TECHNIQUES FOR ESTIMATING REGIONAL FLOOD CHARACTERISTICS OF SMALL RURAL WATERSHEDS IN THE PLAINS REGION OF EASTERN COLORADO

By Russell K. Livingston and Donald R. Minges

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CONVERSION FACTORS

Inch-pound units in this report may be converted to metric (International System) units by using the following conversion factors:

Multiply inch-pound unit	*By*	*To obtain metric unit*
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.0109344	cubic meter per second per square kilometer
foot (ft)	0.3048	meter
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

The following terms and abbreviations also are used in this report:

minute (min)
hour (h)
year (yr)
day (d)

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

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ABSTRACT

Recorded and synthetic flood data for 52 watersheds (35 in Colorado and 17 in adjoining States) were analyzed to develop regional techniques for estimating the magnitude, frequency, volume, and hydrograph shape of floods that typically occur on small rural watersheds in the plains region of eastern Colorado. The analysis of flood magnitude and frequency included 21 flood-frequency relations that were based on recorded annual peak discharges, 2 flood-frequency relations that were based on synthetic annual peak discharges, and 28 flood-frequency relations that were based on recorded and synthetic annual peak discharges (a relation could not be determined for 1 watershed). Similarly, the analysis of flood volumes included volumes for 103 recorded floods and 4,391 synthetic floods. Synthetic flood data were generated from long-term rainfall data from National Weather Service stations and a rainfall-runoff model calibrated for each watershed. The 5-, 10-, 25-, 50-, and 100-year peak discharges were regionalized using ordinary least-squares and generalized least-squares regressions. The smallest errors of prediction were obtained using the generalized least-squares regressions, and the relations developed included the independent variables of effective drainage area, relief factor, and 24-hour, 100-year rainfall intensity; standard errors of prediction ranged from 35 to 50 percent. A relation was developed to estimate flood volume from peak discharge; the standard error of prediction was 78 percent. To develop a flood hydrograph from estimates of peak discharge and flood volume, a dimensionless-hydrograph technique is presented that produces synthetic flood hydrographs very similar in shape to recorded flood hydrographs.

INTRODUCTION

Flood characteristics, such as magnitude of peak discharges, frequency of occurrence, and volumes are major considerations in the design of highway bridges and culverts. Extensive discharge data available for large perennial streams generally have provided flood information necessary for the design of major drainage structures. Previous reports on the estimation of flood characteristics of Colorado streams include Patterson (1964, 1965), Patterson and Somers (1966), Matthai (1968), Livingston (1970), Hedman and others (1972), McCain and Jarrett (1976), U.S. Soil Conservation Service (1975, 1977) and Kircher and others (1985). However, except for the reports by McCain and Jarrett (1976) and the U.S. Soil Conservation Service (1975, 1977), the methods described by these reports generally do not apply to very small watersheds, particularly to watersheds that have ephemeral streams.

McCain and Jarrett (1976) presented regression equations applicable to watersheds that have drainage areas greater than 1 mi^2 in the plains region of eastern Colorado (fig. 1). Their equations, however, were based only on limited data for small watersheds; only 2 of 36 watersheds studied had drainage areas less than 30 mi^2. Procedures for estimating flood characteristics described by the U.S. Soil Conservation Service (1975, 1977) apply to small watersheds, but primarily are based on empirical rainfall-runoff relations developed for regions encompassing many States, rather than local hydrologic areas within any particular State such as Colorado.

In 1968, the U.S. Geological Survey, in cooperation with the Colorado Department of Highways and the Federal Highway Administration, began a study to: (1) Collect data during thunderstorm-caused floods in small (generally

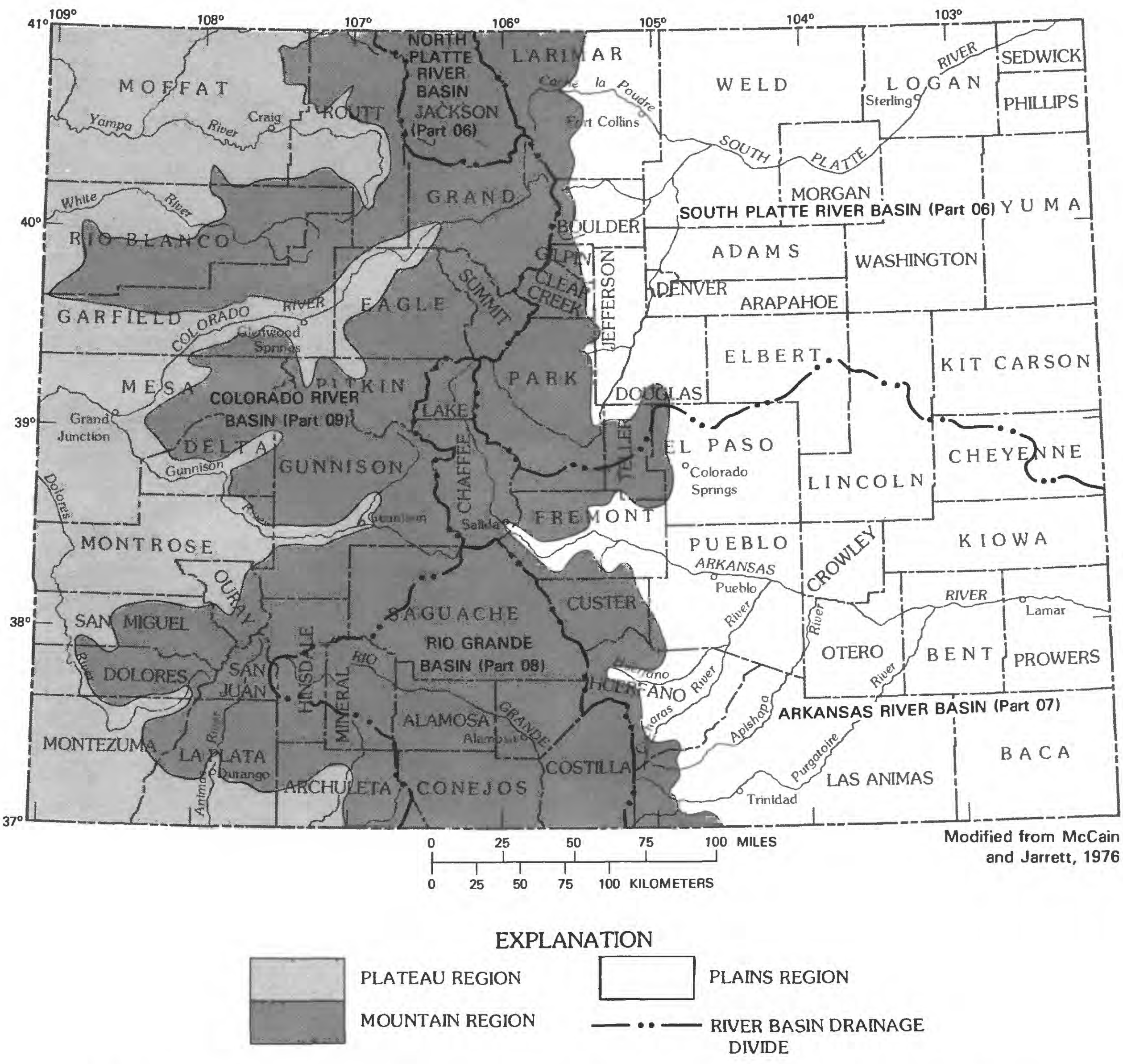

Figure 1.--Flood-characteristic regions and major drainage basins in Colorado.

less than 30 mi^2) rural watersheds in the plains and plateau regions of Colorado, and (2) develop a regional technique for estimating the flood characteristics for these watersheds. The study was limited to ephemeral streams that: (1) Do not experience significant snowmelt-flood discharges (drainages generally below about 8,000 ft); and (2) do not have substantial "sand-hills" areas within their drainages. Areas that are subject to snowmelt-flood discharges and the major "sand-hill" areas of Colorado and adjoining States are shown in figure 2. A research study on flood characteristics in the foothill regions of Colorado, generally above about 7,500 ft in the eastern foothills, currently (1986) is being conducted on streams that experience mixed-population (both rainfall and snowmelt) floods (Jarrett and Costa, 1983).

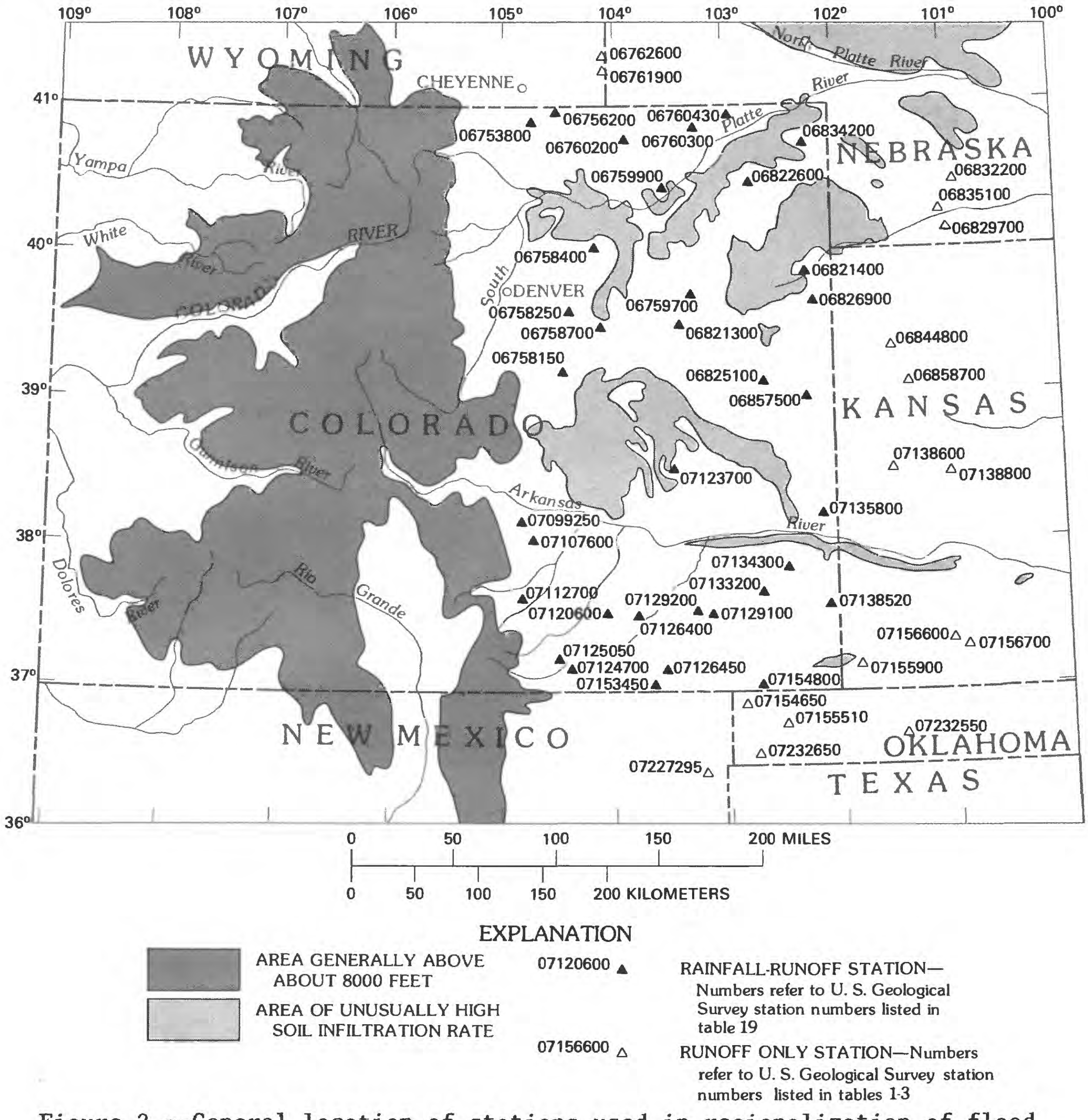

Figure 2.--General location of stations used in regionalization of flood characteristics and areas within the region excluded from study.

Purpose and Scope

This report describes the procedures used for collection of rainfall-runoff and peak-discharge data, determination of flood-frequency relations from recorded and synthetic flood data, and regionalization of flood characteristics. In addition, the report discusses the best techniques for estimating flood characteristics for ungaged and gaged small rural watersheds. A report by Livingston (1981) presented preliminary regional flood characteristics for small watersheds in the plains region of the Arkansas River basin in Colorado. This current report incorporates data for the plains region of the South Platte River basin and summarizes the collection and analysis of data for the entire plains region of eastern Colorado.

The flood characteristics included in the analysis are peak discharges for recurrence intervals of 5-, 10-, 25-, 50-, and 100-yr, flood volume, and flood-hydrograph shape. The analysis was based on rainfall-runoff data collected from 35 gaging stations operated in Colorado from about 1969 through 1979, peak-discharge data available for 17 gaging stations located in adjoining States with periods of record ranging from 8 to 32 yr, daily and storm rainfall for 5 climatological stations for record lengths from 60 to 72 yr, and daily evaporation for 6 climatological stations for record lengths from 25 to 36 yr.

Although the study included data collection in the plateau region of western Colorado, the results of that data collection did not yield sufficient data to provide reliable regional flood characteristics for that area. Because of physiographic differences between the eastern-plains and the western-plateau regions of Colorado as discussed in McCain and Jarrett (1976), a combined analysis using data from the plains and plateau regions would not be appropriate (fig. 1). Therefore, this report only pertains to the plains region. However, a table of rainfall-runoff stations in the plateau region, and some brief discussion of the rainfall-runoff data collected in that region, is presented in the "Supplemental Information" section at the back of the report.

Acknowledgments

Installation of the rainfall-runoff stations was facilitated by the cooperation of municipal and county governments, the Colorado Department of Highways, and numerous private landowners. The authors particularly wish to thank Del Roupp and Gary Johnson of the Colorado Department of Highways for assistance and support in the planning and execution of the study.

COLLECTION OF RAINFALL-RUNOFF AND PEAK-DISCHARGE DATA

Seasonal (generally April through September) rainfall-runoff data were collected for 35 small (ranging in area from 1.15 to 23 mi^2, and having an average of 7.30 mi^2) rural watersheds in the plains region of eastern Colorado (fig. 2; tables 1 and 2). Instrumentation and operation began at 12 rainfall-runoff stations in the South Platte River basin during May 1969.

Table 1.--*Rainfall-runoff stations in the South Platte River basin*

U.S. Geological Survey station number	Station name	Total drainage area, in square miles	Period of seasonal record[1]	Location[2] Latitude	Location[2] Longitude	Basis of stage-discharge relation
06753800	Owl Creek tributary near Rockport	4.28	May 1969-Sept. 1979	40°55'02"	104°46'06"	Step-backwater analysis
06756200	Geary Creek tributary near Rockport	1.15	May 1969-Sept. 1979	40°57'41"	104°34'55"	do.
06758150	Kiowa Creek tributary near Elbert[3]	1.22	[4]Apr. 1970-Sept. 1979	39°12'06"	104°30'06"	Culvert analysis
06758250	Kiowa Creek tributary near Bennett	6.40	Apr. 1970-Sept. 1979	39°36'47"	104°27'01"	Step-backwater analysis
06758400	Goose Creek near Hoyt	3.79	June 1969-Sept. 1979	40°02'10"	104°13'06"	do.
06758700	Middle Bijou Creek tributary near Deertail	1.74	Apr. 1970-Sept. 1979	39°29'33"	104°09'46"	do.
06759700	Sand Creek tributary near Lincoln	2.45	June 1969-Sept. 1979	39°44'01"	103°21'12"	do.
06759900	Antelope Draw near Union[5]	3.19	May 1969-Sept. 1979	40°25'57"	103°36'15"	do.
06760200	Igo Creek near Buchanon[6]	1.53	May 1969-Sept. 1979	40°47'24"	103°57'18"	do.
06760300	Darby Creek near Buchanon	6.67	May 1969-Nov. 1977	40°52'48"	103°10'12"	do.
06760430	Spring Canyon Creek near Peetz	22.9	May 1969-Sept. 1979	40°58'12"	103°00'34"	do.
06821300	North Fork Arikaree River tributary near Shaw	6.55	May 1969-Sept. 1979	39°31'12"	103°26'35"	do.
06821400	North Fork Black Wolf Creek near Vernon	17.0	May 1969-Sept. 1979	39°54'24"	102°16'08"	do.
06822600	Potent Creek near St. Petersburg	2.37	May 1969-Sept. 1979	40°29'50"	102°46'30"	do.
06825100	Landsman Creek tributary near Stratton	7.02	Apr. 1972-Sept. 1979	39°06'43"	102°40'25"	do.
06826900	Sand Creek near Hale	14.6	May 1969-Sept. 1979	39°41'50"	102°10'37"	do.
06834200	Spring Creek tributary near Amherst	23.0	May 1969-Sept. 1979	40°45'09"	102°16'12"	do.
06857500	Big Timber Creek tributary near Arapahoe	13.3	May 1969-Oct. 1977	38°59'18"	102°16'47"	do.

[1]Gages operated from about April 1 through about September 30 (no winter records).
[2]See figure 2 for general location of stations.
[3]Prior to March 27, 1972, at site 800 feet upstream.
[4]Stock ponds constructed in basin during 1976.
[5]Prior to January 1, 1975, at site 0.4 mile downstream.
[6]Prior to March 30, 1972, at site 1.1 miles downstream.

Table 2.--*Rainfall-runoff stations in the Arkansas River basin*

U.S. Geological Survey station number	Station name	Total drainage area, in square miles	Period of seasonal record[1]	Location[2] Latitude	Location[2] Longitude	Basis of stage-discharge relation
07099250	Soda Creek near Livesey	8.35	Apr. 1970-Nov. 1978	38°11'46"	104°50'44"	Step-backwater analysis
07107600	St. Charles River tributary near Goodpasture	2.87	Mar. 1970-Nov. 1978	38°04'05"	104°46'33"	do.
07112700	Butte Creek near Delcarbon	3.10	Apr. 1970-Nov. 1978	37°42'24"	104°51'58"	do.
07120600	Timpas Creek tributary near Thatcher	6.56	Mar. 1970-Oct. 1977	37°34'18"	104°06'10"	do.
07123700	Mustang Creek near Karval[3]	10.4	June 1969-Oct. 1978	38°33'54"	103°31'18"	do.
07124700	Gray Creek near Engleville	8.46	Mar. 1970-Nov. 1978	37°09'36"	104°25'38"	do.
07125050	Tingley Canyon Creek near Ludlow	6.22	Mar. 1970-Nov. 1978	37°16'48"	104°32'04"	do.
07126400	Red Rock Canyon Creek near Bloom	4.14	Mar. 1970-Oct. 1978	37°33'24"	103°50'20"	do.
07126450	Tobe Arroyo near Tobe	8.93	Mar. 1970-Oct. 1977	37°22'43"	103°36'33"	do.
07129100	Rule Creek near Ninaview	7.07	Mar. 1970-Nov. 1978	37°33'57"	103°10'26"	do.
07129200	Muddy Creek tributary near Ninaview	3.31	Mar. 1970-Oct. 1978	37°35'56"	103°19'48"	do.
07133200	Clay Creek tributary near Deora	2.34	Mar. 1970-Oct. 1978	37°43'27"	102°44'24"	do.
07134300	Wolf Creek near Carlton	13.9	June 1969-Oct. 1978	37°52'30"	102°28'54"	do.
07135800	Wild Horse Creek tributary near Hartman	6.28	June 1969-Oct. 1977	38°15'45"	102°09'42"	do.
07138520	Little Bear Creek tributary near Lycan	17.0	June 1969-Nov. 1978	37°37'48"	102°07'30"	do.
07153450	Longs Canyon Creek near Tobe	4.56	Mar. 1970-Oct. 1978	37°05'24"	103°41'09"	do.
07154800	Cimarron River tributary near Edler	3.50	Mar. 1970-Oct. 1978	37°05'10"	102°45'38"	Culvert analysis

[1]Gages operated from about April 1 through about September 30 (no winter records).
[2]See figure 2 for general location of stations.
[3]Prior to March 28, 1972, at site 450 feet downstream.

By April 1970, 17 stations were in operation in that basin, and one additional station was in operation by April 1972; a total of 18 watersheds was studied in the South Platte River basin. Instrumentation and operation began at four stations in the Arkansas River basin during June 1969, and the remaining 13 stations were in operation by April 1970; a total of 17 watersheds was studied in that basin.

Rainfall-runoff stations in the South Platte River basin generally were discontinued after the 1979 data-collection season; stations in the Arkansas River basin generally were discontinued after the 1977 or 1978 data-collection season. In some instances, individual stations were discontinued prior to this schedule when the number of storms recorded was sufficient to provide a reliable model calibration. All rainfall-runoff data analyzed in this report previously have been published (Ducret and Hodges, 1972; Cochran and others, 1979; Cochran and others, 1983).

Station Instrumentation

Each of the 35 stations was instrumented with separate stage (flood-hydrograph) and rainfall recorders, both located at the downstream limit of each watershed. Stage, recorded in hundredths of a foot, was measured inside a 4-in. stilling-well pipe by a small float connected directly to a digital recorder; runoff entered the pipe through numerous ¼-in. holes drilled at several levels in the pipe. Rainfall, recorded in hundredths of an inch, was measured inside a 3-in. pipe by a small float connected directly to a digital recorder; rainfall entered the pipe from a 5- by 10-in. rectangular collector located on top of the shelter. The digital recorders punched all data on a 16-channel paper tape at 5-min intervals. A single cam-type timer was used to activate the rainfall and stage recorders, thus ensuring time-synchronous data.

Theoretical Stage-Discharge Relations

Recorded stage data were converted to discharge using theoretical stage-discharge relations. For the majority of the stations, these relations were determined by step-backwater analyses as described by Bailey and Ray (1966) and Shearman (1976). This method of determining a stage-discharge relation for an ephemeral stream was shown to be within 15 percent of measured discharge in a verification study by Druse (1982). Because changes in channel configuration may affect this type of theoretical relation, stream channels were resurveyed and step-backwater analyses were revised after major floods or evident channel changes. For some stations, the theoretical stage-discharge relations were determined by culvert analysis, as described by Bodhaine (1968). The basis of the stage-discharge relation for each station is listed in tables 1 and 2.

In addition to the theoretical stage-discharge relations developed for each station, indirect determinations of peak discharge were obtained throughout the study to provide additional stage-discharge information for significant floods. A total of 28 such determinations was made at 23 of the 35 stations.

Characterization of Recorded Data

Seasonal flood data for most of the 35 stations were recorded during 7 to 10 consecutive years (tables 1 and 2). The average record length was more than 10 yr for stations in the South Platte River basin, and about 9 yr for stations in the Arkansas River basin. The ranges of annual peak discharges recorded at the stations are shown in figure 3. The maximum annual peak discharge recorded during the study was 7,880 ft^3/s at station 07134300 (Wolf Creek near Carlton) on August 23, 1969. In terms of runoff per unit area, a maximum of 876 $ft^3/s/mi^2$ was recorded at station 06821300 (North Fork Arikaree River tributary near Shaw) on August 10, 1979. No flow occurred at 27 stations during at least 1 water year of the study.

The rainfall-runoff data collected during the study indicates the character of storms and resulting floods that occur in the plains region. For 236 selected storms recorded in the plains region, the average and maximum total quantities of rainfall recorded during 5-min intervals is shown in figure 4. Greatest average total rainfall was 0.17 in. (2.0 in/h), that occurred in the interval between 5 and 10 min after the storm began, and the "average storm" lasted about 45 min. The maximum total rainfall recorded in a 5-min interval was 0.64 in. (7.7 in/h). The seasonal occurrence of the resulting floods is shown by 10-day intervals in figure 5. For the 236 selected floods, about 77 percent occurred during the 90-day period from May 21 to August 18, and about 24 percent occurred during the 20-day period from July 20 to August 18. In a similar analysis of flood occurrences in the Front Range Urban Corridor of Colorado, Hansen and others (1978) determined that 83 percent of floods occurred from May 21 to August 18.

Flood Information From Adjoining States and for Miscellaneous Sites

In addition to the rainfall-runoff data collected at each station, other flood information was included to: (1) Increase the total number of observations in the analysis; (2) broaden the areal extent of the data base to include areas of similar flood hydrology in adjoining States; and (3) document historical floods in eastern Colorado.

Records for peak discharge for 17 stations in adjoining States (fig. 2 and table 3) were selected where either a crest-stage indicator or a water-level recorder were systematically operated. These stations had periods of record ranging from 8 to 32 years and sufficient flood data for frequency analysis and regionalization.

Occasionally, information about the magnitude of a particular flood is available at a miscellaneous site where systematic records are not maintained. These data usually are the result of indirect determinations of peak discharge that are based on extensive field surveys of the stream channel and the high-water marks. Sixty-three determinations of peak discharge for 59 small rural watersheds in the South Platte or Arkansas River basins are listed in table 13 (in the "Supplemental Information" section at the back of the report); 49 of these watersheds are located in Colorado. Although the data for miscellaneous sites were not used in the regionalization of flood characteristics because

Table 3.--*Gaging stations in adjoining States for which systematic flood data were available*

U.S. Geological Survey station number	Station name	Total drainage area, in square miles	Period of record[1]	Location[2]		Basis of stage-discharge relation
				Latitude	Longitude	
06761900	Lodgepole Creek tributary near Pine Bluffs, Wyo.	0.60	1960-81	41°15'23"	104°04'50"	Culvert analysis
06762600	Lodgepole Creek tributary no. 2 near Albion, Wyo.	7.69	1960-81	41°19'11"	104°04'49"	do.
06829700	Thompson Canyon near Trenton, Nebr.	9.06	1966-78	40°09'36"	100°57'36"	Step-backwater analysis
06835100	Bobtail Creek Palisade, Nebr.	24.6	1966-78	40°18'00"	101°06'36"	do.
06839200	Elkhorn Canyon near Maywood, Nebr.	6.74	1952-72	40°36'00"	100°42'00"	do.
06844800	South Fork Sappa Creek tributary near Goodland, Kans.	4.98	1951-82	39°19'12"	101°37'57"	Culvert analysis
06858700	North Fork Smokey Hill tributary near Winona, Kans.	1.13	1957-73	39°01'52"	101°17'06"	do.
07138600	White Woman Creek tributary near Selkirk, Kans.	38.0	1957-73	38°31'30"	101°37'16"	do.
07138800	Lion Creek tributary near Modoc, Kans.	7.00	1957-73	38°28'48"	101°03'00"	do.
07154650	Tesequite Creek near Kenton, Okla.	25.4	1964-80	36°53'53"	102°54'04"	Step-backwater analysis
07155510	Flagg Springs tributary near Boise City, Okla.	5.14	1965-72	36°52'30"	102°31'08"	do.
07155900	North Fork Cimarron River tributary near Richfield, Kans.	75.0	1957-73	37°18'36"	101°46'20"	Culvert analysis
07156600	Cimarron River tributary near Moscow, Kans.	13.0	1957-73	37°20'06"	101°03'00"	do.
07156700	Cimarron River tributary near Satanta, Kans.	2.41	1957-73	37°16'16"	100°55'37"	do.
07227295	Sandy Arroyo near Clayton, N. Mex.	1.25	1952-79	36°23'30"	103°19'05"	do.
07232550	South Fork tributary near Guyman, Okla.	.26	1964-80	36°40'05"	101°29'53"	Step-backwater analysis
07232650	Aqua Frio Creek near Felt, Okla.	31.0	1964-75	36°33'22"	102°47'10"	do.

[1]Gages operated on water-year basis, October 1 through September 30.
[2]See figure 2 for general location of station.

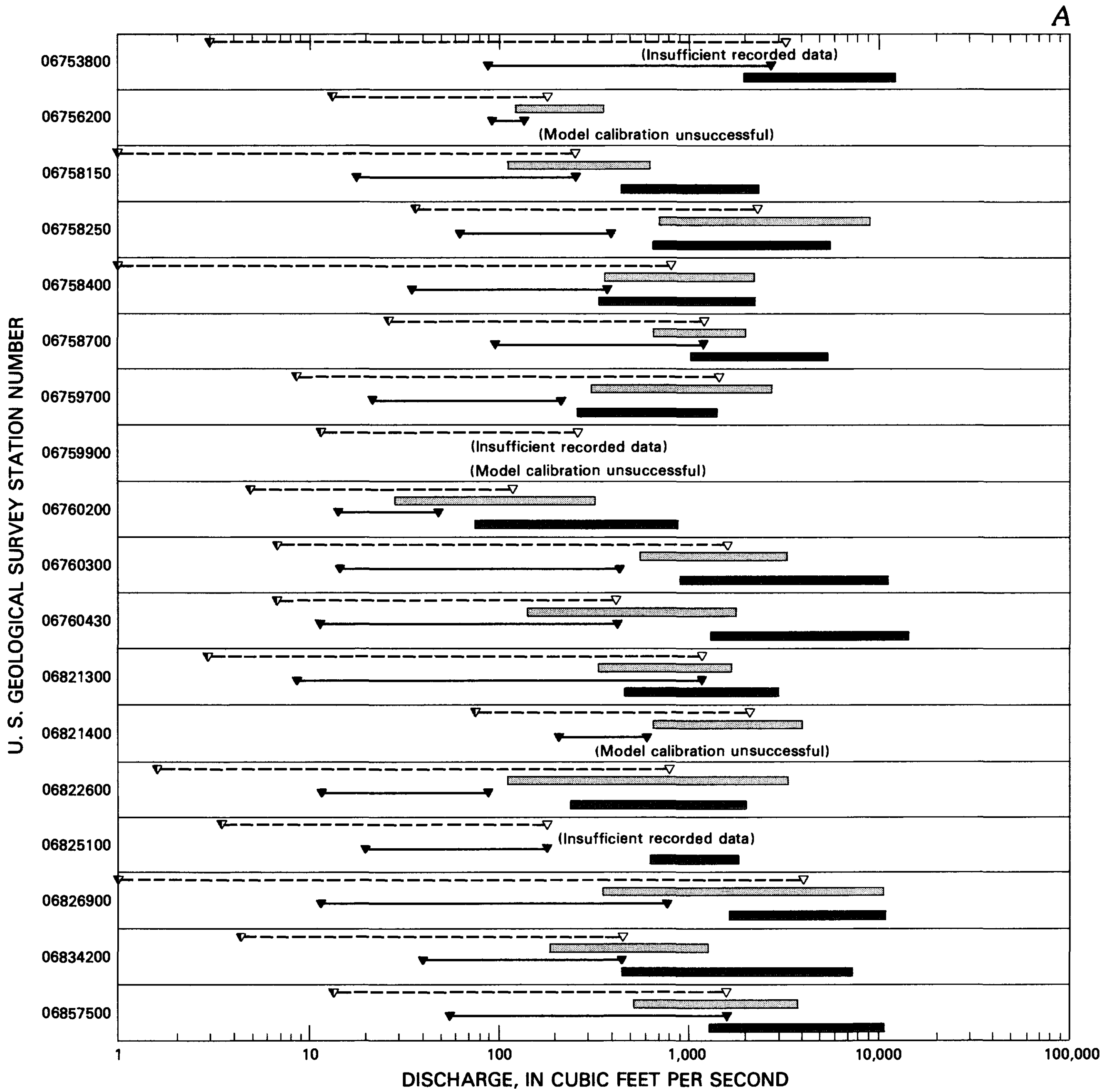

Figure 3.--Ranges in discharge for recorded annual peak flows, floods used in model calibration, and flood frequencies from recorded or synthetic data for: *A*, South Platte River basin.

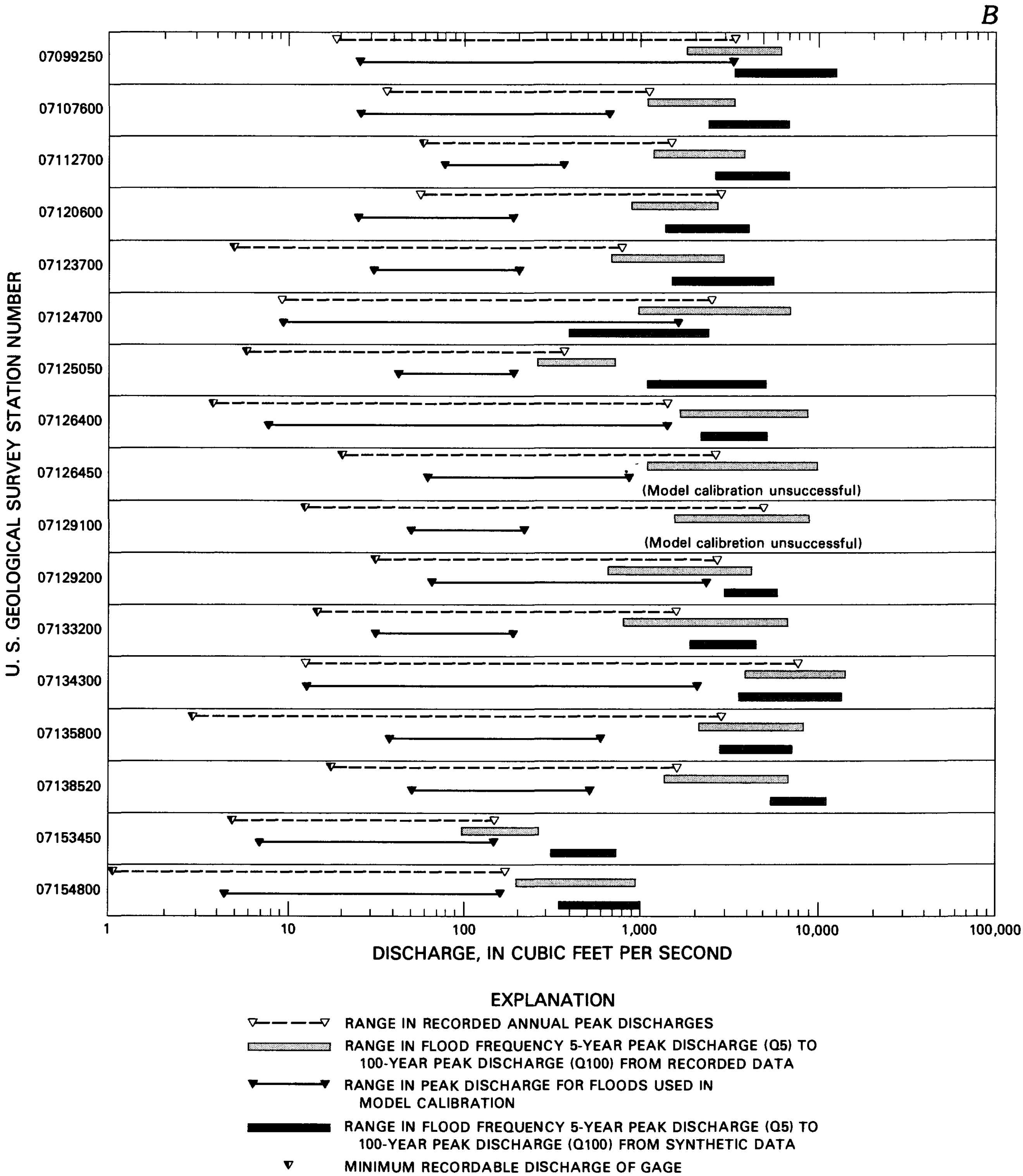

Figure 3.--Ranges in discharge for recorded annual peak flows, floods used in model calibration, and flood frequencies from recorded or synthetic data for: *B*, Arkansas River basin.

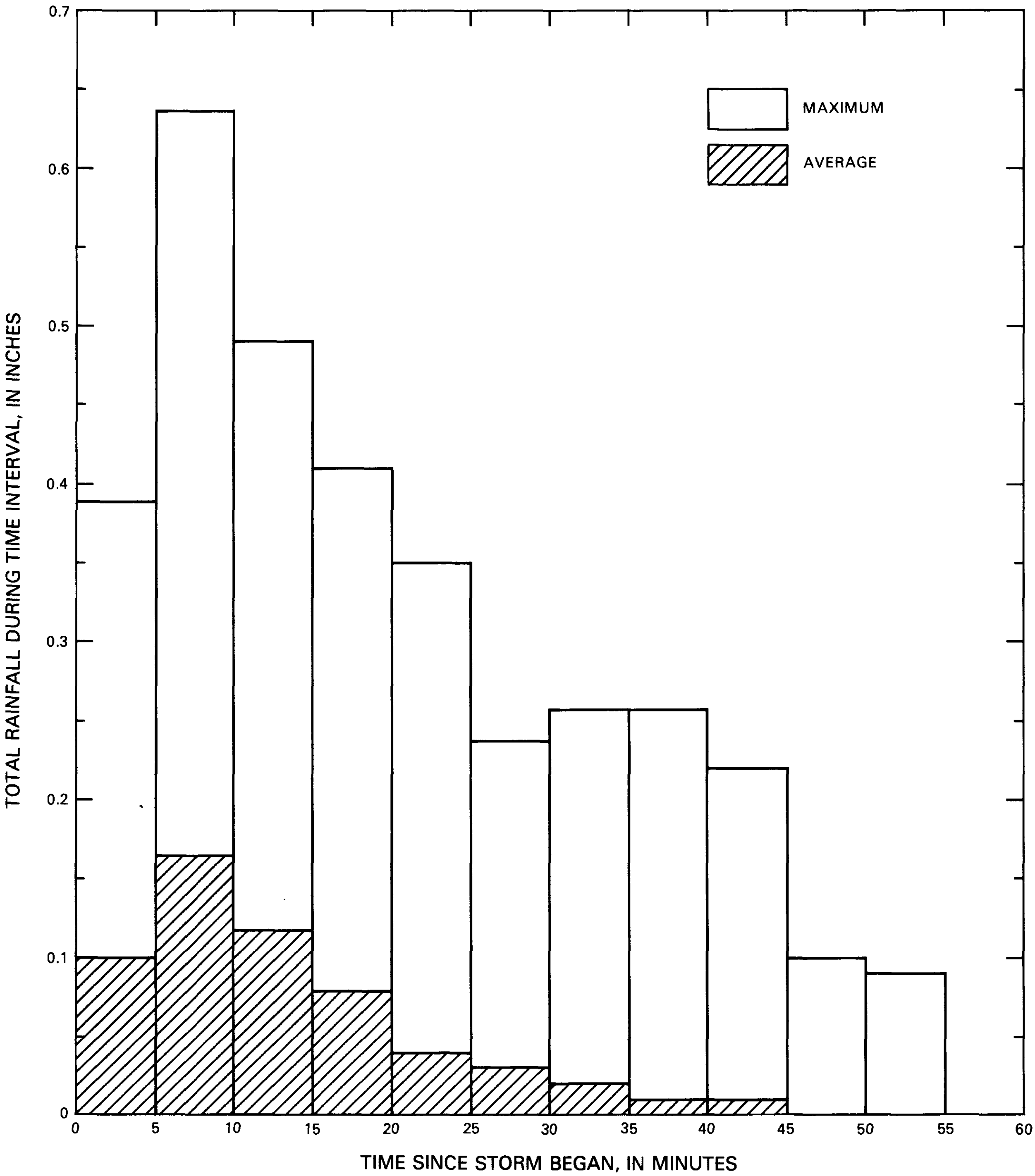

Figure 4.--Average and maximum rainfall by 5-minute intervals for 236 storms in the plains region.

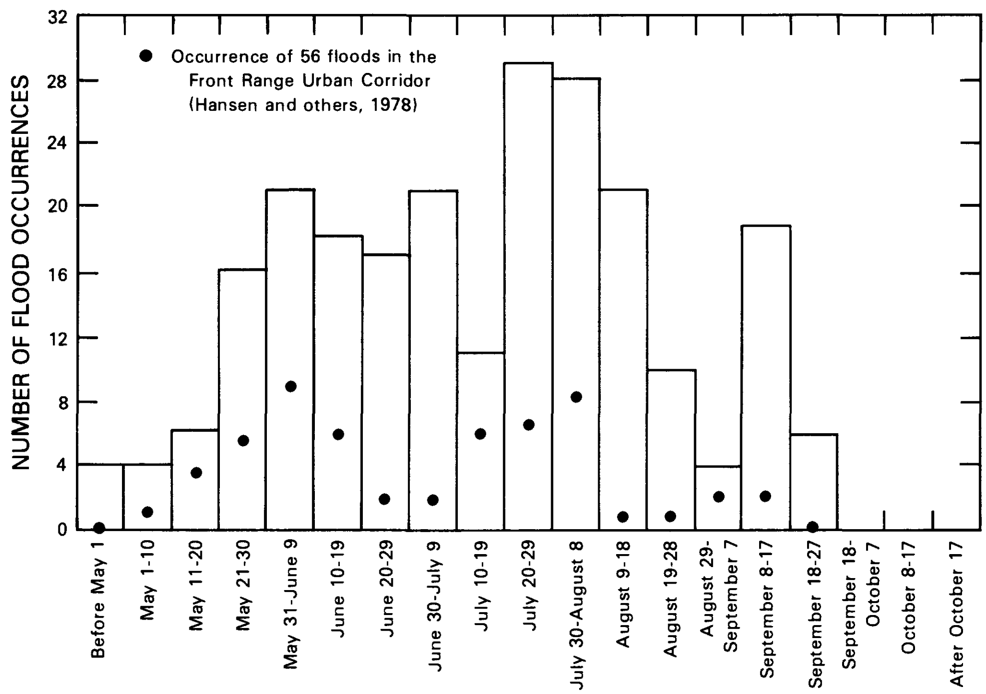

Figure 5.--Seasonal occurrence of 236 floods in the plains region.

flood frequency could not be determined reliably, these data provide documentation for the occurrence for floods of known peak discharge.

FLOOD CHARACTERISTICS

Flood characteristics typically determined for a watershed include a peak discharge (Q_p), which is either a design flow or a historical flood; a peak discharge with an estimated frequency of occurrence (*QT*), where *T* (the recurrence interval) is the average interval of time (usually in years) within which the discharge will be equaled or exceeded once; and a flood volume (*V*). A uniform technique by which flood frequency is developed has been established by the U.S. Water Resources Council (1977, 1981). These guidelines generally are accepted by Federal and State agencies, and were used in this report. The following guidelines as described by the U.S. Water Resources Council (1981) are noteworthy:

1. The log-Pearson Type III distribution, applied to the annual flood series, should be used.
2. The station skew coefficient is weighted with a generalized skew coefficient to obtain a more accurate estimate of skew.

3. Probability calculations are modified for incomplete records and zero-flow years.
4. The existence of outliers is statistically judged and is corrected for improbability calculations.
5. Historical peaks, if available, are incorporated with the systematic record in computing flood frequencies.

Analysis of Recorded Floods

The peak discharges of the annual maximum floods recorded during the study at the 35 stations in the plains region were analyzed to determine frequency, and to relate peak discharge and flood volume. Additionally, peak-discharge frequency was determined from the annual-flood series for the 17 stations in adjoining States.

Peak-Discharge Frequency

Results of the frequency analysis of the annual peak discharges recorded at each rainfall-runoff station are listed in table 4. A sufficient number of annual peak discharges needed to determine a frequency relation were unavailable at three stations in the plains region. The remaining 32 stations had expected 100-yr peak discharges ranging from 270 to 14,400 ft^3/s. As discussed in the section entitled "Analysis of Synthetic Floods," the time-sampling error associated with these frequency analyses is large because of the short periods of record on which they are based; it may result in particularly erroneous discharges for greater recurrence-interval floods, such as the 100-yr peak discharge. A comparison between the range in flood frequency (5- to 100-yr peak discharges) from this analysis and the range in annual peak discharges actually recorded at each station is shown in figure 3. Of the 32 rainfall-runoff stations for which sufficient annual peak discharges were recorded to allow analysis, only 1 station (06758150) did not have a recorded discharge that was at least greater than the expected 5-yr peak discharge.

Also listed in table 4 are the flood-frequency relations based on the annual peak discharges recorded during the period of record at each of the 17 stations located in adjoining States. These relations show 100-yr peak discharges ranging from 200 to 22,400 ft^3/s.

Relation Between Peak Discharge and Flood Volume

In addition to information on expected peak discharges, designers of bridges and culverts may require estimates of flood volumes when planning for embankment storage or flood detention. Although empirical methods frequently are used to make these volume estimates, the large number of flood hydrographs recorded at rainfall-runoff stations operated during this study provided sufficient data from which additional estimating techniques were developed. This section describes only the analysis of recorded flood volumes; analysis of synthetic flood volumes will be discussed in a subsequent section entitled "Analysis of Synthetic Floods."

Table 4.--*Recorded, synthetic, and weighted flood-frequency relations, South Platte and Arkansas River basins, Colorado and adjoining States*

[All values are peak discharge, in cubic feet per second, for indicated recurrence interval; dashes indicate that no value was determined]

U.S. Geological Survey station number[1]	Recorded flood-frequency relation					Synthetic flood-frequency relation					Weighted flood-frequency relation				
	5 years	10 years	25 years	50 years	100 years	5 years	10 years	25 years	50 years	100 years	5 years	10 years	25 years	50 years	100 years
06753800[2]	---	---	---	---	---	2,130	3,660	6,530	9,520	13,300	---	---	---	---	---
06756200[3]	130	180	260	320	390	---	---	---	---	---	---	---	---	---	---
06758150	120	200	350	500	680	490	810	1,370	1,910	2,580	[4]490	[4]810	[4]1,370	[4]1,910	[4]2,580
06758250	760	1,650	3,710	6,230	9,870	700	1,330	2,630	4,700	6,090	742	1,510	3,010	5,030	6,470
06758400	390	670	1,190	1,710	2,370	370	650	1,170	1,710	2,420	384	661	1,180	1,710	2,420
06758700	700	980	1,410	1,780	2,180	1,100	1,800	3,080	4,350	5,940	820	1,350	2,500	3,700	5,560
06759700	330	630	1,270	1,990	2,980	283	450	900	1,140	1,580	315	558	965	1,350	1,720
06759900[2,3]	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
06760200	30	60	130	220	350	80	170	370	610	950	45	110	286	513	890
06760300	610	1,030	1,790	2,570	3,580	990	2,020	4,450	7,490	12,100	724	1,480	3,520	6,260	11,250
06760430	150	310	690	1,180	1,930	1,410	2,760	5,810	9,590	15,300	[4]1,410	[4]2,760	[4]5,810	[4]9,590	[4]15,300
06761900[5]	61	90	134	175	222	---	---	---	---	---	---	---	---	---	---
06762600[5]	217	458	979	1,568	2,365	---	---	---	---	---	---	---	---	---	---
06821300	370	590	990	1,370	1,830	500	870	1,560	2,280	3,210	409	716	1,360	2,050	3,070
06821400[3]	700	1,210	2,160	3,130	4,370	---	---	---	---	---	---	---	---	---	---
06822600	120	330	960	1,920	3,630	260	480	940	1,470	2,190	162	398	947	1,530	2,330
06825100[2]	---	---	---	---	---	680	940	1,320	1,650	2,000	---	---	---	---	---
06826900	380	1,060	3,120	6,250	11,600	1,840	3,190	5,740	8,400	11,800	818	2,020	4,820	7,860	11,780
06829700[5]	587	974	1,650	2,319	3,110	---	---	---	---	---	---	---	---	---	---
06834200	150	280	560	900	1,380	470	1,030	2,510	4,550	7,950	[4]470	[4]1,030	[4]2,510	[4]4,550	[4]7,950
06835100[5]	2,270	4,420	8,850	13,800	20,400	---	---	---	---	---	---	---	---	---	---
06839200[5]	746	1,340	2,470	3,650	5,160	---	---	---	---	---	---	---	---	---	---
06844800[5]	427	1,370	4,599	9,872	19,407	---	---	---	---	---	---	---	---	---	---
06857500	550	1,010	1,900	2,850	4,100	1,420	2,640	5,080	7,730	11,300	811	1,740	3,970	6,510	10,580
06858700[5]	594	807	1,120	1,380	1,660	---	---	---	---	---	---	---	---	---	---
07099250	1,050	1,800	3,140	4,490	6,170	1,860	3,360	6,070	8,840	12,400	1,290	2,500	5,050	7,750	11,780
07107600	630	1,060	1,800	2,530	3,430	1,530	2,400	3,850	5,200	6,800	900	1,660	3,130	4,530	6,460
07112700	750	1,230	2,090	2,920	3,930	1,770	2,690	4,140	5,410	6,860	1,060	1,890	3,420	4,790	6,570
07120600	550	900	1,480	2,040	2,710	840	1,380	2,250	3,080	4,080	640	1,120	1,980	2,820	2,940
07123700	370	690	1,330	2,010	2,920	830	1,500	2,680	3,930	5,600	508	1,060	2,210	3,450	5,330

Table 4.--*Recorded, synthetic, and weighted flood-frequency relations, South Platte and Arkansas River basins, Colorado and adjoining States*--Continued

U.S. Geological Survey station number[1]	Recorded flood-frequency relation					Synthetic flood-frequency relation					Weighted flood-frequency relation				
	5 years	10 years	25 years	50 years	100 years	5 years	10 years	25 years	50 years	100 years	5 years	10 years	25 years	50 years	100 years
07124700	440	980	2,290	3,920	6,340	[6]180	[6]400	[6]900	[6]1,520	[6]2,440	440	980	2,290	3,920	6,340
07125050	170	260	420	560	720	570	1,120	2,170	3,340	4,970	[4]570	[4]1,120	[4]2,170	[4]3,340	[4]4,970
07126400	820	1,700	3,600	5,800	8,880	1,440	2,160	3,170	4,080	5,160	1,010	1,910	3,320	4,510	5,530
07126450[3]	440	1,140	3,300	5,900	9,900	---	---	---	---	---	---	---	---	---	---
07129100[3]	730	1,600	3,550	5,850	9,000	---	---	---	---	---	---	---	---	---	---
07129200	280	650	1,510	2,600	4,200	2,270	3,030	4,040	4,860	5,760	877	1,720	3,160	4,300	5,600
07133200	550	1,220	2,800	4,750	7,620	1,310	1,920	2,800	3,580	4,460	778	1,540	2,800	3,370	4,480
07134300	2,220	3,910	7,070	10,300	14,400	2,020	3,630	6,290	9,800	13,500	2,160	3,780	6,560	9,930	13,590
07135800	1,140	2,200	4,020	5,920	8,360	1,890	2,890	4,330	5,660	7,220	1,370	2,510	4,220	5,730	7,330
07138520	740	1,450	2,950	4,640	6,940	4,200	5,630	7,640	9,330	11,200	1,780	3,330	6,000	8,160	10,770
07138600[5]	255	479	930	1,420	2,090	---	---	---	---	---	---	---	---	---	---
07138800[5]	163	211	277	329	385	---	---	---	---	---	---	---	---	---	---
07153450	60	100	160	210	270	220	320	460	590	740	[4]220	[4]320	[4]460	[4]590	[4]740
07154650[5]	4,450	7,250	12,100	16,700	22,400	---	---	---	---	---	---	---	---	---	---
07154800	100	200	410	640	950	220	350	560	770	1,070	136	268	508	738	1,060
07155510[5]	1,500	2,100	2,990	3,750	4,590	----	----	----	----	---	----	----	----	----	---
07155900[5]	1,010	2,270	5,330	9,180	14,900	----	----	----	----	---	----	----	----	----	---
07156600[5]	1,590	2,370	3,600	4,710	5,980	----	----	----	----	---	----	----	----	----	---
07156700[5]	575	820	1,190	1,510	1,870	----	----	----	----	---	----	----	----	----	---
07227295[5]	147	244	416	583	789	----	----	----	----	---	----	----	----	----	---
07232550[5]	48	75	120	158	200	----	----	----	----	---	----	----	----	----	---
07232650[5]	663	1,430	3,220	5,400	8,520	----	----	----	----	---	----	----	----	----	---

[1]Station names and locations given in tables 1, 2, and 3; general locations are shown in figure 2.
[2]Insufficient number of annual peak discharges for determination of recorded flood-frequency relation.
[3]Synthetic flood-frequency relation not determined because model calibration was unsatisfactory.
[4]Recorded flood-frequency relation not used in determining weighted values.
[5]Non-study station located in adjoining State; synthetic flood-frequency relation was not determined.
[6]Synthetic flood-frequency relation not used in determining weighted values.

Although variations in rainfall distribution, rainfall intensity and duration, and soil-moisture conditions may result in different runoff volume for floods of the same magnitude, a relation between peak discharge and flood volume for the plains region of Colorado was determined using only the largest flood hydrographs recorded for the 35 rainfall-runoff stations (tables 1 and 2). The data included 103 flood hydrographs for which peak discharges ranged from 50 to 3,300 ft^3/s and for which flood volumes ranged from 3 to 229 acre-ft. The relation is:

$$V = 0.164 Q_p^{0.895} \quad (S_e = 78, \ r = 0.75), \qquad (1)$$

where V is flood volume, in acre-feet;

Q_p is peak discharge, in cubic feet per second;

S_e is average standard error of estimate, in percent; and

r is correlation coefficient.

In a previous study of 105 floods on small watersheds in Wyoming, Craig and Rankl (1978) determined the following similar relation:

$$V = 0.131 \, Q_p^{0.878} \quad (S_e = 55, \ r = 0.90) \qquad (2)$$

Analysis of Synthetic Floods

Accuracy in estimating the magnitude and frequency of floods at a site improves with the number of years of flood information on which the analysis is based. The time-sampling error associated with an estimate of the 100-yr peak discharge based on 10 yr of station data is considerably greater than if the estimate is based on 50 yr of station data. For example, Livingston (1970) determined that, for streams in the mountainous region of Colorado, the standard error for the 25-yr peak discharge decreased from 24 percent with a 10-yr record to 11 percent with a 50-yr record.

To improve the flood-frequency relations for stations in this study, a rainfall-runoff simulation model, described in detail by Dawdy and others (1972), was calibrated and used to synthesize a long-term, annual flood series for 30 of the study watersheds.

Description of Data Used as Model Input

From all rainfall-runoff data collected from the 35 stations in the plains region, a data set of 236 storms was selected for use in the calibration of the rainfall-runoff model. Selection of storms for inclusion in this data set was based on: (1) The relative compatibility of rainfall totals or intensities with runoff volumes or peak discharges; (2) the reliability of recorded stage and rainfall data; (3) the time between beginning of rainfall and recording of runoff as an indication of uniform precipitation over the watershed; and (4) a preference for data from periods that had the greatest rainfall and runoff, during which the entire watershed is more likely responding. The 236 selected storms had peak discharges ranging from 4.5 to 3,300 ft^3/s, of which only 74 storms had peak discharges greater than 50 ft^3/s.

The rainfall-runoff model requires daily precipitation and evaporation data in addition to unit (5-min) rainfall and runoff data. Daily rainfall data were recorded either at the rainfall-runoff station or, during missing-record periods, at the nearest National Weather Service station. Daily evaporation data were recorded from the closest of the following National Weather Service stations: Fort Collins (station 3005), Bonney Lake (station 834), or Kingley Dam, Nebraska (station 4455) for the South Platte River basin; and Pueblo City Reservoir (station 6743) or John Martin Reservoir (station 4388) for the Arkansas River basin. For the period of seasonal operation of the rainfall-runoff stations, these data and the unit rainfall and runoff data were used to calibrate the infiltration, soil-moisture accounting, and surface-runoff routing components of the model.

Calibration of Rainfall-Runoff Model

The calibration phase of the modeling process resulted in an optimum set of 10 parameters for each watershed. The definition and application of each parameter and variable used in the modeling process is listed in table 5. Final values of the model parameters are listed in tables 14 and 15 (in the "Supplemental Information" section at the back of the report) for each of the 33 stations for which there were 3 or more rainfall-runoff periods to provide calibration; two stations had less than 3 rainfall-runoff periods. For all stations, the value of one moisture-accounting parameter, DRN, was held constant at 1.00 and the value of one runoff-routing parameter, TP/TC, was held constant at 0.50. Another moisture-accounting parameter, EVC, was determined from Kohler and others (1959) to be 0.7 for all stations. Parameter RR was held constant at 0.95 for stations in the South Platte River basin, while it was allowed to vary from 0.90 to 1.00 for stations in the Arkansas River basin. As described by Alley and Smith (1982), an infiltration parameter, KSAT, was optimized first by minimizing the value of the objective function through a selected range of KSAT values while all other parameter values were held constant. All other parameter values were then determined by optimization during the modeling process.

Early in the calibration process, the recorded peak-discharge-runoff volumes from many stations were determined to be consistently less than the model predicted using the recorded rainfall data and reasonable limits of values for model parameters and variables. Consequently, an effective drainage area was determined for each watershed (effective drainage area is explained in detail in the "Effective Drainage Area" section of the report). Use of this generally smaller area in the modeling process resulted in greatly improved calibrations for most stations.

The correlation coefficient, root-mean-square error, and slope of the regression line between recorded and synthetic peak discharges for the calibration of each station, all of which are measures of the relative success of the calibration, also are listed in tables 14 and 15. One station in the South Platte River basin (06821400) and two stations in the Arkansas River basin (07126450 and 07129100), had statistically unsuccessful calibrations, leaving 30 stations for use in the synthesis phase of the modeling process.

Table 5.--*Definition and application of parameters and variables used in the modeling process*

[modified from Lichty and Liscum, 1978; --, not applicable; ---, dimensionless]

Parameter	Variable	Units	Definition and application
BMSM	--	Inches	Soil-moisture storage at field capacity. Maximum value of base (unsaturated) moisture storage, BMS.
RR	--	---	Proportion of daily rainfall that infiltrates the soil.
EVC	--	---	Pan evaporation coefficient.
DRN	--	---	Drainage factor for redistribution of saturated moisture storage, SMS, to base (unsaturated) moisture storage, BMS, as a fraction of hydraulic conductivity, KSAT.
--	BMS	Inches	Base (unsaturated) moisture storage in active soil column. Simulates antecedent moisture content throughout the range from wilting-point conditions, BMS=0, to field capacity, BMS-BMSM.
--	SMS	Inches	"Saturated" moisture storage in wetted surface layer developed by infiltration of storm rainfall.
--	FR	Inches per hour	Infiltration capacity, a function of KSAT, PSP, RGF, BMSM, SMS, BMS.
KSAT	--	Inches per hour	Hydraulic conductivity of "saturated" transmission zone.
PSP	--	Inches	Combined effects of moisture deficit, as indexed by BMS, and capillary potential (suction) at the wetting front for BMS equal to field capacity, BMSM.
RGF	--	Hours	Ratio of combined effects of moisture deficit, as indexed by BMS, and capillary potential (suction) at wetting front for BMS=0=wilting point, to the value associated with field capacity conditions, PSP.
KSW	--	Hours	Linear reservoir recession coefficient.
TC	--	Minutes	Time base (duration) of triangular translation hydrograph.
TP/TC	--	---	Ratio of time to peak of triangular translation hydrograph to duration of translation hydrograph, TC.
--	SW	Inches	Linear reservoir storage.

In general, stations having unsuccessful calibrations had calibration statistics indicating either a small correlation coefficient, a large root-mean-square error, a regression line slope significantly different than 1.0, or a combination of these factors.

Effective Drainage Area

The U.S. Soil Conservation Service has constructed numerous erosion-control and flood-retarding structures on small watersheds throughout eastern Colorado. These structures generally were designed to retain at least a 25-yr flood. Although an effort was made during selection of study watersheds to avoid those with such structures, essentially all the watersheds selected contained at least one erosion-control structure. The existence of the structures was determined from 7.5-min topographic maps and available aerial photographs; their integrity was confirmed by onsite inspections.

Effective drainage area is the contributing drainage area for more frequent (less than a 25-yr recurrence interval) floods; it is calculated by subtracting the drainage areas upstream from all erosion-control structures or flood-retarding structures in the basin from the total drainage area. A good relation does not appear to exist between total and effective drainage area. Data from 30 of the 35 study watersheds (tables 1 and 2), 13 of the 17 watersheds located in adjoining States (table 3), and 21 randomly selected small watersheds in the plains region are shown in figure 6; watersheds with total drainage area greater than 30 mi^2 were not included. The obvious scatter of data indicates that effective drainage area cannot be estimated reliably from the total drainage area of the watershed.

As previously mentioned in the section entitled "Calibration of Rainfall-Runoff Model," calibration of the rainfall-runoff model was enhanced substantially by use of an effective drainage area rather than total drainage area. It is clear from figure 3 that most of the data available for calibration of the model probably would not have caused any erosion-control structures in the study watersheds to be breached or topped. Thus, the flood retention or detention features of such structures were assumed to be entirely effective for purposes of calibrating the rainfall-runoff model to more frequent (less than a 25-yr recurrence interval) floods that were recorded during this study.

The result of using an effective drainage area for the next phase of the modeling process, synthesis of a long-term annual flood series, is uncertain. Because the model calibration accounted for the soil-moisture and runoff-routing characteristics of only this generally smaller drainage area, the synthesis of peak discharge for a long-term flood history for the watershed necessarily used the same effective drainage area. Unfortunately, it also is likely that for some unknown frequency of peak discharge, or for some extreme antecedent conditions, the drainage areas upstream from the erosion-control structures likely would contribute to (and therefore increase the discharge of) downstream peak discharges. A frequency analysis of the synthetic flood data therefore would yield discharges that would be too small for these conditions.

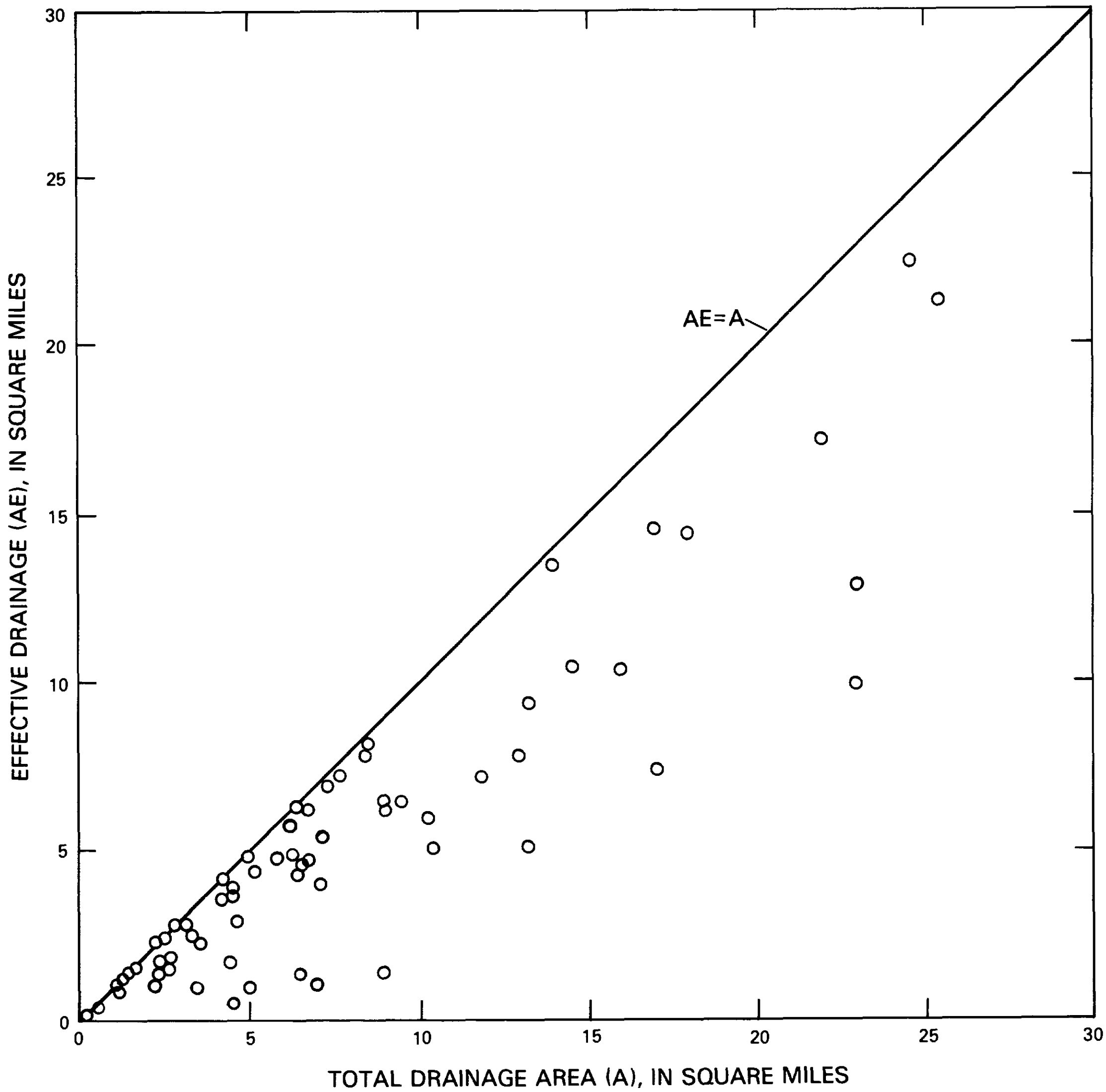

Figure 6.--Relation between total and effective drainage area.

The effectiveness of floodwater-retarding structures in Oklahoma was studied by Tortorelli and Bergman (1984). Using a hydrologic model of a 10.7 mi^2 watershed, the results indicated that for even a 500-yr storm, the storm runoff from the 7.94 mi^2 part of the watershed that was regulated caused no significant increase in simulated peak discharges downstream when the reservoir initially was dry; simulations showed less than a 10-percent increase in simulated peak discharges downstream when initial reservoir capacity was decreased by one-half. Noteworthy is the fact that the structures in the Oklahoma study had uncontrolled outlets designed to empty a full reservoir in 10 days or less; erosion-control structures in Colorado generally do not have such features. On the basis of those findings, the frequency analysis of the synthetic data was assumed to be valid at least through the 100-yr flood extreme determined by this study.

Synthesis of Long-Term Annual Flood Series

The following National Weather Service climatological stations provided the climatic data required for the synthesis phase of the modeling process:

Denver, Colo. (station 2220)------------------rainfall, 1898-1970
John Martin Dam, Colo. (station 4388)---------evaporation, 1950-1975
Pueblo, Colo. (station 6740)------------------rainfall, 1900-1969
Pueblo City Reservoir, Colo. (station 6743)---evaporation, 1950-1975
Amarillo, Tex. (station 23047)----------------rainfall, 1914-1974
Wichita Falls, Tex. (station 13966)-----------evaporation, 1950-1974
Cheyenne, Wyo. (station 1675)-----------------rainfall, 1912-1972
Fort Collins, Colo. (station 3005)------------evaporation, 1950-1979
North Platte, Nebr. (station 6065)------------rainfall, 1916-1977
Kinglsey Dam, Nebr. (station 4455)------------evaporation, 1943-1979
Bonny Lake, Colo. (station 834)---------------evaporation, 1950-1979

Rainfall data consisted of daily rainfall for the indicated period and unit (5-min) rainfall for the three to five greatest storms occurring in each year of the period. One of the three to five storms was assumed to produce the annual maximum peak discharge, although this peak discharge would not necessarily be associated with the greatest total rainfall. Evaporation data consisted of seasonal daily pan evaporation for the indicated period. To be compatible with the long-term rainfall data, daily pan evaporation for the period prior to 1950 (prior to 1943 for Kingsley Dam) was synthesized based on 3-day moving averages calculated from the evaporation data for the actual period of record.

For watersheds in the South Platte River basin, long-term rainfall data for the cities of Denver, Cheyenne, and North Platte were used along with evaporation data for either Fort Collins, Bonny Lake, or Kingsley Dam. For watersheds in the Arkansas River basin, long-term rainfall data for the cities of Denver and Pueblo were used along with evaporation data for either John Martin Dam or Pueblo City Reservoir, and long-term rainfall data for Amarillo were used along with evaporation data for Wichita Falls.

Peak-Discharge Frequency

Because of the number of long-term rainfall records used, the frequency analyses of the synthetic annual-flood series provided several separate estimates of the flood-frequency relation for each rainfall-runoff station. The two synthetic flood-frequency relations for the Arkansas River basin (those based on long-term rainfall records for Pueblo and Amarillo), and the three synthetic flood-frequency relations for the South Platte River basin (those based on long-term records for Denver, Cheyenne, and North Platte) were combined within the respective basins using a weighting procedure. (The synthetic relation based on long-term rainfall records for Denver was not used in the Arkansas River basin because it was within 20 percent of the relations for Pueblo.)

The weighting procedure used to develop a single synthetic flood-frequency relation for each station was based on the relative magnitude of the 1-hour, 100-yr rainfall intensity at the rainfall-runoff station and at the long-term rainfall stations. The 1-hour, 100-yr rainfall intensity was selected for this procedure because storms recorded in the eastern plains average about 45 min in length (fig. 4) and because primary emphasis in the study was on the less frequent storms. In inches, the 1-hour, 100-yr rainfall intensity is 2.7 at Pueblo, 3.5 at Amarillo, 2.5 at Cheyenne, 2.6 at Denver, and 3.3 at North Platte (Miller and others, 1973). Therefore, the weighting equation used for the Arkansas River basin was:

$$Q_{synthetic} = Q_{Pueblo} \frac{(3.5 - I1\_100)}{(0.8)} + Q_{Amarillo} \frac{(I1\_100 - 2.7)}{(0.8)} \; ; \qquad (3)$$

and that for the South Platte River basin was:

$$Q_{synthetic} = \frac{(0.8 - |I1\_100 - 2.5|)\, Q_{Cheyenne} + (0.8 - |I1\_100 - 2.6|)\, Q_{Denver} + (0.8 - |I1\_100 - 3.3|)\, Q_{North\ Platte}}{2.4 - (|I1\_100 - 2.5| + |I1\_100 - 2.6| + |I1\_100 - 3.3|)} \; ; \qquad (4)$$

where I1_100 is the 1-hour, 100-yr rainfall intensity at each rainfall-runoff station (see section entitled "Independent variables" and table 16 in the "Supplemental Information" section at the back of the report). For those stations in the Arkansas River basin with 1-hour, 100-yr rainfall intensities less than 2.7 in., full weight was given to the frequency relation generated using long-term rainfall data for Pueblo. The final synthetic peak-discharge-frequency results using this procedure are summarized in table 4.

As shown in figure 3 and listed in table 4, the values for the synthetic flood-frequency relations generally were larger than values for the recorded flood-frequency relations; a total of 28 stations had both recorded and synthetic flood-frequency relations. In terms of discharge per square mile of contributing drainage area, the average 100-yr flood discharge for these stations was determined to be 990 $ft^3/s/mi^2$ based on the recorded data and 1,410 $ft^3/s/mi^2$ based on the synthetic data.

Relation Between Peak Discharge and Flood Volume

The rainfall-runoff model produces peak discharge and flood volume during the synthesis phase. A simple linear regression of the volume associated with each peak discharge was completed for each long-term rainfall station to determine if the synthetic data might yield a relation similar to that developed from the recorded data (eq. 1). The analysis was accomplished using the individual syntheses from each long-term rainfall station and the combined data from all five syntheses. The Denver syntheses yielded 946 floods, the Cheyenne syntheses yielded 991 floods, the North Platte syntheses yielded 889 floods, the Pueblo syntheses yielded 1,044 floods, and the Amarillo syntheses yielded 521 floods. Peak discharges (Q_p) for these floods ranged from 2 to 9,070 ft^3/s for Denver, 2 to 7,350 ft^3/s for Cheyenne, 4 to 12,680 ft^3/s for North Platte, 3 to 12,900 ft^3/s for Pueblo, and 5 to 15,680 ft^3/s for Amarillo. Flood volume (V) for these floods ranged from 0.59 to 746 acre-ft for Denver, 0.77 to 673 acre-ft for Cheyenne, 0.82 to 1,136 acre-ft for North Platte, 0.98 to 1,889 acre-ft for Pueblo, and 0.98 to 3,893 acre-ft for Amarillo. The following relations were determined:

South Platte River basin data

Denver, Colo.,
long-term record: $V = 0.424Q_p^{0.759}$ (S_e = 84, r = 0.87) (5)

Cheyenne, Wyo.,
long-term record: $V = 0.263Q_p^{0.797}$ (S_e = 84, r = 0.88) (6)

North Platte, Nebr.,
long-term record: $V = 0.274Q_p^{0.859}$ (S_e = 81, r = 0.90) (7)

Arkansas River basin data

Pueblo, Colo.,
long-term record: $V = 0.141Q_p^{0.919}$ (S_e = 62, r = 0.92) (8)

Amarillo, Tex.,
long-term record: $V = 0.139Q_p^{0.964}$ (S_e = 56, r = 0.93) (9)

Combined data

Five long-term records: $V = 0.222Q_p^{0.866}$ (S_e = 78, r = 0.91) (10)

Of equations 5-10, the relation based on the combined syntheses (eq. 10) probably is most representative of less frequent floods in the eastern plains region in Colorado. As shown in figure 7, the individual relations yield a relatively wide range of flood-volume estimates, especially at the extremes of small or large peak discharge. For small peak discharges such as 10 ft^3/s, the flood-volume estimates range from 1.2 acre-ft based on the Pueblo synthesis, to 2.4 acre-ft based on the Denver synthesis. For large peak discharges such as 10,000 ft^3/s, the flood volume estimates range from about 400 acre-ft based on the Cheyenne synthesis, to 1,000 acre-ft based on the Amarillo synthesis. The relation from the combined data (eq. 10) not only is more representative of an extensive region such as the eastern plains of Colorado, but it also results in estimated flood volumes only slightly larger (about 16 percent) than the relation from only recorded data (eq. 1) and indicates a larger correlation coefficient. The fact that recorded data gives a lower estimate of flood volume does, however, suggest the possibility that the relation based on combined synthetic data may overestimate flood volume.

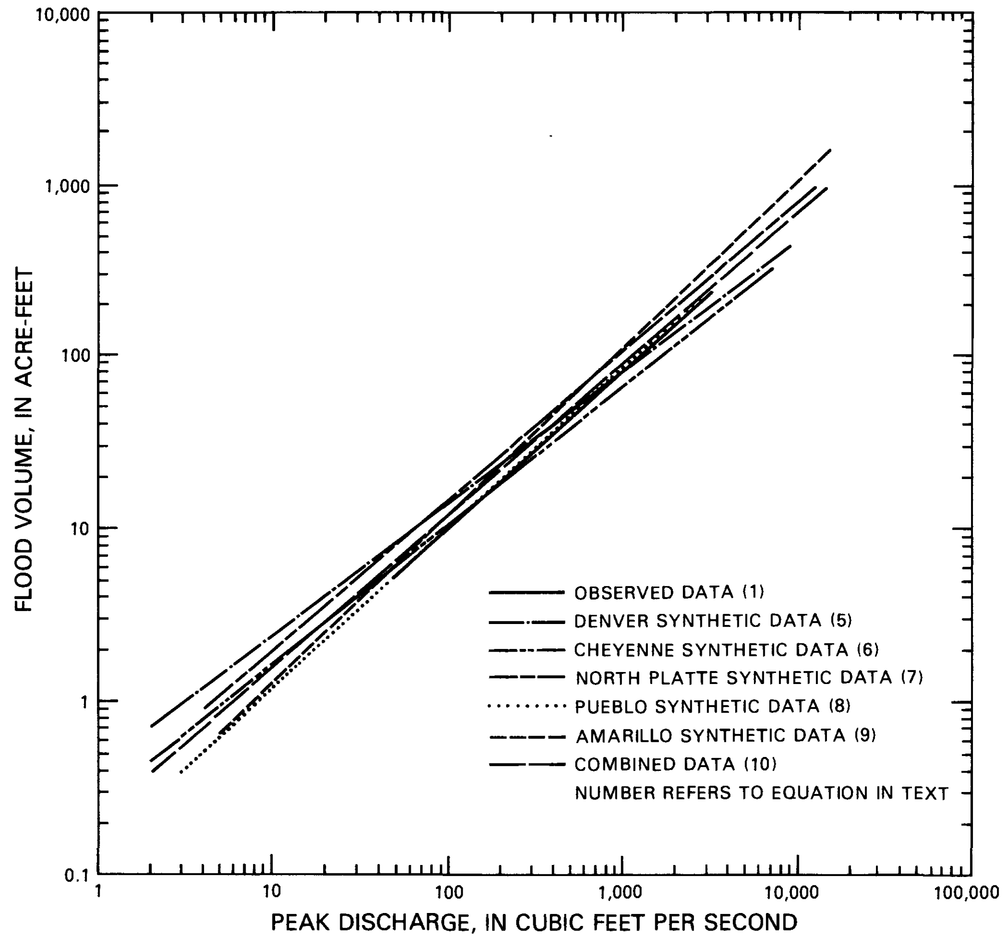

Figure 7.--Relations between flood volume and peak discharge.

REGRESSION ANALYSIS

Very seldom is flood-frequency information required at or near a gaging station where data are available for a station flood-frequency analysis. More typically, particularly for small watersheds in the semiarid West, data of this type are required at an ungaged site. As a result, station flood-frequency information frequently is regionalized (areally extrapolated) for planning and design purposes. Regional information also can be used to improve estimates of station flood frequency by decreasing the time-sampling errors that are associated with short, at-site recorded information (Sauer, 1973; McCain and Jarrett, 1976).

Dependent Variables

The flood characteristics selected as dependent variables for regionalization were the peak discharges for recurrence intervals of 5 yr (Q5), 10 yr (Q10), 25 yr (Q25), 50 yr (Q50), and 100 yr (Q100) for 34 watersheds in Colorado (one watershed had no relation) and 17 watersheds in adjoining States (table 4). Results of two different flood-frequency analyses have been discussed thus far: analysis of recorded annual-flood series and analysis of synthetic annual-flood series. For the 28 watersheds in Colorado that have flood characteristics estimated from both analyses (table 4), a single, combined result was necessary for regionalization purposes.

Combining Recorded and Synthetic Flood Characteristics

Lichty and Liscum (1978) developed a method of computing a weighted average of recorded and synthetic flood-frequency relations based on an analysis of variance; the result by this method was determined to be an improved estimate of the flood characteristic. This method requires that one flood-frequency relation not be biased compared to the other (one relation giving consistently larger or smaller estimates than the other). However, comparisons of recorded and synthetic flood-frequency relations in this study (table 4), indicate that the synthetic estimates generally are larger than the recorded estimates, especially for the Q5 and Q10 flood characteristics. In general, the probable reason for this bias is that the rainfall-runoff model used for this study primarily is designed to simulate larger or less frequent (Q50 and Q100, for instance) floods and, as a result, tends to overestimate the more frequent (Q5, and Q10, for instance) floods. It also is possible that the period of record for which recorded estimates were based generally had smaller or less frequent floods than the long-term period. For this reason, a modified analysis of variance method, as suggested by R.W. Lichty (U.S. Geological Survey, oral commun., 1982) was used where regression (model) variance was computed as the variance of estimates from the regression line of recorded versus synthetic flood-frequency relations rather than from the equality line.

Application of the variance-weighting method was done separately for data from the South Platte and Arkansas River basins. Because of the very large time-sampling error (short period of record) available for analyses, application of this variance-weighting method only was successful for the 5-yr, 10-yr, and 25-yr recurrence intervals. The weighting factors used for the 50-yr and 100-yr recurring intervals were determined by judgment based on the 5-, 10-, and 25-yr factors and the results of previous studies (Thomas and Corley, 1977; Livingston, 1981). The final average weighting factors used for all 28 watersheds are given in table 6.

Table 6.--*Weighting factors used to combine recorded and synthetic flood characteristics*

[Q5, Q10, ...Q100 are the peak discharges for recurrence intervals of 5, 10, ...100 years]

Flood characteristics	Weighting factor for indicated flood-frequency relation	
	Recorded (F_r)	Synthetic (F_s)
Q5	0.70	0.30
Q10	.55	.45
Q25	.35	.65
Q50	.25	.75
Q100	.10	.90

The weighted flood-frequency relation is shown for each of the 28 watersheds in table 4. For most watersheds, this relation was determined using the equation:

$$Q_w = F_r (Q_r) + F_s (Q_s) \qquad (11)$$

where Q_w is the weighted discharge,

Q_r is the recorded discharge,

Q_s is the synthetic discharge, and

F_r and F_s are the weighting factors shown in table 6.

For station 07124700, full weight was given to the recorded flood-frequency relation because the synthetic flood-frequency relation was too low in comparison with relations for other stations. Similarly, full weight was given to the synthetic flood-frequency relation for stations 06758150, 06760430, 06834200, 07125050, and 07153450 because the estimate of the 100-yr peak discharge based on recorded data was less than the estimate of the 10-yr peak discharge based on synthetic data.

Because the factors give substantial weight to the synthetic flood-frequency relations, especially the 25-, 50-, and 100-yr recurrence intervals, a comparison was made between recorded peak discharges and synthetic peak discharges for 71 of the largest storms used in the model-calibration process to determine if a bias existed between the two. For instance, if the synthetic peak discharges were consistently larger than the recorded peak discharges, the relatively large weight given the synthetic 25-, 50-, and 100-yr peak discharges would tend to accentuate this bias. Peak discharges for the 71 storms used for this comparison ranged in peak discharge from 63 to 2,900 ft^3/s; the resulting relation is shown in figure 8. This relation has a correlation coefficient of 0.84, and the slope of the regression line is 0.93. These statistics indicate that the model calibration is unbiased for the larger storms.

Final Flood-Frequency Relations

The dependent variables used in the regression analysis included the weighted flood-frequency relation for 28 watersheds (as explained in the section "Combining Recorded and Synthetic Flood Characteristics"), either the recorded or synthetic flood-frequency relations for the remaining 6 watersheds, and the recorded flood-frequency relations for 17 non-study basins (table 4). These flood-frequency relations were considered the "best estimate" for the subsequent regression analysis; they are presented in table 16 in the "Supplemental Information" section at the back of the report.

Independent Variables

A total of 16 independent variables were selected to describe the physical and climatic characteristics of the watersheds; these variables are defined in table 7. With the exception of the previously discussed variable of effective drainage area, these variables are relatively easy to determine from available topographic maps (usually 7.5-min series) of the watershed and simple field surveys of the channel at the study site. Although it would have been desirable to include an independent variable related to soil infiltration characteristic of each watershed (such as average infiltration rate in inches per hour), this could not be accomplished because of incomplete soils mapping in some of the study area.

Correlation analysis was used to: (1) Evaluate possible improvements in the relation with each dependent variable due to the subtraction of a constant from the value of selected independent variables (linearization of the relation); and (2) determine highly correlated variable pairs that needed to be avoided in the regression analysis (assurance of independence). A range of constants were subtracted from calculated values for each of eight variables (A, AE, E, R, L, WD1, WD5, and LI). Correlation coefficients were improved substantially for two combinations of variable E and R; thus, the following independent variables were produced:

EF (Elevation factor)	Equal to original variable E minus 2,600 ft.
RF (Relief factor)	Equal to original variable R minus 18 ft.

The variables E and R were not used further in the analysis.

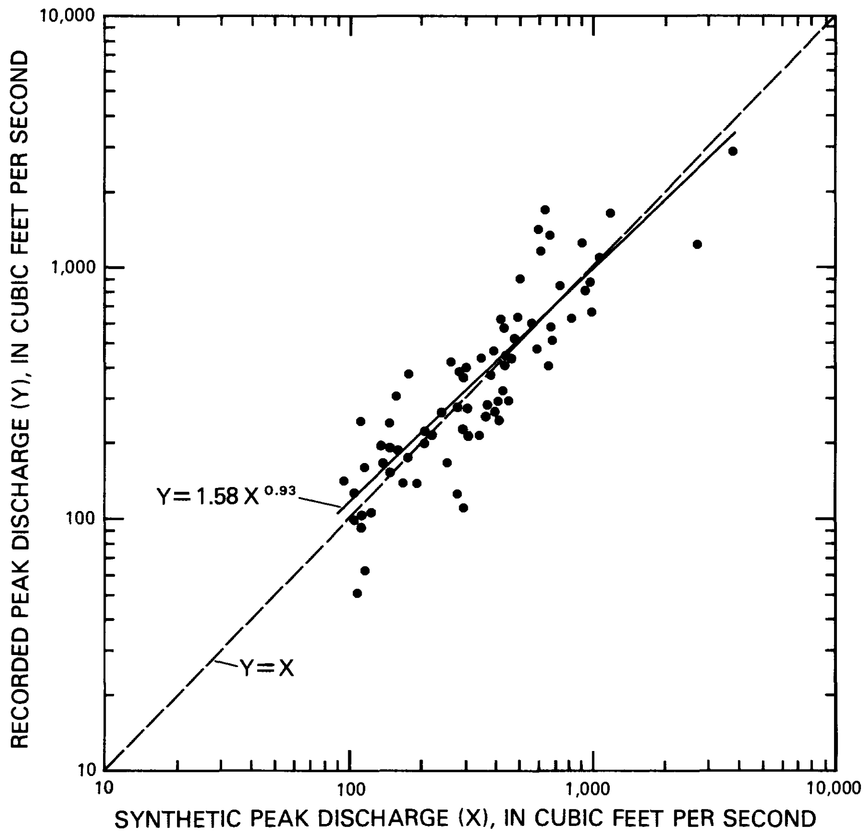

Figure 8.--Relation between recorded peak discharge and synthetic peak discharge for 71 of the largest storms used in model calibration.

Table 7.--*Definition of independent variables used in multiple-regression analysis*

Variable		Units	Definition
Name	Symbol		
Total drainage area	A	Square miles	Total topographic drainage area of the watershed.
Effective drainage	A	Square miles	Contributing drainage area for more frequent floods. Calculated by subtracting drainage areas for all erosion-control or flood-retention structures in the basin from the total drainage area. A more detailed discussion of the variables is given in the "Independent Variables" section of the report.
Elevation	E	Feet	Altitude above sea level of the study site (gage site or point where dependent variables is to be estimated). This variable later replaced by Elevation factor (EF), where EF equals E minus 2,600 feet.
Relief	R	Feet	Altitude difference between that for highest point within effective drainage area and that of study site. This variable later replaced by Relief factor (RF), where RF equals R minus 18 feet.
Mainstem length	L	Miles	Length of main channel from the study site to the watershed divide of the effective drainage area.
Streambed slope	SS	Feet per mile	Slope of main channel from the study site to a point about 10 bankfull widths up-stream.
Channel slope	SC	Feet per mile	Average slope of the main channel. Computed by the 85 percent/10 percent method described by Benson (1962).
Watershed slope	SW	Feet per mile	Average slope of the watershed within effective drainage area. Obtained by measuring lengths in miles of all 100-foot contour lines, multiplying by 100 feet, and dividing resultant product by the effective drainage area.
Channel widths	WD1 WD3 WD5	Feet	Average channel width at 1, 3, or 5 feet above the thalweg. Measured at a minimum of 10 locations in the vicinity of the study area, each spaced about a bankfull width apart.
Rainfall intensities	I1_100 I6_100 I24_100	Inches	Average rainfall intensities for durations of 1, 6, or 24 hours, and recurrence interval of 100 years (Miller and others, 1973).
Latitude index	LI	Degree	Latitude of study site expressed as a decimal minus 36 (for example, 39°30' expressed as 3.50).
Shape factor	S	---	Ratio of the square of the mainstem length divided by the effective drainage area.

A correlation matrix of all 16 final independent variables for the 51-station data set is given in table 8. Correlations greater than 0.70 were determined for the following nine variable pairs:

I6_100	I24_100	(r=0.98)
RF	SC	(r=0.93)
I1_100	I6_100	(r=0.92)
AE	L	(r=0.88)
I1_100	I24_100	(r=0.87)
EF	I1_100	(r=-0.86)
WD1	WD3	(r=0.80)
WD3	WD5	(r=0.79)
EF	I6_100	(r=-0.74)

These combinations of independent variables were avoided in subsequent regression analyses. For example, both AE and L (r=0.88) were not used in any particular regression equation.

Data Transformations

As frequently done when using hydrologic data, values of the dependent and independent variables were expressed as logarithms (base 10) for use in the regression analysis. The objective of this transformation was to ensure that the residuals have approximately a normal distribution and that the relation between the dependent and independent variables is approximately linear. The relation between log (Q25) and log (AE) is shown in figure 9*A*; some nonlinearity is indicated. Tasker and others (in press) suggested that another transformation of the drainage-area variable, specifically $AE^{-0.125}$, might yield a more linear relation with the dependent variable. This transformation of variable AE, shown in figure 9*B*, also indicates some nonlinearity with log Q25, but certainly the relation is no worse than that shown in figure 9*A*. The least-squares equations for the two relations have essentially the same standard errors of estimate and correlation coefficients. Thus, in addition to the logarithms of the 16 independent variables, both $A^{-0.125}$ and $AE^{-0.125}$ were included in the regression analyses. Because of the obviously large degree of cross correlation, both transformations of either AE or A were not used in the regression analysis at the same time.

Ordinary Least-Squares Method

One of the most effective methods presently known for defining streamflow characteristics (such as flood frequency) is to relate them to watershed and climatic characteristics by use of multiple-regression techniques applied to historical data (Benson and Carter, 1973). To estimate regression parameters, the ordinary least-squares (OLS) method typically is used. Application of this method was used to detect outliers in the data set and to determine a regional-regression equation. Initial analyses for the dependent variables Q5, Q25, and Q100 indicated that data for several stations did not adequately fit the regression model. For example, a comparison of observed values to predict regression estimates for Q25, the 25-yr peak discharge is shown in

Table 8.--*Matrix of correlation coefficients and selected statistics for independent variables*

Independant variable[1]	Matrix of correlation coefficient: A	AE	EF	RF	L	SS	SC	SW	WD1	WD3	WD5	I1_100	I6_100	I24_100	LI	S	Mean	Standard deviation	Minimum value	Maximum value
A	1.00	0.66	-0.33	-0.07	-0.52	-0.18	-0.26	-0.20	-0.18	-0.10	-0.11	0.36	0.35	0.35	-0.12	0.01	9.93	12.4	0.26	75.0
AE		1.00	-.32	.14	.88	-.28	-.14	.04	-.20	-.11	-.21	.23	.24	.23	-.02	.14	5.69	5.06	.26	22.6
EF			1.00	.44	-.20	-.02	.60	.33	-.16	-.20	-.13	-.86	-.74	-.67	-.02	.15	1898	1047	75	4280
RF				1.00	.24	.11	.93	.60	-.13	-.23	-.30	-.36	-.24	-.18	-.26	.18	366	500	2.00	3432
L					1.00	-.32	-.02	.08	-.14	-.07	-.22	.06	.13	.15	-.04	.51	4.81	2.56	.91	13.2
SS						1.00	.22	.05	.34	.40	.18	.03	-.03	-.04	.07	-.08	37.4	29.6	2.88	155
SC							1.00	.64	-.12	-.24	-.28	-.50	-.39	-.32	-.22	.12	62.5	59.5	13.7	390
SW								1.00	-.28	-.39	-.44	-.35	-.34	-.32	.04	.10	326	263	39.8	1050
WD1									1.00	.80	.57	.15	.15	.16	-.07	.06	22.5	18.5	3.60	108
WD3										1.00	.79	.19	.17	.16	.02	.03	50.0	34.9	10.3	158
WD5											1.00	.09	-.05	.07	.04	-.07	87.0	58.4	14.0	244
I1_100												1.00	.92	.87	-.29	-.27	3.06	.38	2.40	3.70
I6_100													1.00	.98	-.56	-.19	4.38	.82	3.10	5.60
I24_100														1.00	-.64	-.15	5.34	1.03	3.80	7.00
LI															1.00	.06	2.73	1.48	.39	5.26
S																1.00	4.94	2.12	1.43	12.7

[1]See table 7 for complete description of each independent variable.

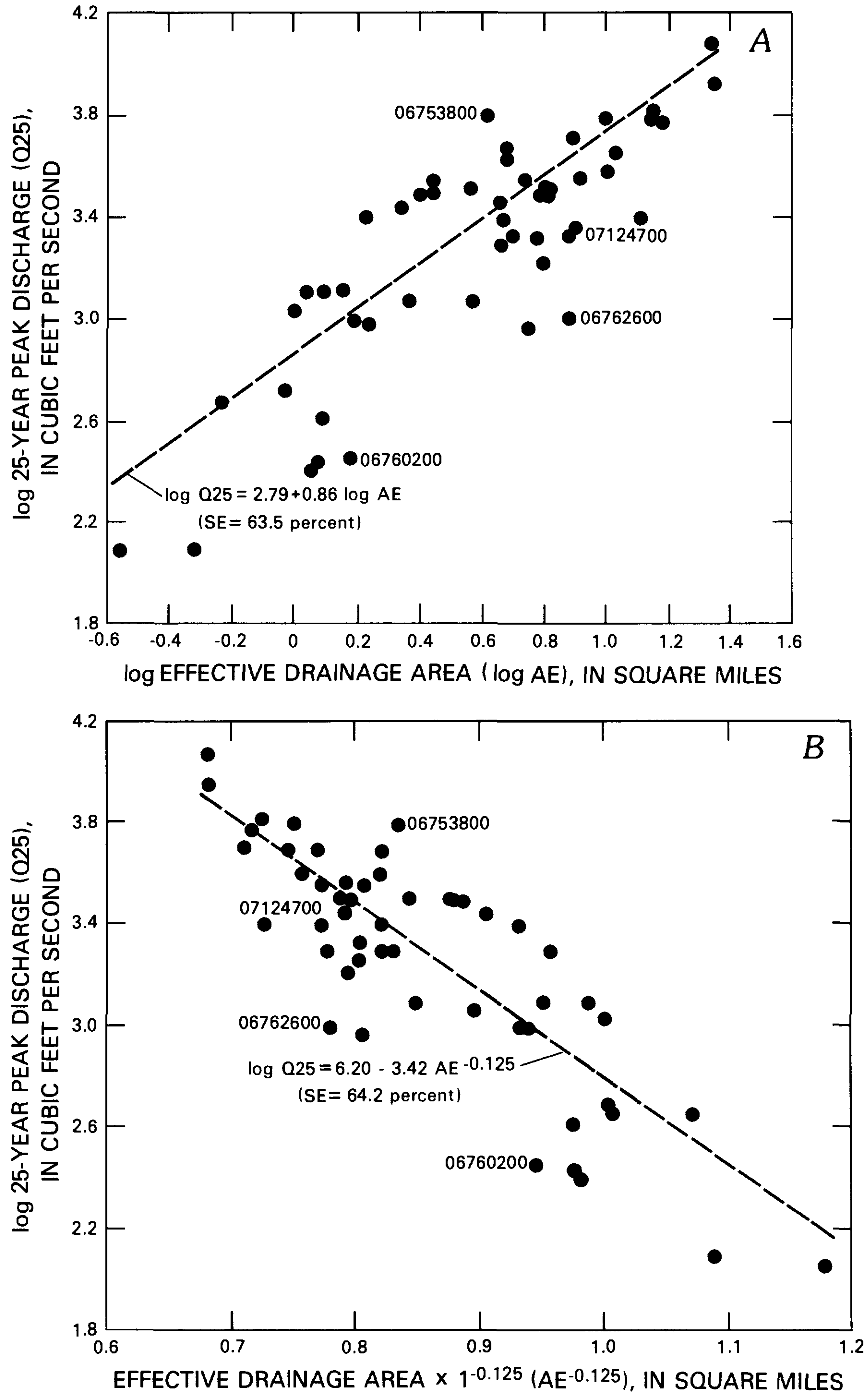

Figure 9.--Relation between log 25-year peak discharge (Q25), and *A*, log effective drainage area (AE), and *B*, effective drainage area ($AE^{-0.125}$).

figure 10. This illustration shows that several stations appear to be outliers: 06753800, 06760200, 06762600, and 07124700. They also are shown to be outliers in figure 9, indicating that the frequency relations developed for these particular stations may be in error. These four stations, in addition to station 06844800 for which the annual-flood series had a standard deviation that exceeded 80 percent of the mean value, were deleted from further analyses.

Using the decreased data set of 46 stations, the OLS method produced regional equations for each dependent variable. The equations are of the form:

$$Y = a + b_1 X_1 + b_2 X_1 + b_2 X_2 + \ldots + b_i X_i; \qquad (12)$$

where Y is a flood characteristic (dependent variable);
a is the regression constant;
$b_1 - b_i$ are regression coefficients; and
$X_1 - X_i$ are watershed and climatic characteristics (independent variables).

Those variables found significant at the 5-percent level in at least one equation included log AE, $AE^{-0.125}$, log RF, and log SW.

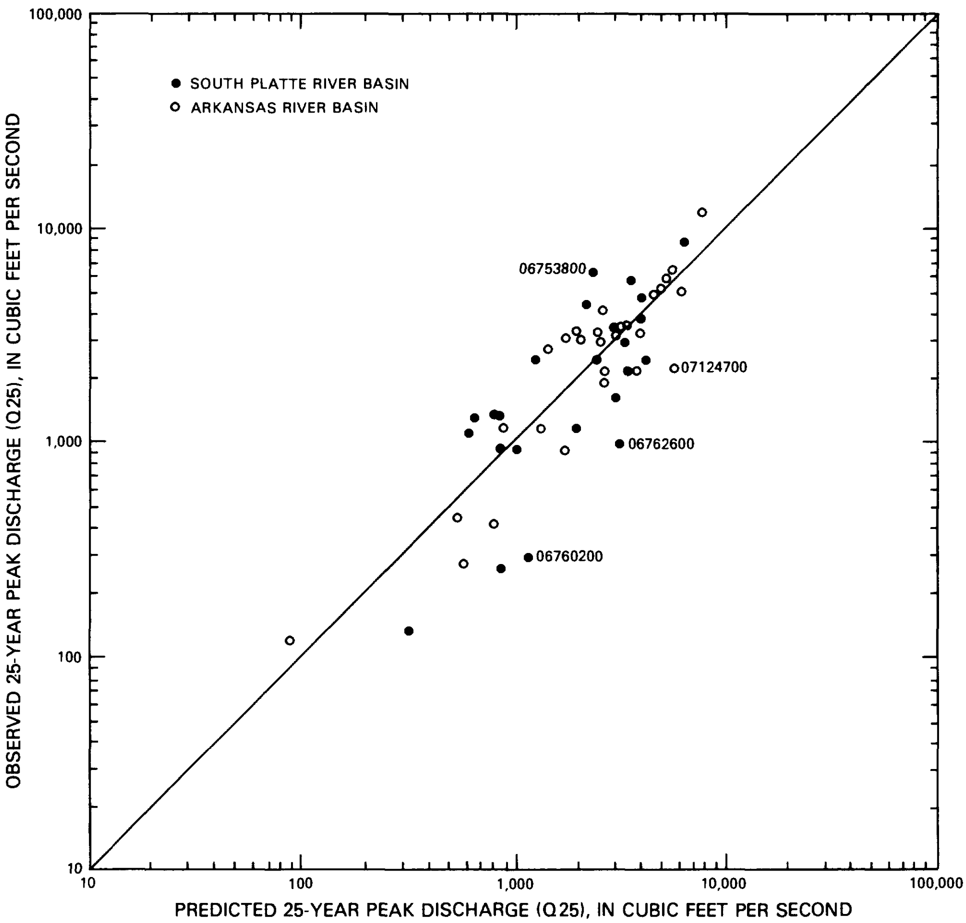

Figure 10.--Relation between observed and predicted 25-year peak discharge (Q25) by ordinary least-squares method.

The relations developed by OLS that had the smallest overall standard errors of regression, and in which all independent variables were significant at the 5-percent level, are given in table 9. Standard errors of regression were smallest for the 10- and 25-yr peak discharge (51 percent) and largest for the 100-yr peak discharge (59 percent). McCain and Jarrett (1976) determined similar results in a previous study of generally larger watersheds. Their relations for the plains region of eastern Colorado had standard errors of regression of 31 percent for Q10, 24 percent for Q50, and 28 percent for Q100; other frequencies were not presented. The smaller errors in that previous study are indicative of the comparatively lesser variability of flood discharges for larger watersheds in the region.

Generalized Least-Squares Method

Unfortunately, some of the basic assumptions for OLS, namely that site-to-site variances of the streamflow characteristic are the same and that concurrent flows are independent, usually are violated because these variances are affected by the length of record on which they are based, and concurrent flows typically are cross-correlated between some watersheds. Stedinger and Tasker (1985) developed a procedure to estimate the covariance matrix that is required for use of the more appropriate techniques of generalized least-squares (GLS) (Johnston, 1972) or of simple weighted least-squares (WLS) (Draper and Smith, 1981). By use of Monte Carlo experiments, Stedinger and Tasker (1985) concluded that WLS and GLS are statistically superior methods to OLS in the estimation of parameters for regional hydrologic-regression models. Additionally, GLS provides an error of prediction that incorporates both the effects of the sampling error and the model error; OLS only provides an error of regression, which is the model error. Application of the GLS method to a regional flood-frequency analysis for Pima County, Arizona, was described by Tasker and others (in press).

The basic regression model using GLS can be written in matrix form as:

$$\underline{\hat{Y}} = \underline{X}\ \underline{B} + \underline{e}; \tag{13}$$

where $\underline{\hat{Y}}$ is an estimated flood characteristic (dependent variable);
$\underline{X}$ is a matrix of basin and climatic characteristics (independent variables);
$\underline{B}$ is a vector of regression coefficients; and
$\underline{e}$ is a vector of random errors.

However, for the T-year event, the OLS estimate of $\underline{B}$ is:

$$\underline{\hat{B}}_{OLS} = (\underline{X}^T\underline{X})^{-1}\ \underline{X}^T\ \underline{\hat{Y}}; \tag{14}$$

while the GLS estimate is:

$$\underline{\hat{B}}_{GLS} = (\underline{X}^T\ \underline{\Lambda}^{-1}\ \underline{X})^{-1}\ \underline{X}^T\ \underline{\Lambda}^{-1}\ \underline{\hat{Y}}; \tag{15}$$

where $\underline{\Lambda}$ is the unknown covariance matrix. Stedinger and Tasker (1985) described a method to estimate the covariance matrix that requires both a matrix

Table 9.--*Summary of final regression results*

[Equations yield peak discharge in cubic feet per second for indicated flood characteristic; Q5, Q10,...Q100, peak discharge for recurrence intervals of 5, 10,...100 years; AE, effective drainage area, in square miles; RF, relief factor, in feet; I24_100, 24-hour, 100-year rainfall intensity; --, not applicable]

Regression method and model	Equation	Average standard error, in percent	
		Regression	Prediction
Ordinary least-squares method:			
Linear model:	$\text{Log Q5}=4.13-2.24AE^{-0.125}+0.24 \text{ Log RF}$	57	--
	$\text{Log Q10}=4.74-2.61AE^{-0.125}+0.23 \text{ Log RF}$	51	--
	$\text{Log Q25}=5.41-3.02AE^{-0.125}+0.21 \text{ Log RF}$	51	--
	$\text{Log Q50}=5.85-3.30AE^{-0.125}+0.19 \text{ Log RF}$	54	--
	$\text{Log Q100}=6.25-3.55AE^{-0.125}+0.17 \text{ Log RF}$	59	--
Generalized least-squares method:			
Linear model:	$\text{Log Q5}=3.99-2.12AE^{-0.125}+0.25 \text{ Log RF}$	--	48
	$\text{Log Q10}=4.56-2.45AE^{-0.125}+0.22 \text{ Log RF}$	--	40
	$\text{Log Q25}=5.18-2.81AE^{-0.125}+0.22 \text{ Log RF}$	--	38
	$\text{Log Q50}=5.60-3.06AE^{-0.125}+0.20 \text{ Log RF}$	--	39
	$\text{Log Q100}=6.01-3.31AE^{-0.125}+0.19 \text{ Log RF}$	--	42
Quadratic model:	$\text{Log Q5}=3.83-1.46(AE^{-0.125})^2 =3.83-1.46AE^{-0.25}$	--	51
	$\text{Log Q10}=4.21-1.62(AE^{-0.125})^2 =4.21-1.62AE^{-0.25}$	--	42
	$\text{Log Q25}=4.61-1.80(AE^{-0.125})^2 =4.61-1.80AE^{-0.25}$	--	39
	$\text{Log Q50}=4.87-1.92(AE^{-0.125})^2 =4.87-1.92AE^{-0.25}$	--	40
	$\text{Log Q100}=5.12-2.04(AE^{-0.125})^2 =5.12-2.04AE^{-0.25}$	--	43
Second-order model:	$\text{Log Q5}=2.56+0.57(\text{Log RF})(\text{Log I24\_100}) -1.09AE^{-0.25}$	--	47
	$\text{Log Q10}=3.05+0.53(\text{Log RF})(\text{Log I24\_100}) -1.29AE^{-0.25}$	--	37
	$\text{Log Q25}=3.64+0.45(\text{Log RF})(\text{Log I24\_100}) -1.53AE^{-0.25}$	--	36
	$\text{Log Q50}=4.03+0.39(\text{Log RF})(\text{Log I24\_100}) -1.70AE^{-0.25}$	--	38
	$\text{Log Q100}=4.41+0.33(\text{Log RF})(\text{Log I24\_100}) -1.85AE^{-0.25}$	--	42

of years of concurrent record by station for each flood characteristic and a matrix of cross-correlations by station.

The OLS method is the correct method to use when the flood-frequency relations for all the stations are equally accurate and not correlated between stations. However, these relations are not equally accurate because they are based on observed and synthetic flood series that have different lengths and reliability, in addition to the difference in the natural variability of flow between stations. In addition, the flood-frequency relations between some stations are highly correlated because the synthetic record is based, at least in part, on a common, observed rainfall record.

The GLS method described by Stedinger and Tasker (1985) uses observed data to estimate $\underline{\Lambda}$ and thus accounts for differences between stations in accuracy of the flood-frequency relations and the cross-correlation of the sample estimates. At each pair of stations used in the regression, this method requires a matrix of their concurrent record length and an estimated matrix of cross-correlations of annual peak discharges.

The matrix of concurrent years of record had to be developed for each recurrence interval because flood-frequency data (Q5 through Q100) for modeled watersheds represent varying effective record lengths. This concept is evident in the previously discussed procedure for weighting the recorded and synthetic estimates for each station (see section entitled, "Combining Recorded and Synthetic Flood Characteristics"). An estimate of the effective record length, $\hat{n}_e$, was calculated for each flood characteristic using the relation:

$$\hat{n}_e = F_r\ (\bar{n}_r) + F_s\ (\bar{n}_s) \tag{16}$$

where F is either the recorded (F_r) or synthetic (F_s) weighting factor (see table 6), and $\bar{n}$ is the average years of record for either the recorded ($\bar{n}_r$) or synthetic ($\bar{n}_s$) annual-flood series (Gary Tasker, U.S. Geological Survey, oral commun., 1985). Because for this study $\bar{n}_r \cong 9$ yr and $\bar{n}_s \cong 60$ yr, the estimated effective record lengths were as follows:

Flood characteristic	Effective record length ($\hat{n}_e$), in years
Q5	24
Q10	32
Q25	42
Q50	47
Q100	55

To calculate concurrent record lengths between station pairs, a period of record (POR) was determined for each station using the following procedure:

1. For stations with weighted estimates, the POR was set at the $\hat{n}_e$ successive years up to and including water year 1978 (approximate end of the data-collection period);
2. For stations with only synthetic estimates, the POR was set at the $\hat{n}_e$ successive years up to and including water year 1971 (average end of the synthetic period); and
3. For stations with only observed estimates, the actual POR for each station was used.

As an example of the outcome of this procedure, table 17 ("Supplemental Information" section at the back of the report) gives the resultant matrix for the 25-yr peak discharge at several selected stations.

The matrix of cross-correlation coefficients for each station pair consisted of relative values (high, medium, low, or none) based on the derivation of each station's flood characteristics (observed, synthetic, or weighted). The following procedure was used:

1. High correlation (H) was assumed if both stations had weighted or synthetic flood frequencies based on synthetic flood series generated from essentially the same long-term precipitation stations.
2. Medium correlation (M) was assumed if both stations had weighted or synthetic flood frequencies based on synthetic flood series generated from a similar combination of long-term precipitation stations.
3. Low correlation (L) was assumed if one or both stations had only an observed flood frequency, or if one or both stations had weighted or synthetic flood frequencies based on synthetic flood series generated from different combinations of long-term precipitation stations.
4. No correlation (Z) was assumed if one station was located in a different drainage basin or State.

An example of the resultant matrix is listed in table 18 ("Supplemental Information" section at the back of the report). Based on statistical analyses using five randomly selected stations (06753800, 06821300, 06822600, 07099250, and 07134300), the relative correlations of H, M, L, and Z were set to values of 0.8, 0.5, 0.2, and 0.0. The assignment of relative correlations and subsequent quantification based on sample results was done because sensitivity of the GLS procedure to individual values within the matrix did not warrant a more exhaustive approach.

Three separate regression models--linear, quadratic, and second order--were analyzed using the GLS procedure. The resulting regression equations are summarized in table 9.

Linear Model

The log transformation of equation 12 yields the linear-regression model:

$$\log Y = B_o + B_1 \log X_1 + B_2 \log X_2 + \ldots + B_i \log X_i . \quad (17)$$

Prior to use of the GLS procedure, a stepwise-regression procedure was used to eliminate those independent variables least significant in the model. From the 18 original variables (log-transformed values of the 16 variables listed in table 7 plus $AE^{-0.125}$ and $A^{-0.125}$), the following 10 variables best explained the log-transformed array of flood characteristics and were subsequently evaluated using the GLS procedure:

log AE	(Effective drainage area)
$AE^{-0.125}$	(Effective drainage area)
log EF	(Elevation factor)
log RF	(Relief factor)
log L	(Mainstem length)
log SS	(Streambed slope)
log SW	(Watershed slope)
log WD1	(Channel width 1 foot above thalwag)
log LI	(Latitude index)
log S	(Shape factor)

Analysis of the linear model using the GLS procedure indicated that the best relation with statistically significant regression coefficients was the transformed variables $AE^{-0.125}$ and log RF (table 9). Of these two variables, the least significant was log RF; however, the standard error of prediction was increased significantly when it was omitted from the regression equation. Errors of prediction were smallest for the 25-yr peak discharge (36 percent) and greatest for the 5-yr peak discharge (48 percent). Estimates of average standard error of prediction by the GLS procedure were 16 to 34 percent less than estimates of average standard error of regression by the OLS method. Most of the decrease in standard error is due to an improved method of estimating the error rather than improved estimates of the regression coefficients.

Quadratic and Power-Transform Models

In a flood study of Pima County, Arizona, Eychaner (1984) determined that use of a quadratic model involving only drainage area yielded statistically better results than a linear-regression model. Because total drainage area (A) was eliminated during the stepwise procedure, the quadratic model evaluated was:

$$\log Y = B_0 + B_1 \log AE + B_2 (\log AE)^2; \quad (18)$$

and the power transform model was:

$$\log Y = B_0 + B_1 AE^{-0.125} + B_2 (AE^{-0.125})^2; \quad (19)$$

or

$$\log Y = B_0 + B_1 AE^{-0.125} + B_2 AE^{-0.250}. \quad (20)$$

Although the linear term ($AE^{-0.125}$) was not significant at the 5-percent level, the model given by equation 19 was judged superior using the GLS procedure because the other model (eq. 18) had significantly larger prediction errors. Average errors for prediction were smallest for the 50-yr peak discharge (36 percent) and largest for the 5-yr peak discharge (50 percent).

Second-Order Model

Eychaner (1984) also determined that use of a generalized second-order model, which uses independent variables as linear (X_i), quadratic (X_i^2), and cross-product ($X_i X_j$) terms, gave statistically better results than the linear-regression model. The generalized form of the model is:

$$\log Y = B_{00} + B_{01} \log X_1 + B_{11} \log X_1^2 + B_{02} \log X_2 + B_{22} \log X_2^2 + B_{12} \log X_1 \log X_2 + \ldots + B_{ij} \log X_i \log X_j \quad (21)$$

Analysis using the GLS procedure indicated that the best relation with statistically significant regression coefficients was the relation that contained the quadratic term $(AE^{-0.125})^2$ and the cross-product term (log RF) (log I24_100) (table 9). Average errors of prediction were smallest for the 25-yr peak discharge (35 percent) and largest for the 5-yr peak discharge (48 percent).

Discussion of Regression Results

A comparison of regional flood-frequency estimates from the regression relations developed in the study with estimates from three other methods indicates that the current regression estimates generally are smaller, especially for more frequent floods (table 10). Comparisons were made with the following methods:

1. Colorado Department of Highways (CDOH) method is similar to the U.S. Soil Conservation Service method (see 3 below) except that no site-specific soil information is used (for example, soil sampling).
2. Colorado Water Conservation Board (CWCB) method (McCain and Jarrett, 1976) gives regression equations developed from recorded flood data for generally larger watersheds in the plains region of eastern Colorado.
3. U.S. Soil Conservation Service (SCS) method (U.S. Soil Conservation Service, 1975) incorporates site-specific soil information with regionalized rainfall intensities and generalized relations of peak discharge to time of concentration.

Flood frequency was calculated for four stations in the Arkansas River basin using each of these three methods and the three regression models in the current analysis. The four stations were selected to ensure the availability of detailed soils information, and to provide adequate areal representation and a range of effective drainage areas. The smaller estimates by the current

Table 10.--*Flood-frequency comparison by selected prediction methods*

[Values are peak discharge in cubic feet per second; CDOH is Colorado Department of Highways; CWCB is Colorado Water Conservation Board; and SCS is U.S. Soil Conservation Service; Q10, Q50, Q100, peak discharges for recurrence intervals of 10, 50, and 100 years]

Prediction method[1]	Station 07099250[2]			Station 07107600[2]			Station 07133200[2]			Station 07134300[2]		
	Q10	Q50	Q100	Q10	Q50	Q100	Q10	Q50	Q100	Q10	Q50	Q100
CDOH	4,680	6,440	7,340	1,680	2,650	3,060	2,060	3,320	4,080	6,000	8,480	10,410
CWCB	4,310	6,200	7,890	2,040	3,870	4,930	1,320	3,020	4,130	3,340	7,080	9,380
SCS	5,310	10,320	12,320	3,280	5,150	5,890	2,040	3,880	4,560	5,670	17,720	22,680
Current study:												
Linear model	2,120	6,910	10,670	1,050	2,960	4,310	760	2,100	3,030	2,360	8,340	13,320
Quadratic model	1,800	5,460	8,250	920	2,480	3,570	780	2,020	2,870	2,330	7,450	11,470
Second-order model	2,040	6,010	9,000	1,040	2,680	3,840	950	2,320	3,250	2,930	8,830	13,340

[1]Description of each method is found in text. Values of the independent variables (defined in table 7) required by the prediction methods are as follows:

Station number	A	AE	RF	SW	I24_100
07099250	8.35	8.25	892	386	4.5
07107600	2.87	2.87	582	512	4.5
07133200	2.34	2.27	262	194	5.8
07134300	13.9	13.7	432	185	6.0

[2]Station names and locations listed in tables 1 and 2; locations shown in figure 2.

analysis may not be indicative of most watersheds in the plains region, since the four stations on which the comparisons were based unfortunately also had relatively large positive residuals (weighted value minus calculated value) for the current analysis. This suggests the possibility that the regional regression model did not fit the dependent variable very well for these particular stations. For most other stations in this analysis, results from the current study likely would show less difference with results of the other three methods.

The comparative results also indicate a generally steeper flood-frequency relation (larger Q100/Q10 ratio) using the methods developed by this study. This characteristic is considered more representative of typical small watersheds in the eastern plains of Colorado. Larger watersheds, and watersheds that have fewer thunderstorm-caused flood flows, have flatter frequency relations because of the integrating effects with drainage-area size and their tendency to experience fewer extreme (very large or very small) floods.

Of the three models tested in the current study by the GLS method, regression statistics and comparisons with other regional relations indicate that either the quadratic or second-order models yield the most satisfactory regional flood-frequency estimates. Monte-Carlo studies (Stedinger and Tasker, 1985) indicate the GLS method not only yields better estimates of the regression constants and coefficients, but it also provides a better estimate of equation accuracy (standard error of prediction) than does the OLS method (standard error of estimate). Using the GLS method, the average errors of prediction were smallest for the second-order model and greatest for the quadratic model. However, as shown in figure 11, the quadratic model appears to fit the data best, and the linear model appears to fit the data worst, particularly for effective drainage areas less than 2 mi^2. All equations seem to be hydrologically sound because larger values for each of the independent variables (AE, RF or I24_100) will result in an expected greater peak discharge. Furthermore, based on the Q10 and Q50 residuals (observed value minus calculated value) for each of the 46 stations used in the analysis, no bias seems to be associated with their areal distribution or with the magnitude of any independent variable in the equation.

The results of the current regression analysis compare favorably with the regional flood-frequency relations for generally larger watersheds and the maximum potential flood. The regional Q10 and Q100 for watersheds with effective drainage areas (AE) ranging from 0.3 to 20 mi^2 from the current quadratic model study and the regional Q10 and Q100 for watersheds with total drainage areas ranging from 100 to 3,000 mi^2 from the study by McCain and Jarrett (1976) are shown in figure 12. No relations are shown for the 20 to 100 mi^2 range because neither study has addressed the apparent transition from effective to total drainage area as an indicator of flood discharges for such watersheds. The maximum potential flood (Crippen and Bue, 1977) is shown in figure 12 as a relation considerably higher than either of the other regional studies. However, the general slope and shape of the two regional studies are quite similar to the relation for the maximum potential flood.

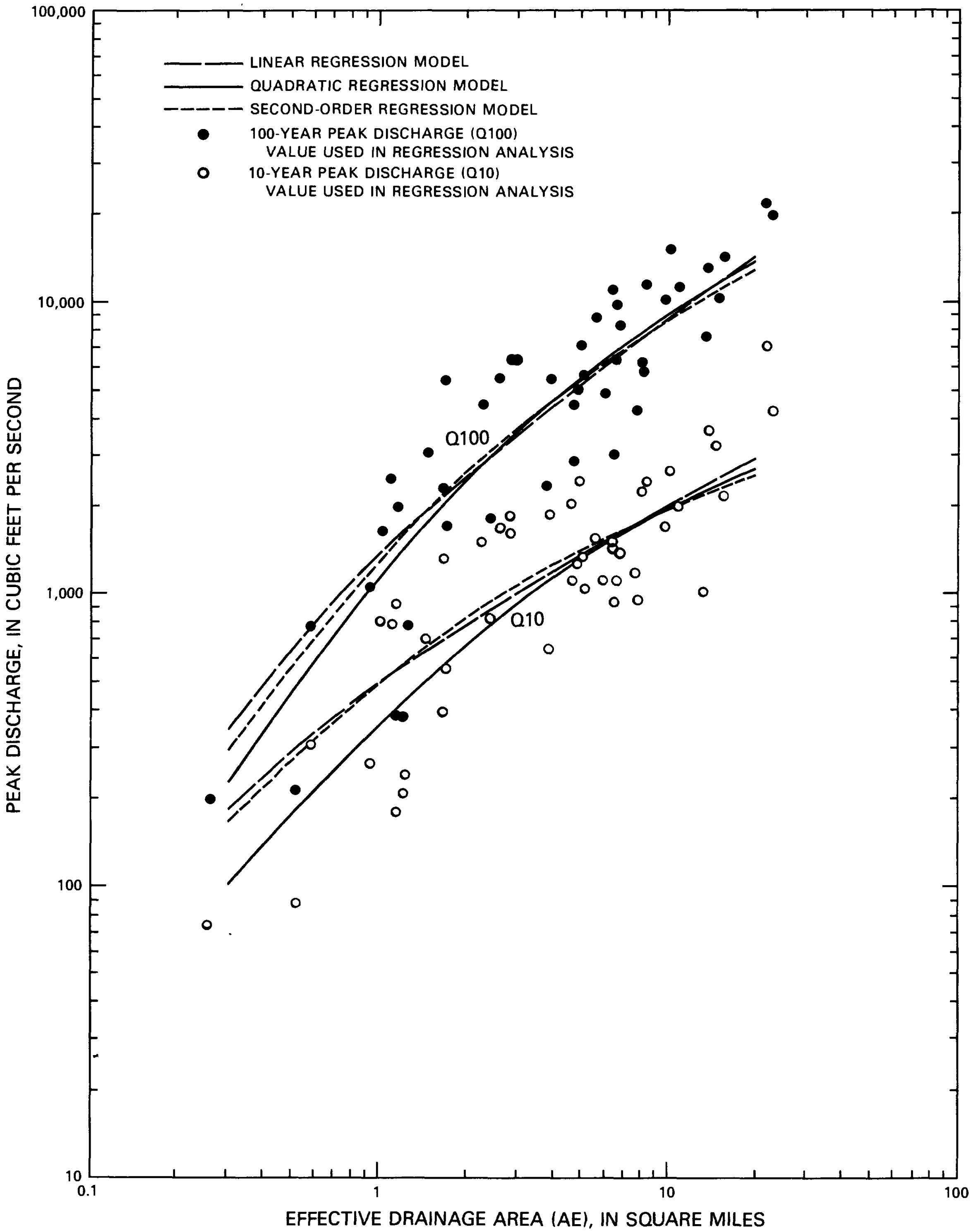

Figure 11.--Comparison of data used in the analysis with resultant regional relations using three different regression models.

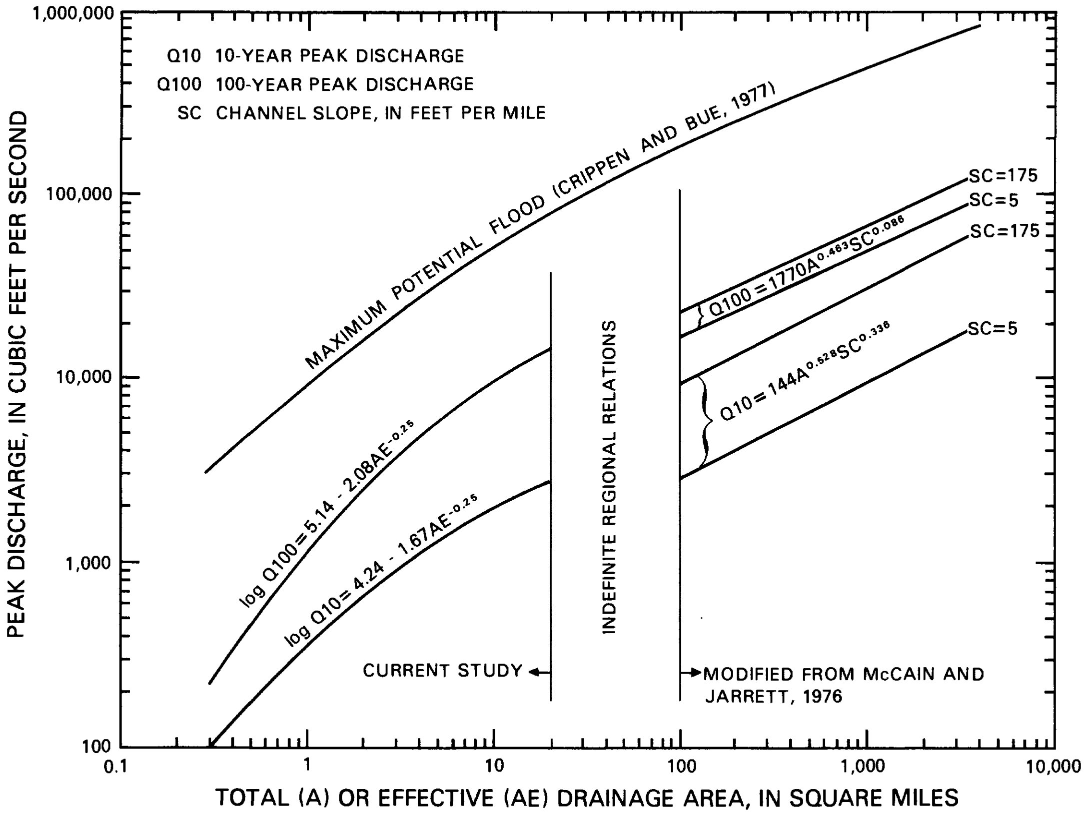

Figure 12.--Regional relations between total or effective drainage area and peak discharge.

TECHNIQUES FOR ESTIMATING THE CHARACTERISTICS OF FLOOD FLOWS FOR SMALL WATERSHEDS

The purpose of the analysis of flood data collected for small watersheds in the plains region of eastern Colorado and the adjoining States was to provide improved estimates of the characteristics of flood flows. Based on this analysis, the following sections briefly discuss the best methods of estimating these flood characteristics for small rural watersheds. These methods supercede previous estimating procedures developed by the U.S. Geological Survey, such as McCain and Jarrett (1976). To aid users in application of these results, the necessary equations are summarized in table 11.

Magnitude and Frequency of Peak Discharges

Peak discharges were studied using regression analysis applied to flood-frequency estimates that were based on recorded data from a network of rainfall-runoff stations and from selected other gaging stations, and on synthetic data from a calibrated rainfall-runoff model. The results of the study indicate that the best estimates of the magnitude and frequency of floods on small rural watersheds in the plains region of eastern Colorado will be provided by either a quadratic or a second-order model developed by a generalized least-squares regression. The equations are listed in table 11 and are applicable to rural watersheds with effective drainage areas from about 0.3 to 20 mi^2, relief factors from about 2.0 to 3,400 ft, and 24-h, 100-yr rainfall intensities from about 3.8 to 7.0 in. A map showing lines of equal 24-h, 100-yr rainfall intensity is given in figure 13; this map can be used in applying the second-order model to a particular watershed. To improve estimates for sites at or near gaging stations where some flood-frequency information is available, equations are given by Sauer (1974) and McCain and Jarrett (1976).

As an example, suppose an estimate of Q25 was required at an ungaged site in the plains region of eastern Colorado, where AE is 8.25 mi^2, RF is 892 ft, and I24_100 is 4.5 in. Using the appropriate second-order equation in table 11, the resultant estimate of Q25 is 4,020 ft^3/s (the quadratic equation would yield an estimate of 3,530 ft^3/s).

Flood Volumes

The relation between peak discharge and flood volume was studied using recorded and synthetic flood data. The resulting equations were similar and compared favorably with the results of a previous study for Wyoming (Craig and Rankl, 1978). However, because the synthetic data base is: (1) Much more extensive with respect to number and size of floods; and (2) a better estimate of the magnitude of rare floods, an equation representing all combined synthetic data probably will provide the best overall estimates of flood volume from peak discharge for small watersheds in the plains region. This relation is listed in table 11 and is applicable to peak discharges greater than 2 ft^3/s and less than about 16,000 ft^3/s. For example, the volume for a 4,020 ft^3/s peak discharge, previously determined using the second-order model to be Q25 for a watershed with an effective area of 8.25 mi^2, is estimated to be 290 acre-ft.

Table 11.--*Summary of equations for estimating the characteristics of flood flows from small rural watersheds in the plains region of eastern Colorado*

[Q5, Q10,...Q100, peak discharges for recurrence intervals of 10, 50, and 100 years; AE, effective drainage area, in square miles; S_e, average standard error of estimate, in percent]

Peak discharge (Q_p), in cubic feet per second

Quadratic model:

$\text{Log } Q5 = 3.83 - 1.46\ AE^{-.25}$	(S_e = 51)
$\text{Log } Q10 = 4.21 - 1.62\ AE^{-.25}$	(S_e = 42)
$\text{Log } Q25 = 4.61 - 1.80\ AE^{-.25}$	(S_e = 39)
$\text{Log } Q50 = 4.87 - 1.92\ AE^{-.25}$	(S_e = 40)
$\text{Log } Q100 = 5.12 - 2.04\ AE^{-.25}$	(S_e = 43)

Second-order model:

$\text{Log } Q5 = 2.56 + 0.57\ (\text{Log RF})(\text{Log I24\_100}) - 1.09\ AE^{-0.25}$	(S_e = 47)[1]
$\text{Log } Q10 = 3.05 + 0.53\ (\text{Log RF})(\text{Log I24\_100}) - 1.29\ AE^{-0.25}$	(S_e = 37)[1]
$\text{Log } Q25 = 3.64 + 0.45\ (\text{Log RF})(\text{Log I24\_100}) - 1.53\ AE^{-0.25}$	(S_e = 36)[1]
$\text{Log } Q50 = 4.03 + 0.39\ (\text{Log RF})(\text{Log I24\_100}) - 1.70\ AE^{-0.25}$	(S_e = 38)[1]
$\text{Log } Q100 = 4.41 + 0.33\ (\text{Log RF})(\text{Log I24\_100}) - 1.85\ AE^{-0.25}$	(S_e = 42)[1]

Flood volume (V), in acre-feet

$V = 0.222\ Q_p^{0.866}$ (S_e = 78)

Synthetic hydrograph constants

Discharge constant (Q'), in cubic feet per second per discharge unit:

$Q' = Q_p/60.$

Time constant (T'), in minutes per time unit:

$T' = 0.748\ V/Q'.$

[1]Values of S_e are standard errors of prediction.

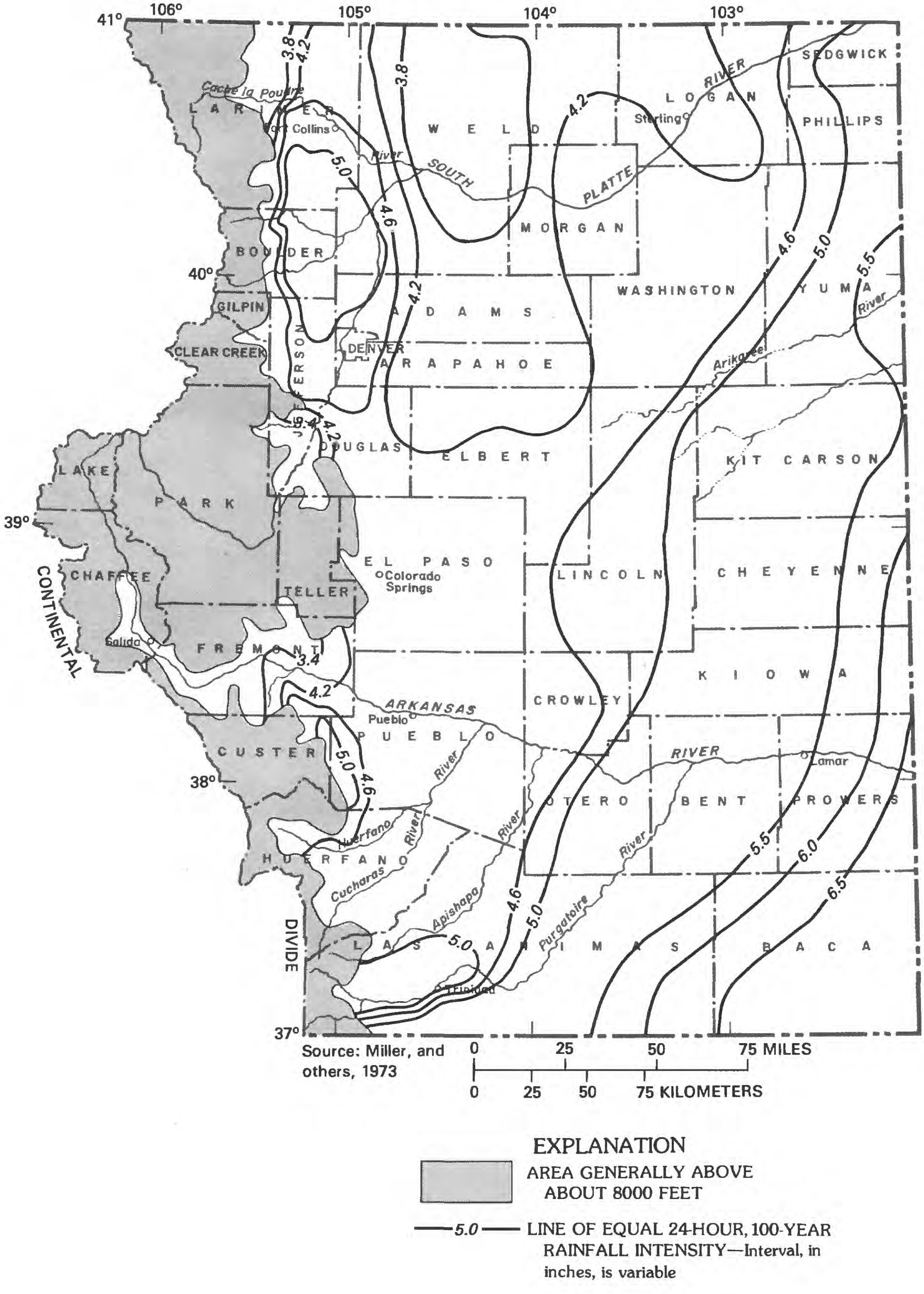

Figure 13.--Lines of equal 24-hour, 100-year rainfall intensity (I24_100) for the plains region of eastern Colorado.

Synthetic Hydrograph

Thus far, methods have been discussed by which the magnitude and volume of floods in the plains region of eastern Colorado can be estimated for small ungaged watersheds. These flood characteristics can be used further to develop a complete synthetic hydrograph as described by Commons (1942). The dimensionless hydrograph developed by Commons was refined for small watersheds in Wyoming by Craig (1970). This refined hydrograph, the composite-mean dimensionless hydrograph, has a volume of 970 square units, a rise time of 12 time units, and a time base of 70 time units. Comparisons with flood hydrographs recorded during the study indicated that this synthetic-hydrograph technique provides satisfactory design hydrographs for small watersheds in the plains region of Colorado.

The dimensionless time and discharge units of the synthetic hydrograph are listed in table 12, which also lists an example calculation of the synthetic hydrograph for Q25 (peak discharge, 4,020 ft^3/s; flood volume, 290 acre-ft) on an 8.25-mi^2 watershed in eastern Colorado. The equations necessary for computing the discharge and time constants are listed in table 11. Using these equations as shown in footnote 2 of table 12, the flow constant for this example is calculated to be 70.0 ft^3/s per discharge unit, and the time constant is calculated to be 3.24 minutes per time unit. The general shape of the resulting hydrograph, shown in figure 14, compares favorably with an observed 3,300-ft^3/s flood that occurred September 13, 1976, at station 07099250, that has an effective area of 8.25 mi^2; this flood would have a recurrence interval of about 20 yr. Also shown in figure 14 is the synthetic hydrograph for the observed peak discharge of 3,300 ft^3/s.

Accuracy and Limitations

The statistical accuracy of the equations developed in this analysis of rainfall-runoff and flood data applicable to the plains region of eastern Colorado is indicated by the standard errors (S_e) listed in table 11. Based on range of data included in the analysis, the regression equations are appropriate to watersheds located in the plains region of Colorado (fig. 1) that have characteristics within the following ranges:

Flood characteristic	Watershed characteristic	Range
Peak discharge magnitude and frequency (Q5-Q100)	Effective drainage area (AE)	0.3 to 20 mi^2
	Relief factor (RF)	2.0 to 3,400 ft
	24-h, 100-yr rainfall intensity (I24_100)	3.8 to 7.0 in.
Flood volume (*V*)	Peak discharge, Q_p	2.0 to 15,680 ft^3/s

Table 12.--*Example calculation of a synthetic hydrograph for the estimated 25-year peak discharge on an 8.25-square-mile watershed*

Dimensionless hydrograph[1]		Constants[2]		Synthetic hydrograph[3]	
Time unit, t	Discharge unit, q	Time constant T', in minutes	Discharge constant Q', in cubic feet per second per flow unit	Time ($t \times T'$) in minutes	Discharge ($q \times Q'$), in cubic feet per second
0	0	3.24	67.0	0	0
3	5.6	3.24	67.0	10	375
5	13	3.24	67.0	16	871
7	25	3.24	67.0	23	1,680
10	49	3.24	67.0	32	3,280
11	57	3.24	67.0	36	3,820
12	60	3.24	67.0	39	4,020
13	59	3.24	67.0	42	3,950
14	55	3.24	67.0	45	3,680
18	38	3.24	67.0	58	2,550
23	23	3.24	67.0	75	1,540
30	12	3.24	67.0	97	800
40	5.2	3.24	67.0	130	348
50	2.0	3.24	67.0	162	134
60	.5	3.24	67.0	194	34
70	0	3.24	67.0	227	0

[1]Modified from Craig (1970).

[2]Based on an estimated 25-year peak discharge of 3,800 cubic feet per second and flood volumes of 280 acre-feet, the time and discharge constants are calculated as follows:

$$Q' = \frac{Q_P}{60} = \frac{4{,}020}{60} = 67.0 \text{ cubic feet per second per discharge unit, and}$$

$$T' = \frac{0.748V}{Q'} = \frac{0.748(290)}{63.3} = 3.24 \text{ minutes per time unit.}$$

[3]Synthetic hydrograph shown in figure 14.

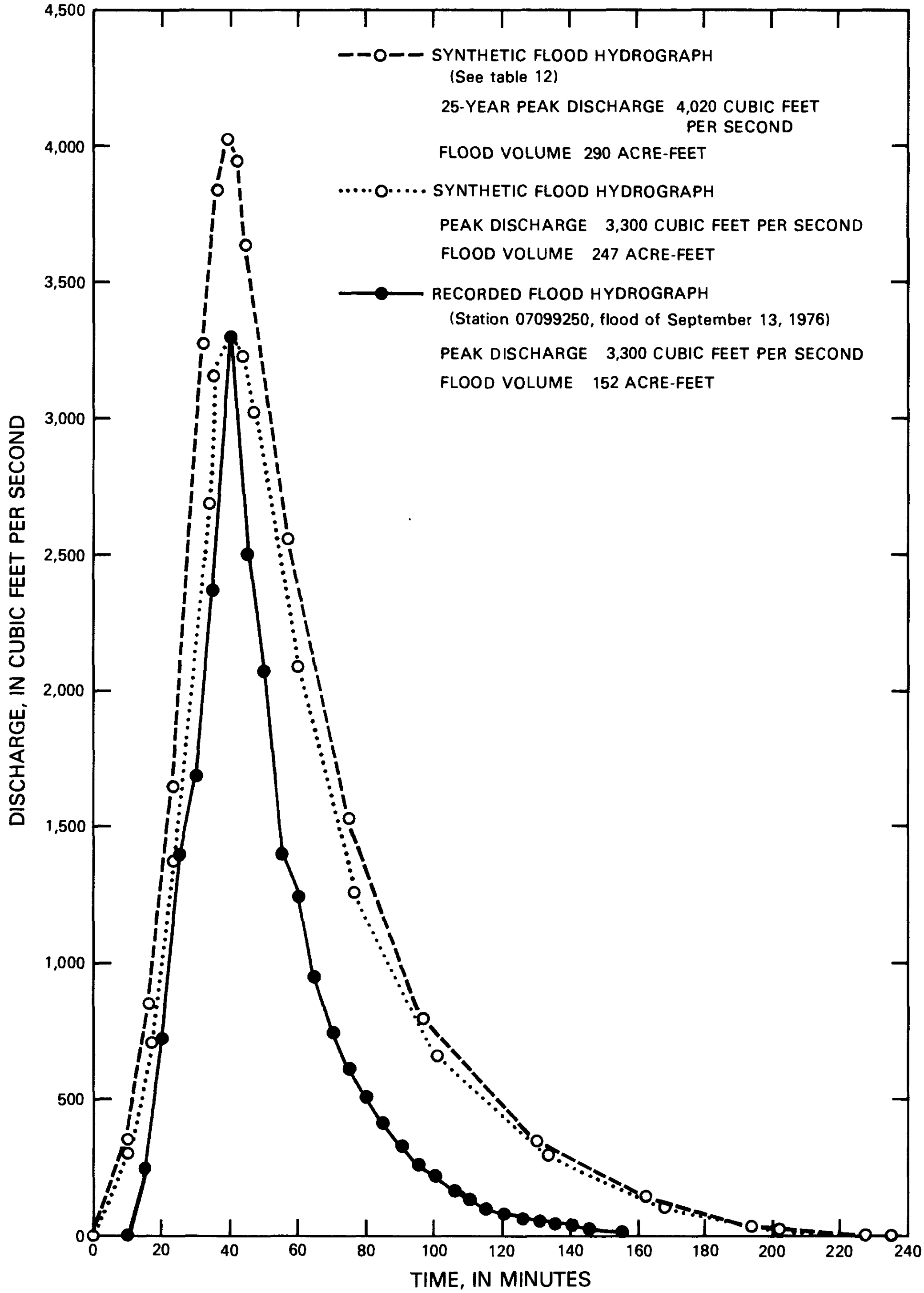

Figure 14.--Comparison of synthetic hydrographs with a recorded hydrograph for an 8.25-square-mile watershed.

In using the second-order model, care needs to be taken not to extrapolate the equations beyond the limit of the data used to estimate the regression constant and coefficients. A plot of log I24_100 against log RF for the gaged stations used in the regression analysis is shown in figure 15. If a station has a combination of these variables that plot outside the cluster of points shown, the quadratic model probably would result in a better estimate. Although the relations may be useful in estimating flood characteristics in adjoining States with similar flood hydrology or for watersheds whose characteristics are beyond this range, the error associated with these estimates is unknown.

The data and analysis presented in this report only have dealt with rural watersheds with natural-flow characteristics and floods resulting from convective storms. The results of this study do not apply to floods resulting from frontal-type storms and are not applicable to urbanized watersheds. A nationwide study concerning urban areas has been completed by Sauer and others (1983) and presents techniques applicable within Colorado for estimating magnitude and frequency of urban floods. For urban watersheds in the Denver-Boulder metropolitan region, a unit-hydrograph procedure described by Wright-McLaughlin Engineers (1969) is commonly used. A drainage-criteria manual is being prepared for urban watersheds in Colorado Springs and El Paso County.

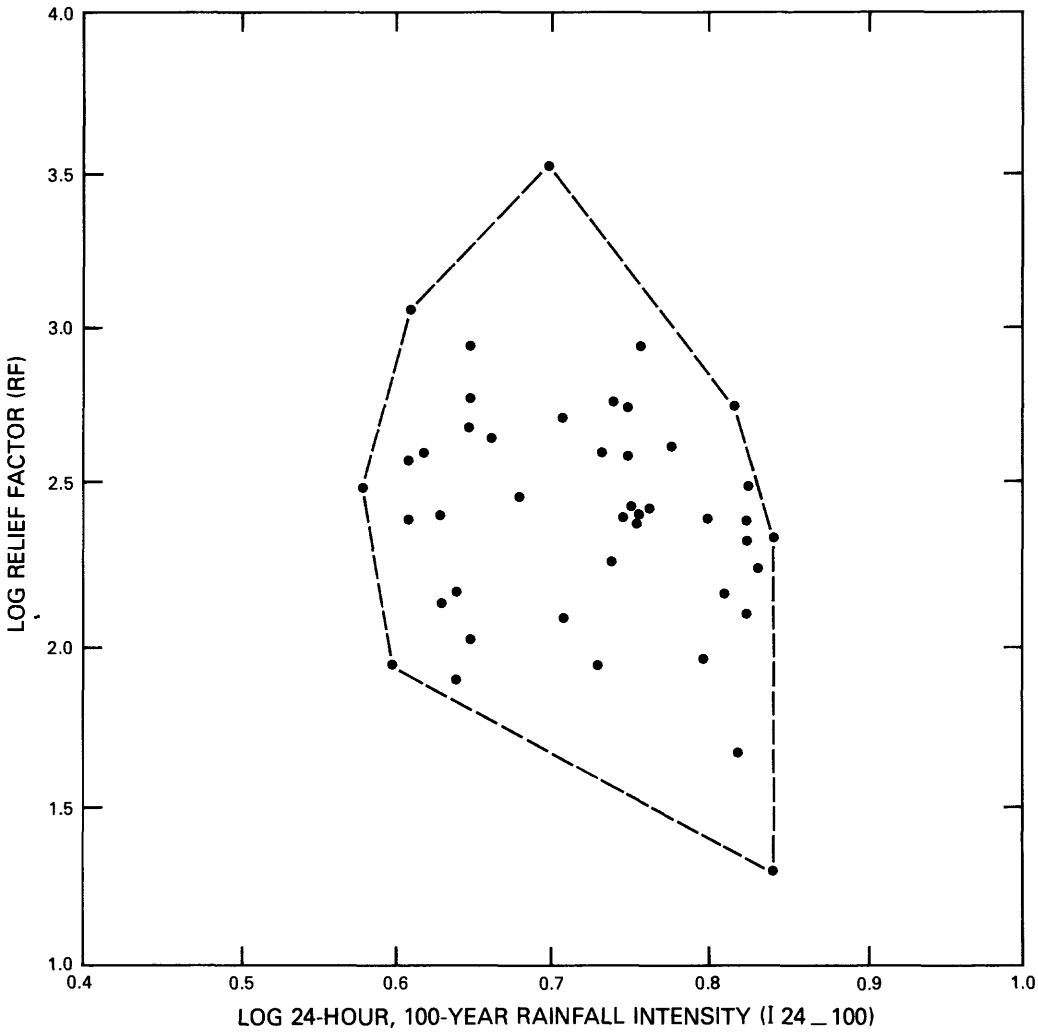

Figure 15.--Relation between log 24-hour, 100-year rainfall intensity (I24_100) and log relief factor (RF) for gaged stations used in regression analyses.

SUMMARY AND CONCLUSIONS

To collect seasonal rainfall-runoff data representative of thunderstorm-caused floods in small watersheds of eastern Colorado, a network of 35 stations was established in the plains region and operated from about 1969 through 1979 (figs. 1 and 2). The stations represented typical rural watersheds with total drainage areas from 1.15 to 23 mi^2, little of which is in the sand-hills areas of the region. Both stage and rainfall data were collected at 5-min intervals; stage data was converted to discharge by use of theoretical stage-discharge relations. Although essentially all stations had at least 1 yr without storm runoff, rainfall-runoff data for a total of 236 storms (peak discharges from 4.5 to 3,300 ft^3/s) were available for analysis. From the data collected during the study, the principal conclusions are:

1. For small ephemeral watersheds, it is not uncommon that no storm runoff will not occur during at least one year in every 10 years.
2. For the runoff recorded at the 35 stations, the largest recorded peak discharge was 7,880 ft^3/s, the largest unit runoff was 876 $(ft^3/s)/mi^2$, and the maximum flood volume was 229 acre-ft.
3. For the rainfall recorded at the 35 stations, the greatest intensity was 0.64 in. in a 5-min period, or 7.7 in/h, and the "average storm" lasted about 45 min with its greatest intensity (2.0 in/h) occurring in the interval between 5 and 10 min after the storm began.
4. Over three-quarters of the recorded floods in the plains region occurred during the 90-day period from May 21 to August 18.

To develop a regional technique for estimating the magnitude, frequency, and volume of floods for ungaged sites in the plains region of eastern Colorado, a multiple-regression analysis was used. In addition to the flood data collected as part of the study, the analysis included annual peak-discharge data from 17 stations on small watersheds (total drainage areas from 0.26 to 75 mi^2) located in adjoining States but judged representative of similar flood hydrologies. The relatively large time-sampling error associated with observed flood-frequency relations for 28 stations was decreased by combining these relations with a synthetic flood-frequency relation. The synthetic relation was determined from the long-term annual flood series generated using long-term rainfall data and a rainfall-runoff model calibrated for each watershed with the recorded rainfall-runoff data. A satisfactory model calibration could not be obtained for five of the watersheds. The 5-, 10-, 25-, 50- and 100-year peak discharges were regionalized using both ordinary least-squares and generalized least-squares regression. Resulting relations included the independent variables of effective drainage area, relief factor, and 24-hour, 100-year rainfall intensity; standard errors of prediction ranged from 35 to 50 percent. A relation also was developed to estimate flood volume from peak discharge that had a standard error of 78 percent. These two estimates, peak discharge and flood volume, then were applied to a dimensionless hydrograph technique to obtain an entire synthetic flood hydrograph. The following are the principal conclusions of the data analysis:

1. For small watersheds in eastern Colorado, effective drainage area is a much better indicator of flood discharge than total drainage area.

2. The generalized least-squares method of regression analysis resulted in relations with standard errors of prediction 9 to 17 percent less than standard errors of regression from the ordinary least-squares method.
3. Of the three regression models tested (linear, quadratic, and second-order), the second-order model generally had the smallest standard errors, but the quadratic model seems to best fit the data, especially for effective areas less than 2 mi^2.
4. Because they are based on more extensive data and statistically are more accurate, the regional relations developed to estimate the magnitude and frequency of floods in small rural watersheds in eastern Colorado supersede previous estimating procedures.
5. The regional flood-frequency relations are applicable to watersheds with effective drainage areas ranging from 0.3 to 20 mi^2, relief factors ranging from 2.0 to 3,400 ft, and 24-hr, 100-yr rainfall intensities ranging from 3.8 to 7.0 in.
6. A relation for estimating flood volume is applicable for peak discharges ranging from 2.0 to about 16,000 ft^3/s.
7. A dimensionless hydrograph technique developed by Commons (1942) and refined by Craig (1970) produces synthetic hydrographs similar in shape to recorded flood hydrographs.

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SUPPLEMENTAL INFORMATION

Table 13.--*Historical peak discharges for selected miscellaneous small rural watersheds in the South Platte and Arkansas River basins*

Site name	Total drainage area, in square miles	Date of occurrence	Peak discharge, in cubic feet per second
South Platte River basin			
South Fork Willow Gulch near Deer Trail, Colo.	0.49	June 25, 1982	355
Kiowa Creek subwatershed no. Q-51 near Elbert, Colo.	.59	June 17, 1965	1,270
Cottonwood Creek tributary at Arapahoe Road, Colo.	.65	August 3, 1963	223
Kiowa Creek subwatershed no. J-33 near Eastonville, Colo.	1.12	June 17, 1965	2,600
Lone Tree Creek at Arapahoe Road, Colo.	1.3	August 3, 1963	930
Draw No. 2 at U.S. Highway 160 near Trinidad, Colo.	1.49	May 19, 1955	375
Kiowa Creek subwatershed no. R-3 near Elbert, Colo.	2.82	June 17, 1965	2,010
Kiowa Creek at K-79 Reservoir. near Eastonville, Colo.	3.2	June 30, 1957 June 17, 1965	5,250 2,370
Grasmack Arroyo near Trinidad, Colo.	3.6	May 19, 1955	820
South Fork Sappa Creek tributary near Goodland, Kans.	4.0	June , 1962	2,600
Joe Creek near Morely, Colo.	4.54	May 19, 1955	642
Owl Creek tributary near Rockport, Colo.	4.56	June 28, 1973	2,620
North Branch Indian Creek near Max, Nebr.	4.76	July 31, 1962	12,900
Cottonwood Creek above Cherry Creek Reservoir, Colo.	7.81	August 3, 1963	3,330
Tucker Gulch at Golden, Colo.	11.2	June 7, 1948	11,600
Newlin Creek near Packer, Colo.	13.6	August 3, 1963	7,620
Cottonwood Creek near Pinewood, Colo.	15.1	August 3, 1951	2,260
James Creek at mouth near Jamestown, Colo.	18.6	May 7, 1969	1,970
Piney Creek near Melvin, Colo.	21.9	June 16, 1965	14,100
Black Wolf Creek near Wray, Colo.	25.0	July 17, 1962	17,800
Kiowa Creek at Elbert, Colo.	28.6	May 30, 1935 June 17, 1965	43,500 41,500

Table 13.--*Historical peak discharges for selected miscellaneous small rural watersheds in the South Platte and Arkansas River basins*--Continued

Site name	Total drainage area, in square miles	Date of occurrence	Peak discharge, in cubic feet per second
	Arkansas River basin		
Carrizozo Creek tributary near Kenton, Okla.	0.15	July 6, 1958	307
Arkansas River tributary no. 2 at Parkdale, Colo.	.16	July 27, 1961	284
Unnamed Arroyo no. 2 near Pueblo, Colo.	.6	June 3, 1921	633
Arkansas River tributary at Parkdale, Colo.	.84	July 27, 1961	930
Draw no. 1 at U.S. Highway 160 near Trinidad, Colo.	.84	July 22, 1954	447
Chicorica Creek tributary near Raton, N. Mex.	1.33	June 17, 1965	1,810
Cimarron Creek tributary at Cimarron, N. Mex.	1.44	June 5, 1958	1,870
Draw no. 2 at U.S. Highway 160 near Trinidad, Colo.	1.49	July 22, 1954	1,130
St. Charles River at Burnt Mill, Colo.	1.66	May 15, 1980	3,300
Canadian River tributary near Hebron, N. Mex.	2.01	June 17, 1965	2,130
Orman's Gulch near Swallows, Colo.	2.66	July 19, 1965	7,000
Springer Arroyo near Colfax, N. Mex.	3.00	June 17, 1965	2,280
Grasmack Arroyo near Trinidad, Colo.	3.6	May 19, 1955	820
		June 17, 1965	1,090
Moline Canyon near Weston, Colo.	4.23	August 10, 1981	5,100
Joe Creek near Morely, Colo.	4.54	June 17, 1965	760
Carpios Canyon near Jensen, Colo.	4.57	August 10, 1981	5,300
Cimarron River tributary no. 3 near Kenton, Okla.	4.9	July 6, 1958	2,410
Turkey Creek Canyon near Cimarron, New Mex.	5.25	June 16, 1965	6,660
Raton Creek near Morely, Colo.	5.27	June 16, 1965	4,660
Arkansas River tributary near Las Animas, Colo.	5.29	July 27, 1963	1,230

Table 13.--*Historical peak discharges for selected miscellaneous small rural watersheds in the South Platte and Arkansas River basins*--Continued

Site name	Total drainage area, in square miles	Date of occurrence	Peak discharge, in cubic feet per second
Arkansas River basin--Continued			
Hogars Gulch near Eden, Colo.	6.1	August 7, 1904	9,640
Blue Ribbon Creek near Pueblo, Colo.	6.7	June 3, 1921	9,130
Templeton Gap near Colorado Springs, Colo.	7.1	May 17, 1922	6,120
Cameron Arroyo near Livesey, Colo.	7.3	June 3, 1921	13,900
Osteen Arroyo near Swallows, Colo.	7.8	June 3, 1921	9,060
Clear Creek near Starkville, Colo.	8.1	June 17, 1965	1,720
Kettle Creek near Black Forest, Colo.	9.01	August 5, 1981	2,300
Chicorice Creek above Malloya Dam, N. Mex.	9.3	May 18, 1955	2,450
Colorado Canyon near Jensen, Colo.	9.88	July, 1954	3,100
Unnamed Arroyo no. 1 near Livesey, Colo.	15.2	June 3, 1921	9,400
Gray Creek near Trinidad, Colo.	16	June 17, 1965	3,540
Black Squirrel Creek Peyton, Colo.	16.3	June 17, 1965	10,400
Granada Creek near Granada, Colo.	17.7	June 17, 1965	12,600
Rush Creek near Swallows, Colo.	19.6	June 3, 1921	4,670
Boggs Creek near Livesey, Colo.	24.9	June 3, 1921	14,500
Burro Canyon at Madrid, Colo.	28.3	June 17, 1965	3,120
Cheyenne Creek near Holly, Colo.	29	June 1949 May 19, 1962	5,900 4,630
Smith Arroyo near Granada, Colo.	29.1	June 17, 1965	10,600

Table 14.---*Results of calibration of rainfall-runoff model, South Platte River basin*

[PSP, combined effects of moisture deficit and capillary potential; KSAT, hydraulic conductivity of saturated transmission zone; RGF, ratio of moisture deficit and suction; BMSM, soil-moisture storage; RR, daily rainfall infiltration; DRN, drainage factor for redistribution of moisture storage; EVC, pan evaporation coefficient; KSW, linear reservoir recession coefficient; TC, time base of triangular translation hydrograph; TP/TC, ratio of time to peak of hydrograph to duration of hydrograph; in., inch; in/h, inch per hour; h, hour; min, minute]

U.S. Geological Survey station number[1]	Number of rainfall/runoff periods in calibration	Infiltration parameters[2]			Soil-moisture accounting parameters[2]				Surface-runoff routing parameters[2]			Statistics for calibration or peak discharge		
		PSP (in.)	KSAT (in/h)	RGF	BMSM (in.)	RR	DRN	EVC	KSW (h)	TC (min)	TP/TC	Correlation coefficient	Root mean square error (percent)	Slope of regression line
06753800	4	1.854	0.062	0.272	17.53	0.95	1.00	0.7	0.230	22.5	0.50	0.92	66	0.81
06756200[3]	2	---	---	---	---	.95	1.00	---	---	---	---	---	---	---
06758150	5	1.596	.053	8.052	5.130	.95	1.00	.7	.450	49.5	.50	.78	67	1.06
06758250	3	3.429	.117	14.56	19.05	.95	1.00	.7	.338	97.0	.50	.98	32	1.55
06758400	4	2.487	.068	12.32	1.730	.95	1.00	.7	1.600	82.0	.50	.99	23	1.26
06758700	6	1.282	.062	8.507	11.22	.95	1.00	.7	.250	47.0	.50	.94	45	.74
06759700	5	2.936	.051	15.63	.776	.95	1.00	.7	1.250	92.5	.50	.71	63	1.00
06759900[3]	1	---	---	---	---	.95	1.00	---	---	---	---	---	---	---
06760200	4	3.987	.160	29.70	2.813	.95	1.00	.7	.360	32.0	.50	.80	60	.55
06760300	12	3.913	.090	25.99	2.531	.95	1.00	.7	.290	45.5	.50	.80	74	.96
06760430	5	3.625	.081	17.60	.993	.95	1.00	.7	.740	86.5	.50	.94	45	.95
06821300	14	1.367	.150	6.834	2.278	.95	1.00	.7	.550	44.0	.50	.96	77	.87
06821400[4]	3	3.838	.175	18.30	18.97	.95	1.00	.7	.457	60.0	.50	.69	55	.47
06822600	8	3.230	.087	17.32	.821	.95	1.00	.7	.855	88.5	.50	.84	41	.65
06825100	4	.459	.050	9.752	2.284	.95	1.00	.7	.820	82.5	.50	.75	74	.64
06826900	9	2.884	.072	13.10	2.032	.95	1.00	.7	1.440	92.0	.50	.88	71	.91
06834200	3	1.367	.085	10.25	2.278	.95	1.00	.7	1.780	225	.50	.83	82	.62
06857500	9	1.367	.350	12.15	18.00	.95	1.00	.7	.825	135	.50	.85	56	.90

[1]Station names and locations listed in table 1; general locations are shown in figure 2.
[2]Parameters are defined in greater detail in table 5.
[3]Calibration not attempted.
[4]Calibration statistically unsuccessful (see text).

Table 15.--*Results of calibration of rainfall-runoff model, Arkansas River basin*

[PSP, combined effects of moisture deficit and capillary potential; KSAT, hydraulic conductivity of saturated transmission zone; RGF, ratio of moisture deficit and suction; BMSM, soil-moisture storage; RR, daily rainfall infiltration; DRN, drainage factor for redistribution of moisture storage; EVC, pan evaporation coefficient; KSW, linear reservoir recession coefficient; TC, time base of triangular translation hydrograph; TP/TC, ratio of time to peak of hydrograph to duration of hydrograph; in., inch; in/h, inch per hour; h, hour; min, minute; ---, not determined]

U.S. Geological Survey station number[1]	Number of rainfall/runoff periods in calibration	Infiltration parameters[2]			Soil-moisture accounting parameters[2]				Surface-runoff accounting parameters[2]			Statistics for calibration or peak discharge		
		PSP (in.)	KSAT (in/h)	RGF	BMSM (in.)	RR	DRN	EVC	KSW (h)	TC (min)	TP/TC	Correlation coefficient	Root mean square error (percent)	Slope of regression line
07099250	9	2.809	0.085	13.02	1.027	0.96	1.00	0.7	0.405	27.00	0.50	0.82	94	0.92
07107600	14	1.624	.056	11.93	1.889	.94	1.00	.7	.315	22.50	.50	.82	70	.78
07112700	3	1.643	.056	8.670	3.028	.95	1.00	.7	.315	27.00	.50	.75	49	.85
07120600	14	1.484	.064	11.19	3.751	.95	1.00	.7	1.28	26.65	.50	.81	46	.67
07123700	10	3.429	.113	17.78	4.952	.97	1.00	.7	.360	29.25	.50	.79	53	.74
07124700	7	3.987	.312	29.70	1.139	.97	1.00	.7	.360	15.75	.50	.88	79	1.10
07125050	6	3.426	.109	15.65	1.215	.97	1.00	.7	.577	27.00	.50	.81	38	.79
07126400	11	2.272	.053	12.74	1.032	.95	1.00	.7	.813	60.19	.50	.92	65	1.07
07126450[3]	3	1.931	.064	13.81	1.011	.95	1.00	.7	.765	82.88	.50	.56	>100	.47
07129100[3]	3	3.987	.156	29.69	1.226	.95	1.00	.7	.646	33.08	.50	.82	51	3.20
07129200	6	1.293	.052	8.654	1.033	.95	1.00	.7	.405	36.00	.50	.87	69	.90
07133200	3	2.263	.080	14.60	2.837	.95	1.00	.7	.450	40.50	.50	.98	18	1.16
07134300	9	3.686	.125	18.78	1.692	.97	1.00	.7	.488	39.00	.50	.92	66	1.06
07135800	9	1.519	.094	13.52	2.298	.95	1.00	.7	.651	53.32	.50	.79	83	.79
07138520	9	2.024	.064	10.29	1.029	.94	1.00	.7	1.88	140.4	.50	.72	67	.83
07153450	14	1.602	.071	10.06	3.750	.98	1.00	.7	.898	69.30	.50	.85	47	.89
07154800	11	3.973	.068	19.52	1.206	.95	1.00	.7	.653	20.25	.50	.87	64	.80

[1]Station names and locations listed in table 2, general locations are shown in figure 2.
[2]Parameters are defined in greater detail in table 5.
[3]Calibration statistically unsuccessful (see text).

U.S. Geological Survey station number	Dependent variables									
	Q5	Q10	Q25	Q50	Q100	A	AE	E	RF	L
06753800[2]	2,130	3,660	6,530	9,520	13,300	4.28	4.22	5,560	570	5.30
06756200	130	180	260	320	390	1.15	1.15	5,620	330	2.70
06758150	490	810	1,370	1,910	2,580	1.22	1.10	6,880	270	2.20
06758250	742	1,510	3,010	5,080	6,470	6.40	6.40	5,720	400	5.00
06758400	384	661	1,180	1710	2420	3.79	3.79	4830	200	3.80
06758700	820	1,350	2,500	3,700	5,560	1.74	1.68	5,650	430	3.50
06759700	315	558	965	1,350	1,720	2.45	1.72	4,920	150	3.20
06760200[2]	45	110	286	513	890	1.53	1.53	5,010	420	4.40
06760300	724	1,480	3,520	6,260	11,250	6.67	6.38	4,390	260	5.20
06760430	1,410	2,760	5,810	9,590	15,300	22.90	9.96	4,310	140	5.50
06761900	61	90	134	175	222	0.60	0.51	5,255	85	1.16
06762600[2]	217	458	979	1,570	2,365	7.69	7.42	5,238	197	7.02
06821300	409	716	1,360	2,050	3,070	6.55	1.45	5,220	110	3.00
06821400	700	1,210	2,160	3,130	4,370	17.00	7.51	3,680	270	6.40
06822600	162	398	947	1,580	2,330	2.37	1.66	4,190	80	2.40
06825100	680	940	1,320	1,650	2,000	7.02	1.13	4,570	90	2.00
06826900	818	2,020	4,820	7,860	11,780	14.60	10.60	3,750	190	4.70
06829700	587	974	1,650	2,310	3,110	9.06	6.40	2,675	280	5.67
06834200	470	1,030	2,510	4,550	7,950	23.00	13.10	3,740	130	8.00
06835100	2,279	4,420	8,850	13,800	20,400	24.60	22.60	2,778	412	9.90
06839200	746	1,340	2,470	3,650	5,160	6.74	4.84	2,800	250	3.56
06844800[2]	427	1,370	4,599	9,872	19,407	4.98	4.98	3,590	122	5.27
06857500	811	1,740	3,978	6,510	10,580	13.30	9.57	4,140	270	6.90
06858700	594	807	1,120	1,330	1,660	1.13	1.01	3,270	95	1.60
07099250	1,290	2,500	5,050	7,750	11,780	8.35	8.25	5,280	910	6.40
07107600	900	1,660	3,130	4,530	6,460	2.87	2.87	5,230	600	3.40
07112700	1,060	1,890	3,420	4,790	6,570	3.10	2.84	6,230	490	3.30

variables used in final regression analysis

	Independent variables[1]									
SS	SC	SW	WD1	WD3	WD5	I1_100	I6_100	I24_100	LI	S
500	82	503	25.0	38.0	55	2.5	3.1	3.9	4.92	6.56
540	113	935	19.0	44.0	82.0	2.5	3.1	3.8	4.97	6.34
350	114	386	14.0	42.0	108	2.6	3.4	4.3	3.20	3.97
220	65.0	342	10.0	16.0	25.0	2.6	3.4	4.1	3.62	3.91
15.0	50.0	159	14.0	66.0	173	2.6	3.4	3.9	4.03	3.81
46.0	88.0	640	29.0	44.0	90.0	2.6	3.4	4.2	3.50	7.04
18.0	38.0	277	23.0	35.0	52.0	2.9	3.6	4.4	3.73	4.18
56.0	86.0	375	18.0	37.0	60.0	2.7	3.3	3.9	4.78	12.7
12.0	59.0	515	23.0	42.0	145	2.9	3.4	4.1	4.88	4.05
20.0	16.0	105	16.0	38.0	98.0	2.9	3.6	4.3	4.97	1.32
105	51.7	98.8	51.7	87.7	118	2.7	3.4	4.0	5.26	2.24
42.8	26.0	146	35.8	132	---	2.7	3.4	4.0	5.26	6.41
16.0	18.0	272	17.0	42.0	94.0	2.9	3.7	4.5	3.52	1.37
7.00	43.0	357	8.0	22.0	33.0	3.2	4.6	5.6	3.90	2.41
48.0	22.0	105	10.0	38.0	186	3.0	3.8	4.4	4.50	2.43
20.0	21	193	14.0	41.0	106	3.2	4.5	5.4	3.12	0.57
8.00	44.0	159	6.0	20.0	61.0	3.2	4.5	5.5	3.70	1.51
21.1	32.0	499	8.8	17.9	32.3	3.4	4.7	5.6	4.16	3.55
9.00	14.0	55.0	18.0	64.0	98.0	3.1	4.3	5.1	4.75	2.78
65.2	24.6	606	4.3	20.8	27.3	3.6	4.9	5.6	4.30	3.98
38.0	41.6	936	3.6	10.3	14.0	3.5	4.9	5.7	4.60	1.88
13.3	13.7	76.4	52.6	142	244	3.4	5.0	6.0	3.32	5.58
41.0	28.0	162	16.0	34.0	48.0	3.3	4.9	5.7	2.98	3.58
155	56.7	154	16.7	114	---	3.6	5.3	6.3	3.03	2.27
35.0	121	386	31.0	61.4	164	2.5	3.5	4.5	2.20	4.91
72.0	111	512	20.0	39.5	56.0	2.5	3.5	4.5	2.07	4.03
52.0	115	368	20.0	31.3	42.0	2.6	3.5	4.5	1.70	3.51

Table 16.--*Dependent and independent variables*

U.S. Geological Survey station number	Dependent variables									
	Q5	Q10	Q25	Q50	Q100	A	AE	E	RF	L
07120600	640	1,120	1,980	2,820	2,940	6.56	4.59	5,340	470	6.00
07123700	508	1,060	2,210	3,450	5,330	10.4	5.04	4,790	310	6.10
07124700[2]	440	980	2,290	3,920	6,340	8.46	7.90	6,180	3,450	7.20
07125050	570	1,120	2,170	3,340	4,970	6.22	5.83	6,220	1,240	5.30
07126400	1,010	1,910	3,320	4,510	5,530	4.14	3.86	4,910	540	3.60
07126450	440	1,140	3,300	5,900	9,900	8.93	6.54	5,780	900	6.60
07129100	730	1,600	3,550	5,850	9,000	7.07	5.54	4,600	600	3.60
07129200	877	1,720	3,160	4,300	5,600	3.31	2.62	4,630	420	2.90
07133200	778	1,540	2,800	3,870	4,480	2.34	2.27	4,280	280	3.00
07134300	2,160	3,780	6,560	9,930	13,590	13.9	13.7	3,860	450	10.7
07135800	1,370	2,510	4,220	5,730	7,330	6.28	4.94	3,790	260	6.00
07138520	1,780	3,330	6,000	8,160	10,770	17.0	14.6	3,720	260	7.40
07138600	255	479	930	1,420	2,090	38.0	5.66	3,578	39	5.89
07138800	163	211	277	329	385	7.00	1.19	3,078	49	1.74
07153450	220	320	460	590	740	4.56	.58	5,760	580	.91
07154650	4,450	7,250	12,100	16,700	22,400	25.4	21.4	4,238	580	13.2
07154800	136	268	508	738	1,060	3.50	.92	4,510	130	1.60
07155510	1,500	2,100	2,990	3,750	4,590	5.15	4.60	3,937	338	3.78
07155900	1,010	2,270	5,330	9,180	14,900	75.0	15.3	3,472	181	6.49
07156600	1,590	2,370	3,600	4,710	5,980	13.0	8.00	2,818	227	8.03
07156700	575	820	1,190	1,510	1,870	2.41	2.41	2,745	143	3.26
07227295	147	244	416	583	789	1.25	1.25	5,110	155	2.45
07232550	48	75	120	158	200	.26	.26	3,125	20	1.00
07232650	663	1,430	3,220	5,400	8,523	31.0	6.67	4,400	225	6.87

[1]Variable defined in table 7.
[2]Station was not included in final analysis.

used in final regression analysis--Continued

Independent variables[1]										
SS	SC	SW	WD1	WD3	WD5	I1_100	I6_100	I24_100	LI	S
20.0	78	317	24.0	79.6	144	2.6	3.8	4.6	1.57	5.49
56.0	54	123	38.0	53.3	111	2.9	3.9	4.8	2.57	3.58
79.0	390	1,050	18.0	27.3	32.0	2.7	3.8	5.0	1.17	6.13
45.0	177	908	18.0	31.6	59.0	2.4	3.3	4.1	1.28	4.52
29.0	96.0	167	12.0	26.3	32.0	3.1	4.3	5.1	1.55	3.13
20.0	127	424	18.0	38.4	49.0	2.9	4.8	5.7	1.20	4.88
25.0	68.0	547	13.0	40.9	34.0	3.0	4.8	5.5	1.57	1.83
34.0	90.0	764	21.0	26.5	42.0	3.2	4.6	5.4	1.60	2.54
32.0	81.0	194	18.0	31.0	50.0	3.4	5.0	5.8	1.72	3.85
17.0	37.0	185	36.0	40.0	44.0	3.0	5.0	6.0	1.87	3.24
20.0	38.0	100	17.0	22.5	28.0	3.1	5.1	6.3	2.27	5.73
15.0	25.0	42.0	19.0	79.1	160	3.4	5.3	6.7	1.63	3.22
75.6	17.0	192	17.5	63.2	146	3.5	5.3	6.5	2.52	0.91
56.4	29.9	54.4	108	152	187	3.7	5.5	6.6	2.48	0.43
13.0	84.0	386	11.0	30.8	44	3.1	4.6	5.6	1.08	0.18
2.88	29.7	678	23.7	70.5	81.7	3.3	5.1	6.6	0.90	6.86
28.0	38.0	142	13.0	30.7	175	3.3	5.2	6.7	1.08	.73
9.12	51.4	411	9.6	16.6	25.5	3.4	5.3	6.7	0.88	2.77
31.0	14.6	53.5	10.3	24.1	47.3	3.6	5.5	6.8	1.19	.56
42.2	31.7	135	41.4	73.8	83.8	3.6	5.6	7.0	1.34	4.96
22.9	43.8	333	23.5	36.4	---	3.6	5.6	7.0	1.27	4.41
40.1	51.7	115	13.4	29.2	---	3.2	5.0	6.5	0.39	4.80
114	14.7	39.8	83.7	158	226	3.6	5.6	7.0	0.67	3.85
3.17	28.2	45.4	14.6	47.3	76.6	3.3	5.2	6.7	0.56	1.52

Table 17.--*Matrix of concurrent years of record for the 25-year peak discharge at selected stations*

[Figures based in part on synthetic periods of record are shown in parentheses]

U.S. Geological Survey station number[1]	U.S. Geological Survey station number[1]									
	06756200	06758150	06758250	06758400	06758700	06759700	06760300	06760430	06761900	06821300
06756200	11									
06758150	(3)	(42)								
06758250	(10)	(36)	(42)							
06758400	(10)	(36)	(42)	(42)						
06758700	(10)	(36)	(42)	(42)	(42)					
06759700	(10)	(36)	(42)	(42)	(42)	(42)				
06760300	(10)	(36)	(42)	(42)	(42)	(42)	(42)			
06760430	(3)	(42)	(35)	(35)	(35)	(35)	(35)	(42)		
06761900	11	(12)	(19)	(19)	(19)	(19)	(19)	(11)	22	
06821300	(3)	(42)	(35)	(35)	(35)	(35)	(35)	(42)	(12)	(42)

[1]Station names and locations listed in table 1; general locations shown in figure 2.

Table 18.--*Matrix of relative correlation between selected stations*

[H = high correlation; M = medium correlation; L = low correlation; and Z = no correlation]

U.S. Geological Survey station number[1]	U.S. Geological Survey station number[1]									
	06756200	06758150	06758250	06758400	06758700	06759700	06760300	06760430	06761900	06821300
06756200	1.0									
06758150	L	1.0								
06758250	L	H	1.0							
06758400	L	H	H	1.0						
06758700	L	H	H	H	1.0					
06759700	L	M	M	M	M	1.0				
06760300	L	M	M	M	M	H	1.0			
06760430	L	M	M	M	M	H	H	1.0		
06761900	Z	Z	Z	Z	Z	Z	Z	Z	1.0	
06821300	L	M	M	M	M	H	H	H	Z	1.0

[1]Station names and locations listed in table 1; general locations shown in figure 2.

INFORMATION CONCERNING DATA FOR THE PLATEAU REGION

In addition to the rainfall-runoff data collected for small watersheds in the plains region of eastern Colorado, similar data were collected for 13 watersheds in the plateau region of western Colorado (fig. 16). Total drainage areas of the watersheds ranged from 0.99 to 13.6 mi^2, and the rainfall-runoff stations were operated seasonally from about April through about September 30 (table 19). Data collected in the Colorado River basin began with the instrumentation of five stations in April 1971; the total network of 12 stations was operational by May 1974. One station in the Colorado River basin was discontinued on June 30, 1977, because of urbanization within its watershed, and a replacement station was instrumented in July 1977.

Stations located in the Colorado River basin (plateau region) recorded the fewest number of floods of the three basins studied. No significant floods were recorded at station 09259750 (Little Snake River tributary near Great Divide) or 09250900 (Lay Creek tributary near Lay). Station 09169800 (East Paradox Creek tributary near Bedrock) recorded no floods during 8 of its 10 yr of operation, and station 09151700 (Deer Creek tributary near Dominguez) had no floods during 7 of its 10 yr of operation. Three stations, 09153200 (Little Salt Wash tributary near Fruita), 09163300 (East Salt Creek tributary near Mack), and 09168700 (Disappointment Creek tributary near Slick Rock), recorded no floods during 6 of their 10 yr of operation. The lack of sufficient data severely limited the number of stations at which successful calibration of the rainfall-runoff model could be obtained. For this reason, and because of the physiographic differences between the western-plateau and the eastern-plains regions of Colorado (McCain and Jarrett, 1976), a combined analysis with the plains region was not attempted.

However, the rainfall-runoff data collected do provide an indication of the character of storms and resulting floods that occur in the plateau region. For 49 selected storms in the plateau region, the average and maximum total quantities of rainfall at 5-min intervals are shown in figure 17. The greatest average total precipitation was 0.09 in. (1.1 in./h) occurring in the first 5-min interval after the storm began, and the average storm lasted about 30 min. The maximum rainfall accumulation recorded in a 5-min interval was 0.32 in. (3.8 in./h). The seasonal occurrence of the resulting floods is shown by 10-day intervals in figure 18. For the 49 selected plateau-region floods, about 84 percent occurred during the 90-day period from June 20 to September 17, and about 22 percent occurred during the 20-day period from August 19 to September 7. Comparison of these percentages with those for the plains region indicate that on an average, floods in the plateau region of Colorado generally occur a month later in the year than do floods in the plains region of Colorado.

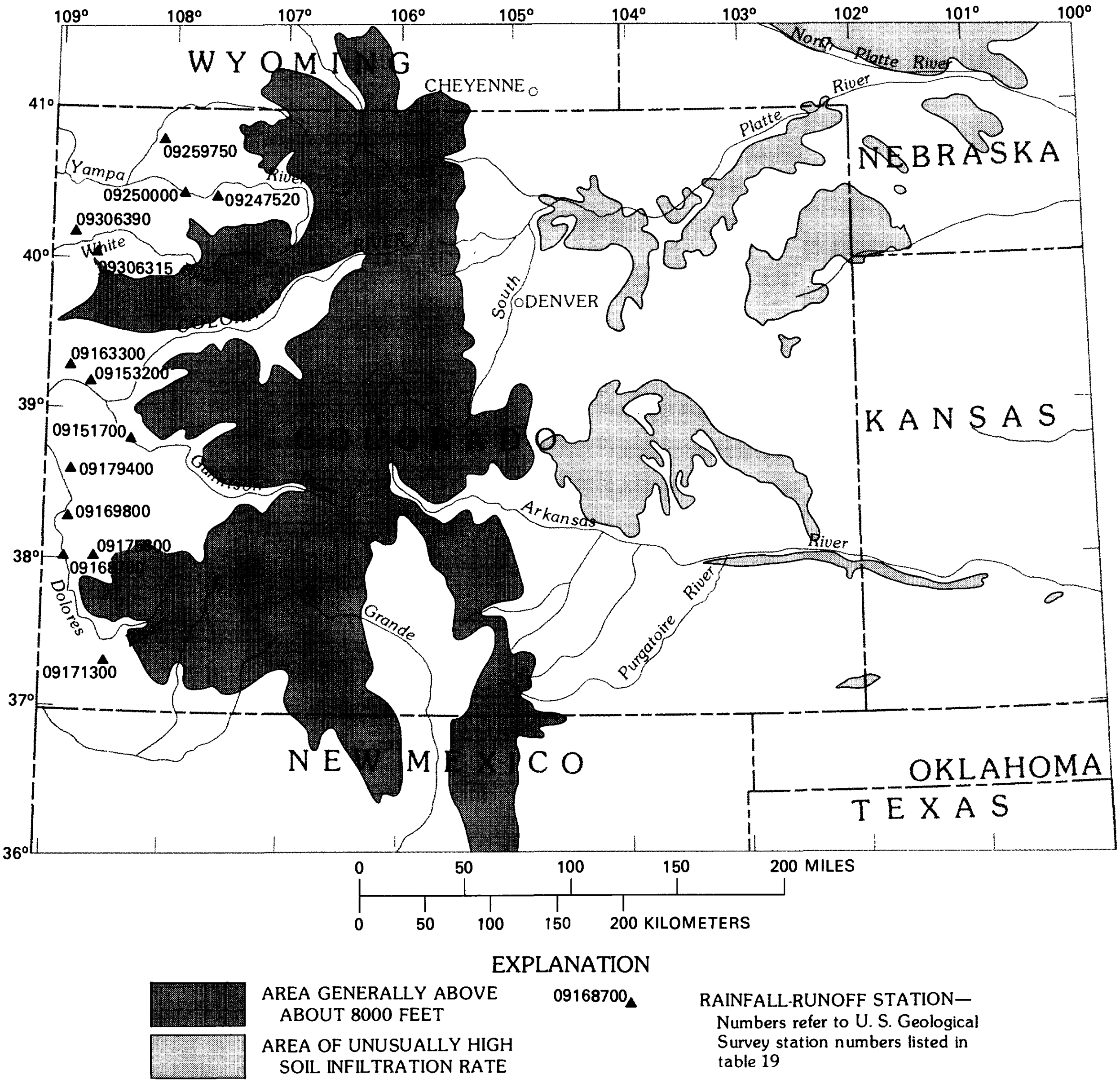

Figure 16.--General location of stations in the plateau region of western Colorado.

Table 19.--*Rainfall-runoff stations in the Colorado River basin*

U.S. Geological Survey station number	Station name	Total drainage area, in square miles	Period of seasonal record[1]	Location[2]		Basis of stage-discharge relation
				Latitude	Longitude	
09151700	Deer Creek tributary near Dominquez	4.79	Apr. 1971-Oct. 1980	38°51'30"	108°18'53"	Culvert analysis
09153200	Little Salt Wash tributary near Fruita	3.13	Apr. 1971-Oct. 1980	39°13'16"	108°38'57"	Step-backwater analysis
09163300	East Salt Creek tributary near Mack[3]	1.48	Apr. 1971-Oct. 1980	39°21'28"	108°48'49"	(footnote 4)
09168700	Disappointment Creek tributary near Slick Rock	1.73	May 1971-Oct. 1980	38°01'33"	108°48'51"	Culvert analysis
09169800	East Paradox Creek tributary near Bedrock	4.14	Apr. 1971-Oct. 1980	38°16'53"	108°48'21"	do.
09175800	Dead Horse Creek near Naturita	5.30	Apr. 1971-Oct. 1980	38°02'37"	108°34'38"	do.
09179400	West Creek tributary near Gateway	2.28	Apr. 1972-Oct. 1980	38°43'01"	108°55'28"	do.
09247520	Cedar Mountain gulch at Craig	6.26	May 1974-June 1977	40°30'52"	107°34'31"	do.
09250900	Lay Creek tributary near Lay	0.99	July 1977-Oct. 1980	40°31'31:	107°55'28"	do.
09259750	Little Snake River tributary near Great Divide	3.42	May 1974-Oct. 1980	40°53'10"	108°05'47"	do.
09306315	Gillam Draw near Rangely	13.6	May 1974-Oct. 1980	40°05'31"	108°44'45"	Step-backwater analysis
09306390	West Twin Wash near Dinosaur	4.22	May 1974-Oct. 1980	40°14'34"	108°57'16"	Culvert analysis
09371300	McElmo Creek tributary near Cortez	4.43	May 1971-Oct. 1980	37°20'51"	108°28'56"	do.

[1]Gages operated from about April 1 through about September 30 (no winter records).
[2]See figure 2 for general station locations.
[3]Prior to March 10, 1978, at site 700 feet downstream; total drainage area 1.69 square miles.
[4]Stage-discharge relation based on culvert analysis at downstream station and on step-backwater analysis at upstream station.

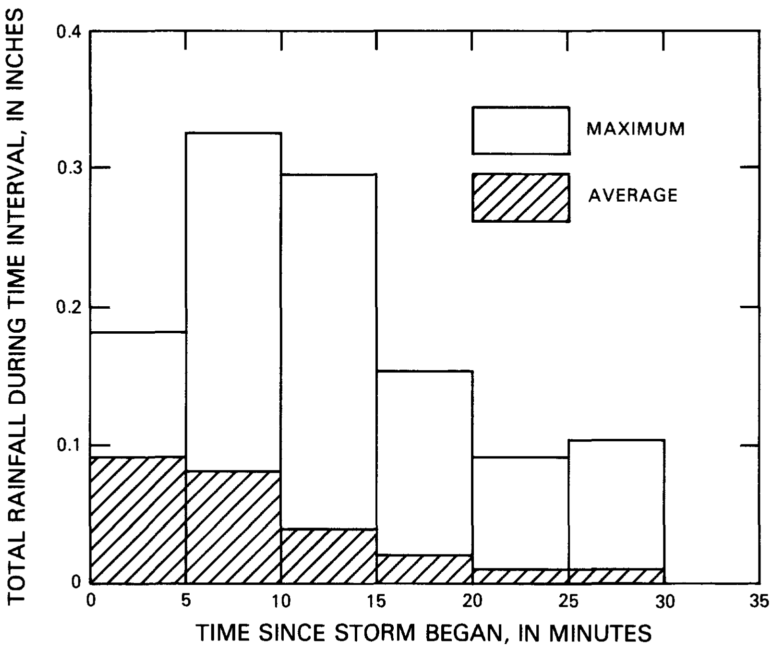

Figure 17.--Average and maximum rainfall by 5-minute intervals for 49 storms in the plateau region.

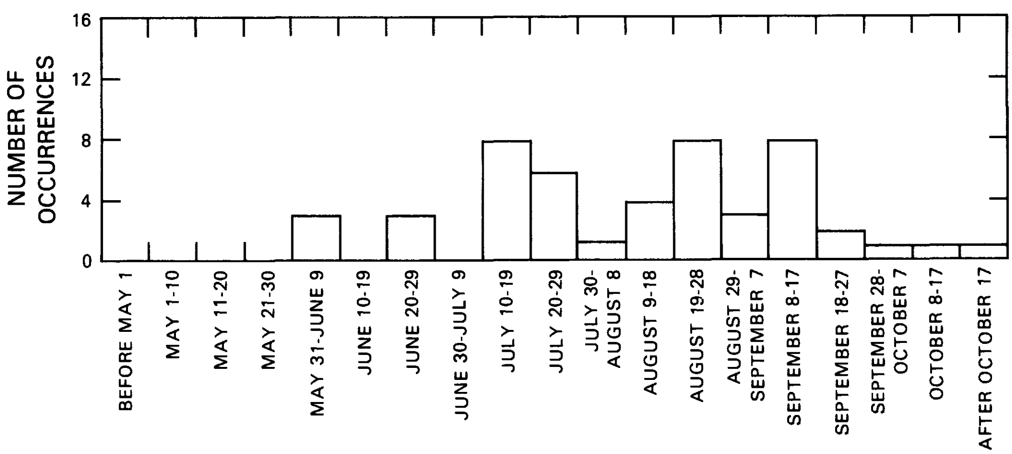

Figure 18.--Seasonal occurrence of 49 floods in the plateau region.

*U.S. GOVERNMENT PRINTING OFFICE: 1987-0-777-258/65336