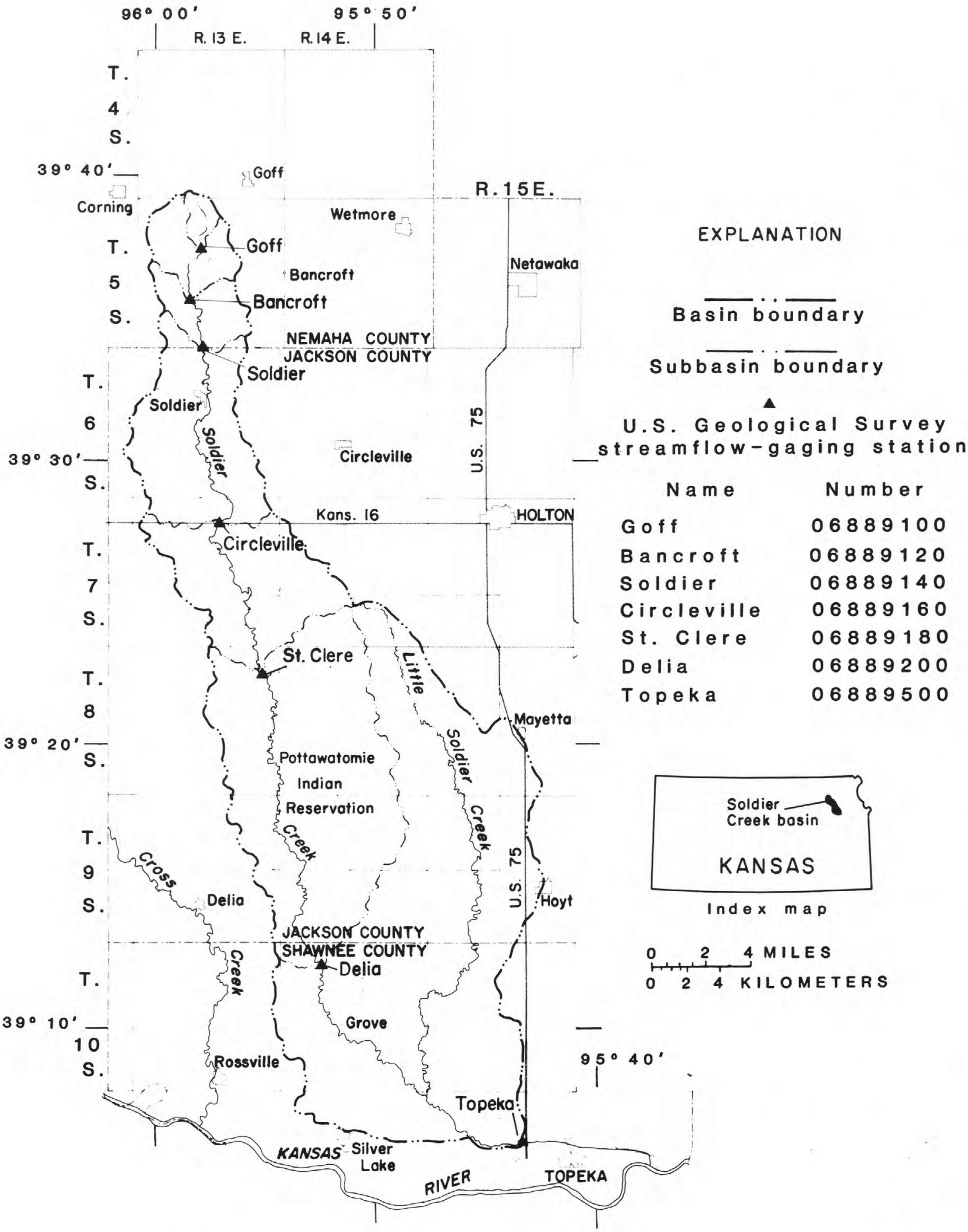


Figure 1.--Location of Soldier Creek basin and streamflow-gaging stations.

Physical Features

Upstream from the Goff gaging station, the soils are predominantly fine-grained material derived from glaciofluvial deposits and loess. Thus, sediment washed into the stream channel consists mostly of fine-grained material. Although the soils in the area upstream from the Bancroft station also are mostly fine-grained material derived from glaciofluvial deposits and loess, the stream channel has increased amounts of coarse glacial material. The weathered character of stream deposits is shown in a recent cut in the bank near the Bancroft station.

In the area upstream from the Soldier station, soils are mostly fine-grained material derived from glaciofluvial deposits; glacial erratics commonly are included. Because hill slopes are gentle, croplands are extensively terraced, and some pasturelands are terraced.

The stream has eroded to limestone bedrock in the vicinity of the Soldier station. At a recent cut in the banks, boulders too large to have been moved by the stream were observed in the old bed material deposits laid down on bedrock, which indicates that glacial activity at some time scoured the area to bedrock.

The area between the Soldier and Circleville stations is a transition zone where the soils are derived partly from glacial till and partly from weathered bedrock. The soils on the hillsides are thin, ranging from 0 to less than 18 inches. The steepness of hill slopes is increased, and terracing of the farmland is minimal. Glacial till is present on the gentler slopes near the stream valley, but large glacial erratics are uncommon. Coarse sand that occurs abundantly in the bed near the Circleville station is derived from glacial and alluvial deposits in other areas in the basin. It is difficult to distinguish the flood plain of the stream from natural terraces in the vicinity of the Circleville station because of farming activities in the valley.

Erosional bedrock areas with steep sidehill slopes become the predominant surface feature downstream from the Circleville station. The areal extent of glacial till is small in the downstream reaches of the basin. Scattered deposits of loess also are located in this part of the basin, but the majority of the soil has been derived from the limestone bedrock.

Upstream from the St. Clere station there is no evidence of appreciable stream cutting into the bedrock. Between the St. Clere and Delia stations, the stream has cut into weathered shale and limestone bedrock in several places; however, in many reaches between St. Clere and Delia, the bedrock is not as weathered, and the stream has not cut as deep. These reaches are characterized by low banks that are easily topped during small floods. Normally, the stream would widen in these reaches to increase the channel capacity required as a result of its inability to cut deeper. However, moderate to dense vegetation on the cohesive silt and clay banks has prevented the stream from widening.

The flood plain downstream from the St. Clere station is very well developed and is generally greater than 0.5-mile wide. For the final 10 miles above the mouth, Soldier Creek flows in a manmade channel that is leveed on both banks. The Topeka station is located within this improved reach of the stream.

PRECIPITATION

A large part of the precipitation in northeastern Kansas occurs as thunderstorms during the warm growing season, April through September. These storms commonly occur during the nighttime hours. Data on the quantity and areal distribution of rainfall during the study, 1964-76, were collected at 56 sites in and adjacent to Soldier Creek basin. Rainfall gages located at five streamflow stations were equipped with recorders to provide the time distribution of rainfall associated with flood hydrographs. The locations of U.S. Geological Survey recording and nonrecording (observer) rainfall gages in and near Soldier Creek basin are shown in figure 2.

The annual precipitation for 1964-76 at Holton, Kans., from the precipitation gage operated by the National Weather Service, is depicted graphically in figure 3. The average annual precipitation for 1929-76 (34.32 inches) also is shown in this figure. The average annual precipitation for 1964-76 is 35.12 inches, which is 2.3 percent greater than the 1929-76 average.

Due to the proximity of the Holton precipitation gage to Soldier Creek basin, the monthly precipitation at Holton can be considered indicative of the distribution in Soldier Creek basin. The average monthly rainfall for April through September (1964-76) is shown in figure 4 for the Holton gage and the five recording rainfall gages in Soldier Creek basin. It was suspected that the differences in monthly averages may indicate a deficiency in catchment at the recording gages.

In an effort to determine the reliability of data from the recording rainfall gages, monthly rainfall (April through September, 1964-76) at the Bancroft gage was compared with monthly rainfall at the National Weather Service gage near Bancroft (1,400 feet east of the recording gage). Assuming that rainfall at the National Weather Service gage is correct, the comparison, as shown in figure 5, indicates an average catch deficiency at the recording gage of approximately 17 percent. Data from the National Weather Service gage were substituted for missing record at the recording gage. Comparison of rainfall at the other recording gages with rainfall measured by the U.S. Geological Survey's rainfall observer nearest the recording gage produced similar catch differences. Because rainfall data were available only during the months of April through September from 1964 to 1976, the total rainfall for those months was included in this test.

As an additional check, the daily rainfall totals at the recording gages were compared with those of the nearest U.S. Geological Survey rainfall observer during April through September, 1964-76. Rainfall at the five recording gages for a 24-hour period, 7 a.m. to 7 a.m., was compared with the observers' rainfall values for the same period, as shown in figure 6. A rainfall of 0.5 inch at the recording gage was used arbitrarily used as a lower limit of comparison. The comparison of daily rainfall totals shows a general trend toward catch deficiency at the recording gages similar to that shown with monthly totals. Assuming that rainfall measured by the observer is correct, the catch deficiency at the recording gage ranges from 5.4 to 13.0 percent.

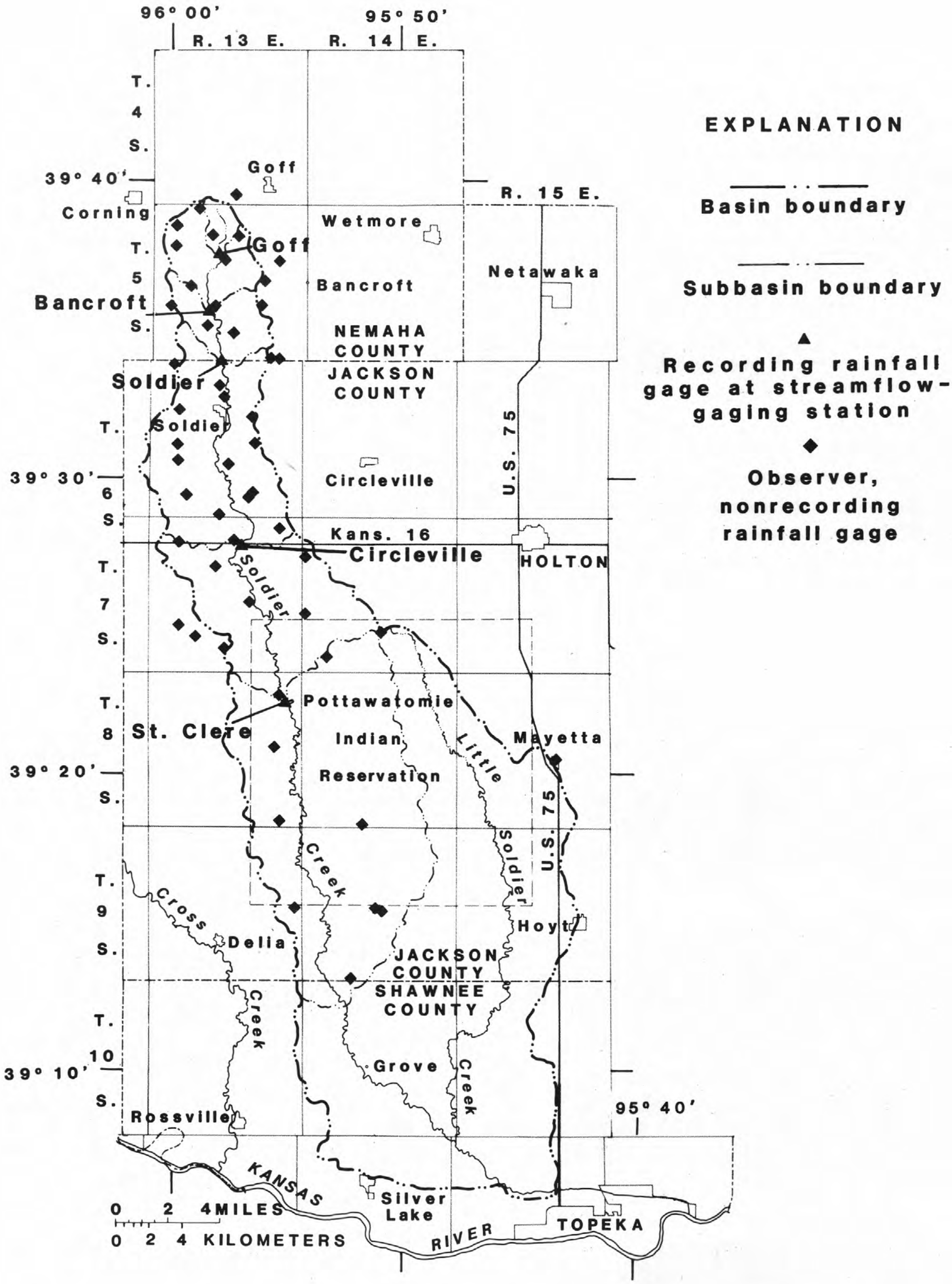


Figure 2.--Location of U.S. Geological Survey rainfall gages in and near Soldier Creek basin.

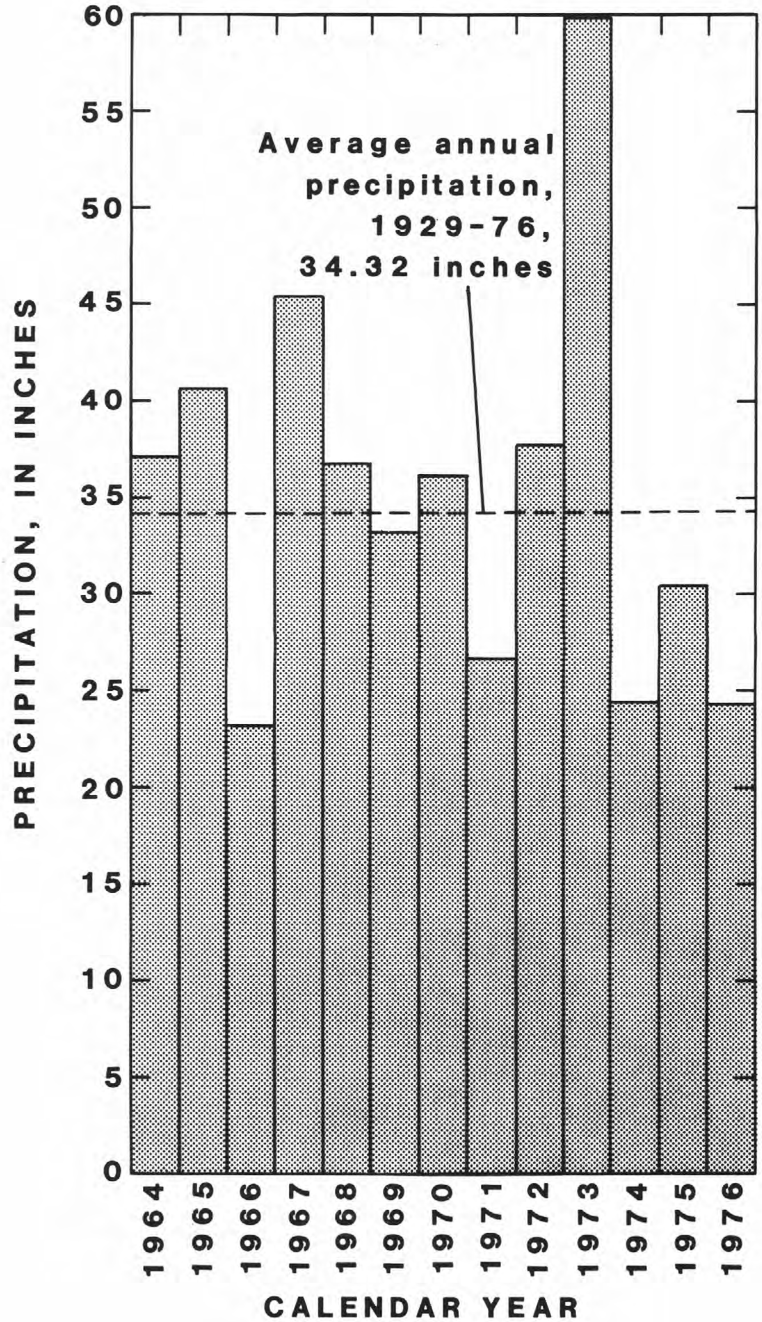


Figure 3.--Distribution of annual precipitation 1964-76 and average annual precipitation 1929-76 for gage at Holton, Kans., operated by the National Weather Service.

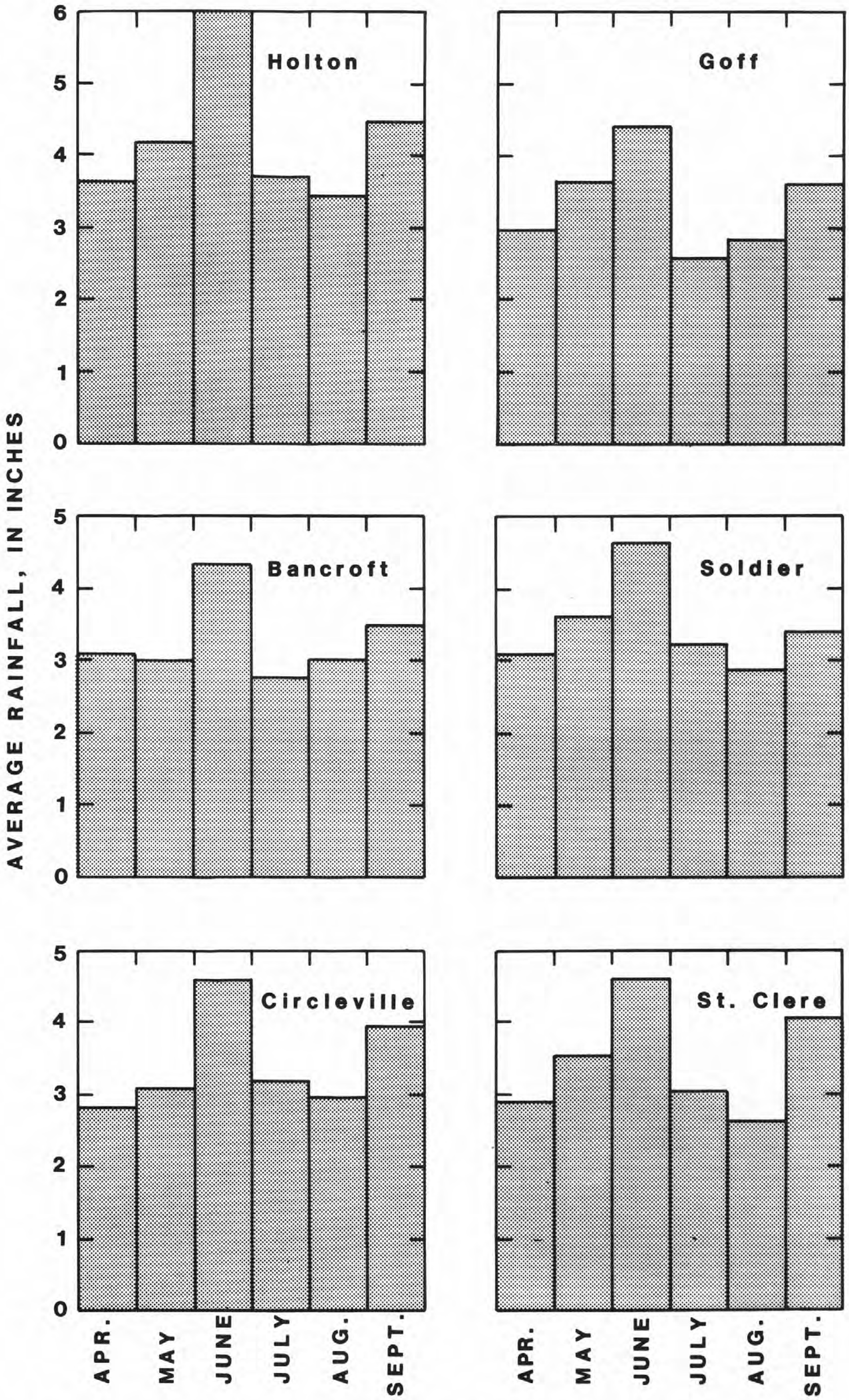


Figure 4.--Average monthly rainfall, April through September, for the National Weather Service gage at Holton and the U.S.Geological Survey recording gages in Soldier Creek basin, 1964-76.

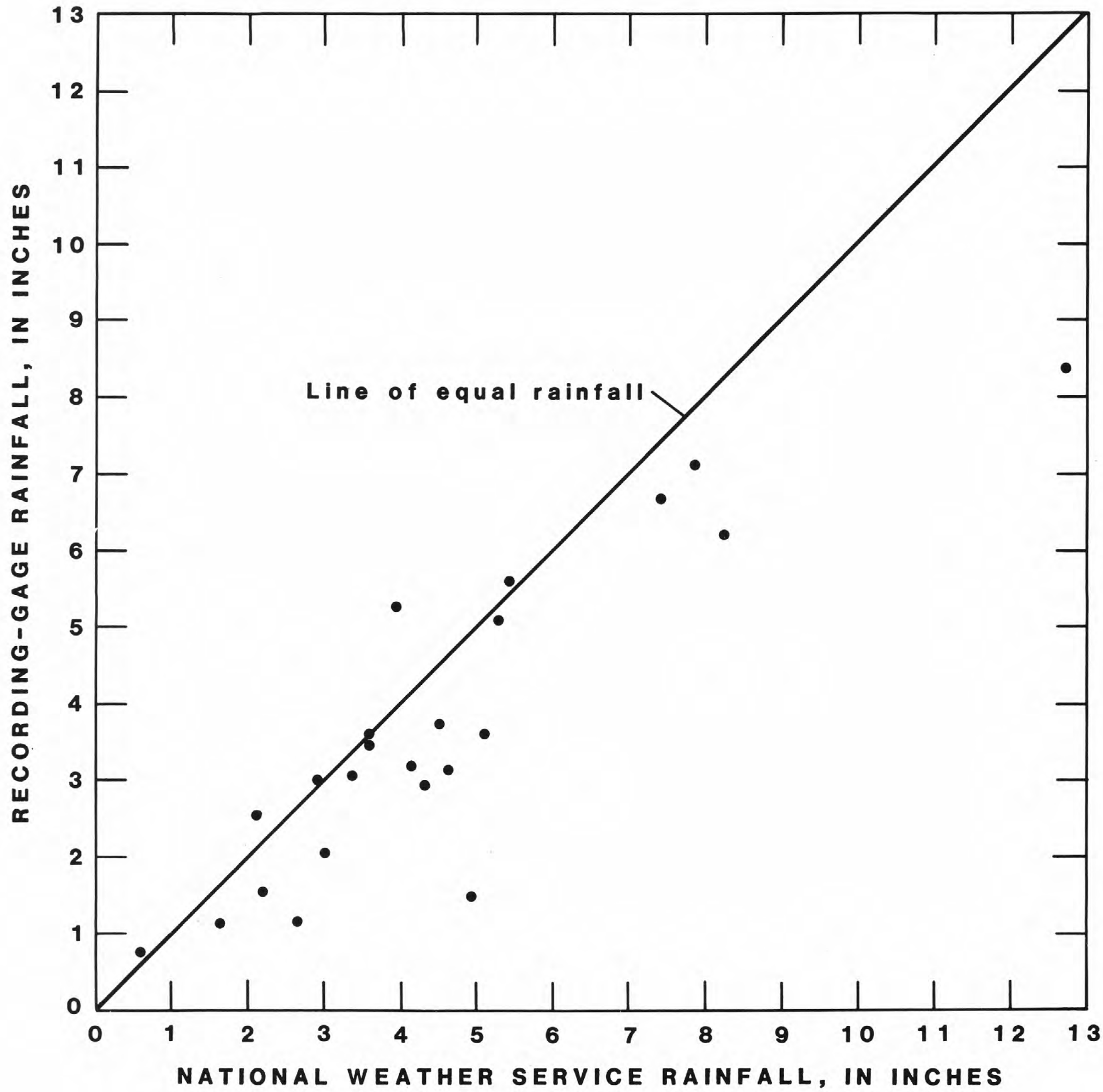


Figure 5.--Comparison of monthly rainfall (April through September, 1964-76) at the National Weather Service gage near Bancroft with the Bancroft recording gage.

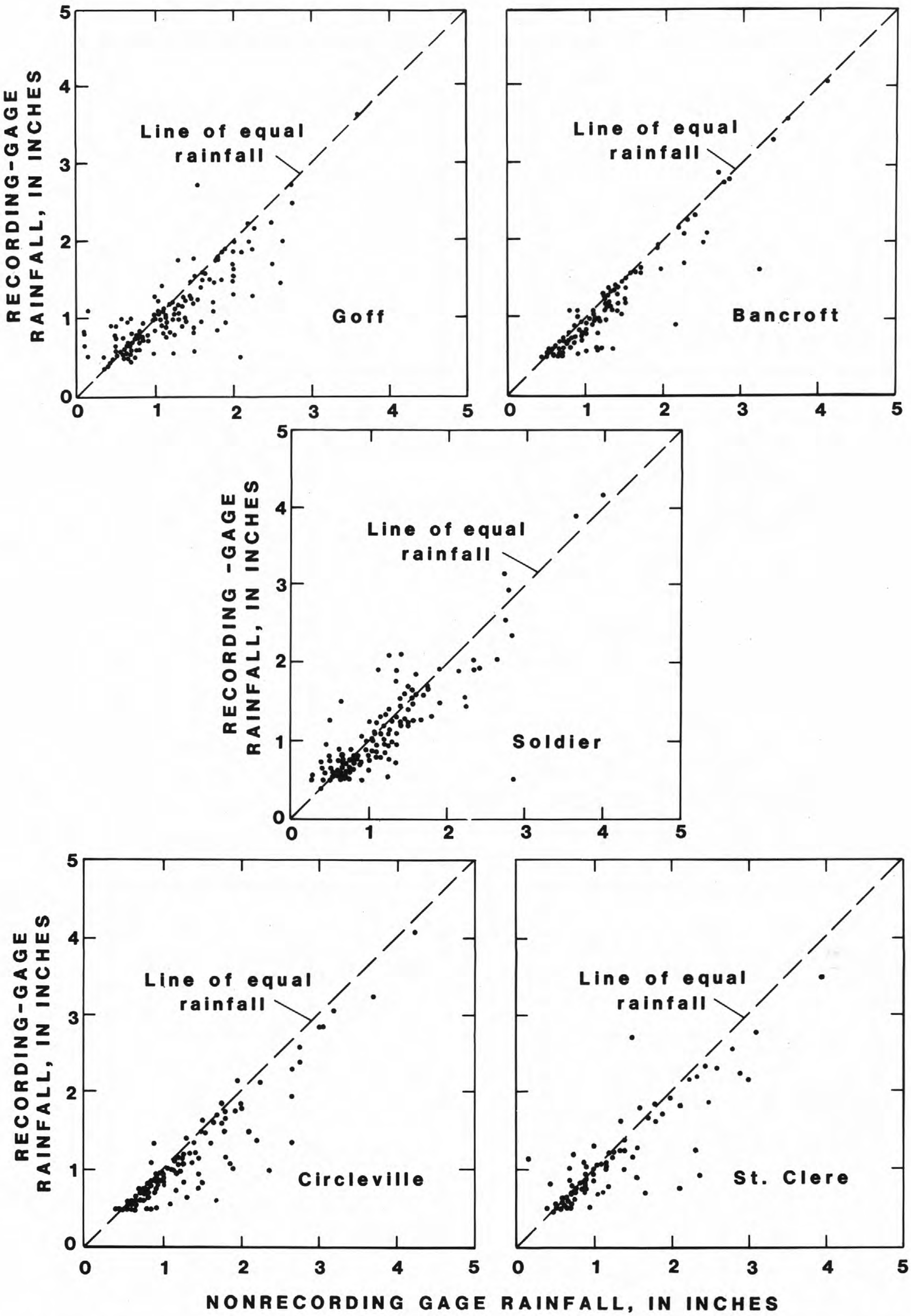


Figure 6.--Comparison of daily rainfall at nearest U.S. Geological Survey nonrecording gage with daily rainfall at each recording gage, 1964-76.

The consistency with which the recording gages have smaller rainfall values than the observer's gage indicates that wind blowing upward over the gage house may carry some of the rain away from the collector. As discussed by Larson and Peck (1974), point rainfall can be subject to considerable catch deficiencies with increased wind speed. The effect of wind speed on gage catch, as determined by four different investigators, is shown in figure 7. The collectors at the recording sites are not sheltered; whereas, the gages at the nonrecording sites are somewhat protected from wind by trees and buildings. Records of rainfall during light showers with small raindrop size would have been most adversely affected. This would account for the monthly totals having a greater deficiency than daily rainfall, for which only amounts greater than 0.5 inch were considered. Other factors, such as variations in areal distribution of rainfall, surface area to be wetted before recording occurs, and inefficient design of recording-gage siphon, could have contributed to the apparent catch deficiency at the recording gages. Errors in recorded rainfall used as input to a rainfall-runoff model will result in a comparable, or greater error, in the discharge values determined as a result of long-term synthesis (Dawdy, Lichty, and Bergmann, 1972).

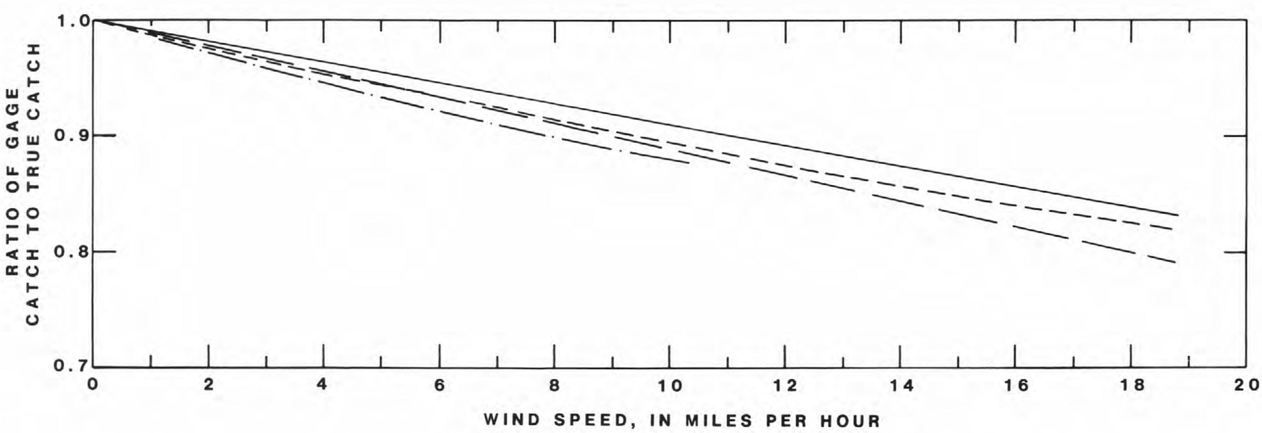


Figure 7.--Wind speed versus gage-catch ratios determined by four different investigators (modified from Larson and Peck, 1974).

Frequency distributions of point rainfall at the Goff and Bancroft recording gages for 15- and 30-minute, 1-, 2-, 3-, 6-, 12-, 24-, and 48-hour durations were determined by fitting a log-normal distribution to the annual series of extremes. Point-rainfall values for each duration were adjusted for apparent gage-catch deficiency prior to analysis. The daily rainfall was adjusted by the catch deficiency determined for each site. Ratios provided by the U.S. Weather Bureau (Herschfield, 1961) were used to adjust the frequency curves to a partial-series frequency curve so they would be in a form comparable to the long-term curves published by the U.S. Weather Bureau. Rainfall-frequency curves for the Goff and Bancroft recording gages are compared with those obtained from the U.S. Weather Bureau (Herschfield, 1961) for rainfall durations of 1, 2, 12, and 24 hours, as shown in figure 8. The Goff and Bancroft sites

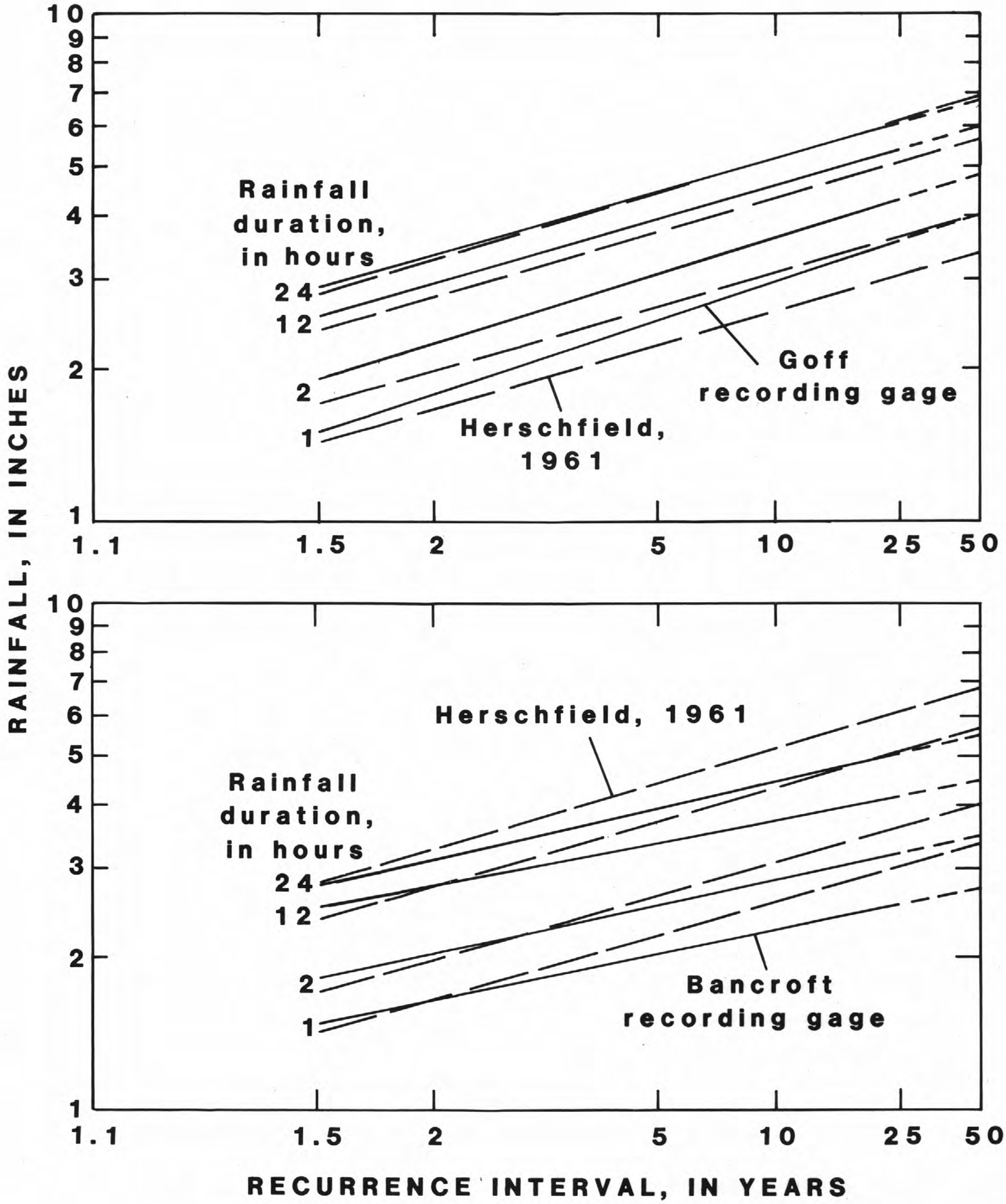


Figure 8.--Comparison of rainfall-frequency curves for Goff and Bancroft recording gages with those obtained from Herschfield, 1961.

were chosen to demonstrate the dramatic differences that can exist between short-term rainfall-frequency curves, even though the data are for identical periods and the collection sites are not extremely far apart. Similar differences may be expected in stream discharges resulting from similar differences in rainfall.

STREAMFLOW

Streamflow characteristics can be considered as those factors that statistically describe the occurrence of streamflow at a particular site. These characteristics are useful in planning, management, and design of projects related to water resources. This section is devoted to a discussion of a wide range of streamflow characteristics that have been obtained by analysis of streamflow data collected in Soldier Creek basin.

Average Discharge

Streamflow in Soldier Creek at Topeka during 1965-76 was 23 percent greater than the long-term average streamflow (1930-76). By comparison, the average precipitation in the basin (measured at Holton, Kans.) during 1964-76 was about 2 percent greater than the long-term average precipitation (1929-76). Much of the increase in streamflow resulted from runoff during 1973, an extremely wet year. The average discharge at the Topeka station for calendar year 1973 was 520 cubic feet per second, which is approximately 3.8 times the long-term average of 136 cubic feet per second (1930-76). The short-term average discharges and the long-term average discharges, where applicable, are given in table 1 on a unit drainage-area basis. The values given for the Topeka station show the effect of an extremely wet year on short-term averages. Deletion of the 1973 data would reduce the 1965-76 average discharge per square mile to 0.469 cubic foot per second, or the same value as shown for 1930-76.

Because the average discharge per square mile is independent of basin size in Kansas (Furness, 1960), the variability of values shown in table 1 is significant. The average discharges per square mile at the Goff, Bancroft, and Soldier stations are similar. The average discharges per square mile at the Circleville, St. Clere, and Delia stations also are similar but are greater than those at upstream stations. These increases probably are related to differences in physiographic characteristics in the drainage areas.

In the drainage area upstream from the Soldier station, characteristics of moderate thickness and permeability of soils, relatively gentle hillside slopes (about 4.0 percent), and extensive terracing tend to increase moisture retention and decrease runoff. In the area downstream from the Soldier station, characteristics of thin and relatively impermeable soils, relatively steep hillside slopes (about 6.5 percent), and minor terracing tend to decrease moisture retention and increase runoff.

Table 1.--Long- and short-term average discharge for streamflow gages in Soldier Creek basin

Streamflow-gaging station	Drainage area (square miles)	Discharge, in cubic feet per second per square mile: Average for 1965-76	Discharge, in cubic feet per second per square mile: Long-term average for period represented
Goff	2.06	0.568	---
Bancroft	10.5	.563	---
Soldier	16.9	.534	---
Circleville	49.3	.615	---
St. Clere	80.0	.638	---
Delia	157	.614	0.567 (1959-76)
Topeka	290	.579	.469 (1930-32, 1936-76)

Variability of Flow

Flow-duration curves supplement the information on average discharge by showing the variability of flow. Average discharge represents the yield of water from the drainage area over a long period of time; whereas, a flow-duration curve represents the variation of daily flows. However, the sequence of occurrence is not shown by the duration curve. The flow-duration curve uses all daily flows ranked in order of magnitude, thus showing the percentage of time that given flows were equaled or exceeded. The variability of streamflow and the natural storage within the basin is indicated by the slope of the duration curve. A flat slope at the lower end of the curve indicates a well-sustained flow from surface or underground storage; whereas, a steep slope throughout the curve denotes a highly variable flow that is largely from surface runoff. Flow-duration curves also are useful in developing concentration-duration curves, as in the sections of the report on "Water Quality" and "Suspended-Sediment Discharge."

In general, the flow-duration curves for Soldier Creek indicate that the flows are highly variable. The flow-duration curves at each streamflow-gaging station, using a concurrent record (1965-76), are shown in figure 9. Ground-water storage may be a significant factor only at the Circleville and Topeka stations. The lack of appreciable ground-water storage in the basin, however,

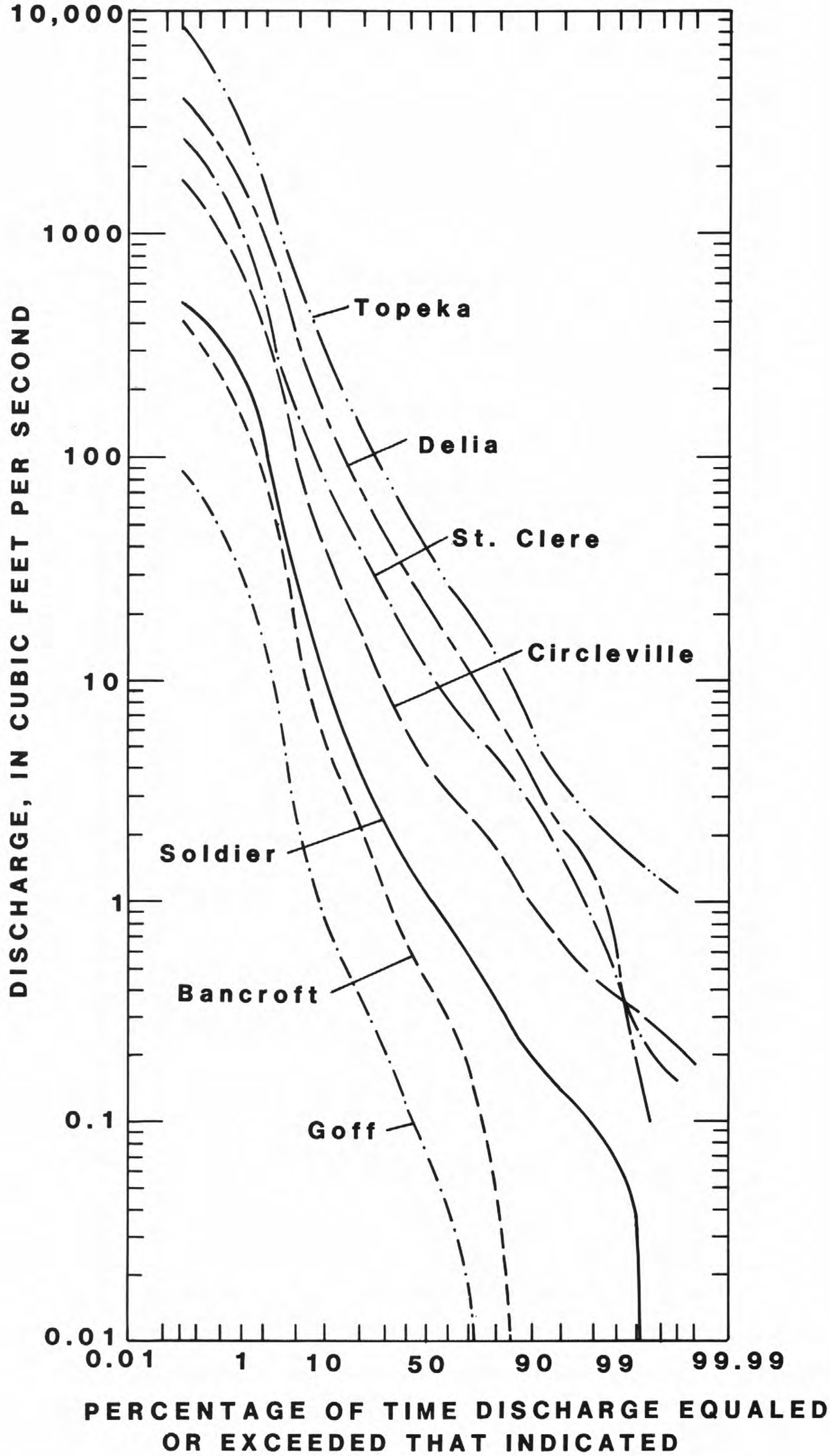


Figure 9.--Flow-duration curves for streamflow-gaging stations in Soldier Creek basin, 1965-76.

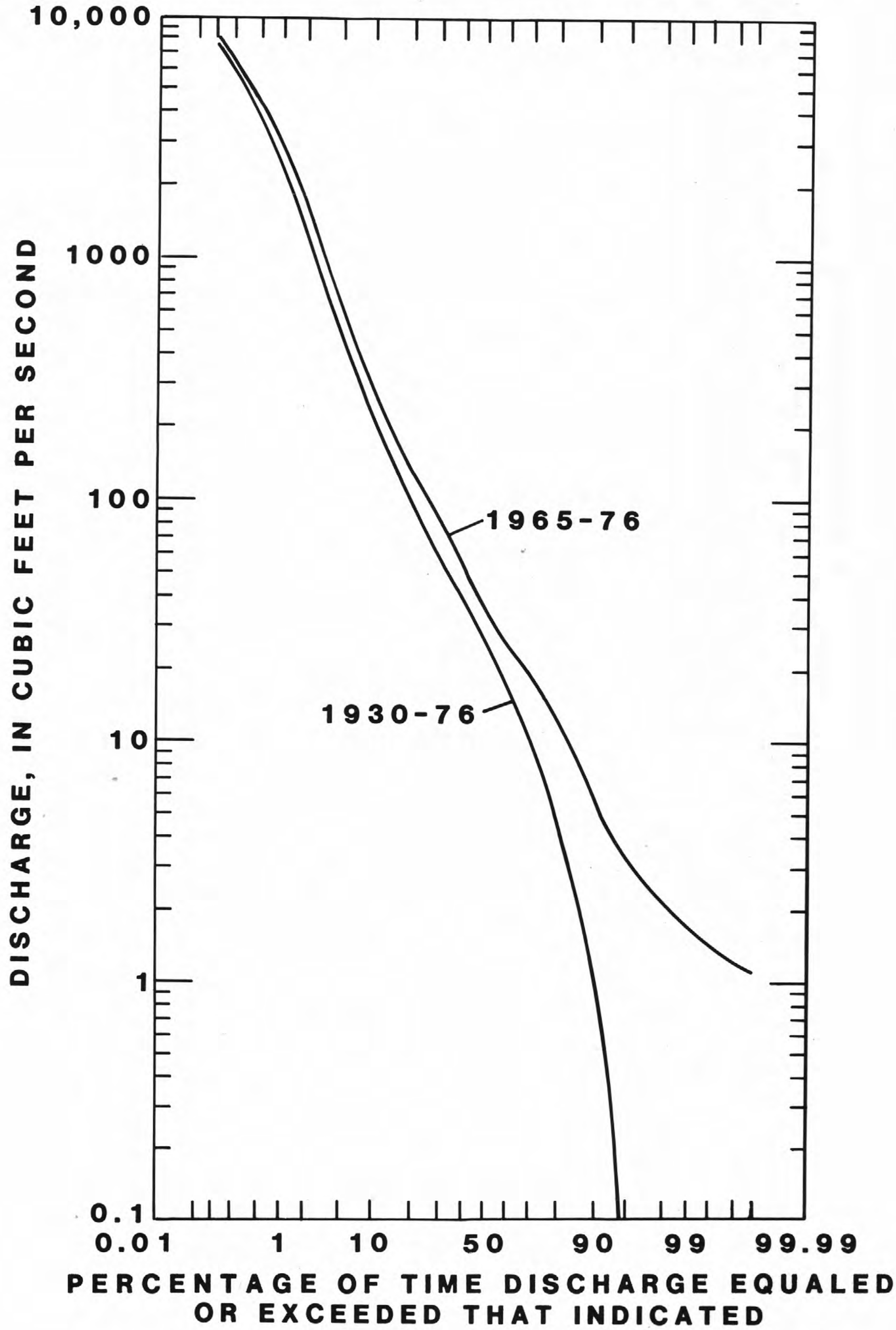


Figure 10.--Topeka flow-duration curves for short-term and long-term periods.

is apparent in the duration curve at the Topeka station for the long-term period (1930-76) shown in figure 10. A comparison of the Topeka flow-duration curves for the short-term and long-term periods is shown in figure 10. The lack of sustained flow during droughts is evident from the curve based on long-term records. Significant effects of ground-water storage at the Topeka station are limited to the alluvial aquifer, which sustains low flows only during relatively short dry periods.

To obtain 47 consecutive years of records at Topeka, discharges for the missing period (September 1932 to August 1935) were determined by graphic correlation techniques using records from the Delaware River at Valley Falls, Kans. (drainage area 922 square miles). The correlation coefficient of 0.68 was considered adequate for obtaining daily discharges for the relatively short missing-record period.

Flow-duration curves for each station in the basin were adjusted to comparable long-term periods (1930-76) as shown in figure 11. The long-term duration curves emphasize the flow variability and the lack of sustained ground-water contribution to flow in the basin. The short-term records were adjusted, using a technique described by Furness (1959), by correlating flow-duration data for concurrent periods of record with flow-duration data from a station having long-term records. Discharges at long-term stations were plotted against the discharges of the same percentage of time at nearby short-term stations. Flow-duration curves were defined at the short-term stations in Soldier Creek basin for 1930-76, using the 1930-76 discharge at the Topeka station for specific durations and the correlation curves established for the concurrent period.

In basins ranging in size between 100 and 3,000 square miles, Furness (1959) found that coordinates of discharge and selected percentage of time on a flow-duration curve were affected by mean discharge, size of basin, and a combination of other factors that could be resolved geographically. The relation line developed by Furness for 1921-56, which has been extrapolated to drainage areas of less than 100 square miles by straight-line log-log extension, is shown in figure 12. Also plotted in figure 12 are the ratios of discharge equaled or exceeded 1 percent of the time to the average discharge. Although there is some scattering of plotted points, the extrapolation of Furness° relation seems to be confirmed.

The position of the mean discharge is a characteristic of the flow-duration curve that differs markedly from extrapolated relations defined by Furness (1959). Furness found that the factors affecting mean discharge could be resolved geographically and that basin size was not a factor. A comparison of the percentage duration of mean discharge to the drainage area, as shown in figure 13, indicates that drainage-area size might be a factor for basins smaller than 100 square miles. As basin sizes decrease, the probability of sustained base flow diminishes and the probability of streamflow from thunderstorm runoff increases. Therefore, a decrease in the percentage duration of mean discharge with a decrease in basin size is very possible. Due to the small number of data points, a definite conclusion could not be made regarding the relationship of the percentage duration of mean discharge to drainage-area size for basins smaller than 100 square miles.

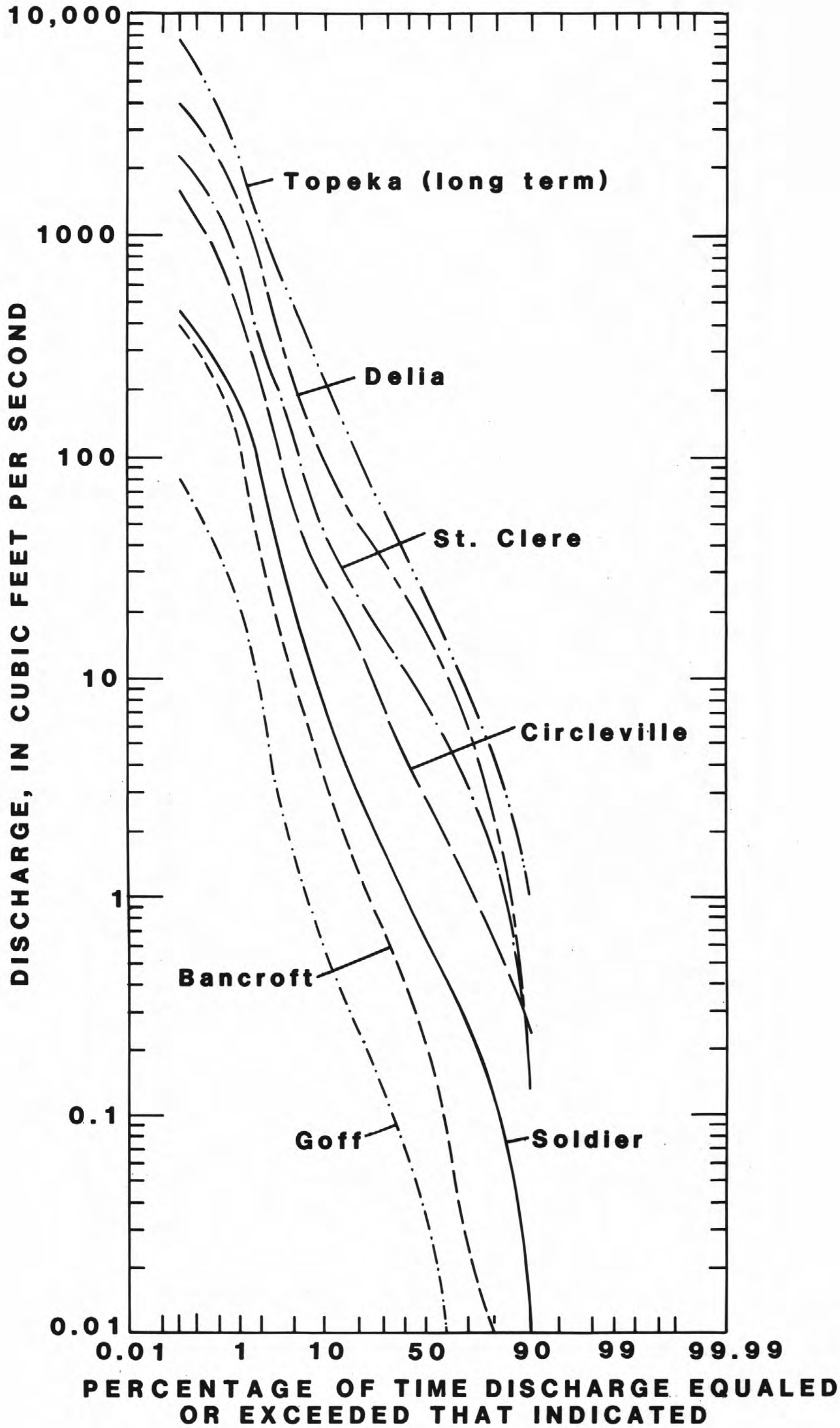


Figure 11.--Adjusted flow-duration curves for streamflow-gaging stations in the basin (1930-76).

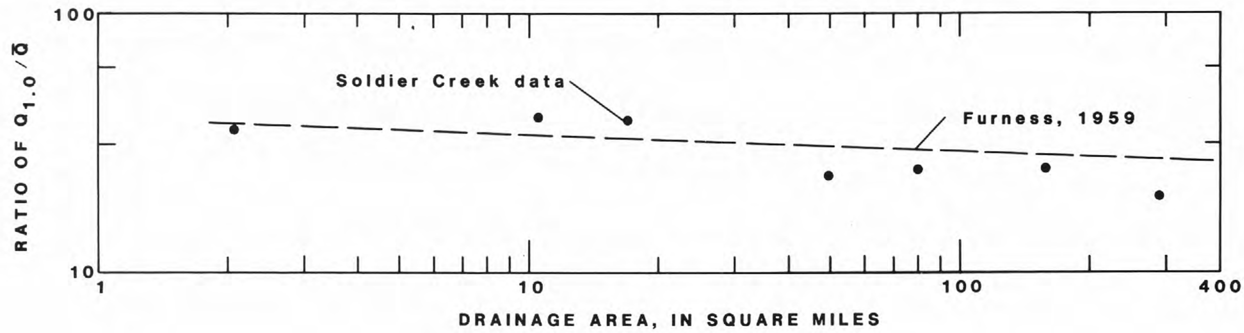


Figure 12.--Relation of drainage area and ratio of discharge equaled or exceeded 1 percent of the time ($Q_{1.0}$) to average discharge ($\bar{Q}$) for 1930-76.

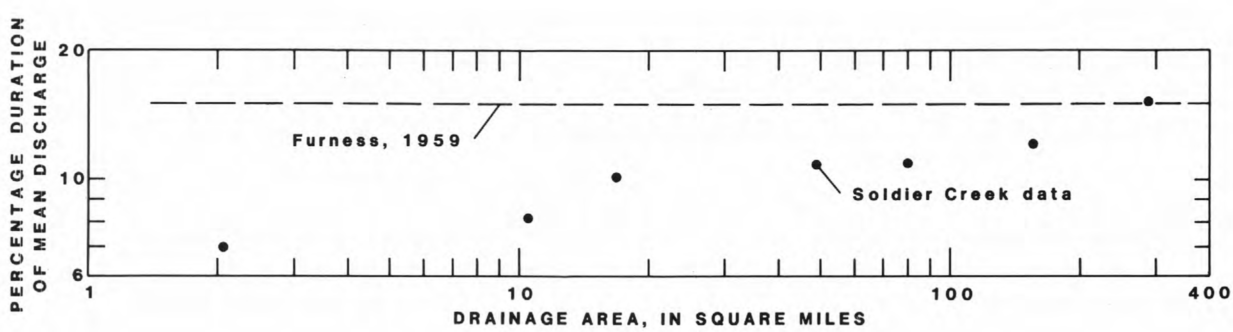


Figure 13.--Relation of drainage area and percentage duration of mean discharge (1930-76).

Low-Flow Frequency

Low-flow frequency curves supplement the information in duration curves by representing the chronological sequence of events. Duration curves represent all daily flows without regard to time of occurrence; whereas, low-flow frequency curves represent low flows for consecutive days. The shapes of these curves indicate the availability of ground water to sustain flows. Low-flow frequency curves also can be used to estimate the potential yield of a stream for studies of water supply and management.

Observations of no flow were made at most of the stations during periods of streamflow record. Days of no flow occurred during most years at the Goff and Bancroft stations and during 4 years at the Soldier station. Minimum flow at the Circleville station was 0.14 cubic foot per second on March 7, 1967. Zero flow occurred at the St. Clere station during part of April 9, 1964 (as a result of beaver activity), and at the Delia station during September 10-12, 1976. During the long-term period of record at Topeka, no flow was observed at various times during 1931, 1935-40, 1953-57, and during 1966 (owing to upstream construction).

A tabulation of the low-flow frequency data, which were defined and evaluated as described by Riggs (1972), is given in table 2. The lowest mean discharges at each station for 1-, 3-, 7-, 14-, 30-, 60-, 90-, 120-, and 183-consecutive days in each climatic year (April 1 through March 31) were obtained. Log-Pearson Type III distributions were fitted to these discharges to provide estimates of low-flow frequencies at each station. At the Delia and Topeka stations, the frequency analyses for both the short-term and the period of record are shown.

Graphic techniques were used to determine the frequency curves for periods that were poorly defined by the log-Pearson Type III distribution. The plotting position of the minimum flows was determined by the formula

$$\text{recurrence interval} = \frac{n + 1}{m},$$

where n is the number of years of record, and m is the order number when the annual events are ranked from smallest to largest discharge. The data then were plotted against the respective recurrence interval on log-Gumbel paper.

Low-flow frequency curves that are concave upward commonly indicate contributions of ground water at low flow. Short-term curves (1965-76) for the Soldier Creek stations, with the exception of Goff and Bancroft, indicate that a ground-water source is available to sustain low flows in Soldier Creek basin. Short-term curves (1965-76) for the Topeka station, which are indicative of curve shapes for short-term streamflow-gaging stations in the basin, are shown in figure 14. However, an examination of low-flow frequency curves for 1931-76 at the Topeka station produces a different conclusion (fig. 15). It is apparent from these curves that low flows are not sustained during dry periods and that the base-flow contribution from aquifers in the basin is not as pronounced as indicated by the short-term records.

Table 2.--Magnitude and frequency of annual minimum average flows for selected durations of consecutive days within climatic years April 1 through September 30

[Flow values in cubic feet per second]

Duration (days)	Recurrence interval, in years				
	1.5	2	5	10	20
			GOFF, 1965-76		
1	0	0	0	0	0
3	0	0	0	0	0
7	0	0	0	0	0
14	0	0	0	0	0
30	0	0	0	0	0
60	0.038	0.020	0.011	0	0
90	.084	.052	.015	0	0
120	.26	.11	.033	0.007	0
183	.38	.18	.038	0.016	0.01
			BANCROFT, 1965-76		
1	0	0	0	0	0
3	0	0	0	0	0
7	0	0	0	0	0
14	0	0	0	0	0
30	0	0	0	0	0
60	0.14	0.054	0.01	0	0
90	0.45	.19	0.01	0	0
120	1.0	.38	0.032	0.01	0
183	1.9	.84	0.15	0.044	0.1
			SOLDIER, 1965-76		
1	0.19	0.10	0.014	0	0
3	.21	.12	.035	0.017	0.01
7	.26	.15	.044	.021	.011
14	.35	.20	.059	.029	.012
30	.41	.26	.11	.075	.054
60	.75	.48	.20	.12	.084
90	1.0	.63	.23	.15	.092
120	1.8	.97	.28	.18	.098
183	2.8	1.6	.45	.24	.13

Table 2.--Magnitude and frequency of annual minimum average flows for selected durations of consecutive days within climatic years April 1 through September 30--Continued

[Flow values in cubic feet per second]

Duration (days)	Recurrence interval, in years				
	1.5	2	5	10	20
		CIRCLEVILLE, 1965-76			
1	1.0	0.76	0.40	0.28	0.19
3	1.1	.80	.43	.29	.21
7	1.2	.85	.46	.32	.24
14	1.4	1.0	.54	.40	.30
30	1.6	1.2	.69	.52	.41
60	2.7	1.9	.90	.62	.45
90	4.0	2.6	1.1	.74	.50
120	6.3	3.7	1.4	.79	.53
183	11	6.1	1.9	1.1	.62
		ST. CLERE, 1965-76			
1	2.1	1.3	0.66	0.50	0.40
3	2.5	1.7	0.79	.57	.43
7	3.1	2.0	1.0	.71	.52
14	3.9	2.3	1.1	.73	.56
30	4.7	2.9	1.3	.90	.79
60	6.9	4.0	1.8	1.2	.85
90	8.9	5.7	2.3	1.5	.95
120	13	7.7	3.1	2.0	1.3
183	22	13	4.7	2.8	1.8
		DELIA, 1965-76			
1	4.1	2.7	0.88	0.32	0.05
3	4.5	3.1	1.1	.48	.09
7	4.8	3.4	1.3	.54	.16
14	5.5	3.9	1.4	.63	.22
30	7.5	5.3	2.1	1.1	.60
60	12	7.8	2.9	1.6	.93
90	17	11	4.0	2.7	1.2
120	28	17	5.8	3.6	1.7
183	45	25	7.7	4.6	2.3

Table 2.--Magnitude and frequency of annual minimum average flows for selected durations of consecutive days within climatic years April 1 through September 30--Continued

[Flow values in cubic feet per second]

Duration (days)	Recurrence interval, in years				
	1.5	2	5	10	20
DELIA, 1960-76					
1	3.7	2.2	0.76	0.40	0.18
3	3.9	2.4	.83	.44	.22
7	4.3	2.6	.95	.53	.29
14	5.2	3.2	1.2	.70	.40
30	7.3	4.7	1.9	1.2	.69
60	12	7.4	2.8	1.5	1.0
90	19	11	3.8	2.1	1.2
120	28	15	4.8	2.7	1.5
183	42	24	7.0	3.7	1.9
TOPEKA, 1965-76					
1	7.4	5.1	1.9	0.9	0.4
3	8.7	6.1	2.4	1.2	.6
7	9.5	6.7	2.7	1.4	.76
14	11	7.3	3.0	1.6	.85
30	13	8.4	4.0	2.2	1.2
60	24	15	5.2	2.7	1.6
90	41	25	7.7	3.7	2.0
120	63	37	11	4.8	2.5
183	83	48	14	6.4	3.3

Duration (days)	Recurrence interval, in years					
	1.5	2	5	10	20	50
TOPEKA, 1931-76						
1	4.3	1.9	0	0	0	0
3	5.2	2.6	0.18	0	0	0
7	5.6	2.8	.30	0	0	0
14	6.9	3.4	.40	0	0	0
30	10	5.2	.52	0.016	0	0
60	20	9.3	1.2	.08	0	0
90	28	15	2.3	.26	0.010	0
120	40	19	2.8	.45	.033	0
183	58	31	5.9	1.7	.40	0.017

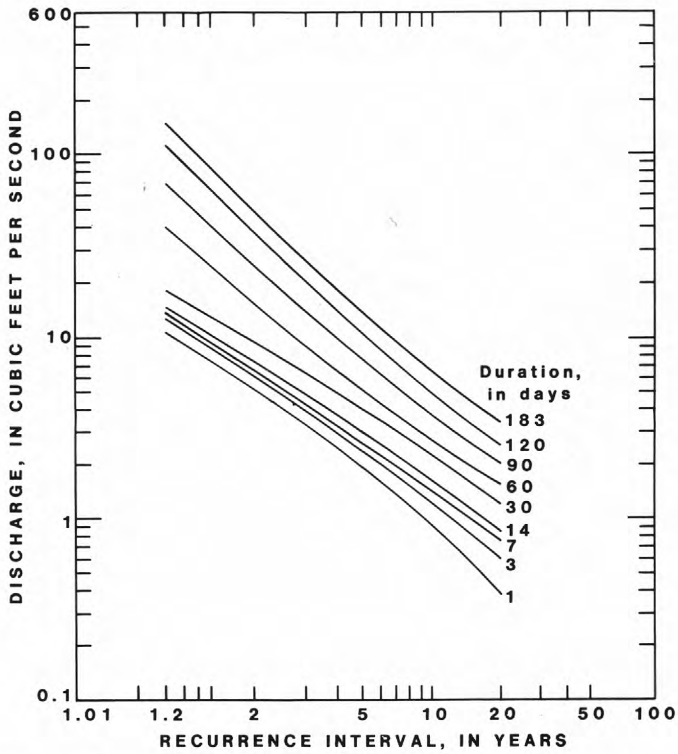


Figure 14.--Low-flow frequency curves for the Topeka station (1965-76).

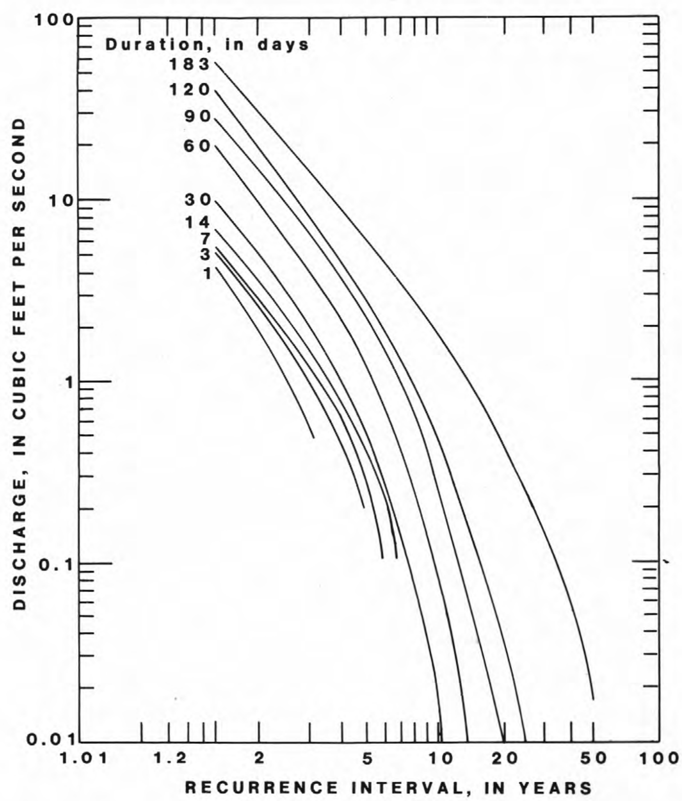


Figure 15.--Low-flow frequency curves for the Topeka station (1939-76).

Furness (1960) discussed low-flow frequency curves for numerous streamflow-gaging stations in Kansas. He also presented a procedure for estimating low-flow frequency curves on ungaged Kansas streams having drainage areas of more than 100 square miles. The viability of this technique, when applied to basins with areas of less than 100 square miles, was tested using observed discharge data in Soldier Creek basin. The 120-day average minimum discharge with a recurrence interval of 2 years, calculated by extrapolating Furness' method to a small basin, is compared to values shown in table 2. Although the plotted points from table 2 are well above the relation line extrapolated from Furness, the slope of a line graphically fitted to the data points is similar to that of Furness (fig. 16). The similar slopes indicate that Furness' method might provide reasonable results for the 120-day average minimum flow if linearly extrapolated to small basins. Further investigation of linear extrapolation to small basins of relations presented by Furness (1960) shows that extrapolation to obtain estimates of 30- and 7- day average minimum discharges should not be used for basins smaller than 100 square miles.

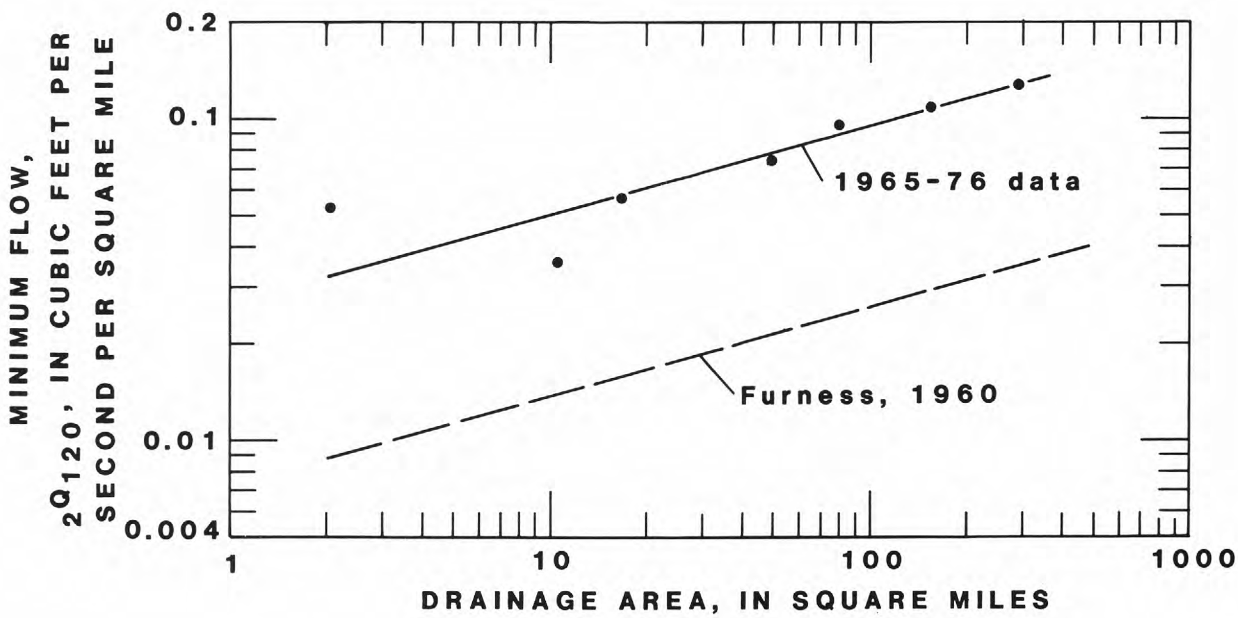


Figure 16.--Relation of drainage area to 120-day average minimum flow with a recurrence interval of 2 years for Soldier Creek basin.

Flood Frequency

Frequency curves of flood flows are useful in the efficient design of highway bridges and culverts, roadbed elevations, levees, dams, and channel capacities. A knowledge of the magnitude and frequency of flooding also is necessary for effective flood-plain management and zoning. Flood-frequency curves for the period of record at each streamflow-gaging station in the basin are shown in figure 17.

The method of frequency analysis used in determining the N-year flood peak at the gaged sites was the fitting of a log-Pearson Type III distribution as specified by the U.S. Water Resources Council (1977). The log-Pearson Type III frequency curve at the Goff gaging station was adjusted due to the extremely high flood peak that occurred during May 1970. The proximity of this peak to the envelope curve developed for eastern Kansas by Jordan and Irza (1975) justifies the treatment of this peak as a high outlier. Because the envelope curve generally represents flows 1.5 to 3.0 times as large as the 100-year flood, the 1970 flood was considered a 200-year flood in computation of the frequency curve.

The relative plotting positions of the frequency curves in figure 17 agree with expected positioning, except those for the Bancroft and Delia stations and to some degree the Topeka station. Some of this consistency results from the adjustment described for the Goff station and the use of a uniform skew coefficient. Explanations for inconsistency at those stations mentioned are discussed in the following paragraphs.

The frequency curve for the Bancroft station (fig. 17) is significantly affected by the May 1970 peak and, therefore, has a steeper slope and higher plotting position than would be expected in comparison with the Soldier station. The frequency curve for the Delia station is positioned in its entirety below the curve for the St. Clere station, which is located 22.6 river miles upstream. Comparison of numerous flood hydrographs for the St. Clere and Delia stations shows a marked difference in hydrograph shape (Carswell, 1978a). The peak segments of the hydrographs at St. Clere are generally "sharp" and of short duration; whereas, peak segments of the hydrographs at Delia are "broad" and of long duration. Peak-flow magnitudes at Delia are diminished, but volume of flow is not reduced (Jordan, 1977, p. 918). Some of the flood-peak attenuation in the reach from the St. Clere station to the Delia station probably is a result of overbank storage. In this reach, the stream has cut a relatively small channel into weathered bedrock. It is assumed that the dense vegetation of the banks has prevented the stream from widening to increase the channel capacity. The inability of the stream to deepen the channel and the effects of vegetation that prevent widening combine to promote overbank flow and storage.

Basin shape also affects the shape of the flood hydrograph. The width of Soldier Creek basin does not change appreciably in relation to length from the headwaters near Goff to the Delia station. A long, narrow basin will tend to produce a broad-crested hydrograph.

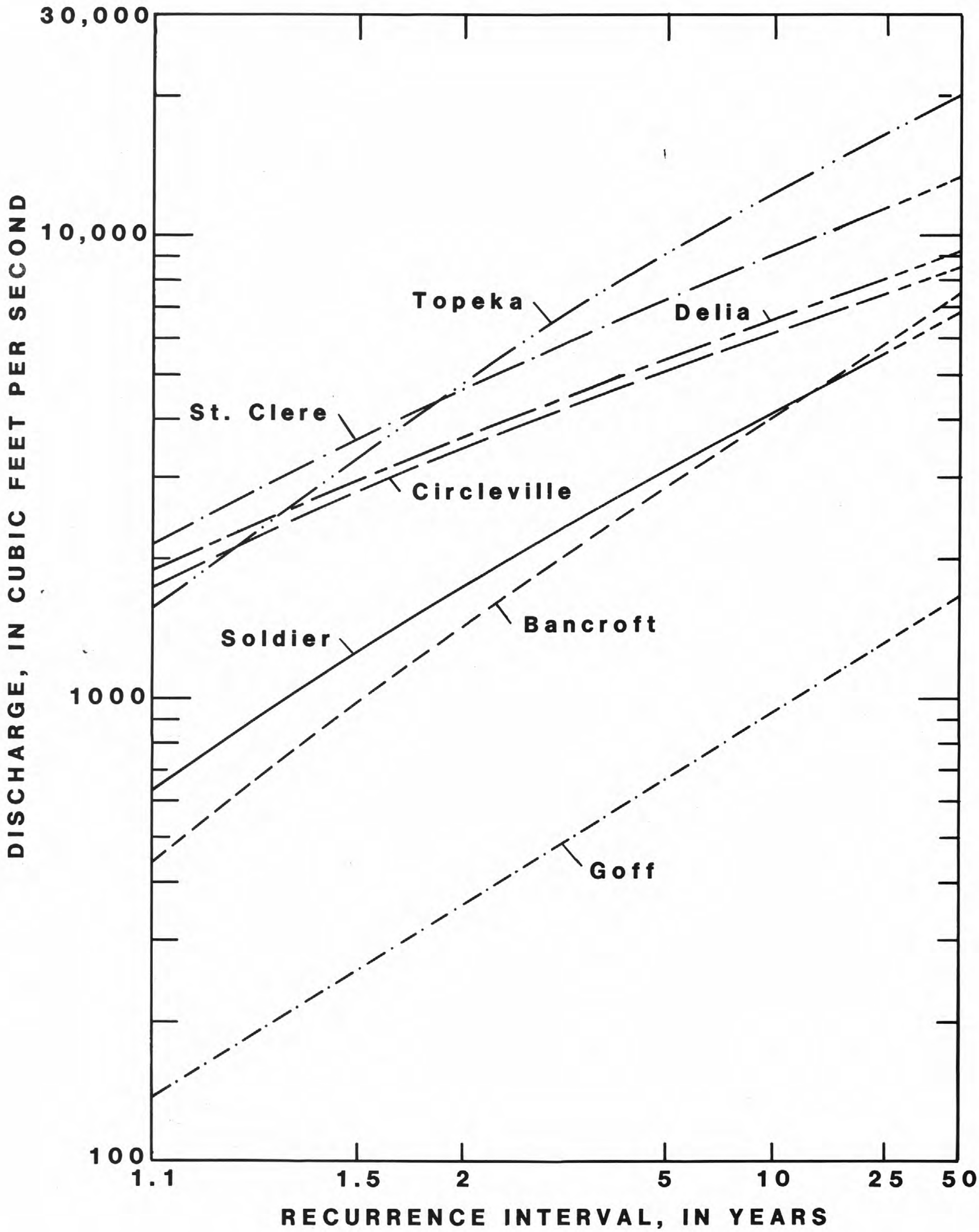


Figure 17.--Flood-frequency curves for period of record at streamflow-gaging stations in Soldier Creek basin.

The Topeka station has a much longer period of record (1930-32, 1936-76) than the other stations in the basin. Included in this longer period of record are the droughts of the 1930's and 1950's. The position of the lower end of the frequency curve for the Topeka station is affected by the drought-year peaks, which have not been included in the shorter period of record (1965-76) at the other stations. There is a marked difference between the frequency curves calculated for Soldier Creek near Topeka using annual peaks for the entire period of record versus the short period of record concurrent with the five upstream sites in the basin (see fig. 18).

Comparison of the frequency curves calculated from recorded data for each station in the basin with frequency curves calculated from statewide relations (Jordan and Irza, 1975), as shown in figure 19, shows a marked difference at most stations. Frequency curves from statewide relations have a much steeper slope (larger range in discharge from low to high recurrence intervals) than frequency curves from recorded data at the short-term record sites except for Bancroft (fig. 19). The probable explanation for this disparity is the absence of extremely low peaks in the short-term records.

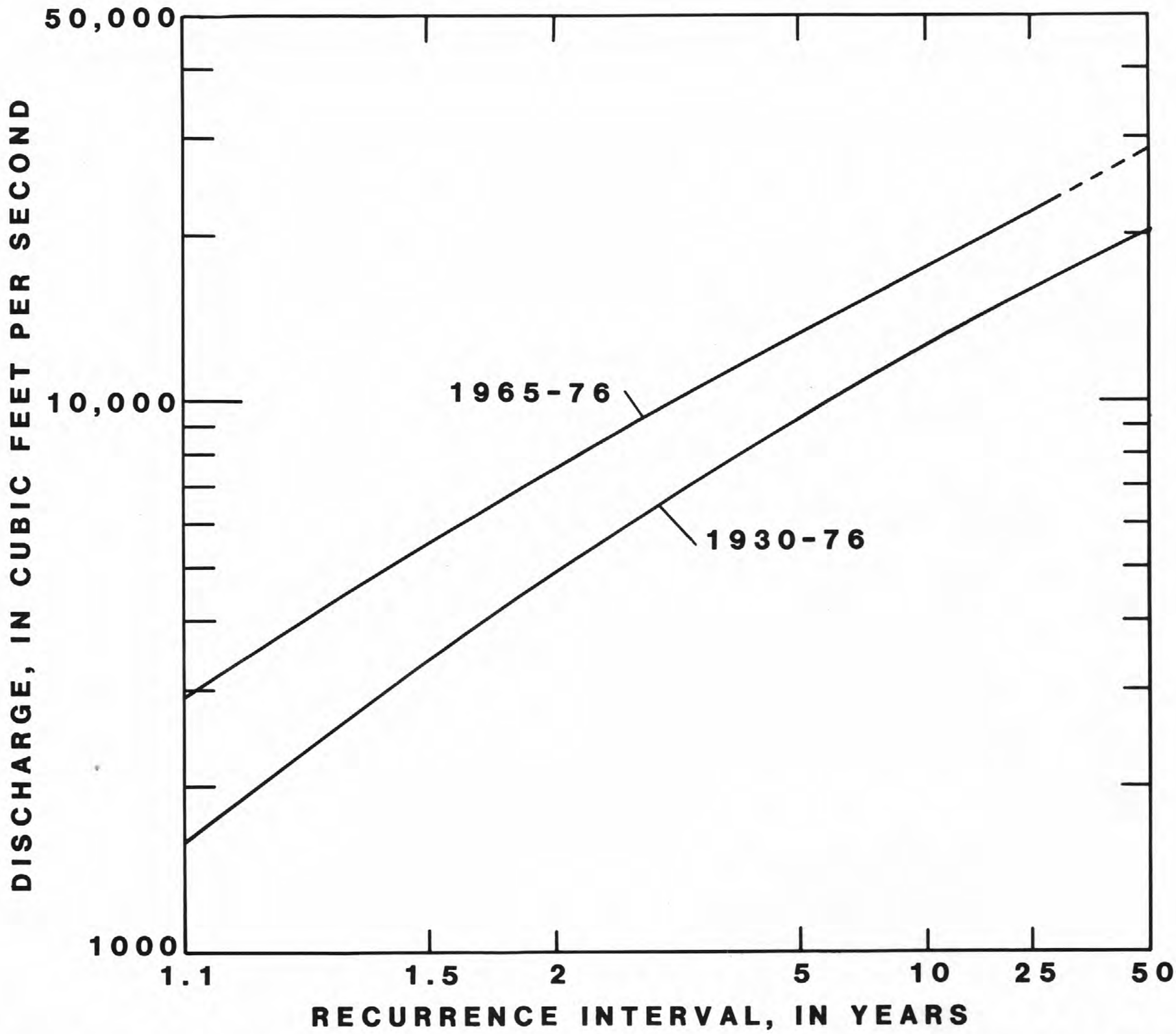


Figure 18.--Flood-frequency curves for Soldier Creek near Topeka using different periods of record.

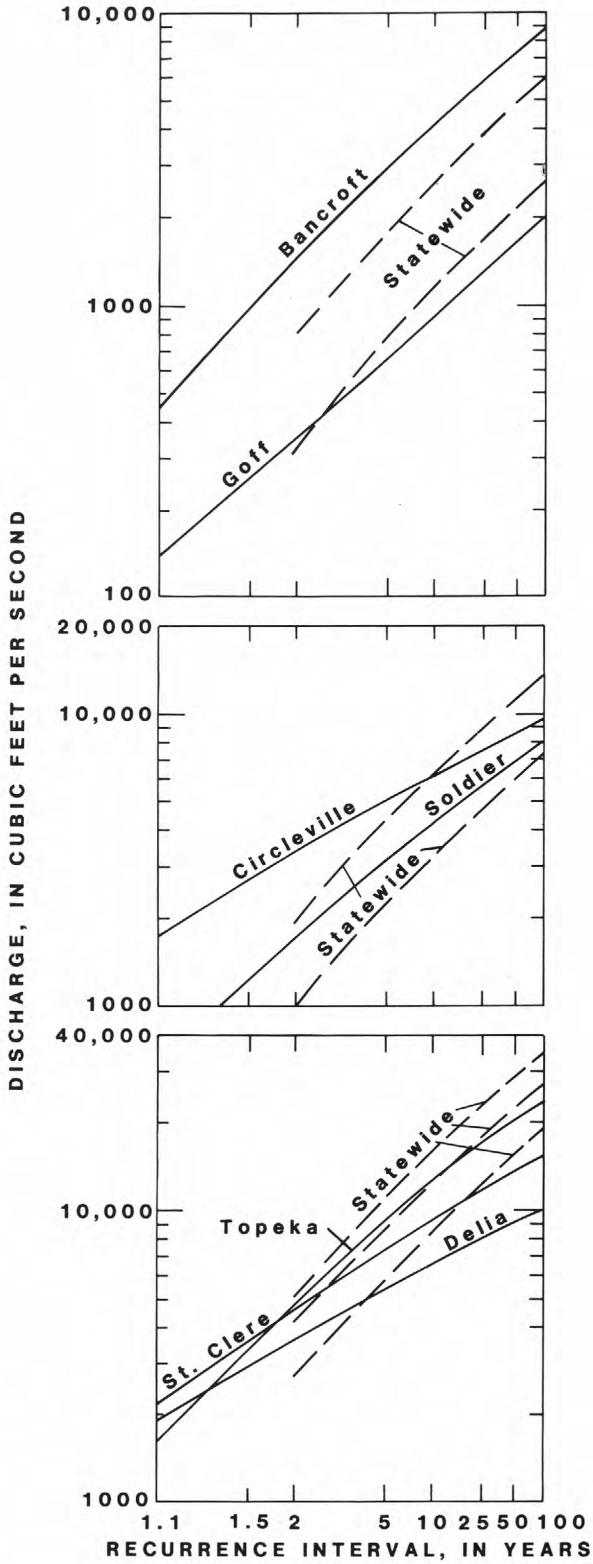


Figure 19.--Comparison of flood-frequency curves for Soldier Creek stations, calculated from observed records and estimated from statewide relations.

High-Flow Frequency

High-flow frequency curves depict the magnitude and frequency of natural flows expected to occur for specified numbers of consecutive days. High-flow frequency curves can be useful in water-resources planning and management. One example is the use of frequency-mass-curve analysis to determine storage requirements to control high flow.

The high-flow time periods used in this report are 24 hours and 1, 3, 7, 15, 30, 60, 90, 120, and 183 days. Gaging-station records for the basin were processed by digital computer to produce the highest average discharge for the selected consecutive time periods for each water year. The log-Pearson Type III distribution was used to provide high-flow frequency estimates at each station. All frequency computations were made by computer.

A tabulation of the high-flow frequency data for the period of record at each station is given in table 3. A comparison of the short-term record (1965-76) to that for 1930-76 for selected numbers of days at the Topeka station is shown in figure 20. If long-term records were available at the other stations in the basin, similar disparities probably would result.

Table 3.--Magnitude and frequency of annual maximum average flows for selected durations of consecutive time

[Flow values in cubic feet per second]

Duration (days)	Recurrence interval, in years				
	1.5	2	5	10	20
			GOFF, 1965-76		
24 hours	53	75	143	202	272
1	50	71	132	182	239
3	24	33	59	78	99
7	14	19	31	38	45
15	5.5	7.6	13	16	18
30	4.6	6.4	11	13	14
60	2.7	3.8	6.1	7.2	8.1
90	2.0	2.8	4.6	5.6	6.2
120	1.7	2.4	3.8	4.6	5.2
183	1.2	1.7	2.8	3.5	4.0

Table 3.--Magnitude and frequency of annual maximum average flows for selected durations of consecutive time--Continued

[Flow values in cubic feet per second]

Duration (days)	Recurrence interval, in years				
	1.5	2	5	10	20
			BANCROFT, 1965-76		
24 hours	248	338	569	710	858
1	220	300	480	590	685
3	104	143	240	305	355
7	58	78	130	158	180
15	36	51	78	89	95
30	24	33	50	56	59
60	14	19	30	34	37
90	11	15	24	27	29
120	8.4	12	20	24	26
183	5.8	8.4	15	18	21
			SOLDIER, 1965-76		
24 hours	365	520	875	1,060	1,190
1	315	445	725	860	940
3	154	217	365	438	490
7	85	122	197	225	242
15	53	73	110	118	123
30	33	48	73	82	87
60	19	28	44	49	53
90	15	21	34	39	43
120	13	18	30	34	37
183	9.1	13	21	26	30
			CIRCLEVILLE, 1965-76		
24 hours	1,180	1,580	2,600	3,200	3,650
1	1,030	1,450	2,150	2,420	2,520
3	540	760	1,230	1,450	1,610
7	290	390	610	705	770
15	170	225	350	405	442
30	115	158	244	280	305
60	70	97	145	168	180
90	55	73	110	130	142
120	43	59	97	115	128
183	31	43	73	88	103

Table 3.--Magnitude and frequency of annual maximum average flows for selected durations of consecutive time--Continued

[Flow values in cubic feet per second]

Duration (days)	Recurrence intervals, in years 1.5	2	5	10	20
	ST. CLERE, 1965-76				
24 hours	1,610	2,300	3,950	4,950	5,750
1	1,330	1,880	3,250	4,100	4,750
3	725	1,030	1,830	2,400	2,850
7	375	525	950	1,200	1,410
15	235	320	560	715	850
30	165	230	390	480	558
60	104	140	235	290	340
90	81	111	183	225	260
120	67	94	160	200	233
183	52	70	118	152	185
	DELIA, 1959-76				
24 hours	2,630	3,550	5,350	6,180	6,800
1	2,150	2,800	4,420	5,400	6,200
3	1,170	1,600	2,880	3,820	4,650
7	630	860	1,500	1,920	2,320
15	405	558	940	1,200	1,430
30	272	380	638	780	920
60	175	233	380	470	550
90	140	189	305	370	425
120	120	160	260	325	380
183	93	120	196	250	300

Duration (days)	Recurrence interval, in years 1.5	2	5	10	20	50
	TOPEKA, 1930-76					
24 hours	3,900	5,570	10,500	14,000	17,700	23,500
1	2,550	3,800	7,500	10,000	12,300	15,000
3	1,420	2,200	4,750	6,700	8,700	11,500
7	810	1,270	2,680	3,700	4,800	6,100
15	520	830	1,750	2,400	3,050	3,900
30	330	530	1,160	1,640	2,000	2,490
60	230	355	715	950	1,150	1,400
90	177	273	550	730	890	1,080
120	153	235	464	610	740	870
183	120	182	355	460	550	650

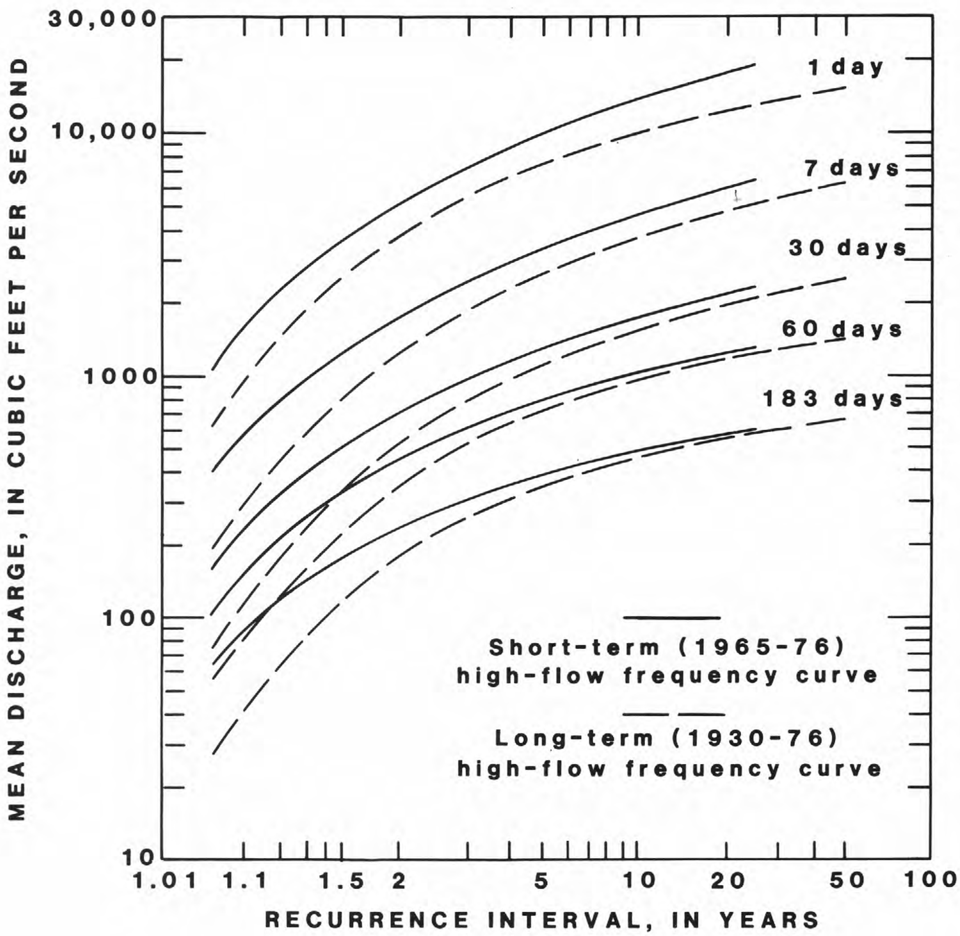


Figure 20.--Short-term and long-term high-flow frequency curves for indicated number of consecutive days for the Topeka station.

Maximum 24-hour discharge is always greater than or equal to the maximum mean daily discharge because the daily runoff hydrograph is split at midnight. Information on the maximum 24-hour discharge is useful for design of structures to contain high flow. The relation between maximum 24-hour and maximum mean daily discharge was developed for the basin by using regression techniques. A linear model for regression was achieved by transforming the flow to logarithmic equivalents. The equation obtained by using the yearly 24-hour and mean daily maximums at each station in the basin was

$$Q_{24\text{-hour maximum}} = 1.16\ Q_{1\text{-day maximum}}.$$

The standard error of estimate is less than 8 percent. Other variables tested in the equation (such as drainage area, length, and slope) were not statistically significant at the 5-percent level.

Natural water contains constituents dissolved from the rocks and minerals of the Earth's crust and from the atmosphere. The concentrations of these constituents vary in relation to factors such as water discharge and differences in geology. For a given stream, chemical quality may vary from one reach to another and within the same reach with time.

The station at Delia is the only site in Soldier Creek basin at which chemical-quality data were collected routinely. These data were collected monthly from November 1965 to September 1975 and are published annually (U.S. Geological Survey, 1966-75). As an additional aid to better define the general hydrologic framework, two seepage-salinity investigations were conducted throughout the basin on November 7, 1963, and July 22, 1964 (M. W. Busby and A. M. Diaz, U.S. Geological Survey, written commun., 1965). The data collected at Delia are sufficient to quantify the chemical characteristics of the water discharge at the Delia station. Also, the data from the two seepage-salinity investigations are sufficient to discuss low-flow chemical-quality characteristics for much of the basin.

Water samples obtained during the two seepage-salinity investigations provide data on the chemical quality of the water in the main stem and its principal tributaries. Main-stem sampling sites are shown in figure 21. Streamflow measurements were made at each site during both seepage-salinity investigations. A plot of the measured discharges by river mile is shown in figure 22. Data from 28 main-stem and 27 of 36 tributary sites were obtained to describe the water quality in the basin. Variations in the concentration of dissolved solids, sulfate, and chloride, and in discharge loads of each concentration are shown in figures 23-25.

Dissolved solids in the water of Soldier Creek are derived from solution of the limestones and shales in the basin. Bedrock exposures upstream from site R14 (fig. 21) are primarily of Permian age; whereas, exposures downstream from site R14 are of Pennsylvanian age. The valley of Soldier Creek is underlain by alluvium of Pleistocene to Holocene age. The large concentrations of dissolved solids and sulfates in the reach from sites R9 to R10 (fig. 23 and 24) probably were derived from solution of limestone and shale of the Council Grove Group of Permian age.

Composition of the dissolved solids in terms of cations and anions indicates that the predominant ions in the water during the surveys were calcium, bicarbonate, and sulfate. Increases in percentage of sulfate occurred locally in the main-stem reach between sites R9 and R10 (fig. 24). Tributaries sampled between sites R10 and R13 also contained large sulfate concentrations. Elsewhere in the basin, the inflow contained larger concentrations of bicarbondate than of sulfate. Sodium plus chloride concentrations generally were less than 15 percent of the total dissolved solids at all sites sampled during the seepage-salinity investigations.

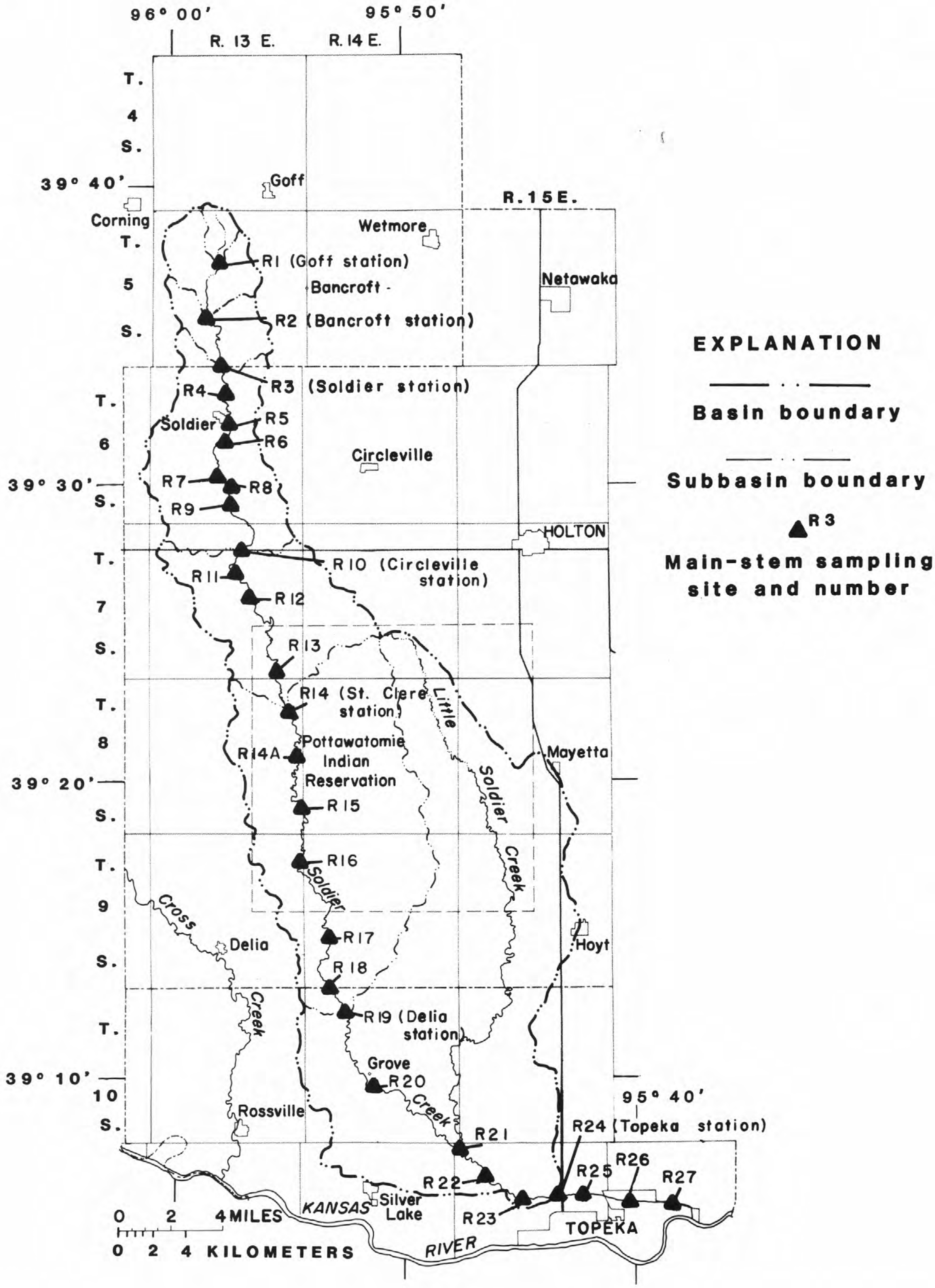


Figure 21.--Location of main-stem sampling sites for seepage-salinity investigations.

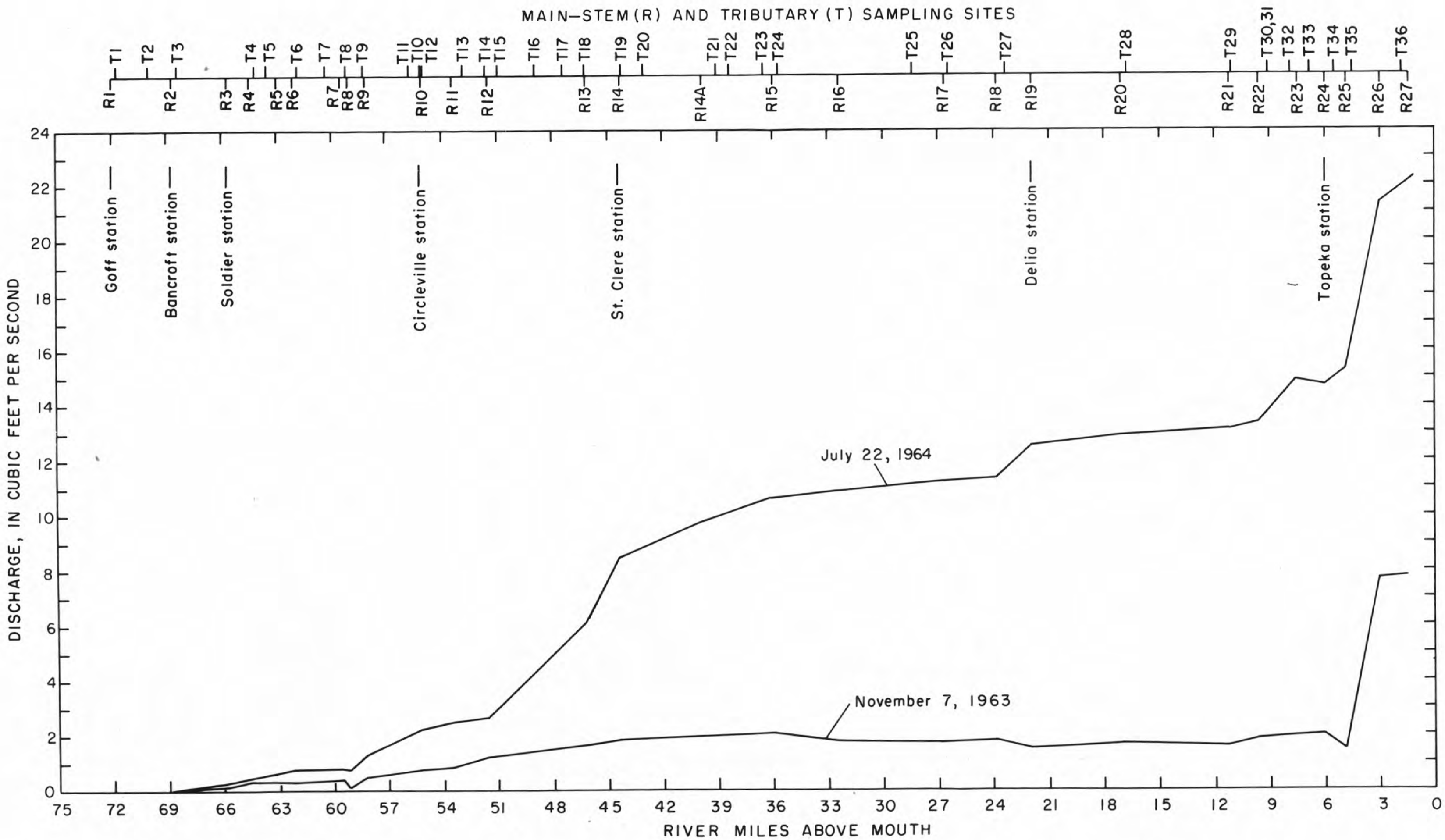


Figure 22.--Water discharges at main-stem sites along Soldier Creek.

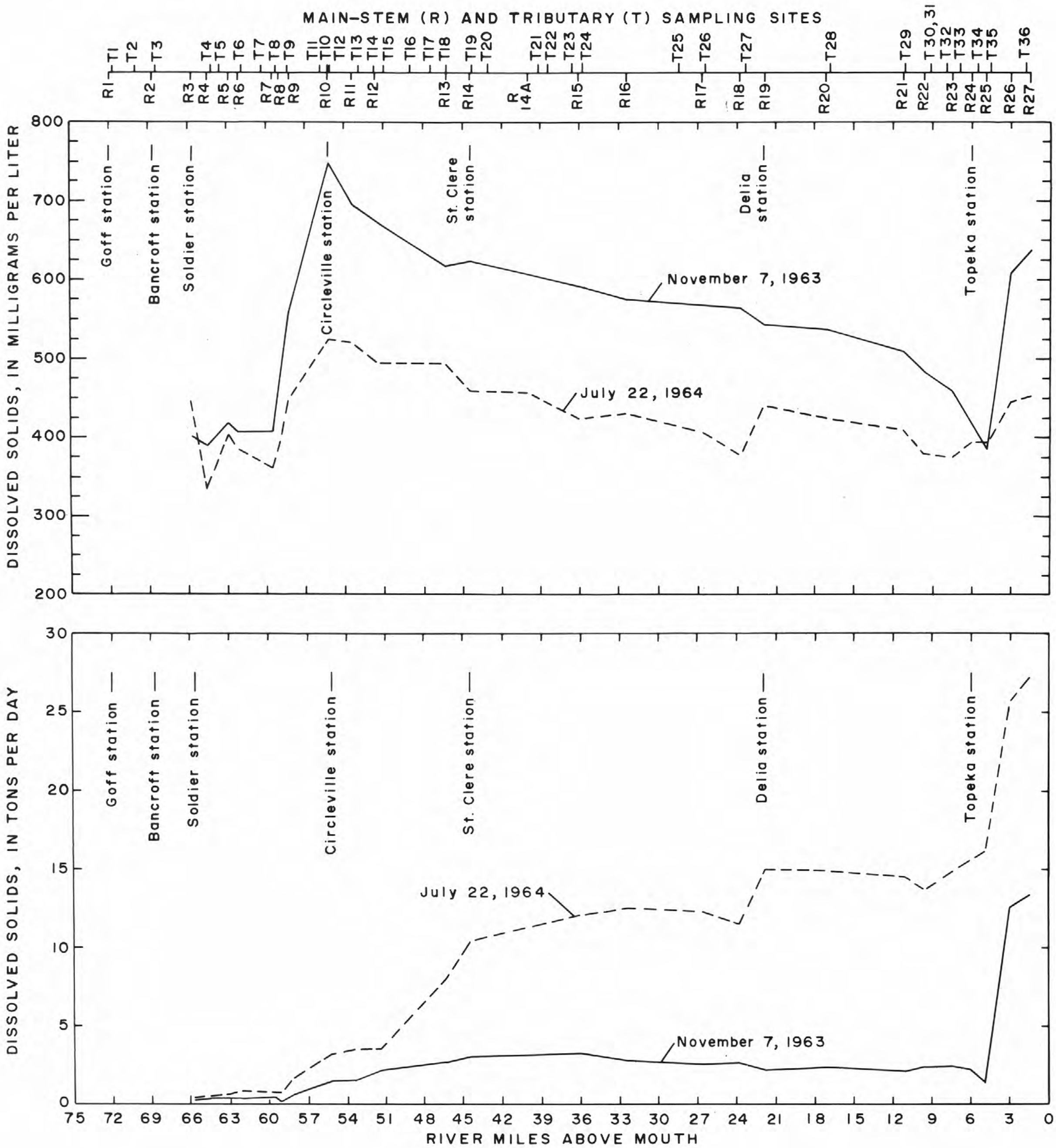


Figure 23.--Dissolved-solids concentrations and discharge loads at main-stem sites along Soldier Creek.

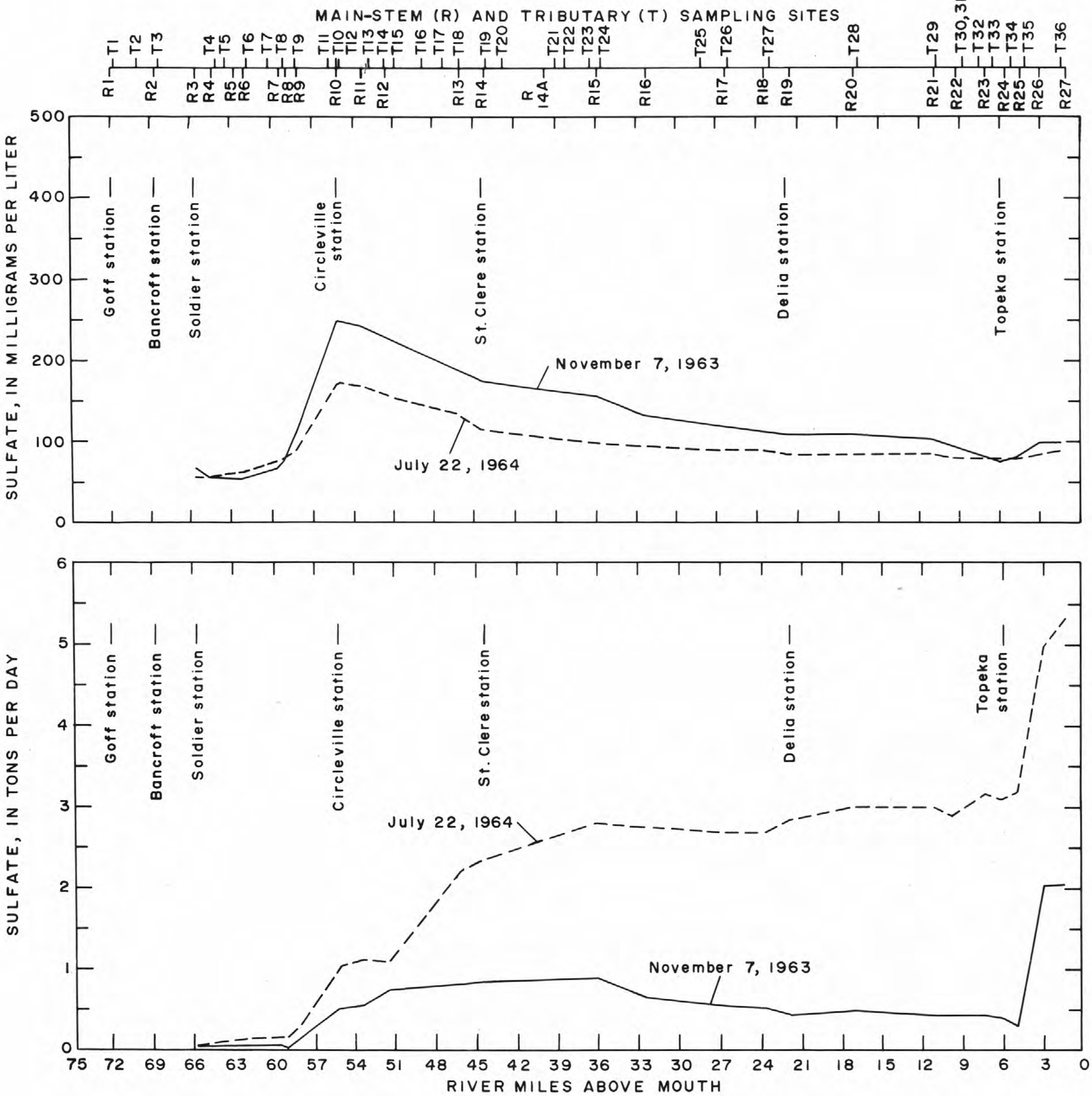


Figure 24.--Sulfate concentrations and discharge loads at main-stem sites along Soldier Creek.

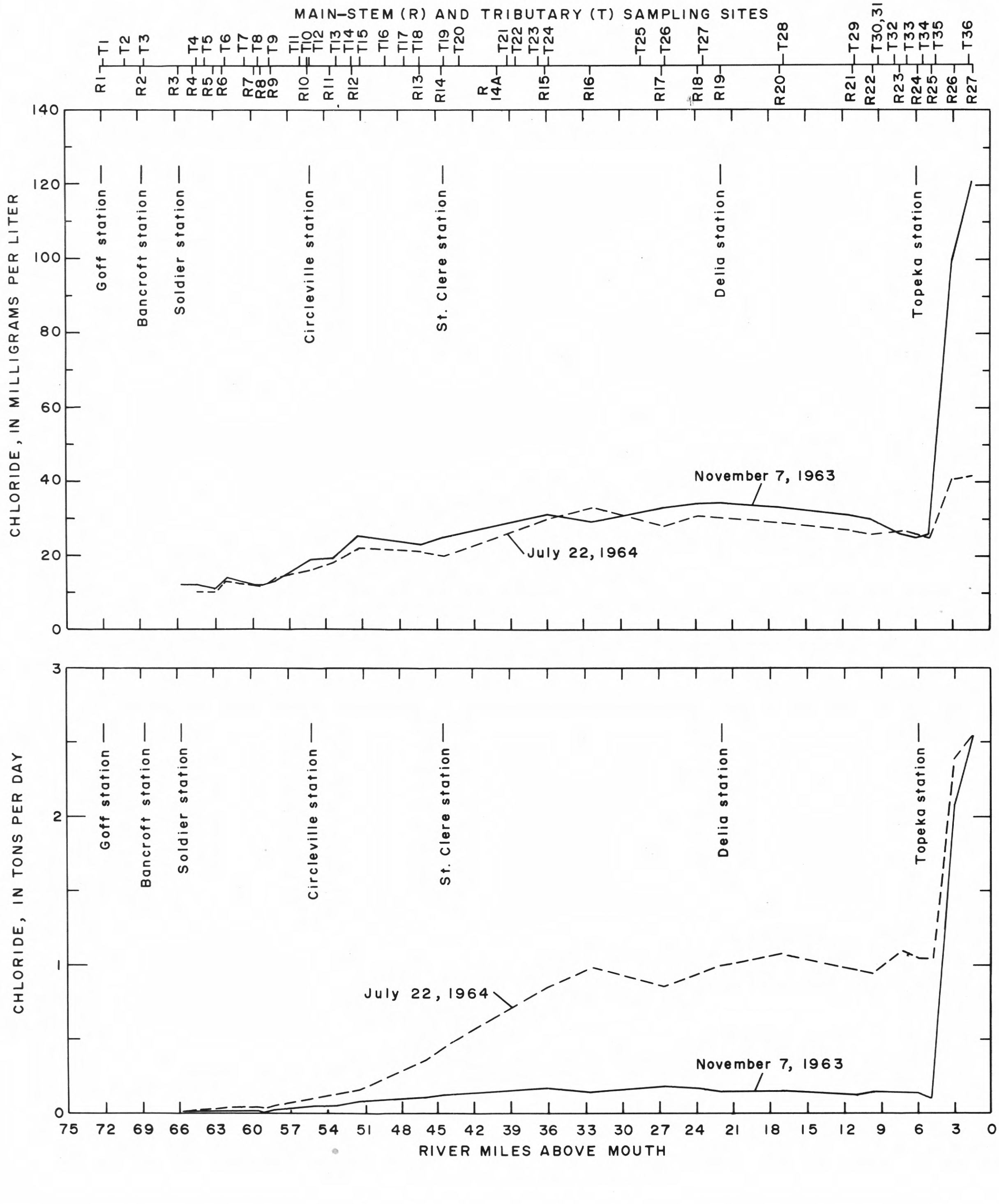


Figure 25.--Chloride concentrations and discharge loads at main-stem sites along Soldier Creek.

Losses in chemical-constituent loads during the 1963 survey at sites R8, R16, R17, R19, R21, R24, and R25 are shown in figures 23-25. Load losses for sulfates (fig. 24) probably were due to replacement of influent surface water that contained large sulfate concentrations by effluent ground water that contained dissolved solids of predominantly calcium and bicarbonate.

Loads of chemical constituents during the 1964 survey increased at all sites except R17, R18, and R22. Load losses shown at several sites were considered negligible because they were within allowable limits of accuracy of the discharge measurements and chemical analyses. Dissolved-solids concentrations of 500 milligrams per liter were exceeded only at sites R10 and R11 during 1964 (fig. 23). During the 1963 seepage investigation, dissolved-solids concentrations of 500 milligrams per liter were exceeded along the main stem at all points between sites R9 and R21.

Profiles of chemical constituent-concentration show the variations in chemical quality in the basin (fig. 23-25). Upstream from site R24, the concentrations shown are for chemical constituents reflecting natural conditions at base flow. Increases in dissolved-solids concentrations downstream from site R24 may have been a result of industrial-waste effluents.

Concentrations of dissolved solids were generally 10 to 25 percent less for the samples obtained during 1964 than for those obtained during 1963. Although the seepage-salinity investigations were conducted at times when surface inflow was considered negligible, the inverse change in chemical quality with an increase in discharge may indicate inflow of less-mineralized water from surface- or ground-water sources during the 1964 investigation. However, during the 1963 investigation, both discharge and dissolved-solids concentrations decreased between sites R15 and R21. These decreases indicate that water containing large concentrations of dissolved solids was being lost to the alluvium in some reaches and that ground water with small concentrations of dissolved solids was being contributed to the stream in other reaches.

The concentrations of dissolved constituents in the water at Delia were inversely related to the water discharge. However, the adequacy of the record for defining long-term quality in Soldier Creek basin may be subject to question. Comparison of the flow-duration curves for the short-term and long-term periods of record can give an indication of the adequacy of the chemical-quality record at Delia. The duration curves shown in figures 9 and 11 indicate that runoff during the period of record (1965-76) was greater than runoff during the long-term period (1930-76). Therefore, the long-term average concentrations of chemical constituents probably would be larger than the averages for the period of record.

Specific conductance is a physical property of water directly dependent on the amount of dissolved constituents. A comparison shows that the water discharge and the specific conductance of the water were inversely related at the Delia station (fig. 26) and elsewhere in the basin. In addition, specific conductance can be related to selected ions. The specific conductance of water at the Delia station also is related to the concentrations of principal chemical constituents, as shown in figure 27. The curves depicted in figure 27 are averages based on the results of chemical analyses for samples collected at the station (November 1965 to September 1975).

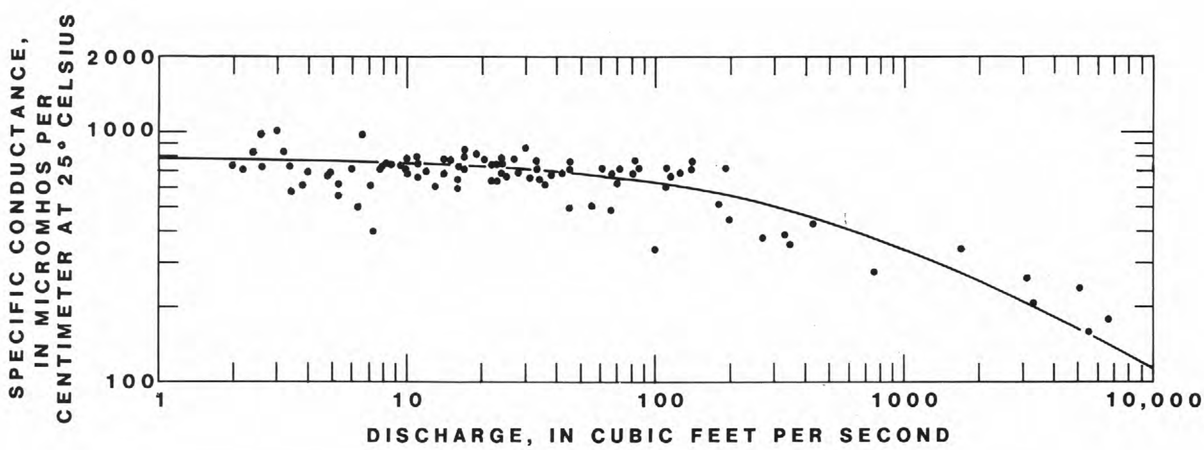


Figure 26.--Relation between water discharge and specific condutance at the Delia station, November 1965 to September 1975.

The relations of specific conductance to principal constituents (fig. 27) and to water discharges (fig. 26) provide a reasonably accurate means of computing the percentage of time that concentrations of specific constituents exceeded given amounts. A specific-conductance-duration curve is obtained by comparing data from the curve relating specific conductance to water discharge (fig. 26) with the Delia flow-duration curve (fig. 9). Discharge for a given percentage of time is used to obtain a specific-conductance value that is assumed to be for the same percentage of time. After numerous values have been obtained and plotted, a smooth curve can be fitted to the plotted values to obtain a specific-conductance-duration curve, as shown in figure 28.

In a similar manner, the specific-conductance-duration curve can be used to compute the percentage of time that the concentrations of the principal constituents and dissolved solids exceeded given concentrations. Results of the computations are given in table 4. The maximum and minimum concentrations are shown for each chemical constituent.

FLUVIAL SEDIMENT

The sediment present in all streams results from weathering of rocks and soils in the watershed. Many factors such as climate, topography, soil, land use, and vegetation cover affect the availability of sediment in a stream. Some of the most erodible soils in Kansas are found in the glacial-till and loess areas of the northeastern part of the State. Collins (1965) found that these highly erodible soils combined with high runoff to give some of the highest sediment yields in the State. Soldier Creek is located in an area where Collins estimated, based on limited data, that the sediment yield would range from 2,000 to 5,000 tons per square mile per year.

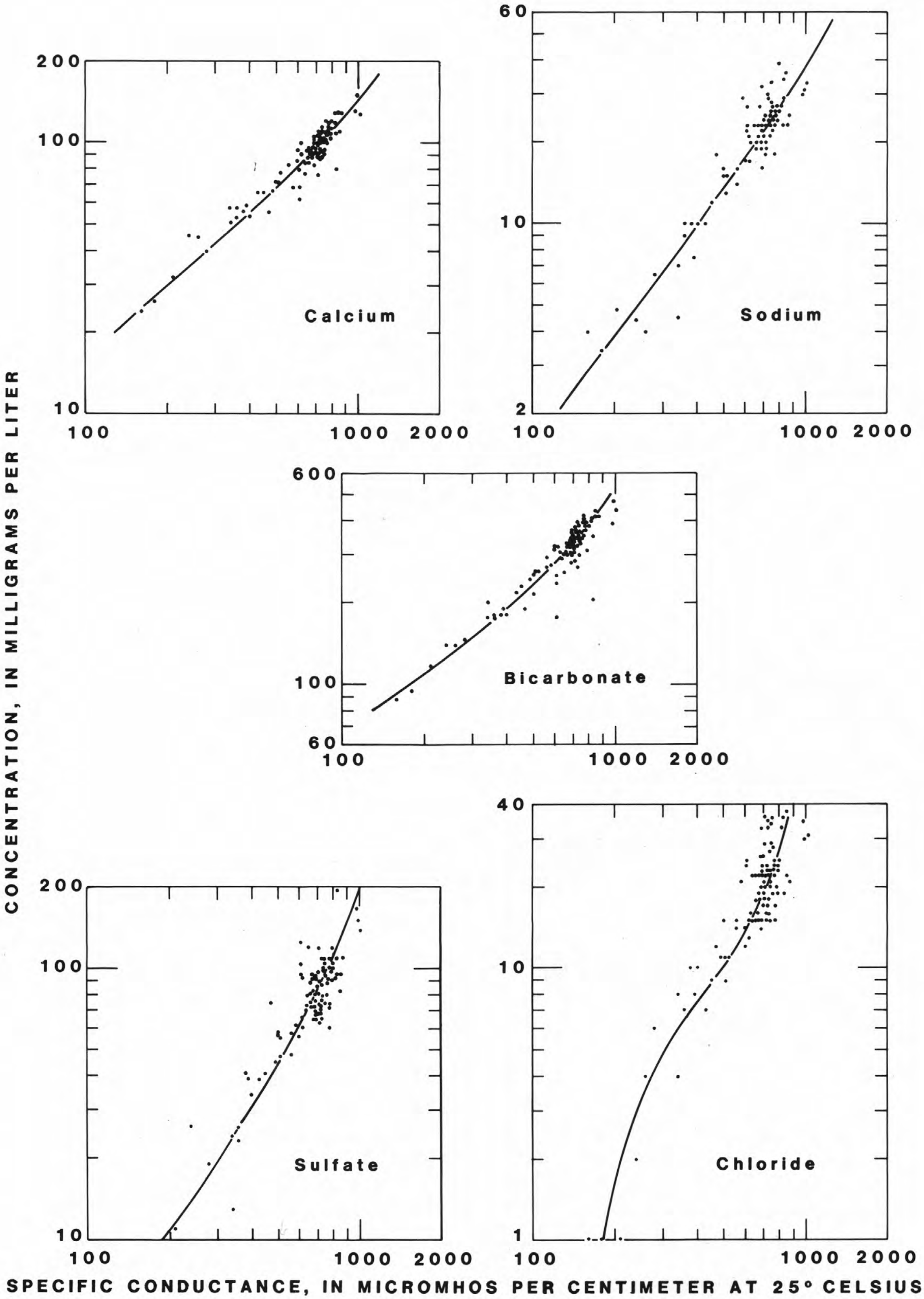


Figure 27.--Relations between specific conductance and concentrations of principal chemical constituents at the Delia station, November 1965 to September 1975.

Table 4.--Concentration-duration data for dissolved solids and principal chemical constituents in water at the Delia station

Constituent	Concentration (milligrams per liter)		Percentage of time constituent exceeded concentration indicated											
			Concentration, in milligrams per liter											
	Minimum	Maximum	5	10	25	50	100	150	200	250	300	350	400	500
			Percentage											
Calcium (Ca)	24	150	--	100	99.9	99	47	0	--	--	--	--	--	--
Sodium (Na)	3.4	39	99	97	20	0	--	--	--	--	--	--	--	--
Bicarbonate (HCO_3)	88	476	--	--	--	100	99.9	98	96	92	83	42	1	0
Sulfate (SO_4)	4.2	196	> 99.9	99.9	98	93	22	0.1	0	--	--	--	--	--
Chloride (Cl)	1.0	38	98	94	4	0	--	--	--	--	--	--	--	--
Dissolved solids	114	668	--	--	--	--	100	99.9	99	97	95	93	87	9
Hardness as $CaCO_3$	72	520	--	--	--	100	99.9	99	97	94	87	57	0.5	< 0.1

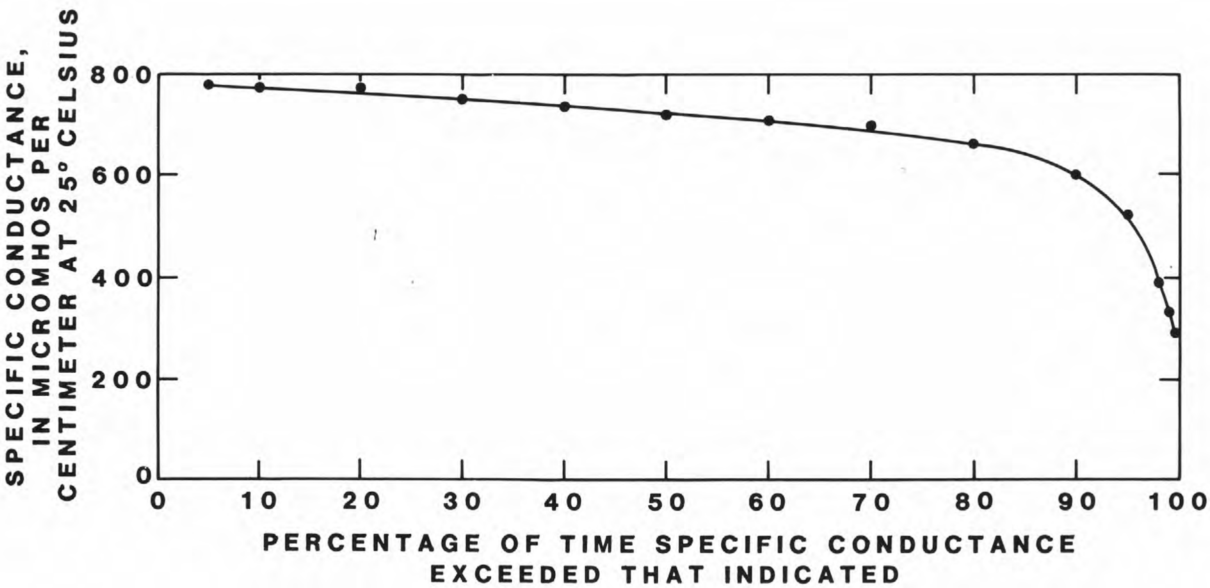


Figure 28.--Specific-conductance-duration curve for the Delia station.

The capacity of a stream to transport sediment depends upon the hydraulic characteristics of the stream. These characteristics are slope, roughness, hydraulic radius, discharge, velocity, velocity distribution, turbulence, tractive force, viscosity and density of the fluid-sediment mixture, and size and gradation of the sediment.

Suspended-Sediment Discharge

The suspended-sediment sampler used to collect water-sediment mixture in the basin samples the zone from the water surface to within about 0.4 foot above the bed. Therefore, only a part of the total sediment discharge is measured. The unmeasured part of the sediment discharge, which includes the bedload and that part of the suspended sediment below the lowest point sampled, may or may not be a significant amount of the total. This section discusses only the sampled (measured) suspended-sediment discharge; the unmeasured sediment discharge will be discussed in a subsequent section.

Suspended-sediment samples generally were collected at all stations in the basin, except for the Topeka station, during each water-discharge measurement. However, base-flow samples that contained no visible suspended material were not analyzed.

Although suspended-sediment discharge is extremely variable with time, relations between infrequent samples and water discharges can be considered as representative of average conditions. These average conditions for the period of record at each station were determined by correlating sediment discharges with water discharges for which the frequency distributions were known (see flow-duration curves, fig. 9). An example of the correlation between suspended-sediment discharge and water discharge is shown in figure 29.

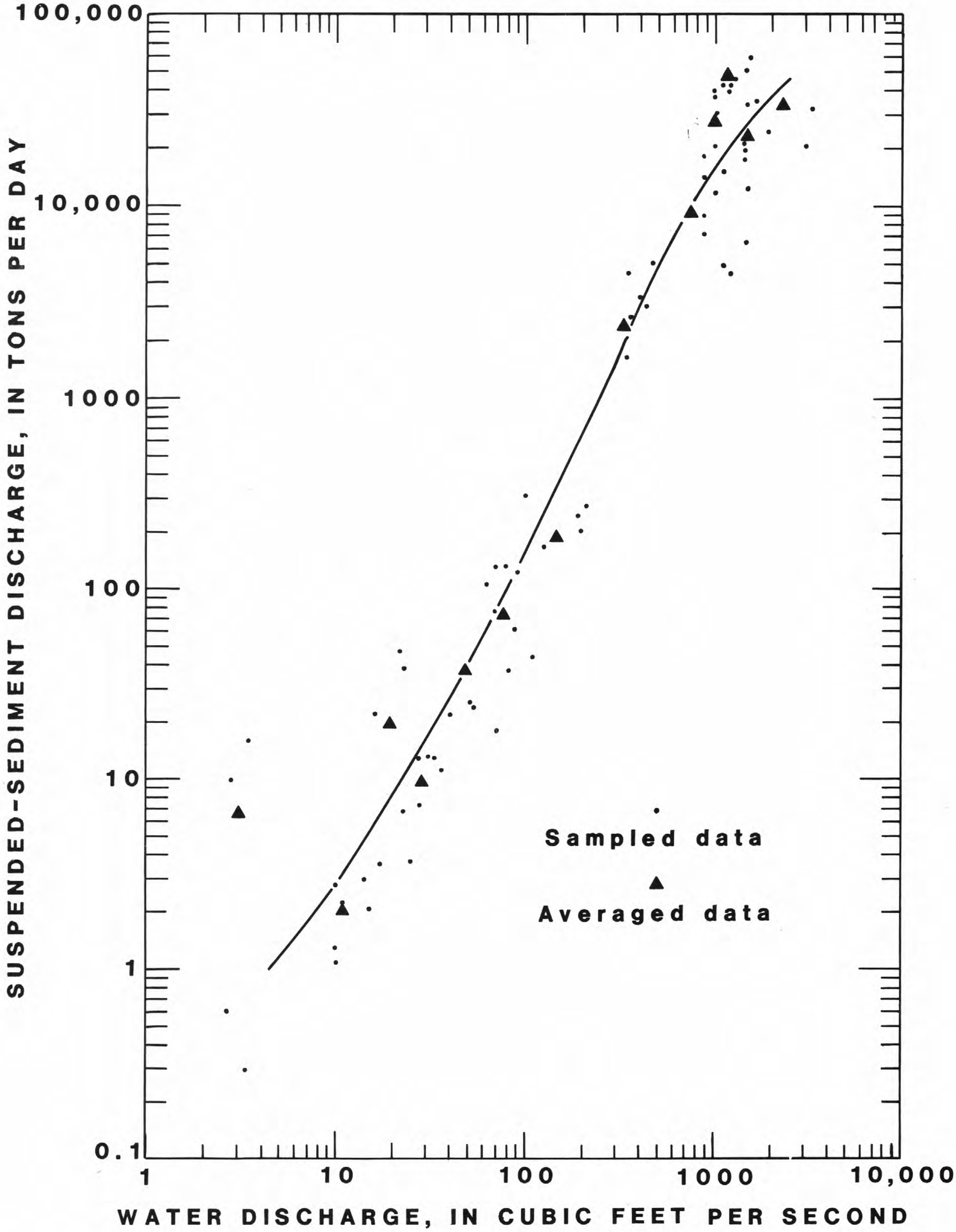


Figure 29.--Relation of water discharge to suspended-sediment discharge at the Delia station (1966-75).

The method used to compute averages of suspended-sediment discharges (Jordan, Jones, and Petri, 1964) was as follows: (1) Discharge values, such as those shown in figure 29, were grouped into several ranges of magnitude; (2) the computed arithmetic average for each range was plotted on the graph; (3) curves were drawn to best fit the points representing the arithmetic average, as shown in figure 29; and (4) the water discharges computed from the flow-duration curves (fig. 9) were used to determine the corresponding sediment discharge indicated from the curve in figure 29. 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. The appropriate average sediment discharge was multiplied by the length of each respective time interval, which was expressed as a percentage of the total time; these products were summed and divided by 100 to give the average suspended-sediment discharge, in tons per day. An example of the computational results, is given in table 5, and the average sediment discharges and concentrations for the period of record at each gaging station are given in table 6.

Because the results of these computations are based on limited suspended-sediment data, the calculated annual load at the Delia station was compared to the results obtained by the U.S. Army Corps of Engineers. Based on daily observer sediment data, the Corps of Engineers determined an annual suspended-sediment yield of 1,520 tons per square mile per year (U.S. Army Corps of Engineers, Kansas City, Mo., oral commun., 1979). The amount cited is for the water years 1959-72 and includes only sampled suspended sediment. The Corps' average annual yield at the Delia station compares well with the calculated value of 1,970 tons per square mile per year because the extremely high water discharge that occurred during 1973 (see section on "Average Discharge") would have increased significantly the sediment yield from the basin.

A sediment concentration can be calculated for each percentage of time for each station listed by using data similar to that given in table 5. This concentration is then plotted against the percentage of time, as shown in figure 30. The resulting curves reflect only average conditions for the period of record at each site and are not necessarily indicative of long-term conditions.

A significant increase in suspended-sediment discharge occurred in the reach between the Soldier and Circleville stations (fig. 31). The increase in average basin hillside slope is the most likely reason for the increased sediment yield between the Soldier and Circleville stations. However, differences in land-use practices upstream from the stations also may contribute to the increase. Terracing of a substantial part of the farmland upstream from the Soldier station could reduce sheet, rill, and gully erosion. Rock quarries located upstream from the Circleville station could be a source of some of the suspended sediment. However, based on site inspection of these quarries, it was concluded that the sediment contribution to the stream from this source would be negligible.

Table 5.--Computation of average suspended-sediment discharge, Soldier Creek near Delia

Percentage of time	Water discharge equaled or exceeded (cubic feet per second)	Suspended-sediment discharge (tons per day)	Interval between succeeding percentages of time	Average suspended-sediment discharge for time interval (tons per day)	Suspended-sediment discharge multiplied by time interval
0	6,340	100,000	0.1	84,000	8,400
0.1	3,780	68,000	.1	61,500	6,150
.2	2,950	55,000	.1	50,800	5,080
.3	2,500	46,500	.1	43,800	4,380
.4	2,200	41,000	.1	39,200	3,920
.5	2,000	37,400	.2	34,300	6,860
.7	1,700	31,200	.3	28,000	8,400
1.0	1,380	24,700	.4	21,500	8,600
1.4	1,110	18,200	.6	15,600	9,360
2	880	13,000	1.0	9,600	9,600
3	565	6,200	2	3,860	7,720
5	295	1,520	2	1,090	2,180
7	200	650	3	470	1,410
10	137	295	5	220	1,100
15	95	140	5	110	550
20	70	76	10	53	530
30	43	30	10	23	230
40	30	16	10	12	120
50	21	8.6	10	6.8	68
60	15	5.0	10	4.0	40
70	10	3.0	30	1.6	48
100	0.02	0.1			
	TOTAL		100		84,746

Average suspended-sediment discharge:
- Tons per day 848
- Tons per year 310,000
- Tons per square mile per year .. 1,970

Table 6.--Average suspended-sediment discharge and concentration for stations in Soldier Creek basin

Station	Suspended sediment		
	Discharge		Discharge--weighted average concentration (milligrams per liter)
	Tons per day	Tons per square mile per year	
Goff	9.94	1,762	3,150
Bancroft	47.6	1,650	2,990
Soldier	65.3	1,410	2,680
Circleville	420	3,110	5,140
St. Clere	565	2,580	4,110
Delia	848	1,970	3,530

Particle Size of Suspended Sediment

The particle-size distribution of suspended sediment in a stream can differ due to numerous factors, including time of year, length of time after rain, source of sediment, concentration, and water discharge. Weighted averages can be used to represent the particle-size distribution that would exist if all the suspended-sediment discharge for several years were collected in one place and thoroughly mixed. These weighted-average, percent-finer values are obtained by using the suspended-sediment discharge as the weighting factor.

If the percent-finer values are not correlated with suspended-sediment discharge, a simple unweighted average of the percent-finer values will be as representative as a weighted average. The percent-finer values were correlated with suspended-sediment discharge for the Goff through Delia stations, but the correlations were found to be extremely low. Therefore, an unweighted average was used to characterize the average particle-size distribution of suspended sediment at each gaged site. Only the analyses in distilled water with chemical dispersion were used in the computations so that the data would be consistent. The results of the computations are shown in figure 32.

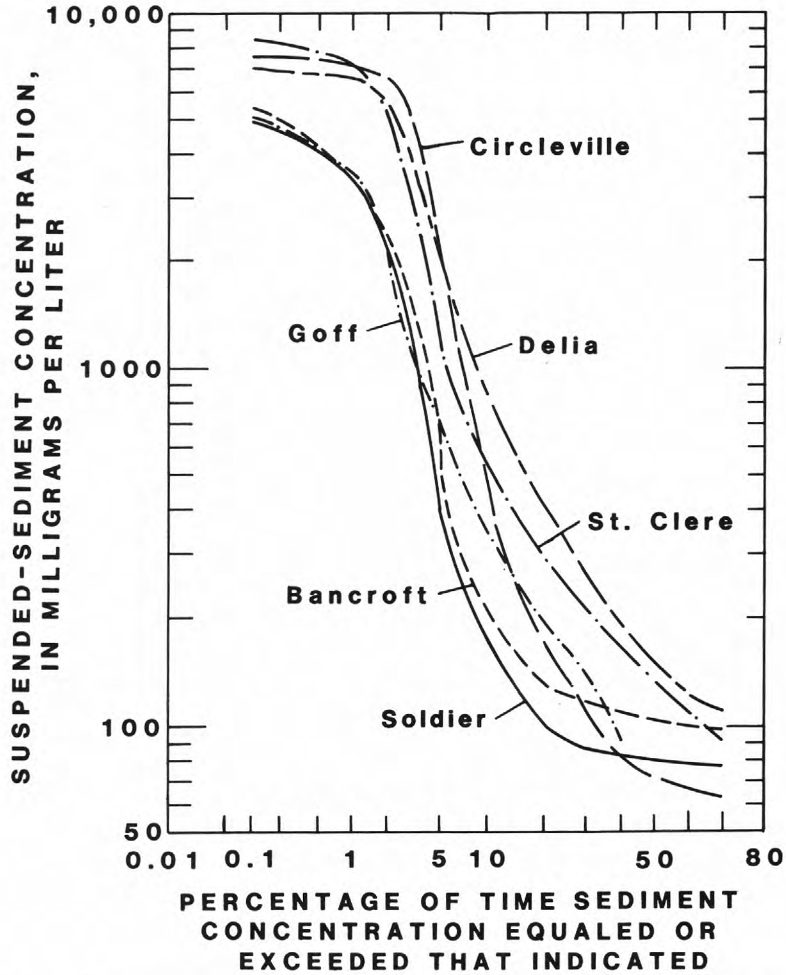


Figure 30.--Suspended-sediment concentration-duration curves for stations in Soldier Creek basin (1966-75).

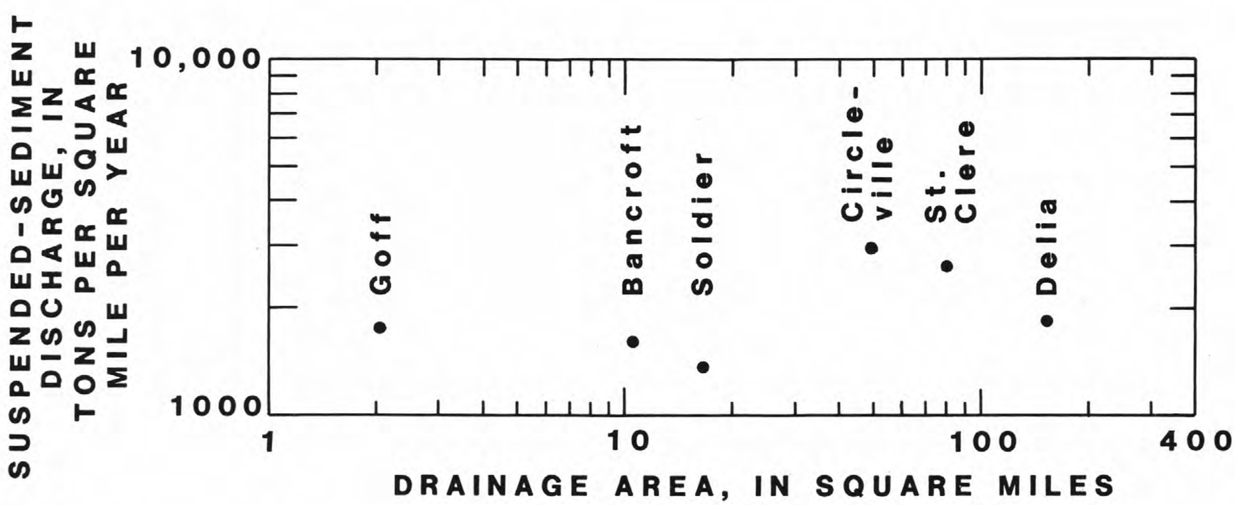


Figure 31.--Relation of drainage area to suspended-sediment discharge in Soldier Creek basin (1966-75).

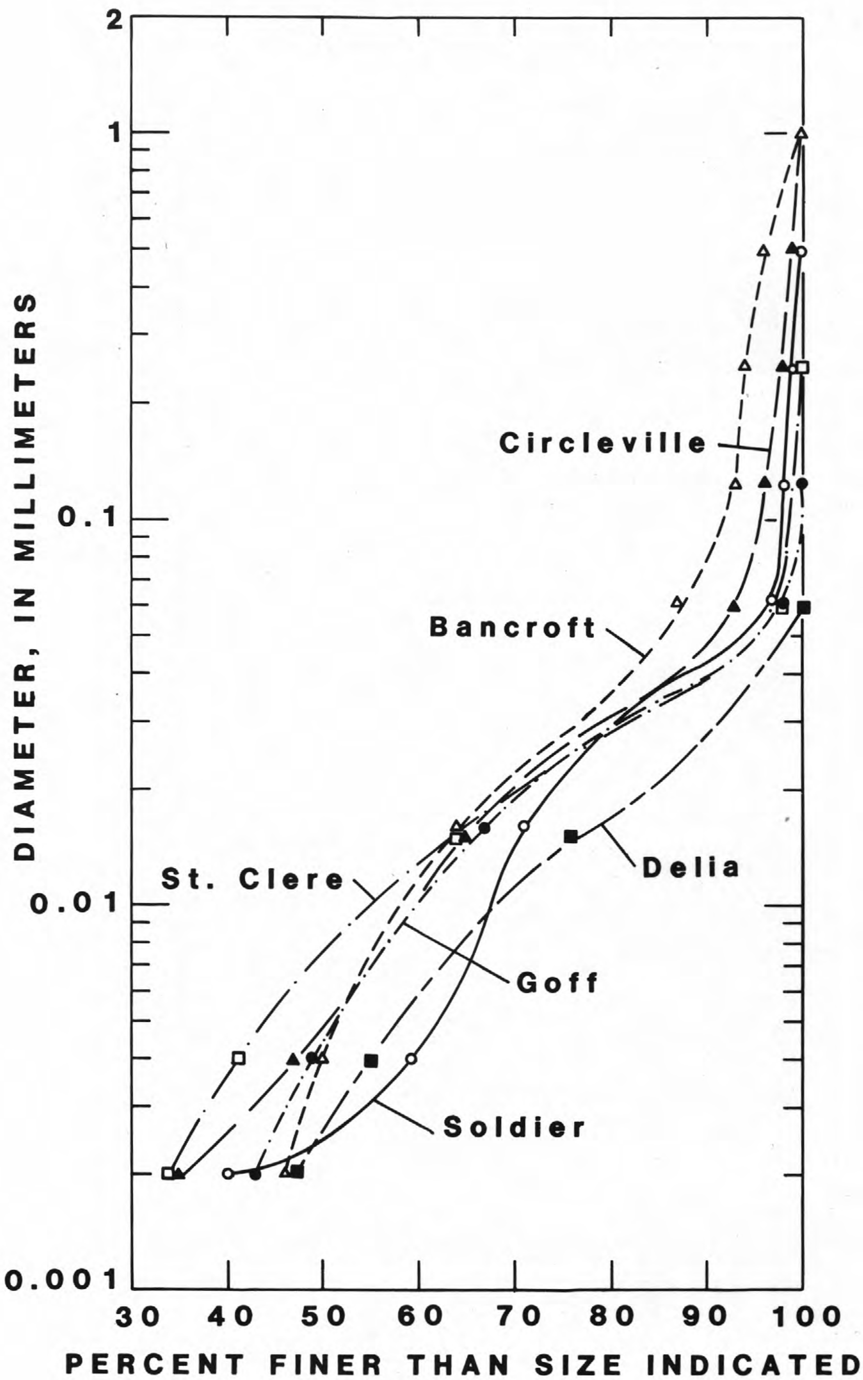


Figure 32.--Average particle-size distributions of suspended sediment for stations in Soldier Creek basin.

The average clay content (finer than 0.004 millimeter) of the suspended sediment at all sites ranged from 41 percent at the St. Clere station to 59 percent at the Soldier station, and the average silt content (0.004 to 0.062 millimeter) ranged from 37 percent at the Bancroft station to 57 percent at the St. Clere station. Approximately 3 percent of the suspended sediment was sand (coarser than 0.062 millimeter) at the Goff, Soldier, and St. Clere stations; whereas 7 percent was sand at the Circleville station, and 13 percent was sand at the Bancroft station. The presence of sand in the suspended sediment at the Delia station was negligible.

Bed and Bank Material

Because very few bed and bank samples were collected at each station, a simple average of percent-finer values was used to determine the average size distributions for both the bed and bank material. These data should not be considered totally representative of bed-material conditions for the entire period of record at each station. The limited data, however, may be considered an indicator of general bed-material conditions at each station. The bank-material samples are representative of bank conditions present in the reach near each station at the time of the sample. Particle-size distributions of both bed and bank material at each site are shown in figures 33-35.

Bank samples shown in these figures were collected from that part of the bank that comprises the active channel. The active channel is defined by Hedman, Kastner, and Hejl (1974, p. 3) as: "...the lower part of the flood plain that is actively involved in the transportation of water and sediment during the usual regime of a stream." These samples from the active-channel bank were collected in the manner described by Osterkamp (1979).

Osterkamp (1980) hypothesized that the lack of medium grain sizes increases the stability of the active-channel banks. This hypothesis is borne out at the Goff, St. Clere, and Delia stations, although the extreme floods during 1970, 1973, and 1977 may have widened, to some degree, the distance between the active-channel banks at all gaged sites.

Unmeasured Sediment Discharge

In most streams, the suspended-sediment concentration varies in a vertical direction. The maximum concentration is at the bed, and the minimum concentration is at or near the water surface. Sand and coarser particles commonly are found in suspension near the bed rather than near the surface. Because the concentration of sand and coarse particles is greatest in the unsampled zone near the bed, the sediment concentration from depth-integrated samples generally is less than the mean concentration in the total depth.

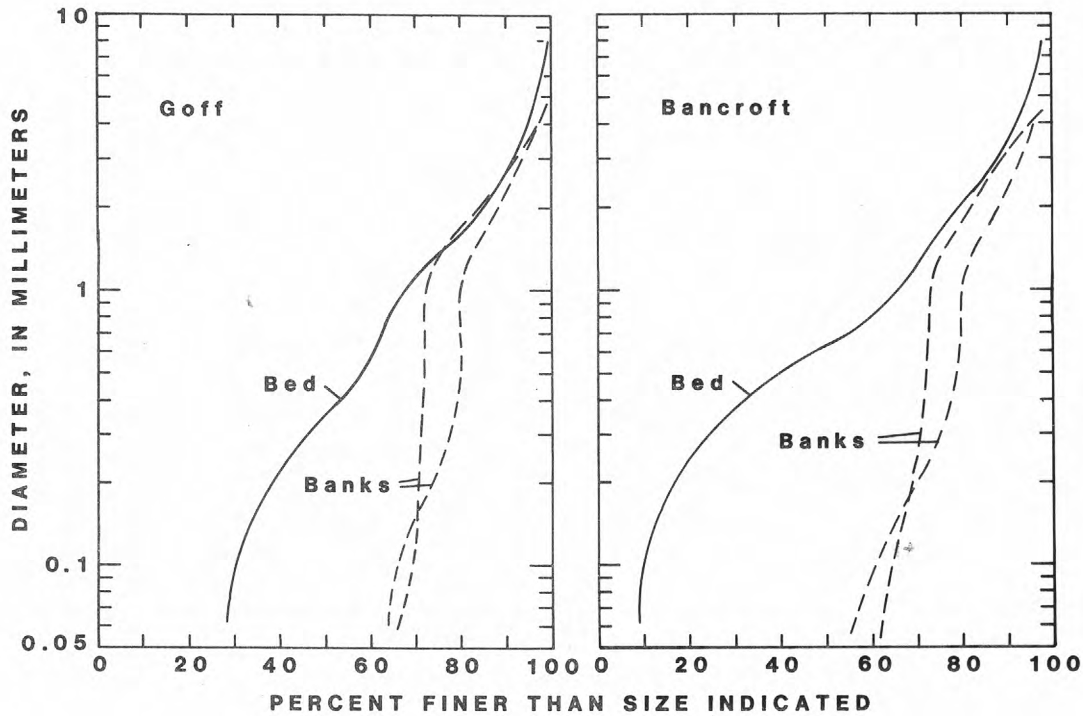


Figure 33.--Particle-size distribution of bed and bank material at the Goff and Bancroft stations.

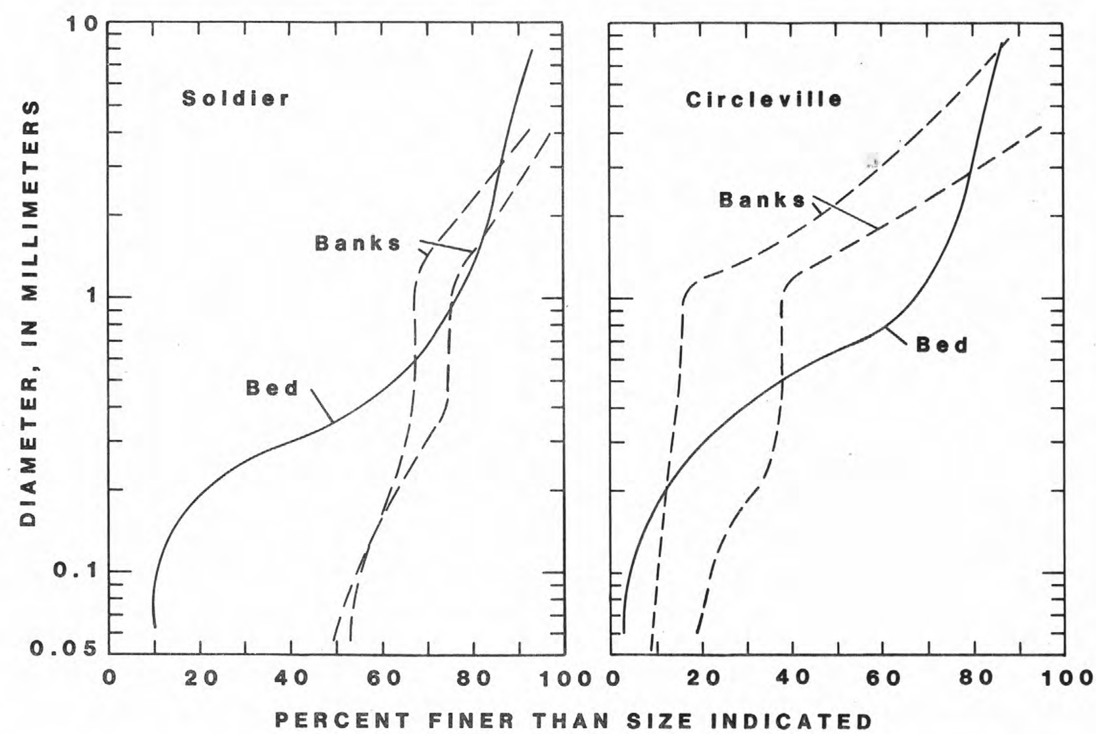


Figure 34.--Particle-size distribution of bed and bank material at the Soldier and Circleville stations.

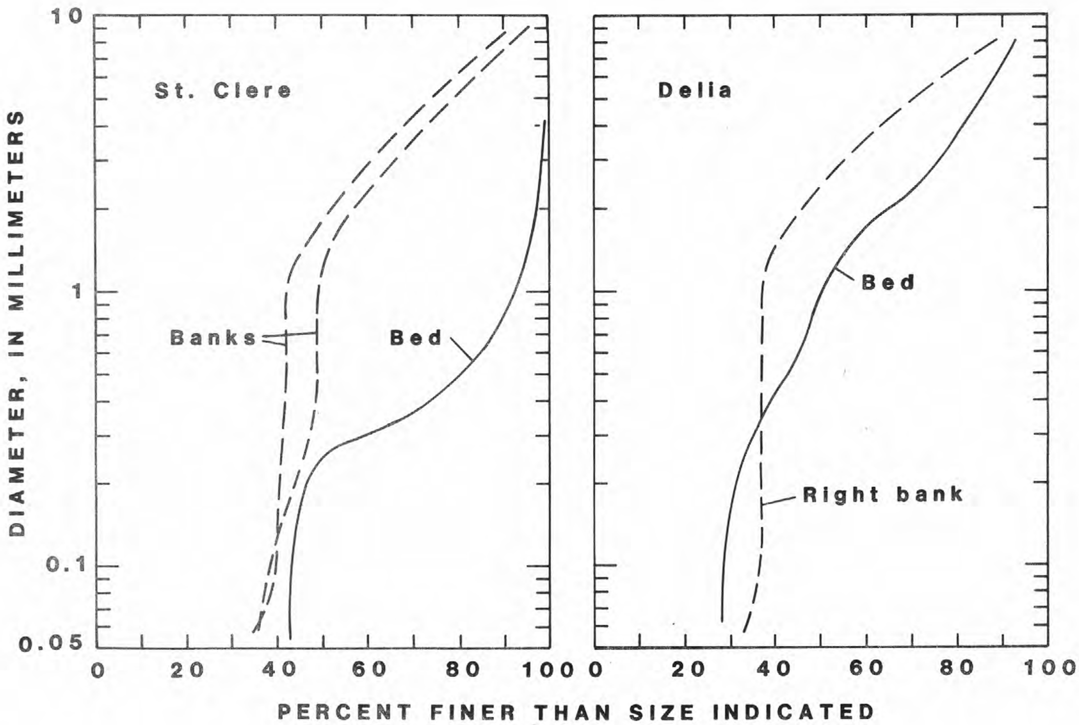


Figure 35.--Particle-size distribution of bed and bank material at the St. Clere and Delia stations.

The measured suspended-sediment discharge is computed by multiplying the concentration determined from depth-integrated or single-stage sediment sample by the water discharge for the entire depth and an appropriate unit-conversion factor. Because the water discharge includes the entire depth, the measured suspended-sediment discharge determined in this manner includes all of the suspended-sediment discharge in the sampled zone and part of the suspended-sediment discharge in the unsampled zone.

The sediment discharge not computed as measured suspended-sediment discharge is called unmeasured sediment discharge. 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 all comprise the unmeasured sediment discharge. The unmeasured sediment discharge is composed principally of sand or coarser particles. The unmeasured sediment discharge may or may not be a significant part of the total sediment discharge.

The unmeasured sediment discharges were computed for each gaging station using the method presented by Colby (1964). The Colby method requires the following data: Mean velocity, mean depth, median size of bed material, water temperature, and fine-sediment concentration. The computational procedure was modified by using long-term averages for median size of bed material and fine-sediment concentration along with mean velocity, mean depth, and water temperature of selected discharge measurements. Long-term averages were used for median size of bed material and fine-sediment concentration because bed-material samples were not taken at the time of the depth-integrated, suspended-sediment samples. The method used to compute averages of unmeasured sediment discharge was the same as that used for computing averages of suspended-sediment discharges. The resulting average unmeasured sediment discharge, total sediment discharge, and percentage of unmeasured sediment discharge to total suspended-sediment discharge are shown in table 7.

The data available for calculation of unmeasured sediment discharge are less than ideal. The lack of data has prescribed the manner in which the calculations have been made. Due to the lack of data, the values for unmeasured sediment discharge are estimates.

Table 7.--Estimated average unmeasured and total sediment discharge at six streamflow-gaging stations

	Tons per day			
Station	Unmeasured sediment discharge	Measured sediment discharge	Total sediment discharge	Percentage of unmeasured sediment discharge to total sediment discharge
Goff	1.62	9.94	11.6	14.0
Bancroft	0.68	47.6	48.3	1.4
Soldier	6.82	65.3	72.1	9.5
Circleville	2.95	420	423	0.7
St. Clere	46.2	565	611	7.6
Delia	1.66	848	850	0.2

GROUND WATER

In August 1963, 31 observation wells were installed in the alluvial deposits beneath the flood plain of Soldier Creek. At the streamflow-gaging stations near Goff, Bancroft, Soldier, Circleville, St. Clere, and Delia, wells were located in a line approximately perpendicular to the stream (fig. 36). For monthly observations, holes were bored to bedrock and cased with 1.0- or 1.25-inch pipes that generally were fitted with 2-foot lengths of screen. Two wells at the St. Clere site were cased with 5-inch pipe and equipped with float-operated graphic recorders for continuous measurements. A complete listing of the location, description, and years of available record for each well is given by Carswell (1978a).

The ground-water data-collection network was designed to determine the relation between base flow and water levels in the alluvium. However, the relation could not be quantified because the network was not dense enough to define the complex properties of the alluvial aquifers. The alluvium most likely is composed of zones of widely varying hydraulic conductivity. These zones probably run parallel to the stream and are composed of various bars, channel fillings, and natural levees. Therefore, they would intersect the stream at some distance up or downstream, if at all. Wells located at right angles to the direction of streamflow would not be hydraulically connected directly with the stream at the nearest point. In retrospect, a better-designed network may have shown quantifiable relationships between stream levels and ground-water levels.

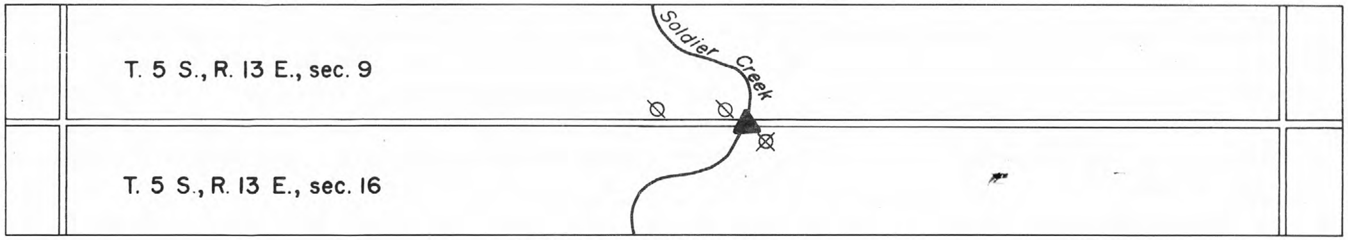
The ground-water data-collection network did not include the effect of bedrock in the basin. However, gross relationships derived from data in Walters' (1953, pl. 2) report show that the ground-water gradient is toward both streambanks in the bedrock underlying the basin. This indicates that Soldier Creek is generally a gaining stream. In some reaches, however, data on the chemical quality of water indicate that losses may occur from the stream to alluvial or bedrock aquifers as shown in figure 22.

SUMMARY

Soldier Creek basin is a long, narrow area encompassing about 290 square miles almost directly north of Topeka, Kans. A wide range of hydrologic data has been collected in the basin since the spring of 1964. These data include rainfall, stream discharge, chemical quality of water, sediment concentrations, and ground-water levels.

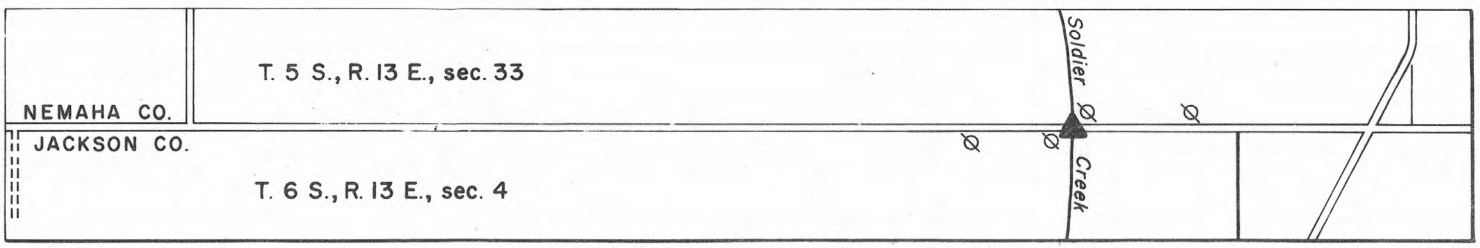
The data-collection network consists of 7 recording streamflow stations, 5 recording rainfall stations, 51 nonrecording rainfall stations, and 31 ground-water observation wells. Samples for chemical-quality and suspended-sediment analyses were collected intermittently at selected sites.

The Soldier Creek basin is in the Dissected Till Plains and Attenuated Drift Border sections of the Central Lowlands physiographic province. Geologic formations in the area consist principally of glacial till, limestone, and shale. The resulting soils and hillside slopes associated with these materials, along with agricultural development, significantly affect the quantity and quality of streamflow in different parts of the basin.



GOFF STATION

BANCROFT STATION



SOLDIER STATION

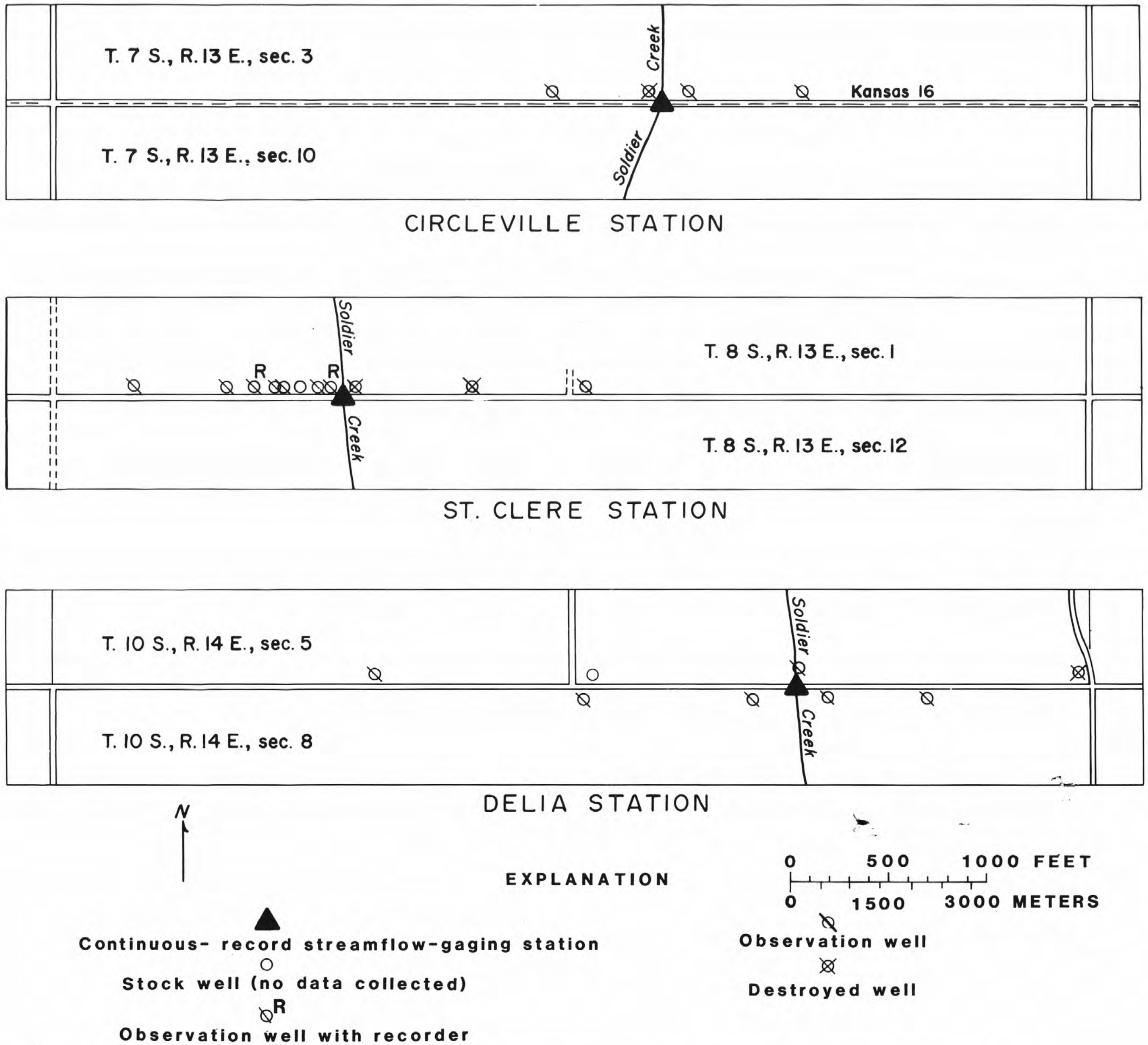


Figure 36.--Location of wells near streamflow-gaging stations in Soldier Creek basin.

Two seepage-salinity investigations in the basin provide data on the chemical quality of the water in the stream and its principal tributaries. Predominant ions in the water were calcium, bicarbonate, and sulfate. Dissolved solids in the water of Soldier Creek are derived from solution of limestones and shales.

Average suspended-sediment discharge at gaged sites ranged from 9.94 tons per day at the Goff station to 848 tons per day at the Topeka station. A significant increase in sediment yield per unit area that occurred between the Soldier and Circleville stations was attributed to changes in average basin hillside slope and land-use practices. The suspended sediment had average clay contents ranging from 41 to 59 percent, average silt contents ranging from 37 to 45 percent, and average sand contents ranging from negligible to 13 percent. The percentage of unmeasured sediment discharge to total sediment discharge ranged from 0.2 to 14.

Relationships between base flow in the stream and water levels in the alluvium could not be quantified with the available data due to the complex nature of the alluvial aquifers. The alluvium most likely is composed of zones of widely varying permeability that are parallel to the stream. A large number of wells, ideally spaced, probably would be required to quantify the relationship between base flow and water levels in the alluvium.

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