Factors Affecting the Occurrence of Floods in the Southwest

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1580-D

Factors Affecting the Occurrence of Floods in the Southwest

By M. A. BENSON

FLOOD HYDROLOGY

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A study of the relation of annual peak discharges to many hydrologic factors in the western Gulf of Mexico basin within the United States

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1964

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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FLOOD HYDROLOGY

FACTORS AFFECTING THE OCCURRENCE OF FLOODS IN THE SOUTHWEST

By M. A. Benson

ABSTRACT

This report describes the relations between flood peaks and hydrologic factors in the western Gulf of Mexico basin, a region having a climate that varies from humid to arid and that has large diversities in topography and geology. Statistical multiple-regression techniques have been used to examine the relations of peak discharges of several recurrence intervals to many topographic and climatic factors.

It was found necessary to subdivide the entire region into two parts. The first comprises most of the basin and within it the annual flood peaks are caused by local thunderstorms or by widespread tropical storms. The second, a small part of the whole, is that within which the annual flood peaks are caused almost wholly by snowmelt.

Many of the factors that influence flood peaks are interrelated, and part of the investigation consisted of determining the most effective factor in each of several groups of highly correlated variables. Peak discharges within the rainstorm-flood area were found to be significantly related to seven factors: drainage-area size, rainfall intensity for a given duration and frequency, main-channel slope, basin length, surface area of lakes and ponds, the ratio of runoff to rainfall during the months of annual peak discharge, and the annual number of thunderstorm days. The last two factors, although statistically significant, play only a small part in the variability of flood peaks.

Peak discharges within the snowmelt-flood area were found to be significantly related to six factors: drainage-area size, main-channel slope, surface area of lakes and ponds, altitude, mean annual precipitation, and the annual number of thunderstorm days.

After use of the significant variables, most of the variability remaining is random and is believed attributable to the great variability of storm occurrence in this region. However, some of the residual variations in peak discharge appear to show some local patterns that indicate the influence of important factors not included.

INTRODUCTION

Flood discharge from a drainage basin may affect man's home or his livelihood and may even endanger his life. It is also a phenomenon that occurs erratically in time and varies widely in intensity from one place to another. To plan for protection against floods, for the use of flood water, or for the wise and efficient utilization of flood plains requires an understanding of flood occurrence. Such understanding involves, first, the reduction of the mass of flood data to a form that reveals its pattern in time, and, second, a study of the climatic and physical characteristics that cause variations in flood discharge from place to place.

Some procedure must first be adopted for analyzing the data to determine the probability distribution of flood occurrence. As a preliminary to this investigation, a study of alternative methods of flood-frequency analysis was made by Benson (1962a). This study reviewed briefly the history of flood-frequency analysis, proceeding from simple flood formulas to statistical methods of flood-frequency analysis on a regional basis. Currently used techniques were described and evaluated. Also, the significance and predictive values of flood-frequency relations were discussed. The study led to the adoption of some of these procedures in the investigations described in this report. The decision was made to use, for individual gaging sites, graphically drawn flood-frequency curves from which to determine the floods of various recurrence intervals, and to make independent studies at the various recurrence intervals in an attempt to relate hydrologic factors to the floods of those levels.

Another report by Benson (1962b) describes the study of the relation of hydrologic characteristics to flood peaks within New England, which typifies a humid region of the United States. The present report describes studies of similar relations for a large region most of which is semiarid and arid.

This study was made as part of a research project on areal flood frequency. The project leader was M. A. Benson; M. W. Busby and J. R. Crippen, engineers, assisted in the work and contributed significantly to the findings. R. U. Grozier, Austin, Tex., L. A. Wiard, Santa Fe, N. Mex., and C. T. Jenkins, Denver, Colo., directed the compilation of streamflow and topographic data, the preparation of flood-frequency curves, and the search for historical flood data within their States. Also acknowledged is the cooperation of H. O. Ogrosky of the U.S. Soil Conservation Service in furnishing information on the hydrologic soils index and of W. T. Wilson and D. M. Hershfield of the U.S. Weather Bureau in furnishing data on rainfall-intensity frequencies.

DESCRIPTION OF STUDY REGION

The general objective of the project of which this study is a part is to find explanations for the variations in flood magnitudes and frequencies throughout the range of terrain and climatic conditions in the

United States. The first study (Benson, 1962b) was made in New England, a humid region of nearly homogeneous climate. The study described in this report has been made for the western Gulf of Mexico basin within the United States, an area that comprises most of Texas and New Mexico and small parts of Louisiana and Colorado. Within this area the climate varies from humid to arid, though most of it would be classified as semiarid. This area corresponds to part 8 of the Water-Supply Paper series of the Geological Survey entitled, "Surface-Water Supply of the United States."

The western Gulf of Mexico basin is a region of extreme range in climatic, physiographic, geologic, and hydrologic characteristics. The altitude varies from sea level at the Gulf to about 8,000 feet in southwest Texas and about 14,000 feet in Colorado. The annual precipitation ranges from 58 inches in Louisiana to 8 inches in New Mexico. The terrain varies from humid swamps to arid deserts; from flat, monotonous plains to rugged, spectacular mountains; from wasteland to fertile valleys and forested slopes. There are wide areas of white sands, sand dunes, and bleak lava beds; regions of limestone, having caves, hot springs, and typical karst topography; mountains of igneous origin and mountains of sedimentary origin; and there are large closed basins into which water drains into interior lakes or drains downward into the soil and disappears.

Within this basin, the annual peak floods occur at different times during the year, as shown in figure 1. In Louisiana and eastern Texas, floods occur in winter and early spring. Westward, floods occur in the spring, then in spring and early summer. In western Texas, the flood season lasts from spring to fall; the fall floods result from tropical storms. Summer thunderstorm floods occur in west Texas and in New Mexico. Spring snowmelt floods occur in Colorado and northern New Mexico. Some parts of the basin have storms of only one type and, thus, only a short flood season; other parts have two or three types of storms, and their seasons may be separated or may merge into one long period.

SELECTION OF GAGING-STATION RECORDS

Gatewood (1956) contains a list of all the sites where streamflow records have been collected in the study region. Ten years of record of the annual momentary peak discharge was set as the minimum length of record to be considered for use in the flood-frequency analysis. All 10-year or longer records were examined for suitability based on various criteria.

Where gaging stations on the same stream drain areas of nearly equal size, the records of peak discharge represent to a large extent a duplication of information. If two stations on the same stream

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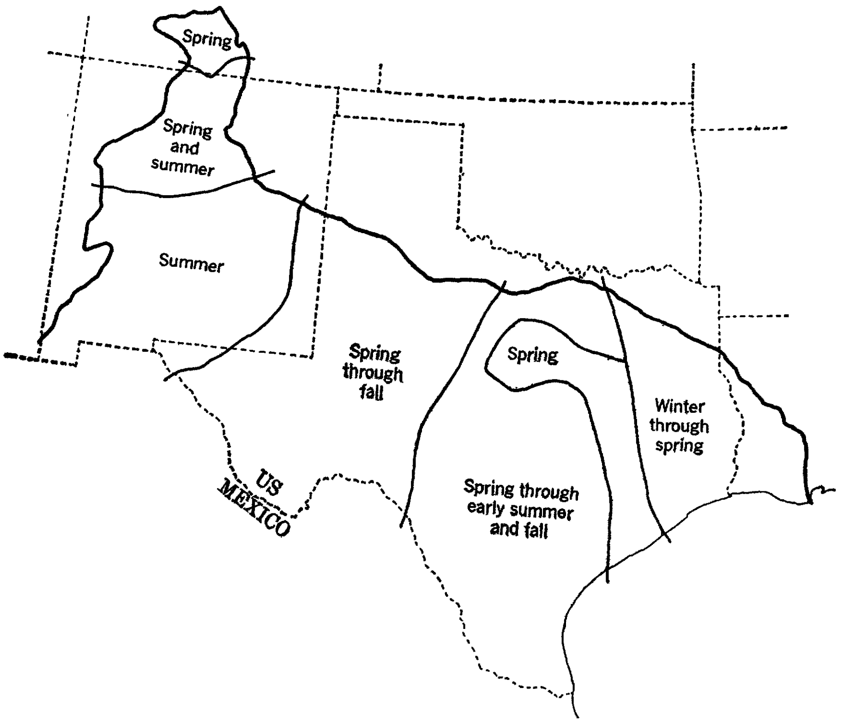

FIGURE 1.—Map showing time of year of annual peak discharges.

drained areas differing by less than 25 percent only the one having the longer record was used. If the drainage areas of two stations differed by less than 10 percent and if the periods of record differed, the records were combined. Combining was accomplished by determining the average ratio of discharges during overlapping periods or by a ratio based on the size of drainage areas.

Records that contained annual peak discharges excessively affected by artificial storage, regulation, or diversion could not be used. An average decrease or increase of 10 percent or more in the peak discharge as the result of artificial regulation was considered to be excessive. In the New England study, Benson (1962b) found that a usable storage volume of 4.5 million cubic feet (approximately 100 acre-feet) per square mile reduced the peak discharges about 10 percent. For the present study an investigation was made of the ratios of peak discharges at nearby comparable stations, before and after the construction of a large reservoir on the stream above one of them. It was found that usable storage volumes of 50 acre-feet per square mile could reduce peak discharges by more than 10 percent.

Based on the present study the following rules were set up for acceptance or rejection of records:

1. Records were eliminated that included periods during which the basin contained more than 100 acre-feet per square mile of usable storage.
2. Records for a basin having less than 50 acre-feet per square mile of usable storage were used unless the gaging station was located just downstream from the reservoir that contained all or most of the storage, in which case the record was not used.
3. Records of basins having between 50 and 100 acre-feet per square mile were examined individually. If there was an unregulated period of sufficient length preceding the regulation, studies were made (1) by constructing double-mass curves, using either an unregulated station or rainfall records as a control, and (2) by computing, for the periods both before and after regulation started, the medians of ratios of annual peaks at the station in question to annual peaks at comparable nearby stations or to composite annual-rainfall records. If the median changed by more than 10 percent, the record after the regulation started was eliminated. Results by the two methods of analysis were almost the same.

The usable storage within each basin was computed from published information on reservoir capacities collected by the U.S. Geological Survey (1960), the U.S. Department of Agriculture (1958), the State of New Mexico (1959), Thomas and Harbeck (1956), the Texas Board of Water Engineers (1956; 1958) and from unpublished information available in Survey district offices.

On advice of the several district Survey offices involved, no stations were eliminated because of diversion for irrigation, for such diversions do not cause excess regulation of flood peaks. However, several stations were eliminated where diversions into other basins were made through floodways—where flood water bypassed the gage. One station was eliminated because of backwater during times of flood, another because the stage-discharge relation was not defined within the range of the annual peak discharges. Stations on streams entering the Rio Grande from Mexico were not used.

After deletion or combining of records, 219 station records remained for use in the flood-frequency analysis. The drainage areas for these stations ranged from 1 to 35,000 square miles. The locations of the selected stations are shown on plate 1; their names are listed in table 1.

TABLE 1.—*Gaging-station names, numbers, and T-year peak discharges experienced and computed, in cubic feet per second*

[Upper line for each station shows observed discharges, lower line computed discharges. Median residual: Median of ratios of actual to computed flood peaks at each recurrence interval]

Station (pl. 1)	Station name	Recurrence interval in years							Median residual
		1.2	2.33	5	10	25	50	100	
100	Bayou des Cannes Near Eunice, La	2,030	4,500	7,100	9,600	13,200	--------	--------	2.35
		670	1,920	3,140	4,020	6,120	--------	--------	
120	Bayou Nezpique near Basile, La	4,320	7,080	9,200	12,100	--------	--------	--------	1.59
		2,290	4,500	5,930	7,500	--------	--------	--------	
130	Calcasieu River near Glenmora, La	9,350	20,600	29,600	37,200	47,300	55,100	63,200	1.42
		3,830	11,300	18,700	26,100	34,100	39,500	54,100	
135	Calcasieu River near Oberlin, La	8,730	18,700	25,800	33,100	45,400	57,400	--------	1.46
		3,260	10,300	18,300	26,200	33,800	38,200	--------	
145	Whiskey Chitto Creek near Oberlin, La	4,650	15,200	24,200	35,600	64,000	--------	--------	1.19
		3,770	12,700	21,900	32,500	43,900	--------	--------	
150	Bundick Creek near Dry Creek, La	2,220	12,200	19,400	23,100	28,700	33,500	--------	1.50
		1,420	5,680	10,800	16,200	22,100	25,500	--------	
155	Calcasieu River near Kinder, La	14,900	34,400	50,900	70,600	108,000	148,000	--------	1.47
		9,380	24,800	39,800	55,700	69,600	73,500	--------	
164	Beckwith Creek (head of West Fork Calcasieu River) near De Quincy, La	2,310	6,700	10,700	13,500	16,400	--------	--------	1.30
		1,080	4,340	8,260	12,400	17,400	--------	--------	
166	Hickory Branch at Kernan, La	2,200	4,870	5,920	6,290	6,620	6,830	--------	.95
		621	2,770	5,290	8,020	12,400	14,600	--------	
185	Sabine River near Mineola, Tex	7,910	32,300	45,700	55,900	68,800	78,000	--------	1.26
		8,940	21,000	31,900	42,200	57,800	72,400	--------	
190	Lake Fork Sabine River near Quitman, Tex	4,410	16,900	32,200	46,600	63,600	74,400	--------	1.20
		7,190	18,600	28,700	38,000	47,500	63,300	--------	
195	Big Sandy Creek near Big Sandy, Tex	1,290	4,290	8,510	13,500	21,700	29,700	39,600	.84
		1,710	6,190	11,200	16,200	23,900	32,000	41,300	
200	Sabine River near Gladewater, Tex	5,910	22,000	41,600	55,300	72,000	84,800	98,900	.96
		12,400	27,900	42,500	55,700	74,000	89,300	103,000	
225	Sabine River at Logansport, La	8,700	22,500	35,700	45,000	57,600	67,300	77,900	.83
		11,900	26,300	41,900	54,300	72,000	85,400	81,300	
240	Bayou San Miguel near Zwolle, La	1,150	4,210	8,910	14,600	--------	--------	--------	.88
		1,520	5,310	9,110	12,900	--------	--------	--------	
244	Sabine River near Milam, Tex	13,700	26,600	51,600	64,000	73,800	79,800	84,700	.86
		14,800	32,700	52,600	68,800	88,200	101,000	98,000	
275	Bayou Anacoco near Leesville, La	1,990	7,500	16,100	26,800	--------	--------	--------	1.75
		1,160	4,850	8,970	13,400	--------	--------	--------	
305	Sabine River near Ruliff, Tex	23,700	43,500	61,900	77,800	99,800	117,000	134,000	1.10
		15,000	34,300	57,400	77,500	99,500	106,000	112,000	
320	Neches River near Neches, Tex	2,850	9,620	17,400	26,800	39,300	51,700	66,600	.87
		5,410	14,300	23,400	30,800	41,400	53,800	52,000	
325	Neches River near Alto, Tex	2,690	11,100	24,700	35,100	47,900	--------	--------	.91
		5,990	15,900	27,100	35,800	46,000	--------	--------	
330	Neches River near Diboll, Tex	3,740	14,400	25,700	37,000	52,500	65,000	79,800	.99
		5,790	15,700	27,900	37,300	47,700	58,500	48,400	
335	Neches River near Rockland, Tex	5,740	16,700	27,200	35,900	46,600	54,500	62,600	.78
		7,270	19,700	35,000	47,700	60,900	71,600	66,100	
345	Mud Creek near Jacksonville, Tex	2,030	5,890	9,700	13,500	19,000	--------	--------	1.33
		1,800	4,420	6,360	8,240	16,600	--------	--------	
370	Angelina River near Lufkin, Tex	3,440	10,700	18,400	26,200	38,100	--------	--------	.78
		5,720	14,500	23,500	30,800	43,200	--------	--------	

TABLE 1.—*Gaging-station names, numbers, and T-year peak discharges experienced and computed, in cubic feet per second*—Continued

[Upper line for each station shows observed discharges, lower line computed discharges. Median residual: Median of ratios of actual to computed flood peaks at each recurrence interval]

Station (pl. 1)	Station name	Recurrence interval in years							Median residual
		1.2	2.33	5	10	25	50	100	
380	Attoyac Bayou near Chireno, Tex.	1,470	9,000	16,700	23,900	33,900	41,800	50,400	1.30
		2,030	7,110	13,100	18,200	25,100	32,100	33,600	
395	Angelina River at Horger, Tex.	9,010	20,600	31,400	41,000	54,000	64,100	75,000	.86
		8,920	22,400	37,400	49,900	65,000	74,700	75,800	
410	Neches River at Evadale, Tex.	15,200	35,900	56,200	74,000	96,200	112,000	126,000	1.29
		12,400	26,400	41,500	54,900	81,700	86,700	106,000	
415	Village Creek near Kountze, Tex.	3,700	10,800	19,600	33,900	--------	--------	--------	.75
		4,240	14,800	26,100	38,500	--------	--------	--------	
435	West Fork Trinity River at Bridgeport, Tex.	3,650	7,470	11,300	14,700	19,700	--------	--------	.50
		3,890	12,600	22,800	32,100	39,900	--------	--------	
440	Big Sandy Creek near Bridgeport, Tex.	666	3,840	10,500	20,200	--------	--------	--------	.72
		2,050	6,740	12,100	17,000	--------	--------	--------	
455	West Fork Trinity River at Lake Worth Dam, above Fort Worth, Tex.	2,650	5,000	6,540	7,620	--------	--------	--------	.69
		2,960	6,720	10,300	13,800	--------	--------	--------	
475	Clear Fork Trinity River at Fort Worth, Tex.	5,220	12,500	18,200	24,800	--------	--------	--------	1.08
		2,570	10,200	19,500	30,100	--------	--------	--------	
480	West Fork Trinity River at Fort Worth, Tex.	5,250	10,600	16,900	24,300	--------	--------	--------	1.12
		4,320	10,100	15,600	21,300	--------	--------	--------	
505	Elm Fork Trinity River near Sanger, Tex.	1,550	7,340	15,900	26,200	--------	--------	--------	1.10
		1,790	7,070	13,600	20,900	--------	--------	--------	
510	Isle du Bois Creek near Pilot Point, Tex.	1,540	6,100	13,600	20,200	--------	--------	--------	.77
		2,900	9,280	15,500	22,000	--------	--------	--------	
515	Clear Creek near Sanger, Tex.	1,250	7,380	13,900	20,500	--------	--------	--------	1.14
		1,460	6,100	11,900	18,500	--------	--------	--------	
540	Denton Creek near Roanoke, Tex.	3,920	11,600	21,200	31,600	48,500	63,800	--------	1.38
		2,490	8,890	16,700	24,700	33,500	43,500	--------	
570	Trinity River at Dallas, Tex.	9,220	28,100	52,200	76,300	113,000	145,000	179,000	1.27
		12,500	25,300	36,100	49,300	88,800	95,500	200,000	
615	East Fork Trinity River near Rockwall, Tex.	6,390	24,000	40,400	55,000	75,300	--------	--------	1.17
		7,110	20,500	33,100	47,200	63,900	--------	--------	
630	Cedar Creek near Mabank, Tex.	5,800	22,300	28,100	31,700	35,900	38,400	41,000	.85
		5,870	16,900	27,200	37,400	51,900	66,800	92,700	
635	Richland Creek near Richland, Tex.	5,030	29,000	46,300	55,800	62,300	--------	--------	.99
		7,420	23,600	39,200	56,500	81,400	--------	--------	
645	Chambers Creek near Corsicana, Tex.	5,500	19,500	30,000	37,300	44,500	48,700	--------	.88
		5,760	18,400	32,000	46,100	64,200	83,100	--------	
650	Trinity River near Oakwood, Tex.	14,100	39,000	73,000	106,000	152,000	186,000	--------	.96
		23,300	49,100	74,200	103,000	161,000	172,000	--------	
665	Trinity River at Romayor, Tex.	22,700	45,300	64,000	79,800	99,700	115,000	--------	.78
		21,600	48,100	78,000	109,000	161,000	169,000	--------	
680	West Fork San Jacinto River near Conroe, Tex.	4,190	18,000	36,800	59,000	93,500	--------	--------	1.09
		6,720	20,700	33,800	46,700	58,700	--------	--------	
685	Spring Creek near Spring, Tex.	1,490	6,860	15,100	24,200	38,000	49,100	--------	.72
		2,850	11,700	21,800	32,500	43,500	51,200	--------	
690	Cypress Creek near Westfield, Tex.	635	5,100	9,540	13,300	18,100	22,000	--------	1.04
		855	4,220	8,930	13,200	17,300	21,400	--------	
695	West Fork San Jacinto River near Humble, Tex.	8,230	19,500	41,400	70,000	121,000	174,000	239,000	.87
		12,400	36,400	58,400	80,800	89,300	109,000	178,000	

TABLE 1.—*Gaging-station names, numbers, and T-year peak discharges experienced and computed, in cubic feet per second*—Continued

[Upper line for each station shows observed discharges, lower line computed discharges. Median residual: Median of ratios of actual to computed flood peaks at each recurrence interval]

Station (pl. 1)	Station name	Recurrence interval in years							Median residual
		1.2	2.33	5	10	25	50	100	
700	East Fork San Jacinto River near Cleveland, Tex	1,250	8,920	21,100	33,100	48,500	--------	--------	1.21
		2,490	9,520	17,500	25,600	34,000	--------	--------	
705	Peach Creek at Splendora, Tex	349	2,510	6,800	12,000	20,200	27,200	--------	.85
		729	3,980	8,430	13,400	19,400	23,400	--------	
710	Caney Creek near Splendora, Tex	724	2,910	6,510	11,000	--------	--------	--------	.90
		656	3,530	7,480	11,800	--------	--------	--------	
715	San Jacinto River near Huffman, Tex	8,820	30,600	63,200	102,000	168,000	230,000	301,000	.83
		22,000	58,400	88,600	123,000	150,000	159,000	301,000	
745	Whiteoak Bayou at Houston, Tex	950	2,820	5,200	7,670	11,400	14,400	--------	.70
		806	4,000	8,080	12,000	16,000	20,700	--------	
750	Brays Bayou at Houston, Tex	1,580	4,310	5,760	6,770	7,910	--------	--------	.68
		931	4,320	8,430	11,600	13,400	--------	--------	
770	Clear Creek near Pearland, Tex	410	922	1,360	1,720	2,200	--------	--------	.36
		410	1,920	3,780	5,100	6,380	--------	--------	
780	Chocolate Bayou near Alvin, Tex	671	2,510	4,590	6,620	--------	--------	--------	.79
		781	3,260	6,060	8,190	--------	--------	--------	
795	Double Mountain Fork Brazos River at Lubbock, Tex	7.9	83	510	1,660	--------	--------	--------	.28
		52	434	1,380	2,200	--------	--------	--------	
805	Double Mountain Fork Brazos River near Aspermont, Tex	10,300	21,400	30,300	39,900	57,000	75,800	--------	2.17
		1,170	5,510	12,800	20,200	29,700	42,400	--------	
807	White River at Plainview, Tex	9	96	561	1,790	6,220	14,200	--------	.54
		68	497	1,500	2,490	3,860	6,420	--------	
820	Salt Fork Brazos River near Aspermont, Tex	9,150	20,100	28,400	35,000	41,500	50,400	--------	1.30
		1,980	8,860	19,500	31,100	45,500	62,400	--------	
825	Brazos River at Seymour, Tex	11,400	33,200	59,400	73,800	86,000	100,000	--------	1.52
		5,260	17,800	35,500	53,800	74,700	96,900	--------	
840	Clear Fork Brazos River at Nugent, Tex	3,020	9,480	17,800	27,100	42,000	--------	--------	.69
		4,970	14,500	25,900	33,300	37,700	--------	--------	
855	Clear Fork Brazos River at Fort Griffin, Tex	3,810	8,720	15,000	21,700	32,600	--------	--------	.50
		5,150	17,000	32,200	46,900	65,500	--------	--------	
870	Clear Fork Brazos River near Crystal Falls, Tex	5,950	12,700	18,500	23,300	29,600	34,300	39,000	.39
		6,940	22,100	41,400	60,300	83,900	106,000	138,000	
890	Brazos River near Palo Pinto, Tex	16,100	39,500	55,300	68,200	85,000	98,000	--------	.76
		11,900	35,400	66,800	99,500	137,000	165,000	--------	
915	Paluxy Creek at Glen Rose, Tex	4,220	16,500	40,500	46,400	52,800	57,000	61,500	1.90
		1,510	7,500	15,700	24,400	35,200	49,100	72,800	
920	Nolands River at Blum, Tex	6,810	11,100	14,700	17,700	--------	--------	--------	1.13
		1,880	8,290	15,900	24,000	--------	--------	--------	
935	Aquilla Creek near Aquilla, Tex	5,200	9,280	12,900	--------	--------	--------	--------	.82
		2,960	11,300	20,400	--------	--------	--------	--------	
950	North Bosque River near Clifton, Tex	7,480	24,100	34,300	39,300	50,000	64,500	89,600	.85
		3,900	15,600	30,200	46,500	70,500	93,700	149,000	
965	Brazos River at Waco, Tex	26,200	64,000	92,000	114,000	150,000	182,000	222,000	1.18
		14,800	36,900	65,800	96,700	151,000	174,000	241,000	
995	Leon River near Hasse, Tex	2,140	7,400	16,200	27,800	49,300	--------	--------	.65
		3,300	13,900	27,700	41,000	54,700	--------	--------	
1025	Leon River near Belton, Tex	8,060	18,600	29,000	38,800	52,900	64,600	--------	.66
		4,970	19,700	40,900	62,500	88,700	114,000	--------	

TABLE 1.—*Gaging-station names, numbers, and T-year peak discharges experienced and computed, in cubic feet per second*—Continued

[Upper line for each station shows observed discharges, lower line computed discharges. Median residual: Median of ratios of actual to computed flood peaks at each recurrence interval]

Station (pl. 1)	Station name	Recurrence interval in years: 1.2	2.33	5	10	25	50	100	Median residual
1040	Lampasas River at Youngsport, Tex.	8,100	19,800	32,300	45,200	65,000	82,200	--------	0.93
		3,530	16,300	33,400	51,600	73,300	96,900	--------	
1050	San Gabriel River at Georgetown, Tex.	5,860	18,000	29,100	38,400	--------	--------	--------	1.75
		2,020	9,290	18,600	29,500	--------	--------	--------	
1055	San Gabriel River at Circleville, Tex.	4,170	13,900	28,900	47,100	--------	--------	--------	1.40
		2,210	10,200	20,800	33,100	--------	--------	--------	
1065	Little River at Cameron, Tex.	9,830	31,500	63,000	101,000	173,000	--------	--------	.82
		11,900	40,300	77,200	116,000	163,000	--------	--------	
1100	Yegua Creek near Somerville, Tex.	1,680	10,000	20,500	31,900	50,800	--------	--------	.67
		5,180	17,600	30,500	42,700	56,500	--------	--------	
1105	Navasota River near Easterly, Tex.	3,360	15,500	31,100	44,900	61,000	72,000	82,200	.97
		5,250	17,200	29,600	41,700	58,300	74,200	104,000	
1140	Brazos River at Richmond, Tex.	36,600	67,800	86,700	100,000	115,000	125,000	--------	.63
		27,500	68,200	121,900	180,000	268,000	288,000	--------	
1190	Bluff Creek near Ira, Tex.	407	1,020	1,720	2,430	--------	--------	--------	1.15
		135	769	1,780	2,710	--------	--------	--------	
1235	Champlin Creek near Colorado City, Tex.	1,020	5,950	8,330	9,830	--------	--------	--------	1.26
		713	3,650	7,680	11,800	--------	--------	--------	
1265	Colorado River at Ballinger, Tex.	10,200	21,600	31,200	41,600	58,800	76,000	--------	1.43
		4,410	12,000	21,500	29,600	45,100	61,800	--------	
1270	Elm Creek at Ballinger, Tex.	3,120	9,050	20,600	33,600	46,200	51,800	--------	1.32
		2,070	8,220	15,300	22,800	35,800	52,100	--------	
1280	South Concho River at Christoval, Tex.	580	5,560	15,000	28,900	57,500	90,000	134,000	1.14
		2,300	9,470	17,800	25,400	35,700	56,400	68,000	
1285	Middle Concho River near Tankersly, Tex.	3,070	10,700	17,800	22,900	28,200	--------	--------	1.35
		1,310	6,060	13,200	19,900	29,400	--------	--------	
1310	Spring Creek near Tankersly, Tex.	1,840	11,000	18,800	24,200	30,400	--------	--------	1.12
		1,640	7,360	14,700	22,200	36,100	--------	--------	
1335	North Concho River at Sterling City, Tex.	580	3,100	6,170	9,000	12,600	15,200	--------	.54
		1,290	5,740	11,300	16,200	22,900	35,000	--------	
1340	North Concho River near Carlsbad, Tex.	1,900	16,600	41,000	59,500	77,300	87,000	94,000	1.12
		4,400	14,900	26,500	37,800	54,000	79,000	105,000	
1360	Concho River near San Angelo, Tex.	7,660	27,100	50,200	74,000	113,000	155,000	212,000	1.05
		8,310	27,100	47,800	68,600	100,000	135,000	214,000	
1365	Concho River near Paint Rock, Tex.	6,500	24,600	46,000	67,800	103,000	--------	--------	.89
		8,180	28,000	51,400	75,300	109,000	--------	--------	
1380	Colorado River at Winchell, Tex.	18,000	31,400	42,600	54,500	73,600	--------	--------	.76
		11,200	31,400	55,900	78,500	110,000	--------	--------	
[1] 1445	San Saba River at Menard, Tex.	1,160	10,900	34,700	63,000	105,000	144,000	--------	1.49
		3,110	14,200	25,800	38,500	49,800	76,000	--------	
1450	Brady Creek at Brady, Tex.	1,890	6,040	13,400	23,600	44,100	66,800	97,700	.79
		2,390	10,700	21,400	32,000	45,500	68,100	87,100	
1460	San Saba River at San Saba, Tex.	3,650	15,200	37,000	63,400	114,000	165,000	--------	.73
		6,990	27,600	53,900	82,000	119,000	161,000	--------	
1470	Colorado River near San Saba, Tex.	18,300	35,400	63,000	93,200	143,000	188,000	242,000	.92
		17,800	43,600	72,800	101,000	153,000	188,000	266,000	
[1] 1485	North Llano River near Junction, Tex.	1,430	16,000	52,200	72,300	84,000	88,200	92,000	.82
		4,710	19,600	33,400	51,200	73,600	111,000	167,000	

See footnotes at end of table.

TABLE 1.—*Gaging-station names, numbers, and T-year peak discharges experienced and computed, in cubic feet per second*—Continued

[Upper line for each station shows observed discharges, lower line computed discharges. Median residual: Median of ratios of actual to computed flood peaks at each recurrence interval]

Station (pl. 1)	Station name	Recurrence interval in years: 1.2	2.33	5	10	25	50	100	Median residual
[1]1500	Llano River near Junction, Tex.	1,790	17,700	70,000	114,000	164,000	--------	--------	1.20
		10,000	36,600	58,400	86,600	117,000	--------	--------	
1515	Llano River at Llano, Tex.	8,050	41,000	89,500	143,000	230,000	309,000	405,000	1.07
		11,800	44,700	83,700	126,000	180,000	237,000	405,000	
1530	Pedernales River at Stonewall, Tex.	4,210	11,000	19,200	27,700	--------	--------	--------	.82
		2,320	12,400	26,000	40,400	--------	--------	--------	
1535	Pedernales River near Johnson City, Tex.	4,920	20,400	46,800	81,000	146,000	163,000	--------	1.62
		2,980	15,100	31,500	49,900	74,400	101,000	--------	
1540	Pedernales River near Spicewood, Tex.	2,960	18,100	51,100	102,000	163,000	--------	--------	1.48
		3,540	16,500	34,500	55,800	89,200	--------	--------	
1580	Colorado River at Austin, Tex.	28,700	56,500	102,000	178,000	324,000	475,000	670,000	1.37
		20,900	54,000	93,300	134,000	212,000	250,000	396,000	
1600	Dry Creek at Buescher Lake, near Smithville, Tex.	167	780	1,300	1,740	--------	--------	--------	1.76
		37	371	918	1,670	--------	--------	--------	
1635	Lavaca River at Hallettsville, Tex.	2,600	8,210	14,700	22,000	--------	--------	--------	1.80
		906	4,320	8,630	13,200	--------	--------	--------	
1640	Lavaca River near Edna, Tex.	3,510	12,100	22,000	32,500	50,500	68,800	91,300	.88
		3,980	14,400	26,900	38,400	48,400	60,900	69,500	
1645	Navidad River near Ganado, Tex.	5,900	12,700	20,400	30,000	50,000	72,000	101,000	.83
		5,290	18,800	34,200	48,600	59,900	72,500	92,100	
1660	Johnson Creek near Ingram, Tex.	68	1,240	3,520	8,650	26,500	58,500	126,000	.57
		464	3,760	9,140	15,100	23,200	36,200	62,200	
1670	Guadalupe River at Comfort, Tex.	3,300	13,300	44,000	100,000	152,000	180,000	200,000	1.54
		2,340	13,100	28,500	44,800	64,600	92,400	148,000	
1685	Guadalupe River above Comal River, at New Braunfels, Tex.	3,080	11,700	34,600	57,800	92,000	120,000	--------	1.39
		2,010	10,800	25,300	41,700	64,800	85,600	--------	
1710	Blanco River at Wimberley, Tex.	1,600	10,100	28,000	51,000	87,200	116,000	--------	1.84
		1,210	7,130	16,000	26,500	43,000	58,500	--------	
1720	San Marcos River at Luling, Tex.	3,470	13,300	26,000	39,000	59,000	--------	--------	1.34
		1,340	8,160	19,500	33,000	52,100	--------	--------	
1730	Plum Creek near Luling, Tex.	2,260	8,550	18,000	29,100	49,000	68,200	92,200	.92
		2,670	11,300	21,200	31,700	44,800	60,300	92,200	
1735	San Marcos River at Ottine, Tex.	4,840	15,800	36,300	129,000	189,000	216,000	237,000	1.59
		3,050	14,700	31,200	51,500	82,700	101,000	202,000	
1765	Guadalupe River at Victoria, Tex.	6,570	18,500	36,500	57,200	94,300	127,000	170,000	.71
		5,920	24,800	52,900	85,900	133,000	153,000	264,000	
1770	Coleto Creek near Schroeder, Tex.	1,080	11,200	27,200	38,200	--------	--------	--------	1.52
		1,650	7,820	16,000	23,600	--------	--------	--------	
1775	Coleto Creek near Victoria, Tex.	1,670	13,600	35,600	52,200	70,000	82,400	93,500	1.56
		2,110	9,950	20,300	30,400	40,500	52,700	71,400	
1785	San Pedro Creek at San Antonio, Tex.	239	766	1,090	1,330	1,600	1,780	1,960	1.06
		27	286	775	1,250	1,980	3,630	3,620	
1790	Medina River near Pipe Creek, Tex.	2,780	15,000	31,600	44,700	58,500	67,000	--------	1.
		1,360	8,080	18,200	30,000	48,600	69,500	--------	61
1840	Cibolo Creek near Bulverde, Tex.	8.5	2,670	11,500	17,100	23,000	--------	--------	.96
		455	3,640	9,230	15,600	23,900	--------	--------	

See footnotes at end of table.

TABLE 1.—*Gaging-station names, numbers, and T-year peak discharges experienced and computed, in cubic feet per second*—Continued

[Upper line for each station shows observed discharges, lower line computed discharges. Median residual: Median of ratios of actual to computed flood peaks at each recurrence interval]

Station (pl. 1)	Station name	Recurrence interval in years							Median residual
		1.2	2.33	5	10	25	50	100	
1850	Cibolo Creek at Selma, Tex.	14	1,890	17,600	36,300	56,000	--------	--------	1.92
		471	3,540	9,150	15,400	23,700	--------	--------	
1860	Cibolo Creek near Falls City, Tex.	2,560	9,150	15,100	20,200	27,000	32,100	--------	.76
		1,230	7,380	17,800	30,000	47,200	60,800	--------	
1885	San Antonio River at Goliad, Tex.	2,910	10,700	16,900	22,200	29,400	35,100	--------	.34
		4,880	21,500	45,700	73,100	113,000	135,000	--------	
1895	Mission River at Refugio, Tex.	633	8,000	17,000	24,700	33,600	40,200	--------	.84
		1,630	8,790	19,400	29,600	39,000	51,400	--------	
[1]1900	Nueces River at Laguna, Tex.	800	12,900	60,200	116,000	189,000	244,000	302,000	1.73
		5,340	20,700	34,800	54,400	86,000	131,000	196,000	
[1]1905	West Nueces River near Brackettville, Tex.	1.2	10,500	51,000	105,000	224,000	363,000	565,000	3.06
		1,980	10,700	21,300	34,300	50,100	77,400	106,000	
[1]1920	Nueces River below Uvalde, Tex.	280	12,500	63,000	162,000	309,000	433,000	572,000	2.50
		4,390	21,100	40,300	64,700	93,800	138,000	197,000	
[1]1930	Nueces River near Asherton, Tex.	2,530	6,180	11,500	17,500	28,000	--------	--------	.21
		6,600	29,600	55,100	88,800	133,000	--------	--------	
[1]1940	Nueces River at Cotulla, Tex.	3,090	9,210	18,300	29,000	47,500	65,500	87,000	.30
		7,880	33,400	60,900	97,600	146,000	199,000	310,000	
[1]1945	Nueces River near Tilden, Tex.	3,320	10,800	20,300	30,700	47,800	63,200	--------	.26
		10,800	43,800	78,100	125,000	185,000	237,000	--------	
[1]1950	Frio River at Concan, Tex.	451	4,140	25,600	57,000	105,000	142,000	179,000	.98
		4,100	16,200	27,000	42,900	72,500	110,000	183,000	
[1]1980	Sabinal River near Sabinal, Tex.	830	6,220	10,700	15,200	--------	--------	--------	1.06
		713	5,100	11,200	18,900	--------	--------	--------	
[1]2055	Frio River near Derby, Tex.	1,660	6,750	14,000	26,800	63,800	122,000	234,000	.22
		10,100	42,500	73,400	119,000	178,000	235,000	476,000	
[1]2070	Frio River at Calliham, Tex.	3,360	9,380	17,000	25,700	--------	--------	--------	.22
		10,400	43,600	77,200	126,000	--------	--------	--------	
2080	Atascosa River at Whitsett, Tex.	1,520	5,400	15,300	27,100	38,600	45,500	52,700	.54
		3,500	15,300	30,700	45,200	59,000	79,200	98,400	
[1]2100	Nueces River near Three Rivers, Tex.	5,250	15,600	32,800	50,100	68,500	78,200	86,000	.20
		27,800	93,300	150,000	234,000	328,000	398,000	762,000	
[2]2180	Goose Creek near Wagonwheel Gap, Colo.	219	476	746	1,010	1,380	--------	--------	.67
		416	710	997	1,350	1,410	--------	--------	
[2]2195	South Fork Rio Grande at South Fork, Colo.	970	1,780	2,570	3,250	--------	--------	--------	2.44
		361	811	1,220	1,570	--------	--------	--------	
[2]2200	Rio Grande near Del Norte, Colo.	3,370	5,500	7,270	8,750	10,700	12,100	--------	.66
		5,150	8,330	10,600	13,800	12,500	--------	--------	
[2]2205	Pinos Creek near Del Norte, Colo.	96	227	378	525	750	--------	--------	1.80
		53	164	261	328	381	--------	--------	
[2]2235	Rock Creek near Monte Vista, Colo.	31	124	153	171	192	--------	--------	.60
		50	146	227	289	355	--------	--------	
[2]2245	Kerber Creek at Ashley Ranch, near Villa Grove, Colo.	50	118	196	274	--------	--------	--------	.64
		77	204	312	402	--------	--------	--------	
[2]2270	Saguache Creek near Saguache, Colo.	156	463	641	722	768	780	--------	.31
		507	1,410	2,050	2,560	2,610	--------	--------	
[2]2275	North Crestone Creek near Crestone, Colo.	57	128	217	318	507	715	--------	1.01
		66	127	198	270	294	--------	--------	

See footnotes at end of table.

TABLE 1.—*Gaging-station names, numbers, and T-year peak discharges experienced and computed, in cubic feet per second*—Continued

[Upper line for each station shows observed discharges, lower line computed discharges. Median residual: Median of ratios of actual to computed flood peaks at each recurrence interval]

Station (pl. 1)	Station name	Recurrence interval in years 1.2	2.33	5	10	25	50	100	Median residual
[2]2305	Carnero Creek near La Garita, Colo	63	243	--------	--------	--------	--------	--------	0.64
		101	319	--------	--------	--------	--------	--------	
[2]2310	La Garita Creek near La Garita, Colo	85	253	--------	--------	--------	--------	--------	1.08
		78	234	--------	--------	--------	--------	--------	
[2]2360	Alamosa Creek above Terrace Reservoir, Colo	678	1,150	1,690	2,190	--------	--------	--------	2.55
		240	534	761	962	--------	--------	--------	
[2]2405	Trinchera Creek above Turners Ranch, near Fort Garland, Colo	63	163	281	403	595	--------	--------	.65
		111	253	385	505	585	--------	--------	
[2]2410	Trinchera Creek above Mountain Home Reservoir, near Fort Garland, Colo	40	147	256	--------	--------	--------	--------	.25
		160	370	549	--------	--------	--------	--------	
[2]2415	Sangre de Cristo Creek near Fort Garland, Colo	75	237	478	782	1,350	1,930	--------	.60
		139	421	654	820	1,010	--------	--------	
[2]2425	Ute Creek near Fort Garland, Colo	90	164	228	290	384	--------	--------	.86
		80	191	294	385	501	--------	--------	
[2]2455	Conejos River at Platoro, Colo	770	1,070	1,240	1,350	1,440	--------	--------	1.85
		312	578	767	1,000	1,070	--------	--------	
[2]2465	Conejos River near Mogote, Colo	1,950	2,900	3,650	4,250	5,100	5,850	--------	1.70
		745	1,600	2,130	2,690	3,000	--------	--------	
[2]2475	San Antonio River at Ortiz, Colo	249	610	961	1,220	1,620	1,860	--------	.89
		281	697	955	1,220	1,760	--------	--------	
[2]2480	Los Pinos River near Ortiz, Colo	910	1,670	2,110	2,520	3,000	3,310	--------	1.81
		395	923	1,300	1,680	2,100	--------	--------	
[2]2485	San Antonio River at mouth, near Manassa, Colo	419	1,220	1,520	1,750	2,050	--------	--------	.86
		425	1,160	1,640	2,060	2,680	--------	--------	
[2]2490	Conejos River near La Sauses, Colo	558	2,470	3,030	3,500	4,040	4,450	--------	1.35
		455	1,430	2,050	2,470	2,960	--------	--------	
[2]2515	Rio Grande near Lobatos, Colo	1,710	6,250	8,820	10,300	12,000	14,200	--------	.97
		2,330	6,420	8,750	10,500	10,800	--------	--------	
[2]2525	Costilla Creek above Costilla Dam, N.Mex	31	93	174	266	--------	--------	--------	.52
		68	160	231	292	--------	--------	--------	
[2]2530	Casias Creek near Costilla, N.Mex	28	102	114	122	128	--------	--------	.62
		45	115	176	228	290	--------	--------	
[2]2535	Santistevan Creek near Costilla, N.Mex	4.7	9.9	15	18	19	--------	--------	.73
		6.1	14	22	28	28	--------	--------	
[2]2630	Latir Creek near Cerro, N. Mex	28	55	83	106	131	--------	--------	.83
		26	66	107	142	197	--------	--------	
[2]2640	Red River near Red River, N.Mex	58	129	191	232	276	--------	--------	1.74
		28	74	116	145	162	--------	--------	
[2]2650	Red River near Questa, N. Mex	157	365	540	685	870	--------	--------	.93
		149	394	597	765	1,040	--------	--------	
[2]2660	Cabresto Creek near Questa, N.Mex	25	79	135	175	212	--------	--------	.73
		46	108	172	214	228	--------	--------	
[2]2675	Rio Hondo near Valdez, N.Mex	106	212	321	420	562	--------	--------	1.22
		69	173	273	358	485	--------	--------	
[2]2685	Rio Hondo at Arroyo Hondo, N.Mex	71	241	489	--------	--------	--------	--------	.91
		78	217	354	--------	--------	--------	--------	

See footnotes at end of table.

TABLE 1.—*Gaging-station names, numbers, and T-year peak discharges experienced and computed, in cubic feet per second*—Continued

[Upper line for each station shows observed discharges, lower line computed discharges. Median residual: Median of ratios of actual to computed flood peaks at each recurrence interval]

Station (pl. 1)	Station name	Recurrence interval in years							Median residual
		1.2	2.33	5	10	25	50	100	
[2]2690	Rio Pueblo de Taos near Taos, N.Mex.	92	248	443					1.12
		81	221	352					
[2]2710	Rio Lucero near Arroyo Seco, N.Mex.	82	156	207	245	288			1.40
		47	112	174	230	319			
[2]2760	Rio Pueblo de Taos at Los Cordovas, N.Mex.	162	480	811	1,120	1,560			1.16
		141	455	761	960	1,310			
[2]2790	Embudo Creek at Dixon, N.Mex.	432	1,160	1,600	1,880	2,190			1.52
		277	731	1,180	1,540	2,260			
[2]2795	Rio Grande at Embudo, N.Mex.	1,910	6,300	8,820	11,000	14,000	16,200		.91
		2,370	6,800	9,900	12,100	13,800			
[2]2835	Rio Chama at Park View, N.Mex.	2,550	4,400	6,050	7,500				2.43
		985	1,940	2,840	3,770				
[2]2845	Willow Creek near Park View, N.Mex.	618	1,270	1,740	2,690	4,730			.84
		794	1,510	2,180	2,960	4,370			
[2]2880	El Rito near El Rito, N. Mex.	120	285	510	760	1,170			.80
		160	356	537	717	1,010			
[2]2890	Rio Ojo Caliente at La Madera, N.Mex.	594	1,350	2,060	2,640	3,330			2.25
		192	600	991	1,260	1,680			
[2]2900	Rio Chama near Chamita, N.Mex.	2,820	5,740	8,220	10,300	12,800			.70
		3,640	7,670	11,400	15,000	19,900			
2910	Santa Cruz River at Cundiyo, N.Mex.	170	395	710					.28
		371	1,380	2,630					
2920	Santa Clara Creek near Espanola, N.Mex.	19	132	398	932				.40
		73	378	888	1,650				
2950	Rio Nambe near Nambe, N.Mex.	40	253	745	1,510	3,200			.35
		263	1,050	2,020	3,790	9,180			
3025	Tesuque Creek above diversions, near Santa Fe, N.Mex.	13	87	242	411	632			.54
		15	154	448	932	2,029			
[2]3130	Rio Grande at Otowi Bridge, near San Ildefonso, N.Mex.	4,950	10,500	14,700	18,000	21,800	24,700		1.16
		3,220	9,070	13,400	16,400	18,600			
3131	Canada Ancha Tributary near Santa Fe, N.Mex.	.8	50	133	200	275			1.12
		5.3	40	105	179	318			
3160	Santa Fe River near Santa Fe, N.Mex.	39	105	193	285				.26
		125	414	734	1,320				
3180	Galisteo Creek at Domingo, N.Mex.	3,780	8,180	12,700	17,100	23,500			1.98
		1,120	3,460	6,410	9,870	14,700			
[2]3240	Jemez River near Jemez, N.Mex.	847	2,200	3,360	4,300	5,500	6,420		1.12
		879	1,730	2,780	3,820	4,580			
3290	Jemez River below Jemez Canyon Dam, N.Mex.	1,950	7,200	12,000	16,500	22,000			3.28
		354	1,640	3,660	6,130	10,000			
3300	Rio Grande at Albuquerque, N.Mex.	4,300	9,550	15,000	20,000	27,600			.86
		5,050	13,100	19,600	24,600	29,700			
3405	Chico Arroyo near Guadalupe, N.Mex.	3,110	7,530	10,500	11,700				1.43
		1,990	4,810	8,090	11,100				
3420	Bluewater Creek near Bluewater, N.Mex.	63	132	578	870	1,090			1.95
		21	120	295	446	651			

See footnotes at end of table.

TABLE 1.—*Gaging-station names, numbers, and T-year peak discharges experienced and computed, in cubic feet per second*—Continued

[Upper line for each station shows observed discharges, lower line computed discharges. Median residual: Median of ratios of actual to computed flood peaks at each recurrence interval]

Station (pl. 1)	Station name	Recurrence interval in years							Median residual
		1.2	2.33	5	10	25	50	100	
3435	Rio San Jose near Grants, N.Mex	115	325	600	900	1,370	--------	--------	0.25
		286	1,330	3,050	4,470	5,530	--------	--------	
3513	Rio San Jose at Correo, N.Mex	852	2,790	5,090	7,240	10,100	--------	--------	.63
		1,770	4,490	8,100	11,500	15,800	--------	--------	
3525	Rio Puerco at Rio Puerco, N.Mex	6,220	9,300	14,000	19,100	26,400	32,800	39,700	.98
		3,530	8,240	14,300	20,100	26,000	43,000	44,000	
3540	Rio Salado near San Acacia, N.Mex	1,880	7,380	12,100	16,200	21,600	25,700	29,800	1.37
		1,370	4,120	7,770	11,800	17,900	31,100	39,100	
[2]3585	Rio Grande at San Marcial, N.Mex	3,890	11,500	18,500	24,600	33,000	39,600	47,000	.63
		6,670	18,200	27,600	34,700	43,100	--------	--------	
3600	Alamosa River near Monticello, N.Mex	1,000	3,010	5,710	8,750	--------	--------	--------	1.12
		641	2,620	5,300	8,310	--------	--------	--------	
3740	Alamito Creek near Presidio, Tex	4,410	8,300	11,400	13,700	16,300	--------	--------	.55
		1,900	9,410	20,700	32,700	50,100	--------	--------	
3745	Terlingua Creek near Terlingua, Tex	3,930	11,600	20,100	27,500	36,100	--------	--------	1.14
		1,780	8,100	17,600	27,700	44,100	--------	--------	
[3]3785	Pecos River near Pecos, N.Mex	338	816	1,250	1,630	2,140	--------	--------	1.07
		346	787	1,160	1,510	1,830	--------	--------	
3795	Pecos River near Anton Chico, N.Mex	2,980	8,430	15,100	22,000	33,000	43,000	54,000	2.11
		1,020	3,180	6,320	10,400	17,900	26,900	43,200	
3805	Gallinas River near Montezuma, N.Mex	230	1,020	2,300	3,850	6,400	8,700	--------	.61
		423	1,600	3,010	5,360	11,000	17,100	--------	
3830	Pecos River at Santa Rosa, N.Mex	4,910	14,300	24,500	33,600	45,200	51,800	61,000	1.78
		2,750	6,430	11,400	17,600	28,600	41,500	59,300	
3835	Pecos River near Puerto de Luna, N.Mex	5,500	14,700	26,000	37,000	52,000	63,000	74,000	1.46
		3,760	8,730	15,300	23,500	37,200	52,900	76,900	
3880	Rio Ruidoso at Hondo, N. Mex	333	1,350	2,870	4,750	8,100	11,500	--------	.88
		223	1,350	3,310	5,690	9,060	16,000	--------	
3895	Rio Bonito at Hondo, N. Mex	1,150	3,680	6,030	7,450	9,210	10,500	--------	1.34
		404	1,840	4,000	6,450	10,000	18,200	--------	
3905	Rio Hondo at Diamond A Ranch, near Roswell, N. Mex	1,070	4,240	8,280	12,500	19,200	25,200	--------	.93
		1,150	4,210	8,460	13,500	21,200	35,400	--------	
3945	Rio Felix at old highway bridge, near Hagerman, N.Mex	2,380	8,010	16,200	25,900	42,300	58,300	78,000	2.19
		2,440	3,440	7,170	11,800	20,700	34,200	47,600	
3965	Pecos River near Artesia, N.Mex	2,960	8,200	23,000	37,800	57,500	72,300	--------	.98
		4,940	12,900	24,500	36,700	51,100	71,900	--------	
4055	Black River above Malaga, N.Mex	1,000	6,980	15,400	22,500	29,900	33,900	--------	4.12
		206	1,330	3,460	5,920	9,710	17,400	--------	
4065	Pecos River near Malaga, N.Mex	1,150	6,800	16,000	27,300	47,400	--------	--------	.51
		7,590	17,700	32,000	46,900	66,700	--------	--------	
4085	Delaware River near Red Bluff, N.Mex	2,110	8,700	19,000	32,100	56,000	80,000	--------	1.98
		1,140	4,530	9,280	14,700	24,000	41,700	--------	
4115	Salt (Screwbean) Draw near Orla, Tex	445	2,400	6,450	12,300	24,700	49,200	--------	.70
		1,870	5,650	10,300	15,500	26,000	46,700	--------	
4245	Madera Canyon near Toyahvale, Tex	176	1,650	2,950	4,060	5,500	--------	--------	.88
		200	1,160	2,760	4,700	9,310	--------	--------	

See footnotes at end of table.

TABLE 1.—*Gaging-station names, numbers, and T-year peak discharges experienced and computed, in cubic feet per second*—Continued

[Upper line for each station shows observed discharges, lower line computed discharges. Median residual: Median of ratios of actual to computed flood peaks at each recurrence interval]

Station (pl. 1)	Station name	Recurrence interval in years							Median residual
		1.2	2.33	5	10	25	50	100	
4475	Pecos River near Comstock, Tex.	4,190	22,200	56,500	89,600	113,000	--------	--------	1.18
		9,220	23,100	43,800	64,400	95,600	--------	--------	
[1]4490	Devils River near Juno, Tex.	785	26,300	58,000	92,000	173,000	284,000	476,000	1.54
		6,660	24,000	39,500	59,800	91,800	134,000	204,000	
[1]4495	Devils River near Del Rio, Tex.	3,620	30,000	95,500	172,000	304,000	430,000	582,000	2.09
		7,020	28,300	49,700	78,600	121,000	173,000	278,000	
[1]4530	San Felipe Creek near Del Rio, Tex.	2,130	8,200	13,400	21,100	41,600	--------	--------	4.13
		192	1,630	3,940	6,450	10,100	--------	--------	
[1]4550	Pinto Creek near Del Rio, Tex.	1,430	6,820	16,300	34,600	119,000	--------	--------	1.49
		958	5,540	11,500	18,200	27,600	--------	--------	
4775	Mimbres River near Faywood, N.Mex.	1,100	4,220	8,120	11,800	16,800	20,400	--------	1.78
		412	1,910	4,330	6,980	11,000	20,600	--------	
4815	Rio Tularosa near Bent, N.Mex.	187	1,170	3,140	5,170	7,780	9,650	--------	1.14
		158	1,030	2,530	4,500	7,860	14,200	--------	

[1] Station near western end of Balcones fault zone. Not used in establishing relations within rain-flood area, but computed peaks are based on those relations.
[2] In snowmelt-flood area.

DATA USED IN ANALYSIS

PEAK-DISCHARGE DATA

The annual peak discharges were listed for all 219 stations selected as being suitable for flood-frequency analysis. The values of discharge were obtained from streamflow reports of the U.S. Geological Survey; they represent the momentary peak discharges for each water year. The water year starts on October 1 and ends on September 30 of the following year.

In addition to the annual peak-discharge data obtained during the operation of the gaging stations, information was obtained of outstanding historical floods that occurred prior to the start of record. Where outstanding floods occurred during the period of record, information frequently was obtained of the relative rank of such a flood over a period of time much longer than the period of gaging-station operation. For example, on the Sabine River near Mineola, Tex., where systematic records have been collected only since 1940, it was determined that in 1890 a flood (of uncertain discharge) had occurred that was probably higher than any subsequent flood, and that the floods of April 1945 and June 1943 were, respectively, the second and third highest floods in the period 1890 to 1958. As another example, on the North Basque River near Clifton, Tex. (period of consecutive record, 1924 to date), it was determined that the October 1959 flood was the highest since at least 1854, the 1887 flood having been the second highest since that time.

Information on historical floods was obtained from newspapers, books, and municipal records, and from interviews with long-time residents living near rivers. Much previously unknown information was thus collected, and the data were invaluable in helping define the upper range of the flood-frequency relations at most gaging stations.

HYDROLOGIC CHARACTERISTICS

Most floods are caused by excessive rainfall or snowmelt; other floods are caused by dam failures, ice gorges, high tides, or backwater. Rainfall and snowmelt floods are those considered in this study. The initial causes for either rainfall or snowmelt floods are meteorologic variables.

After precipitation reaches the ground, in some form and varying magnitude distributed in time, the conversion to runoff is affected mainly by the physical characteristics of the basin. Meteorologic factors that affect snowmelt or evaporation, such as temperature, dewpoint, winds, and radiation, have some effect on the amount of runoff but once the runoff has started, its pattern is controlled by the basin characteristics. Some of these characteristics, such as the size of the drainage area or the amount of land slope, are relatively stable; others, such as the ground cover or cultivation, are variable.

The meteorologic and the basin characteristics together are the hydrologic variables that affect flood peaks, and both must be considered in any study that relates flood peaks to environmental factors.

The study of such relations must start with a consideration of all hydrologic factors that may be expected to be causally related to flood peaks. The factors should be in as simple and basic a form as possible, they should be expressible quantitatively rather than qualitatively, and they should have as little interdependence as possible.

A set of hydrologic factors that are entirely independent of each other would be preferable, but this is not possible in flood hydrology. The most important factor is, intuitively, the size of drainage area (its importance is confirmed in this study). The larger the area, the larger the volume of rain that may fall on it and, in general, the larger the peak discharge. Once drainage-area size has been selected as a factor, most other variables that may be chosen will be related to drainage-area size and interrelated among themselves. The general magnitude of rainfall over a region is virtually independent, being a climatic factor, yet, on an individual basin, rainfall intensities vary with size of the drainage area and rainfall distribution varies with the orientation and the orographic position of the basin. On the other hand, soil characteristics, cover, channel slope, and channel dimensions may be affected by the amount of rainfall generally available. There is, therefore, some degree of mutual interdependence between climatic and topographic factors. Topographic factors may be highly interrelated. For example, valley-side slopes, main-channel slope, tributary slopes, stream densities, and altitudes are interrelated, and each is related to the size of the drainage area. Cover has some relation to both slope and altitude.

The choice of hydrologic factors requires a knowledge of hydrologic, hydraulic, geologic, and meteorologic principles. Statistical methods are then applied to finding those factors that are most significant, to establishing the relations between flood peaks and their causes, and to assessing their relative importance. In statistical terms, the hydrologic factors are the independent variables that are to be associated with the flood peaks, which are the dependent variables.

Tables 2 and 3 list, by station, the values of all the variables that were used in the study and other variables for which there was information at all or most stations. The separation of stations into the rain-flood area (table 2) and the snowmelt-flood area (table 3) was based on an analysis of the data that is described on pages 47, 48.

TABLE 2.—*Independent variables, by station, in rain-flood area*

A, contributing drainage area, in square miles.
S, main-channel slope (85 to 10 percent points), in feet per mile.
St, percentage of area in lakes and ponds, increased by 1 percent.
E, altitude index (mean of 85 and 10 percent points), in feet above mean sea level.
L, basin length (total length of main channel), in miles.
H, basin rise (elevation difference between 85 and 10 percent points), in feet.
P, mean annual precipitation, in inches.
I, 10-year, 24-hour rainfall intensity, in inches.
N, mean annual number of thunderstorm days.
R, ratio of runoff to precipitation during months when annual peak discharges occur.
R_a, mean annual runoff, in inches.
w_{10}, top width of main channel near outlet, for 10-year peak discharge, in feet.
d_{10}, mean depth of main channel near outlet, for 10-year peak discharge, in feet.

Station (pl. 1)	*A*	*S*	*St*	*E*	*L*	*H*	*P*	*I*	*N*	*R*	R_a	w_{10}	d_{10}
100	131	1.61	1.66	40	30.7	37	60	7.49	70	0.86	26.4	--------	------
120	527	2.16	2.39	44	48.8	79	60.5	7.34	70	.96	20.4	--------	------
130	499	3.36	1.07	182	49.6	125	58.5	7.01	67	.81	21.1	--------	------
135	753	2.52	1.06	142	82.9	157	59.5	7.10	68	.73	22.4	--------	------
145	510	5.11	1.02	156	48.2	185	60	7.19	70	.68	23.0	7,000	6.6
150	238	4.58	1.03	144	41.7	143	59	7.36	70	.68	23.0	3,430	7.2
155	1,700	2.43	1.04	118	99.5	181	60	7.19	70	.78	22.2	--------	------
164	148	4.67	1.04	88	34.6	121	58	7.54	70	.91	19.3	4,320	6.0
166	82.2	6.27	1.18	96	22.6	106	58.5	7.75	70	.74	21.0	--------	------
185	1,445	3.17	1.19	438	80.8	192	42	6.01	50	.69	9.88	7,150	5.7
190	586	4.18	1.02	429	41.2	129	43	6.10	50	.77	10.2	1,430	13.7
195	236	6.57	1.11	392	36.5	180	44.5	6.26	50	.64	11.6	1,970	8.3
200	2,846	2.20	1.21	389	127	209	43	6.14	50	.62	9.48	2,270	13.0
225	4,858	1.25	1.27	300	235	221	44.5	6.33	49	.65	9.00	1,380	20.8
240	113	6.17	1.12	225	21.6	100	51	6.94	55	1.00	12.2	2,040	5.5
244	6,543	1.13	1.20	265	292	248	46.5	6.45	51	.68	11.5	10,000	10.9
275	114	7.22	1.03	262	21.6	117	56	7.21	66	.66	18.5	--------	------
305	9,440	.96	1.18	203	427	308	49	6.78	57	.69	12.7	29,800	4.6
320	1,143	2.29	1.21	357	88.6	152	43.5	6.30	47	.65	9.09	5,830	4.8
325	1,943	1.57	1.17	306	146	172	44	6.37	48	.62	8.17	7,510	8.5
330	2,714	1.25	1.16	266	214	201	44.5	6.50	50	.62	8.59	7,330	5.5
335	3,623	1.29	1.13	232	253	245	45.5	6.61	52	.63	8.95	3,840	6.7
345	376	4.27	2.16	344	36.6	117	43	6.37	48	.56	10.1	6,430	5.9
370	1,604	1.80	1.33	258	114	153	45	6.62	50	.64	10.6	5,710	5.9
380	501	2.76	1.19	246	65.9	136	48	6.84	51	.54	13.1	1,890	7.9

TABLE 2.—*Independent variables, by station, in rain-flood area*—Continued

Station (pl. 1)	A	S	St	E	L	H	P	I	N	R	R_a	w_{10}	d_{10}
395	3,512	1.28	1.21	188	208	200	47	6.84	53	0.66	12.7	3,800	6.4
410	7,923	1.07	1.49	178	350	281	47	6.82	54	.67	10.7	6,540	7.2
415	857	3.88	1.09	143	71.2	207	52.5	7.46	64	.56	13.7	2,920	8.4
435	1,147	4.28	1.01	903	82.0	263	29	5.43	51	.30	2.44	------	------
440	332	5.34	1.00	858	42.5	170	31	5.51	52	.50	3.60	1,260	5.7
455	2,069	3.34	2.08	817	133	334	30	5.55	51	.38	2.05	224	11.3
475	526	11.1	1.00	832	55.8	465	33	5.65	47	.40	3.05	2,350	4.8
480	2,627	3.58	1.85	786	144	386	30.5	5.61	50	.38	2.22	290	17.6
505	379	9.94	1.00	793	49.0	365	34.5	5.65	54	.42	4.58	3,920	4.0
510	261	8.70	1.00	678	26.7	174	36	5.72	55	.56	5.20	3,910	5.8
515	296	11.6	1.00	792	42.5	370	33	5.63	53	.40	2.79	4,130	4.6
540	621	6.08	1.00	779	66.5	303	32	5.65	53	.41	3.52	4,200	4.4
570	6,120	3.67	1.72	696	188	518	32	5.68	52	.43	3.33	8,020	12.1
615	840	7.20	1.01	548	50.5	273	38	5.84	53	.54	7.72	1,220	10.4
630	734	5.30	1.12	396	49.8	198	41	6.10	48	.56	8.52	1,930	8.4
635	737	8.40	1.01	482	50.8	320	37	6.10	42	.65	7.18	6,670	6.5
645	971	5.69	1.02	481	75.0	320	37.5	6.01	45	.58	6.20	6,140	7.8
650	12,912	2.56	1.40	539	339	650	35	5.92	49	.48	5.08	4,540	10.4
665	17,192	1.67	1.31	415	530	664	37.5	6.19	50	.52	5.80	5,050	11.4
680	832	3.53	1.06	189	52.0	177	45	7.10	56	.54	8.54	5,640	8.2
685	400	5.97	1.00	206	41.0	184	44	7.25	57	.46	7.37	2,960	8.3
690	262	3.47	1.08	155	48.2	125	43.5	7.33	58	.32	7.37	3,090	5.3
695	1,811	3.13	1.04	156	74.0	174	45	7.24	57	.46	8.15	4,290	5.7
700	330	4.74	1.00	216	42.5	151	47.5	7.28	60	.66	9.40	3,080	6.5
705	120	8.14	1.00	186	28.8	176	48.5	7.53	61	.48	8.29	1,950	5.2
710	104	7.58	1.00	229	27.4	156	46.5	7.44	60	.51	8.52	2,040	4.6
715	2,791	3.31	1.03	134	84.7	210	46	7.28	58	.53	9.54	9,650	11.1
745	92.0	5.56	1.00	74	22.5	94	44	7.65	57	.57	10.0	310	11.6
750	100	3.18	1.00	58	19.8	47	44.5	7.70	56	.43	11.3	166	12.2
770	38.4	2.68	1.13	55	14.3	29	45.5	8.07	55	.66	10.2	138	16.6
780	88.1	2.89	1.25	43	21.2	46	46	7.95	51	.64	13.1	3,100	2.8
795	250	5.80	1.12	3,420	98.0	426	17	3.96	40	.027	.09	500	1.52
805	1,510	7.45	1.05	2,180	175	977	20	4.52	40	.13	1.61	353	10.3
807	300	8.39	1.17	3,850	126	794	17.5	3.87	42	.051	.22	1,100	.95
820	2,060	9.52	1.03	2,270	164	1,170	20.5	4.51	41	.12	1.06	478	7.7
825	5,250	5.24	1.03	1,880	281	1,100	21	4.64	43	.19	1.15	739	9.3
840	2,220	2.33	1.10	1,810	110	191	22	4.92	40	.17	.84	2,860	5.6
855	3.974	4.53	1.14	1,570	198	673	22.5	4.96	42	.18	.90	2,950	4.8
870	5,658	4.18	1.13	1,490	244	763	23.5	5.03	42	.19	1.05	259	21.4
890	13,520	3.76	1.07	1,560	451	1,270	23	4.92	43	.20	1.21	805	18.0
915	399	11.5	1.00	872	47.7	411	32.5	5.64	41	.22	2.06	370	9.7
920	276	11.8	1.00	734	31.8	281	34	5.78	43	.31	2.65	211	10.8
935	309	9.88	1.00	610	32.3	239	35.5	5.92	41	.46	4.67	3,370	5.4
950	971	9.76	1.01	991	84.3	617	33	5.70	39	.38	2.78	206	19.2
965	19,260	2.77	1.23	1,230	706	1,470	26	5.14	43	.38	1.85	556	21.0
995	1,242	6.70	1.02	1,370	86.1	433	28.5	5.46	39	.18	1.76	1,320	7.5
1025	3,513	4.38	1.02	981	250	820	31	5.69	38	.28	2.45	309	15.9
1040	1,242	8.82	1.00	988	89.3	591	31	5.79	38	.20	2.97	628	14.6
1050	415	16.0	1.00	992	48.7	584	31	5.48	39	.32	4.26	398	10.9
1055	602	13.6	1.00	887	65.0	663	31.5	5.52	40	.29	3.07	3,550	5.8
1065	7,000	3.98	1.01	836	315	941	31.5	5.86	39	.34	3.41	4,360	11.7
1100	990	4.63	1.11	304	59.3	206	36	6.37	47	.32	3.76	1,040	8.8
1105	949	4.95	1.12	416	65.5	243	36.5	6.30	45	.44	5.78	6,750	6.6
1140	34,780	2.11	1.14	920	1,010	1,600	30	5.69	43	.45	2.86	490	31.6
1190	38	14.8	1.13	2,320	18.7	208	20	4.72	40	.24	.92	84	8.0
1235	158	18.6	1.00	2,270	25.3	353	20.5	4.77	40	.17	1.29	153	7.8
1265	5,240	3.52	1.42	2,000	245	647	18.5	4.41	39	.16	.98	750	11.0
1270	458	14.0	1.15	1,860	41.5	436	22.5	5.03	38	.23	1.52	594	8.6
1280	434	11.9	1.08	2,230	34.5	308	20	4.92	33	.17	1.46	2,500	3.5
1285	1,128	7.78	1.16	2,330	109	636	17.5	4.62	34	.11	.50	3,240	6.1
1310	734	13.9	1.24	2,250	58.8	613	18	4.78	34	.12	.66	228	16.6
1335	615	10.9	1.26	2,450	40.3	329	17.5	4.54	37	.062	.25	1,280	4.6
1340	1,410	9.46	1.14	2,310	70.5	500	18	4.60	36	.16	.46	2,910	4.2
1360	4,217	7.86	1.21	2,250	127	749	15.5	4.74	35	.12	.54	1,310	9.8
1365	5,263	7.33	1.17	2,120	167	918	16.5	4.78	35	.12	.59	2,320	5.2
1380	12,680	3.65	1.25	1,840	337	922	18.5	4.60	37	.13	.76	426	25.9
1445	1,151	7.98	1.08	2,110	60.0	359	21.5	5.05	32	.084	1.00	1,570	7.1
1450	575	11.0	1.01	1,910	52.5	433	23	5.24	34	.21	.53	420	8.8
1460	3,042	8.66	1.03	1,720	144	938	24	5.24	33	.19	1.12	4,060	6.6
1470	18,700	3.31	1.36	1,690	416	1,030	20.5	4.83	37	.18	1.07	750	21.8
1485	914	13.2	1.03	1,990	52.0	515	22.5	5.10	31	.18	1.02	1,360	6.8
1500	1,874	10.0	1.02	1,950	66.6	500	23	5.12	30	.17	1.36	595	19.8
1515	4,233	8.84	1.01	1,620	147	977	25	5.38	32	.19	.87	724	16.4
1530	647	13.3	1.00	1,720	51.5	514	29.5	5.60	34	.14	1.26	401	10.1
1535	947	12.8	1.00	1,540	73.0	701	30	5.69	35	.18	2.15	605	14.3

TABLE 2.—*Independent variables, by station, in rain-flood area*—Continued

Station (pl. 1)	A	S	St	E	L	H	P	I	N	R	R_a	w_{10}	d_{10}
1540	1,294	11.9	1.00	1,270	114	1,020	30.5	5.74	36	0.30	2.49	404	21.1
1580	26,500	3.47	1.33	1,360	587	1,530	22.5	5.01	36	.20	1.28	1,140	24.3
1600	1.48	65.6	1.00	388	2.13	105	37	7.00	47	.49	3.40	----	----
1635	101	9.41	1.00	293	24.0	169	36.5	6.74	50	.61	5.14	1,320	4.9
1640	887	3.29	1.00	164	80.7	199	36.5	6.71	49	.47	3.63	3,780	5.8
1645	1,116	3.24	1.00	154	80.0	194	38.5	6.90	51	.42	5.16	6,150	8.4
1660	115	28.3	1.00	1,940	20.2	429	27.5	5.63	32	.090	1.32	196	6.8
1670	836	13.3	1.00	1,740	64.0	638	30	5.53	32	.12	2.07	1,890	11.9
1685	1,516	8.68	1.00	1,260	170	1,110	31.5	5.69	36	.21	3.02	425	16.9
1710	364	17.2	1.00	1,180	54.0	697	33	5.88	38	.24	3.67	314	13.5
1720	833	11.4	1.00	874	110	938	33.5	6.04	40	.19	4.83	2,820	14.8
1730	356	9.49	1.00	474	37.2	265	35	6.24	43	.39	3.30	5,670	5.0
1735	1,249	10.9	1.01	832	119	971	34	6.10	41	.31	4.97	3,730	10.7
1765	5,161	5.23	1.03	794	351	1,380	33	6.14	41	.32	3.86	11,600	6.2
1770	365	5.48	1.00	250	45.9	189	32	6.55	45	.28	1.86	365	10.4
1775	514	5.90	1.00	190	56.0	248	32.5	6.60	45	.28	2.18	1,090	10.9
1785	2.64	26.1	1.04	665	3.58	70	29.5	6.51	38	.22	4.18	----	----
1790	457	18.1	1.01	1,540	59.0	801	30	5.57	33	.19	2.58	390	16.9
1840	198	18.9	1.00	1,320	37.2	527	32.5	5.87	37	.10	.44	----	----
1850	280	13.2	1.00	1,160	59.3	587	32.5	5.90	38	.13	.42	758	6.2
1860	831	9.93	1.00	782	122	912	30.5	6.02	40	.21	1.83	555	10.9
1885	3,918	5.86	1.07	726	258	1,130	30	6.05	39	.24	1.75	555	13.2
1895	643	5.36	1.00	189	73.1	1,180	31.5	6.55	42	.19	1.49	1,790	8.3
1900	764	14.8	1.00	1,550	61.0	677	23	5.22	29	.42	2.23	455	13.3
1905	700	13.8	1.00	1,740	62.8	650	21.5	5.07	30	.13	.28	1,770	8.7
1920	1,947	10.4	1.00	1,410	116	902	22.5	5.17	29	.14	.35	935	12.1
1930	4,082	8.32	1.06	1,120	188	1,180	22	5.28	29	.14	.47	4,290	2.0
1940	5,260	7.27	1.08	1,040	222	1,210	22	5.34	30	.15	.71	1,300	12.5
1945	8,192	6.01	1.09	898	282	1,270	22	5.55	32	.15	.64	5,750	5.5
1950	405	20.0	1.00	1,610	43.5	653	25	5.35	30	.61	3.09	993	8.7
1980	206	22.5	1.00	1,460	32.8	554	27	5.46	31	.12	1.20	305	8.2
2055	3,493	11.5	1.02	1,070	129	1,120	26.5	5.50	32	.17	.52	4,180	7.1
2070	5,491	7.80	1.03	820	203	1,190	26	5.69	34	.17	.60	6,560	3.1
2080	1,171	5.29	1.01	374	86.0	341	26.5	6.05	39	.21	1.55	935	10.3
2100	15,600	5.45	1.06	852	312	1,280	24	5.64	34	.17	.68	9,680	4.1
2910	86	320	1.00	8,650	16.7	4,000	20	2.42	58	.21	5.01	----	----
2920	36.7	200	1.00	7,680	18.2	2,730	20	2.46	54	.15	----	----	----
2950	38.2	400	1.00	8,280	12.3	3,690	20.5	2.66	56	.40	4.02	108	3.0
3025	11.6	450	1.00	8,710	8.3	2,800	20	2.72	56	.039	3.96	29	2.23
3131	1.23	142	1.00	6,610	2.63	280	12.5	2.67	54	.12	----	----	----
3160	22.3	343	1.49	9,120	11.5	2,950	23	2.67	55	.68	7.31	30	1.40
3180	640	37.6	1.02	6,010	47.0	1,320	13	2.61	52	.083	.22	240	5.8
3290	1,040	60.6	1.22	6,720	65.2	2,960	18	2.28	50	.013	.58	----	----
3405	1,390	21.9	1.10	6,620	51.8	850	14.5	2.24	47	.044	.26	305	9.4
3420	7.8	52.1	1.00	7,020	6.4	250	14	2.43	42	.073	.61	----	----
3435	964	20.0	1.18	6,810	57.2	860	13.5	2.24	42	.007	.11	60	2.49
3513	2,410	17.2	1.15	6,290	104	1,340	13	2.26	44	.046	.075	256	5.1
3525	4,960	15.1	1.09	5,880	136	1,540	13.5	2.27	46	.041	.20	128	8.0
3540	1,380	35.6	1.09	5,950	75.0	2,000	12.5	2.30	42	.051	.14	286	3.2
3600	403	73.5	1.00	7,020	28.1	1,550	16	2.30	40	.030	.28	95	8.3
3740	1,504	31.2	1.02	3,830	85.0	1,990	14	3.29	25	.046	.20	549	2.24
3745	1,070	26.5	1.00	3,320	90.5	1,800	14.5	3.43	25	.10	.59	457	4.6
3795	1,050	35.7	1.03	6,820	110	2,940	17.5	2.69	55	.15	1.80	480	7.4
3805	84	196	1.00	8,180	16.3	2,400	21.5	2.78	59	.24	2.91	76	3.9
3830	2,650	19.8	1.07	6,010	169	2,520	16	2.73	55	.20	.79	241	14.6
3835	3,970	17.1	1.08	5,750	198	2,550	15	2.80	53	.17	.80	232	12.2
3880	290	77.6	1.01	6,460	36.7	2,140	20	2.60	41	.023	.89	134	5.1
3895	295	58.5	1.02	6,190	33.6	1,480	19.5	2.60	41	.045	.47	----	----
3905	947	42.8	1.03	5,480	66.6	2,140	18.5	2.64	41	.062	.45	111	15.9
3945	932	39.4	1.02	5,210	108	3,200	15.5	2.70	41	.14	.30	600	6.4
3965	15,300	8.95	1.13	4,780	414	2,780	15.5	2.78	47	.052	.28	1,660	2.6
4055	343	47.6	1.05	4,180	56.7	2,020	15	2.90	35	.031	.53	362	6.8
4065	19,190	7.29	1.15	4,540	487	2,660	15.5	2.92	45	.080	.21	238	18.1
4085	689	39.5	1.05	3,920	60.2	1,780	14	2.96	34	.087	.31	401	7.8
4115	464	30.9	1.01	3,520	53.5	1,240	12	3.12	33	.32	.13	366	8.5
4245	53.8	80.7	1.00	5,490	22.9	1,390	16	3.38	29	.24	1.10	116	4.8
4475	35,293	4.83	1.24	3,430	849	3,070	14.5	3.28	39	.080	.21	422	22.8
4490	2,733	9.75	1.20	2,020	108	790	17	4.76	30	.14	.97	1,220	8.6
4495	4,185	10.2	1.13	1,700	162	1,240	17.5	4.78	29	.12	.19	1,100	14.0
4530	46	24.8	1.02	1,050	16.0	298	18.5	5.13	26	.11	18.2	325	6.7
4550	249	14.6	1.02	1,120	40.6	445	20.5	5.10	27	.18	1.36	183	11.6
4775	460	51.3	1.03	6,170	51.0	1,960	17.5	2.46	36	.038	.39	1,040	2.7
4815	120	146	1.00	6,820	20.6	2,260	21	2.62	40	.030	1.18	54	10.3

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TABLE 3.—*Independent variables, by station, in snowmelt-flood area*

A, contributing drainage area, in square miles.
S, main-channel slope (85 to 10 percent points), in feet per mile.
St, percentage of area in lakes and ponds, increased by 1 percent.
E, altitude index (mean of 85 and 10 percent points), in feet above mean sea level.
L, basin length (total length of main channel), in miles.
H, basin rise (elevation difference between 85 and 10 percent points), in feet.
P, mean annual precipitation, in inches.
I, 10-year, 24-hour rainfall intensity, in inches.
N, mean annual number of thunderstorm days.
R_a, mean annual runoff, in inches.
t_1, mean number of degrees Fahrenheit below freezing in January.
t_6, mean June temperature, in degrees Fahrenheit.
Sn, mean total annual snowfall, in inches.
W, equivalent water content of snow, in inches.
w_{10}, top width of main channel, near outlet, for 10-year peak discharge, in feet.
d_{10}, mean depth of main channel, near outlet, for 10-year peak discharge, in feet.

Station (pl. 1)	*A*	*S*	*St*	*E*	*L*	*H*	*P*	*I*	*N*	R_a	t_1	t_6	*Sn*	*W*	w_{10}	d_{10}
2180	53.6	193	1.17	9,920	13.8	1,990	25.5	2.57	46	------	26	44.0	370	23.7	72	1.29
2195	216	137	1.27	9,320	19.2	1,970	21	2.40	46	13.8	23	46.5	301	20.2	68	5.8
2200	1,320	28.0	1.43	8,980	84.2	1,770	24.5	2.36	46	9.59	26	43.7	301	20.2	221	6.7
2205	53	268	1.02	9,820	13.2	2,650	18	2.36	48	6.30	23.5	46.9	271	20.2	12	4.0
2235	33.6	252	1.05	9,770	13.4	2,540	18	2.36	48	5.0	23.5	47.1	276	20.2	--------	------
2245	38	252	1.00	9,880	8.4	1,590	19.5	2.36	48	4.58	25.5	46.0	218	14.8	--------	------
2270	595	75.2	1.00	9,320	40.8	2,300	18.5	2.28	46	1.73	23.5	47.3	184	12.1	--------	------
2275	10.7	660	1.26	10,200	6.0	2,970	26	2.45	49	13.3	31	41.4	375	25.2	89	1.74
2305	117	134	1.00	9,440	21.4	2,160	16.5	2.26	47	1.29	22	48.5	168	12.0	--------	------
2310	61	160	1.01	9,630	23.4	2,820	17	2.33	47	3.13	22.5	47.9	176	14.3	--------	------
2360	107	116	1.45	9,860	25.5	2,220	22	2.30	49	14.7	25.5	44.6	370	24.2	102	3.8
2405	45	340	1.09	9,960	9.7	2,480	25.5	2.61	56	6.65	23.5	44.8	252	12.6	70	2.6
2410	61	180	1.07	9,340	15.1	2,030	22.5	2.40	55	3.89	20.5	48.1	178	8.0	--------	------
2415	187	143	1.01	9,100	20.6	2,200	19	2.48	54	1.64	17.5	51.7	136	1.6	--------	------
2425	32	253	1.16	9,380	11.9	2,250	21.5	2.54	54	8.04	23	46.8	201	12.7	--------	------
2455	44.4	120	1.30	10,400	12.2	1,100	24.5	2.36	48	34.0	27	43.3	407	26.6	95	1.26
2465	282	42.2	1.32	9,220	48.3	1,530	20.5	2.21	49	17.5	22	48.3	294	18.6	145	4.4
2475	110	53.3	1.07	8,960	28.2	1,130	18.5	2.28	53	3.27	16.5	52.6	128	11.4	77	2.8
2480	167	81.7	1.03	9,160	33.4	2,050	20.5	2.21	51	9.78	20	49.8	210	16.2	--------	------
2485	348	47.3	1.04	8,700	55.0	1,950	17.5	2.21	51	3.46	11.5	58.1	72	6.0	74	5.9
2490	887	34.4	1.13	8,680	84.4	2,180	16.5	2.20	52	3.17	12	57.2	105	6.4	--------	------
2515	4,760	14.7	1.26	8,330	159.3	1,760	17	2.26	49	1.89	19	51.1	165	7.2	--------	------
2525	26	227	1.42	10,400	10.0	1,700	25	2.67	59	------	23	44.0	266	15.9	48	1.07
2530	19	461	1.00	10,400	5.2	1,800	25	2.67	59	------	23.5	44.5	261	16.9	--------	------
2535	2.5	862	3.00	10,700	3.4	2,200	25.5	2.75	59	------	24	43.6	284	18.5	6.4	.87
2630	10	704	1.00	9,880	5.4	2,850	23.5	2.60	58	8.00	23	44.5	260	18.7	9.0	2.22
2640	19.1	477	1.42	10,600	6.2	2,220	25	2.67	60	11.6	21.5	44.5	280	17.7	28	1.51
2650	113	137	1.09	8,910	22.8	2,340	21	2.56	59	7.26	18	49.2	188	9.4	50	1.76
2660	36.7	212	2.36	9,280	14.1	2,250	22	2.59	58	4.75	19	47.8	201	11.8	32	1.12
2675	36.2	336	1.06	9,320	11.7	2,950	23	2.61	59	14.5	19.5	47.3	227	13.4	48	.90
2685	65.6	219	1.03	8,450	19.5	3,200	19.5	2.40	59	5.70	15.5	51.5	155	6.7	--------	------
2690	66.6	210	1.09	8,740	15.3	2,410	20.5	2.41	60	7.10	15.5	50.6	169	7.3	--------	------
2710	16.6	406	1.12	9,610	8.8	2,680	24	2.70	60	20.2	20	46.2	253	15.3	27	1.43
2760	359	141	1.03	8,080	23.2	2,450	18	2.53	59	2.24	12	53.8	128	2.6	59	3.3
2790	305	113	1.02	7,760	39.6	3,360	19	2.50	58	3.72	12	54.4	134	3.2	--------	------
2795	7,460	16.0	1.22	7,510	231.2	2,780	16.5	2.37	53	1.82	16	52.8	136	4.8	124	10.6
2835	405	79.8	1.18	8,410	33.0	1,980	22	2.19	50	11.8	17.5	51.6	175	12.2	293	3.0
2845	193	48.3	1.23	7,600	29.8	1,080	18.5	2.22	50	1.38	10	58.6	109	5.8	68	4.8
2880	50.5	166	1.10	8,760	17.8	2,210	21	2.26	54	5.07	15	53.5	120	7.3	--------	------
2890	419	104	1.06	7,900	35.9	2,790	16.5	2.28	54	2.39	12	56.4	70	4.8	83	2.7
2900	3,200	22.3	1.17	6,870	123.6	2,060	18	2.23	52	2.57	10.5	58.2	82	3.5	209	5.8
3130	11,360	16.0	1.19	7,310	258.3	3,100	17	2.37	54	1.91	13.5	54.7	112	2.8	157	14.6
3240	470	140	1.07	7,750	36.3	3,820	22	2.26	51	1.84	11.5	56.6	110	.1	211	3.9
3300	14,500	13.6	1.17	6,800	333.7	3,390	16.5	2.37	53	.90	11	56.7	93	1.6	1,210	3.6
3585	24,560	10.1	1.12	6,400	450	3,400	14.5	2.37	50	.77	7.5	61.4	54	.3	485	8.4
3785	189	144	1.06	9,140	23.2	2,500	24.5	2.58	58	6.95	16	50.5	193	10.0	--------	------

TOPOGRAPHIC CHARACTERISTICS

The choice of topographic characteristics to be used in the analysis must first be made by considering which factors may be expected to be influential in determining the size of flood peaks. The size of the basin, as previously discussed, is very important, and experience has shown that it merits first consideration. When water falls on a basin, it first flows mainly by an overland route to small channels, thence it flows to larger and larger streams through a complex drainage pattern to the principal stream on which the gaging point is located. The land slopes, tributary slopes, and main-channel slopes are important factors in determing the velocity of this flow. Ground cover and channel-bed materials are retarding influences, representing the roughness (the friction coefficients in hydraulic formulas), and should be considered if possible. Because some of the water travels by subsurface or underground routes, the type of soil and the geology affect the rate of runoff. The drainage pattern influences the timing of the flood peak and should therefore be evaluated, possibly as a lag factor or as a basin-shape factor. The stream density and length of the main channel also influence the timing. Altitude or orientation of the basin with respect to storm pattern may influence the amount or the distribution of rainfall and thus merit consideration. Runoff stored in lakes, ponds, reservoirs, swamps, river channels, or flood plains may reduce the peaks of floods.

All these topographic characteristics may not need to be used in the final flood-frequency relations. Because of their interdependence, only one of many related factors may be sufficient. Many of the important factors have not yet been successfully evaluated, for example, geologic influences have not yet been reduced to simple numerical indices. Data may be lacking by which other factors thought to be effective, such as soil depths or land treatment, can be appraised. There is considerable latitude in the method of defining some variables; simplicity is much to be desired in any method that is chosen. Many of the complex topographic factors that hydrologists have used or geomorphologists have proposed are little justified in view of the current lack of knowledge of the relation of flood peaks to even the simplest variables.

DRAINAGE AREA

The contributing drainage areas in square miles were used as shown in the latest Survey streamflow reports. Within the study region there are many areas that do not contribute directly to surface flow. Blood (1960) mentions that 15,000 square miles in Texas have no drainage to the sea:

> This territory lies in the High Diablo Plateau of the Trans-Pecos; portions of the High Plains, where, because of level surface and nature of the soil, drainage is into shallow lakes and into the underground reservoirs; the sand dune area in the vicinity of Ward County; and the area lying inland from the Gulf coast between the lower Rio Grande Valley and Kingsville.

Other estimates place the total of such areas in Texas closer to 30,000 square miles. In New Mexico, there are large closed basins and areas of deep sands and volcanic materials where most of the water falling on the surface is absorbed and little runs off in surface channels. These areas are mainly in the Plains of Saint Augustine, the Jornada del Muerto, the Mimbres, Estancia, Tularosa, and Sacramento valleys, and in regions east of the Pecos River. The San Luis Valley in Colorado, an area having interior surface drainage and many irrigation canals, does not contribute directly to surface flow outside of the valley.

The boundaries of the noncontributing areas are somewhat uncertain. "Noncontributing area" as used in the streamflow reports of the U.S. Geological Survey means that part of the drainage area that does not ordinarily contribute to runoff through surface streams. It can easily be conceived that, under some circumstances, an area that is noncontributing during periods of normal flow may contribute during high flood periods, and that the extent of the contributing area may change with the severity or duration of the flooding. However, because information is not available to define such variations in the contributing drainage area, in this study the published figures on contributing area have been used for all basins. Inaccuracies of total contributing area are one of the sources of error that cannot be eliminated and that may be expected to increase the scatter or the variance in the relations established by this study.

In spite of such uncertainties, the size of the contributing drainage area was found to be the most important variable affecting peak discharge.

MAIN-CHANNEL SLOPE

In the New England study by Benson (1962b), some measure of the basin slope was shown to be next in importance to drainage-area size in explaining variations in peak discharge. In the course of that study a simple yet efficient index of the slope of the main channel was arrived at (Benson, 1959) and was found to be more effective than other related variables such as land slope, tributary slope, and drainage density in representing the general effect of slope in the basin.

For most of the study region, the only recent topographic maps available were 1:250,000 scale, generally having 50-foot contour intervals. The lack of recent large-scale topographic maps having adequate contouring made it impracticable to attempt to use any but the simplest index of basin slope. Drainage density could not have been generally evaluated over the area, and land slopes could not have been determined accurately; therefore, the main-channel slope index formulated during the New England study was used.

The main-channel slope index is the slope between two points along the main channel upstream from the gaging point at distances equal to 10 and 85 percent of the total main-channel length. The main channel from the gaging point and proceding upstream, is defined, above each junction, as that stream draining the largest area.

To define the channel length on a topographic map, the main channel is extended upstream (as indicated by contours) beyond the end of the blue line delineated on the map to the top of the ridge forming the watershed boundary. The total main-channel length includes the extension.

Because of the extremely small slopes of channels in Louisiana, and despite the 5- or 10-foot contour intervals mapped there, it was found necessary to determine the slope of several streams by surveying. In the remainder of the study area, main-channel slopes could be determined accurately enough by interpolating between contours on available maps.

Within this study area, the main-channel slope was found to be statistically significant at the 1 percent level in the snowmelt-flood area (roughly north of Santa Fe, N. Mex.) and significant at the 5 or 1 percent level within the rain-flood area at recurrence intervals of more than 2.33 years.

ALTITUDE

Altitude is a factor that is not in itself a direct cause of variation in flood peaks, but, because some factors that are not easily evaluated may vary with altitude, altitude may serve as an index of their combined effect. For example, the depth and type of soil vary with altitude. Radiation, evaporation, temperature, vegetation, and forest cover, all of which affect rates of snowmelt, also vary with altitude.

The computation of mean altitudes for a large number of drainage basins is extremely laborious; for this reason, a simple index of altitude was sought. When main-channel slope was computed, elevations were obtained at the 10 and 85 percent points along the main channel. It was thought that an average of these might serve as an effective index of the basin altitude.

Alternative indices of altitude were studied by use of data for 33 basins in New England that had been used in the study by Benson (1962b) and for which additional information on altitudes had been listed by Langbein and others (1947). For each of those stations, the elevations of the gage at the basin outlet, the 10 percent point, the 85 percent point, and the ridge at the upstream end of the main channel were obtained, and the mean elevation of the basin was used, as listed by Langbein and others (1947). The four elevations were combined in several ways: method 1, the average of all four; method 2, the average of all but the gage elevation; method 3, the average of the 10 and 85 percent points; method 4, the 85 percent point alone.

Each of the four index elevations so obtained was expressed as a ratio of the mean elevation. For each of these four sets of ratios the mean ($\overline{X}$), standard deviation (S), and coefficient of variation (CV), were computed with the following results:

Method	$\overline{X}$	S	CV (*percent*)
1	0.842	0.162	19.3
2	1.004	.208	20.6
3	.694	.100	15.3
4	.967	.165	17.0

Use of the 10 percent, 85 percent, and ridge elevations (method 2) provides elevations close to the basin means as shown by the fact that $\overline{X}$ is almost 1. However, the average of the 10 and 85 percent elevations (method 3) was chosen as the best index of the mean elevation because, although the mean of its ratio was farthest from unity, it had the least standard deviation and coefficient of variation. Because method 3 showed the least variation, it was judged the most suitable as an index.

Other values or averages taken from the stream profile might give a better agreement with the mean elevation of the basin, but the four elevations used in the study were readily available for the test data, and the 10 and 85 percent elevations are those used for computing the main-channel slope.

The altitude index was found to be a significant variable in the snowmelt-flood region but was not found to be significant in the rain-flood area.

LENGTH OF BASIN

The length of the basin was tested as a variable. On hydrologic grounds it is expected that, at least for short-duration storms, a long narrow basin having no large tributaries will produce a smaller peak than a fan-shaped basin of the same size that has several large tributaries discharging simultaneously at the outlet. The long basin will provide more opportunity for channel storage and, in arid terrain, more loss of water through the perimeter of the channel. For storms of longer duration, that is, storms having a duration approaching or exceeding the time of concentration, length of basin may not have much effect on peaks.

There are several ways of defining the basin length, but the preferable definition should be the one that is most meaningful hydrologically. One way to define the basin length is to measure the longest straight line that may be drawn from the outlet to the watershed boundary. If a main channel folds back on itself or spirals, the basin is hydrologically equivalent to a long basin, but the longest length to the outside boundary would not reflect that fact. Another definition of basin length is the length of the longest watercourse in the basin. Still another, related to the method used by Benson (1959) for computing an index of slope, is the length of the main channel, where the main channel (extended upstream to the watershed boundary) is defined as that draining the most area. The main-channel length, so defined, has been used in this study as the basin length, because it appears to be the measure that is most meaningful hydrologically.

The measurement of the length of a stream from a map is not as simple a procedure as it might seem. A map measure is difficult to use where meandering is extreme. Maps of the same area, but having different scales or different dates, show varying degrees of meandering, and investigation during this study showed no consistent ratios with which to convert stream lengths from one map scale to another. It must also be considered that above bankful stage, part of the water flows over the flood plain in a shorter path than that followed by water within the meanders, hence an effective length is somewhat shorter than the meander length and varies with the stage, though how much it varies is not known.

As a means of obtaining consistency, the stream length was measured by using a pair of draftsman's dividers, set at 0.1 mile for map scales between 1:24,000 and 1:125,000 and at 0.25 mile for 1:250,000-scale maps, to step off distances. Where there is a great deal of meandering, the length so obtained is to some extent a compromise between the gross length of meanders and the lesser flood-plain distance. The length of the main channel as measured on the map was extended beyond the upstream end of the stream, as shown by the full or dashed blue line, to the drainage divide, but it was terminated at the boundary of the noncontributing area, where such existed.

The basin length was found (by statistical test) to have a highly significant influence on peak discharges in the rain-flood area.

SHAPE FACTOR

As previously noted, the shape of the basin is expected to have an effect on the size of peak discharges. The ratio L/W, also expressed L^2/A, in which L equals the length, W the width, and A the contributing drainage area of the basin, was computed for each basin. This ratio, or form factor, was not significantly related to peak discharge if tested after the effect of drainage area and basin length had been taken into account. The size of drainage area and of basin length, when used together, provide a measure of shape and, once area and length are used, the form factor no longer adds any information.

Other shape factors occasionally used, such as the compactness coefficient, the circularity ratio, and the elongation ratio, are more complex and are considered to be less suitable as an index of basin shape. Each is a measure of departure from circular shape and gives no consideration to the drainage pattern; none was used in this study.

STORAGE AREA

The criteria for selecting the station records to be used excluded those basins having an excessive amount of usable storage, that is, storage subject to regulation. However, some artificial and much natural storage that may effectively reduce the peak flow always remains. Such storage may be in lakes, ponds, reservoirs, or swamps. Lakes, ponds, and reservoirs have fairly permanent bounds and probably can be measured accurately from maps. The size of swamp areas varies with the seasons of the year and also from year to year, and their extent as shown on maps may depend on when the map was made and on mapping standards.

Benson (1962b) found that in New England swamp areas on recent maps commonly showed a twofold or threefold increase over the size of the same swamp areas shown on older maps. Benson also found that a storage factor limited to the area of lakes and ponds correlated with peak discharge as well as or better than a factor that included areas of lakes, ponds, and swamps. For this reason it was decided to omit swamp areas in this study.

The surface areas of lakes and ponds were measured for all drainage basins from maps. The measurements were made easily and accurately by use of a transparent grid composed of squares of known area (usually 0.01 or 0.04 sq mi). The grid was placed on the map over the lake to be measured and a count was made of squares or partial squares covering the lake area, or more simply, the number of grid intersections within the area was multiplied by the unit area.

The total of all the surface areas of lakes and ponds was expressed as a percentage of the total basin area and increased by 1.0 percent. This increase served to make the relation with peak discharge linear and to insure that where there was no storage area, the discharge would not thereby appear to be equal to zero (the form of the relation being multiplicative). If there is no storage, the storage index is 1 percent, and the fact that this value raised to any power is still 1 facilitates computation.

The area of lakes and ponds was found to be a significant factor in both the snowmelt-flood and the rain-flood areas.

CHANNEL GEOMETRY

The storage in the channel system may in part have the same effect as reservoirs in reducing peak flow. Therefore, an important factor in influencing the size of peak discharges may be the amount of water stored in the channel system, including the flood plains, as the water rises. The larger the channel storage, the greater will be the potential reduction in peak discharge.

It is extremely difficult to obtain directly data of the total amount of channel storage for a flood of given recurrence interval. To do so, it would be necessary to know the stages throughout the basin for an average, or typical, flood having that recurrence interval at the outlet, and also to have complete data on the cross sections of all streams within the basin. Such data were not available; hence, various indices based on channel geometry were used in an attempt to represent the effect of channel storage.

For most basins, a cross section of the main channel that represented fairly well the typical shape of the channel nearby was available at or near the gage. From known stage-discharge relations, the stages corresponding to the discharges for various recurrence intervals were selected. For each stage the following were determined: (1) channel width, (2) channel width/depth ratio; (3) channel cross-sectional area; and (4) channel cross-sectional area times length of main channel.

It was believed that either the channel width or the channel cross-sectional area times length of main channel might best show a relation to flood peaks. At any particular stage the rate of storage, at least in the vicinity of the gage, is a function of the channel width and the rate of change of stage. The channel cross-sectional area times length of main channel is a volume that is three times the total storage in the main channel, if the channel dimensions are considered to vary linearly along its length, with each dimension starting from zero at the upper end.

A graphical study of the relations of these four indices of channel storage with residual errors in peak discharge showed no reduction in scatter by their use, after other significant factors had been included. This lack of reduction may be because channel storage, if effective, is related to other variables, mostly basin slope and basin length, that had already been used and that reflected most of the effect of channel storage.

STREAM ORDER

The degree of development of the drainage pattern may show some relation to flood peaks, and may be expressed by the order number of the stream at the outlet point, starting from the smallest tributary streams as first-order streams. Order numbers were assigned according to Strahler's (1957, p. 914) modification of Horton's (1945) original system. In Strahler's system the smallest fingertip tributaries are designated order 1. Where two first-order channels join, a channel segment of order 2 is formed; where two of order 2 join, a segment of order 3 is formed, and so forth.

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Only the 1:250,000-scale topographic maps give complete coverage of the study area, and these maps were used to determine order numbers of streams.

An investigation of streams within the study area that appear on maps of more than one scale showed that, in general, the order number of a stream at the outlet, determined from a 1:250,000-scale map, was the same as that determined from a 1:125,000-scale map and one less than the order number from 1:24,000- or 1:62,500-scale maps.

It is known that the smallest streams shown on maps of even 1:24,000 scale may be highly developed and may have actual order numbers of 3 or sometimes higher. Although the order numbers determined from the 1:250,000-scale map are not correct, they tend to be consistent and can be used as an index of the true order number.

The order-number index was not found to be a significant variable in relation to peak discharge.

SOIL AND GEOLOGY

The effect of soils and geologic characteristics is known to be highly important throughout most of the study area. It is known, for example, that in many streams discharges caused by headwater storms may be high in the upper reaches of the stream but may disappear entirely as the flood wave progresses downstream. This phenomenon is attributable not only to the high porosity and transmissibility of the soil but to the long dry periods that account for a normally low ground-water table and low soil moisture. In limestone areas and highly faulted zones, much of the storm runoff may disappear into fissures and underground channels. The geologic features are difficult to evaluate numerically. However, there are several ways in which soil characteristics may be expressed, such as by permeability, transmissibility, depth, and infiltration capacity.

Detailed information of such soil characteristics throughout the area of this study is not available. However, Mockus (1958) has formulated a soils classification system that represents the infiltration capacity of the soil and is intended to serve as a hydrologic index. All the soils of the United States have been divided into four hydrologic soil groups, A, B, C, and D. "The soils are classified on the basis of intake of water at the end of long-duration storms occurring after prior wetting and opportunity for swelling, and without the protective effects of vegetation." Classes are also established for land use and treatment; these classes are then combined with the soil groups into hydrologic soil-cover-complexes. The complexes are assigned numbers to represent their relative values as direct runoff producers. "The higher the number, the greater the amount of direct runoff to be expected from a storm."

Detailed information on land use and treatment was not available for the basins used in this study, and average conditions (fair, pasture or range) were assumed for each basin. The index for each basin was computed by weighting the complex for each soil type on the basis of the surface area of each.

The hydrologic soils index was not found to be a significant variable in relation to peak discharge. In the opinion of Dorroh (1946, p. 22), "* * * the complexity of soil types within the Southwest makes it impossible to attempt a delineation of any sizable areas or zones as having high or low infiltration rates."

ORIENTATION

The rate at which snow melts is considerably faster on a south-facing slope than on one facing north. Wind, which hastens the snowmelt rate, usually has a prevailing direction. Therefore, it appears worthwhile to examine the relation of the general orientation of the basin to the magnitude of peak discharges within the snow-melt-flood area.

The general direction of flow from the headwater to the gage was expressed as an azimuth in degrees, measured from north as zero azimuth. The variable is circular and 0° is the same as 360°. The azimuths were plotted against the ratios of actual discharges of a specified frequency to discharges computed using all significant variables. No regression relation was apparent.

FORESTED AREA

Where snow falls on forested area within a drainage basin, there are various complex relations between the amount and type of forest cover on one hand, and the rate of snowmelt, the total runoff, and the peak rate of discharge on the other hand. In some ways, cover acts to decrease the peak discharge, and in other ways to increase it. The net effect may be either a decrease or increase in the peak, although generally the protraction of the melting period caused by forest cover probably results in a decrease in the peak.

Decreases in peak discharge may be caused by:

1. Larger interception of precipitation by tree tops, hence, more loss by evaporation (Wilm, 1948).
2. Capacity of the soil cover under forests to absorb snowmelt.
3. Slowing of wind by cover, which decreases rate of melt at time of peak discharge (Light, 1941).
4. Decreased radiation through trees at time of peak discharge (Wisler and Brater, 1959).
5. Desynchronization of melting caused by presence of both wooded and open areas in a basin (Wilson, 1941).

Increases in peak discharge may be caused by:

1. Slowing of wind by cover, which reduces evaporation and melting prior to time of peak discharge (Wilm, 1948).
2. Decreased radiation through trees prior to time of peak discharge.
3. Reduced melt by heat of soil because of duff layer between the soil and snow (Wisler and Brater, 1959).

Not all the maps within the snowmelt-flood area showed forest cover; however, for many basins the percentage of forested area could be determined from the overlay in green shown on the maps. These percentages were plotted against the ratios of actual discharge to discharge computed by using the significant variables. This plot indicated no relation of forested area to peak discharge.

BASIN RISE

In the high mountains of the southwest and west, as well as in the northeastern part of the country, snow collects throughout the winter period. However, the pattern of spring runoff in the two regions is different. In the northeast, where humid conditions prevail, much rain may fall in the spring. The first rains in the spring are usually absorbed by the snow. As the season progresses, the snow becomes increasingly warmer and higher in water content, until a rain finally triggers a period of rapid runoff during which the combination of rain and snowmelt produces a flood.

In the southwest and west, where semiarid or arid conditions prevail, there is little rain in the spring. The warming temperatures and the direct rays of the sun cause gradual melting, which is faster during the sunshine hours of the day than at night. A general slow rise and fall in the discharge hydrograph occurs and may last for 1 to 2 months. Superimposed on the general rise are diurnal fluctuations. The peak discharge is not much higher than the daily discharge or the discharge of adjacent days.

In the southwest, the snow melts differentially, that is, the melting starts at low altitudes and gradually proceeds to higher altitudes. The distribution in time of the snowmelt runoff is therefore a function of both altitude and the total rise in the basin. The basin rise was examined as a variable affecting peak discharges in the snowmelt-flood area. The rise used was the altitude difference between the 10 percent and 85 percent points along the length of the main channel, as previously computed for determining main-channel slope (p. 22, 23).

The variables of length, slope, elevation, and basin rise are highly correlated. Slope is a combination of length and rise, and the inclusion of slope, length, and rise in the regression relation produces some indeterminate results. Either slope separately, or length and rise together, could be used. It was found that the standard errors by either method were almost identical. However, the use of slope provided more consistent results and a smaller total number of variables throughout the range of recurrence interval. Slope has been used as an alternative for rise, but it may represent the effect on peak discharge of the amount of rise in the basin.

OTHER VARIABLES

Other variables are known to have some effect on peak discharges but were not studied because of lack of data. One such variable is the effect of crops and land use. A comprehensive study of the effect of land use would require complete and detailed data on crops and land treatment for the entire study area during the past 30 or 40 years. These data are not all available, and, in any event, such a comprehensive study is beyond the scope of this investigation.

Another important factor is the effect of urbanization on flood peaks. Only a few gaging stations are now wholly or partly within urbanized areas and, during their periods of record, there have been progressive changes in the degree of urbanization. Studies of the effect of urbanization require specific projects and data collection designed to answer that specific problem. At present, the necessary data are not available, the proper techniques have not been evolved, and the effects of urbanization are not known.

METEOROLOGIC CHARACTERISTICS

RAINFALL

Precipitation is the primary cause of river discharge, and some measures of its rate and duration must, therefore, be very closely related to the magnitude of peak discharges. If the precipitation characteristics were uniform over an area, they would affect only the general size of peak discharges and not their variability. In New England, where rainfall is fairly uniform, Benson (1962b) found that rainfall intensity, though a statistically significant variable, was not one of the more important factors affecting flood peaks. In the southwest, however, the outstanding characteristic of precipitation is its variability. Several indices of rainfall were studied in the course of this investigation.

MEAN ANNUAL PRECIPITATION

The mean annual precipitation is a general measure of the amount of water supplied to the surface of the ground and is the simplest and most comprehensive index of precipitation. It was investigated as a climatic variable. If the season during which the annual peak discharge occurs had been uniform over the study area, it would have been preferable to use seasonal rather than annual precipitation.

However, because the peak-discharge season occurs at different times over various parts of the area, the use of precipitation during a common season was not feasible.

The most recent U.S. Weather Bureau maps of mean annual precipitation have been prepared by Berry (1959), Sanders (1959), Von Eschen (1959), and Blood (1960) for Colorado, Louisiana, New Mexico, and Texas, respectively. Mean annual precipitation in fairly flat terrain can be mapped adequately on the basis of the precipitation records ordinarily available. The precipitation stations in mountainous terrain, however, are not spaced closely enough to define the changes with altitude and orographic position—in particular there are very few stations at the high altitudes. For accurate representation of mean precipitation in rough or mountainous terrain, some consideration needs to be given to the topography.

Knox and Nordenson (1955) prepared maps of mean annual precipitation for New England on the basis of precipitation records, index elevation, orientation, distance to coast, distance from eastern barrier, exposure, latitude, drainage zones, and runoff data. The methods they used followed those developed by Russler and Spreen (1947) for western Colorado, which contains the upper Rio Grande basin, a part of the present study area. Russler and Spreen used precipitation records, rise, orientation, and zone of environment to map contours of normal annual precipitation for 1910–45.

Russler's and Spreen's maps were considerably more detailed within the mountain areas of Colorado than Berry's (1959). Maps containing detail similar to that of Russler and Spreen were not available elsewhere within the study area. It was necessary, therefore, to derive some consistent means that made use of the more recent precipitation records and that took topography into account in determining mean annual precipitation.

The most recent long-term precipitation normals published by the Weather Bureau (1921–50 or 1931–55) were used for stations within the study area. There were 35 stations in Louisiana, 241 stations in Texas, 111 stations in New Mexico, and 80 stations in Colorado. It was obvious, from examination of the altitude-precipitation relationship, that altitude had little or no effect in Louisiana and Texas. The stations in these States were not used for further study of the altitude-precipitation relation.

Altitude was plotted against precipitation for all the stations in New Mexico and Colorado. This plot showed a very rough relation between the two, hence the various basins and subbasins were identified and an average within-basin relation was determined graphically. The slope of this relation line represented an increase of 3.5 inches of precipitation per 1,000 feet increase in altitude. Studies in other countries had shown slopes ranging from almost 0 in South America to 25 inches per 1,000 feet in India. In the United States, slopes ranging from 6.5 to 10 inches per 1,000 feet had been found in California, 10 inches per 1,000 feet in Idaho, 3.33 inches per 1,000 feet in Colorado, and 12 inches per 1,000 feet in the East. The value of 3.33 in Colorado was at Wagon Wheel Gap in the Rio Grande Valley; it agrees closely with the value found in this study.

An altitude-precipitation rating table was composed, and precipitation values for each station were determined from the published altitudes. The deviations of the observed value from the computed value at each station, ranging from +10.77 to −12.41 inches, were plotted on a map (fig. 2), and smooth contours were drawn through the points. To aid in definition within the southeast corner of New Mexico, four stations in Texas were used. No points north of 40° lat, in Colorado, were used.

From this map of anomalies (fig. 2), values were selected and deducted from the observed mean annual precipitation at each station. A new altitude-precipitation plotting was made by using the adjusted mean annual precipitation for all the stations in New Mexico and 21 stations in and near the study area in Colorado. The plot had little scatter and defined a line that had the same slope of 3.5 inches per 1,000 feet, but that was shifted slightly in position. No further adjustment of the anomaly map was necessary. The linear relation is expressed by the formula:

$$P=0.90+3.5\frac{(E-2{,}500)}{1{,}000},$$

where E is the altitude at the precipitation station in feet, and P is mean annual precipitation.

By using the altitude-precipitation formula and the anomaly map of figure 2, the adjusted mean annual precipitation can be determined for any point in the area. A map of precipitation adjusted for altitude could have been drawn, but this would have been difficult and unnecessary.

To determine the adjusted mean annual precipitation for a basin in the upper Rio Grande basin in Colorado or New Mexico, it is necessary to locate from 10 to 30 random points within the basin, usually by the grid system, and to determine the altitude, precipitation, and adjustment factor for each point. The mean of the adjusted precipitations is used as the mean annual precipitation for the basin. Experience has shown that at least 20 and preferably 30 or more altitudes are needed in mountainous terrane, while only 10 to 15 altitudes are sufficient for nonmountainous basins.

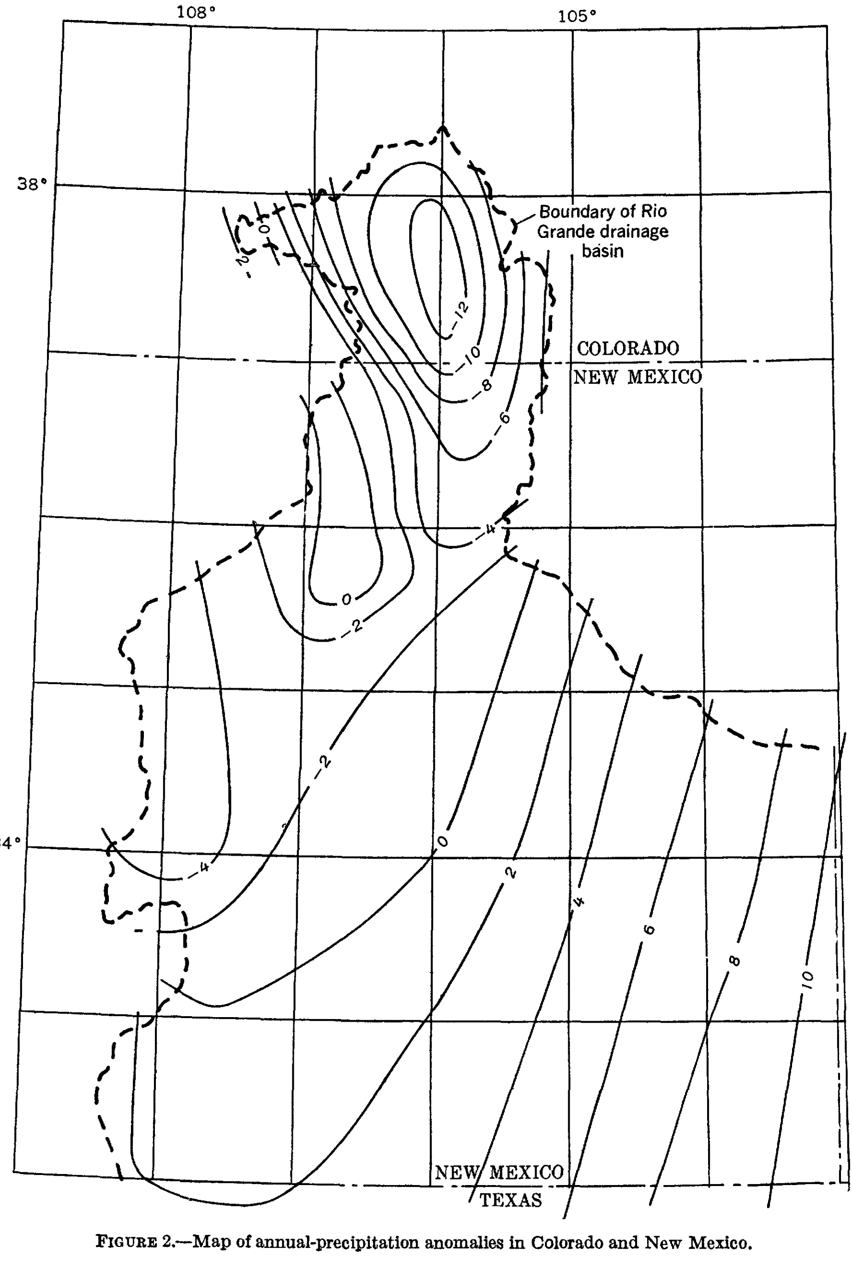

FIGURE 2.—Map of annual-precipitation anomalies in Colorado and New Mexico.

The results from this method were checked against values of mean precipitation for various basins in Colorado as determined from the map published by Spreen (1947). The two methods led to results within about 10 percent. For New Mexico, where the Weather

Bureau has not published maps of precipitation adjusted for altitude, the difference from values obtained from generalized mean annual precipitation maps may be as much as 100 or 200 percent. This method gave larger values than the Weather Bureau maps, particularly in the mountainous regions.

In Louisiana and Texas, where altitude does not have a noticeable effect on precipitation, the Weather Bureau's published maps of mean annual precipitation were used to obtain the mean annual precipitation over the basin. For basins numbered 2180 to 3600, 3785 to 4065, 4475, 4775, and 4815 (see table 1), the mean annual precipitation used in this study was based on the use of the altitude-precipitation formula and figure 2.

Mean annual precipitation was found to be a significant variable within the snowmelt-flood area.

INTENSITY

It may be expected that some index of rainfall that involved a short duration and an element of frequency would be highly correlated with the momentary peak discharge of a given frequency. In New England, Benson (1962b) found that either mean annual precipitation or rainfall intensity-frequency could be related to peak discharge, but that the latter showed the closer relation. For that region the most efficient rainfall index was the rainfall intensity for a 24-hour duration and a recurrence interval equal to that of the peak discharge.

Hershfield (1961) published a rainfall-frequency atlas of the United States that included maps delineating the rainfall intensities for durations ranging from 30 minutes to 24 hours and for return periods ranging from 1 to 100 years. Investigation in this study showed that rainfall intensities of different recurrence intervals were highly interrelated. In correlating rainfall intensities with peak discharges, no stronger relation was found for any one duration or recurrence interval of rainfall. For simplicity, therefore, the 10-year 24-hour rainfall intensity was used with all recurrence intervals of peak discharges.

Rainfall intensity was found to be a significant variable within the rain-flood area, second in importance only to size of drainage area in its effect on peak discharges.

THUNDERSTORM DAYS

At the time this study was started, current data on rainfall intensity and frequency were not available and a substitute index was sought. Hershfield, Weiss, and Wilson (1955) had shown that the mean annual number of thunderstorm days was a readily available climatic factor that could be used to estimate rainfall intensity-frequency. This variable was investigated during this study. The weighted-average annual number of thunderstorm days was computed for each basin by use of the maps of that variable published by the U.S. Weather Bureau (1952).

During the investigation, the Weather Bureau made available in advance of publication the data and maps of rainfall intensity (Hershfield, 1961). Although the data on rainfall intensity-frequency showed that variable to be highly significant, the number of thunderstorm days, used as an additional variable, also proved to be significant, though not as important as intensity.

SNOW

Although some snow may fall in parts of Louisiana and Texas, within the limits of the study area, it does not produce snowmelt floods there; snowmelt floods occur only in Colorado and northern New Mexico. The best index to relate to peak discharge would probably be one similar to rainfall intensity, such as the maximum 10-year 12-hour rate of snowmelt; however, such data are not available. In the absence of such an index, two measures of snow depth or volume were used: the total depth of snowfall and the water equivalent of snow.

MEAN ANNUAL SNOWFALL

One of the indices of snowfall used was the total mean annual snowfall in inches. Data of mean annual snowfall were available from Weather Bureau publications (Climatic Summary of the United States—Supplement for 1931 through 1952) for 191 stations in Colorado and 149 stations in New Mexico, though many of these stations were not close to the study area. Total snowfall was plotted against altitude and a mean snowfall-altitude curve was drawn. Departures from the mean curve were plotted on a map, and anomaly lines of equal departure were drawn on the maps. The anomaly map (fig. 3) together with table 4, the relation of snowfall and alti-

TABLE 4.—*Annual snowfall-altitude relation in Colorado-New Mexico*

[Tabular values are inches of mean annual snowfall and are to be adjusted by anomaly values mapped in figure 3]

Altitude (feet)	0	100	200	300	400	500	600	700	800	900
3,000	22	22	22	22	23	23	23	24	24	24
4,000	24	25	25	25	26	26	26	26	27	27
5,000	27	28	29	30	31	32	33	34	35	37
6,000	39	41	43	45	47	49	51	53	56	59
7,000	62	65	68	71	74	77	81	85	89	93
8,000	97	101	105	110	115	120	125	131	137	143
9,000	149	155	161	168	175	182	189	196	203	210
10,000	218	226	234	242	251	259	268	277	286	295
11,000	304	313	322	332	341	350	360	370	380	390

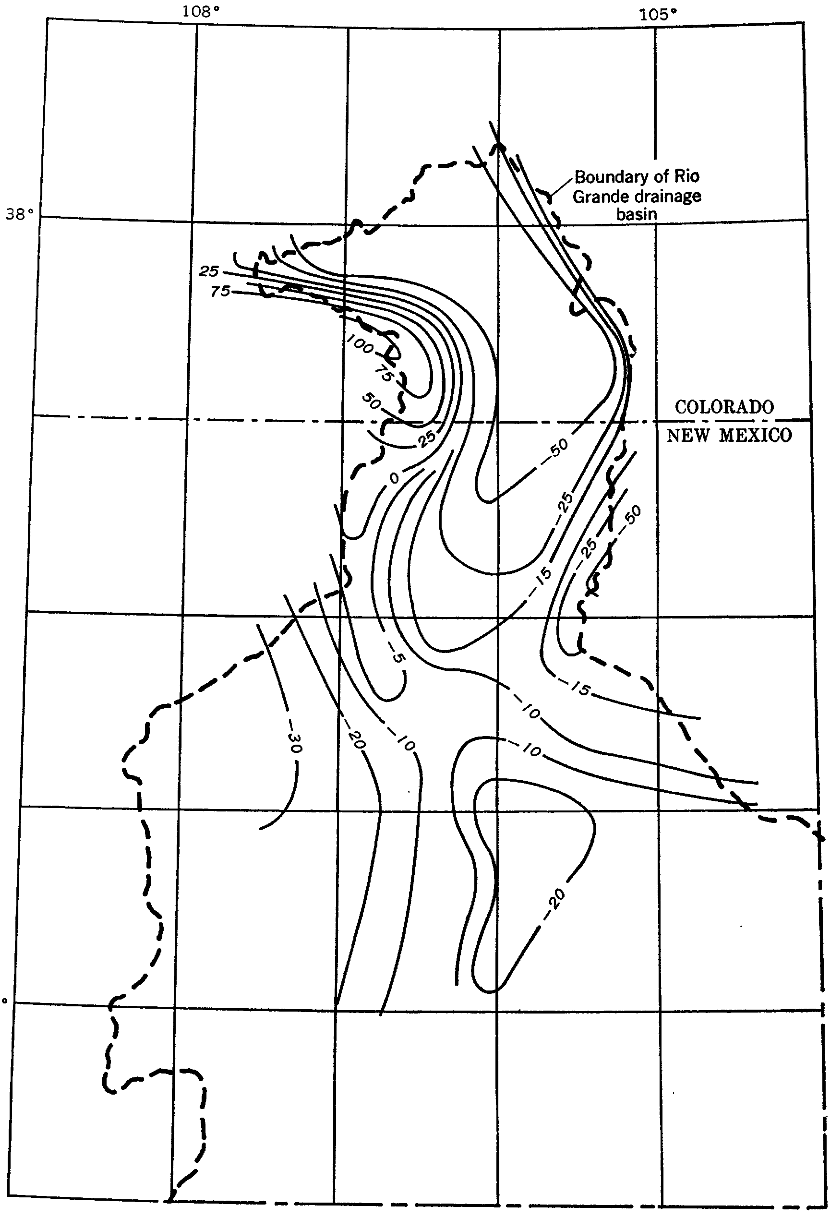

FIGURE 3.—Map of annual-snowfall anomaly in Colorado and New Mexico.

tude, may be used to compute the mean annual snowfall for any basin in the area.

The mean annual snowfall was not found to be a significant variable with relation to annual peak discharge.

WATER EQUIVALENT

The equivalent water content of snow near the time of the spring runoff would be expected to be more strongly related to annual peak discharge than would the total depth of snowfall throughout the winter season, for two reasons: first, the depth of snow is a poor indicator of its water content; second, any part of the snowfall that has melted and run off during the winter is not available for flood runoff in the spring. The equivalent water content at a date shortly prior to the usual maximum melting period would represent closely the total available supply for melting.

The U.S. Dept. of Agriculture (1952; 1957) has published summaries of snow-survey measurements in this region. The average water equivalents on April 1 for 39 snow-survey courses in and around the snowmelt area were plotted against the altitudes of the courses, and an average curve of relation was drawn. The relation of water equivalent to altitude is shown by table 5. Departures at each station from the average curve were plotted on a map of the region (fig 4), and contours of equal departure were drawn. From these contours the average departure for each basin was determined, and the departure was applied as an adjustment to the water equivalent obtained by use of table 5 and the mean basin altitudes. The final adjusted water equivalent for each basin was plotted against the residual error of the peak discharge after using all the factors found significant. No relation was apparent. Tchebotarev and Protasjev (1961) have found that in the arid regions of the U.S.S.R. there is no direct relation between the volume of spring runoff and the water equivalent of snow, and that, with the same water content of snow, the rate of stream flow in floodtime may vary within several hundred percent.

TABLE 5.—*Mean April 1 water equivalent-altitude relation in snowmelt-flood area of Colorado and New Mexico*

[Tabular values are inches of equivalent water and are to be adjusted by anomaly values mapped in figure 4]

Altitude (feet)	0	100	200	300	400	500	600	700	800	900
7,000	0	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
8,000	1.0	1.2	1.4	1.6	1.8	2.1	2.5	2.9	3.3	3.7
9,000	4.2	4.8	5.6	6.4	7.2	8.0	8.8	9.6	10.4	11.2
10,000	12.0	12.8	13.6	14.4	15.2	16.0	16.8	17.6	18.4	19.2
11,000	20.0	20.8	21.6	22.4	23.2	24.0	24.8	25.6	26.4	27.2

TEMPERATURE

The amount of ice or snow that accumulates in the winter period is a function of the winter temperatures as well as of the available precipitation. The rate of melting of the accumulated snowpack in the spring is a function of temperature, wind, exposure to the sun, and

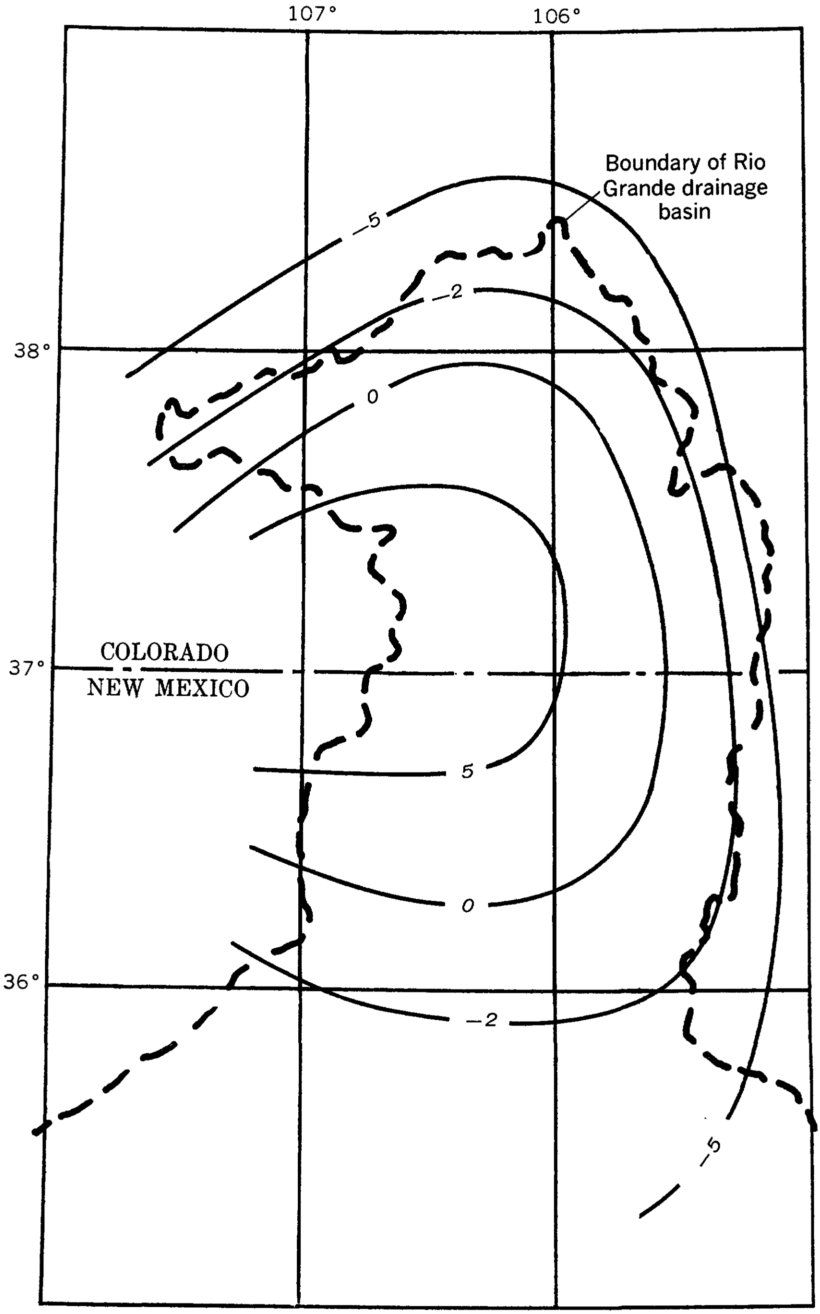

FIGURE 4.—Map of April 1 water-equivalent anomaly in snowmelt-flood area.

so forth. Both winter and spring temperatures were examined as variables having a possible effect on flood peaks.

WINTER TEMPERATURE

In the study similar to this in New England, a region of mainly snow-augmented floods, Benson (1962b) found that winter temperature, represented by the mean number of degrees below freezing in January, was a variable significantly related to peak discharge. The winter-temperature index has been used as an index of the total accumulated water content of snow, for which direct data were inadequate. Although snowmelt characteristics in the study area are different from those in New England, the same index was investigated for its relation to peak discharges.

As was true of rainfall and snowfall data, temperatures vary broadly with geographical location and locally with altitude and other less important features. Because the available temperature maps have been drawn from information collected mostly at valley stations, the contours of equal temperatures show neither the detailed variation nor the extreme values actually present in the mountain areas. A study of the variation of temperature with altitude was made by use of January mean temperatures at Weather Bureau stations as listed in Berry (1959) for Colorado, Von Eschen (1959) for New Mexico, and Blood (1960) for Texas.

An average curve of temperature versus altitude was obtained, departures from the average curve were computed for each station, and these departures were mapped. Smoothed contours, as defined by the departures, were then drawn. Values of the temperature anomaly were selected for each station from the contours, and these values were used to adjust the mean temperature at each station. A second plot relating temperature to altitude was then made. The process was repeated until a minimum scatter remained on the temperature-altitude plot. The resulting well-defined line of relation shows a decrease of 4.45° for each 1,000 feet of rise in altitude and is expressed by the formula:

$$t_1=56.9-\frac{4.45E}{1,000},$$

where t_1 is the mean January temperature in degrees Fahrenheit and E is the altitude in feet. The temperature-altitude relation and the final anomaly map, figure 5, provide a means of obtaining a temperature, related to the general area and the specific altitude, at any place. Temperatures for each drainage basin within the snow-affected area were obtained by using the mean basin altitude. These basin values were then converted to degrees below freezing by subtracting the

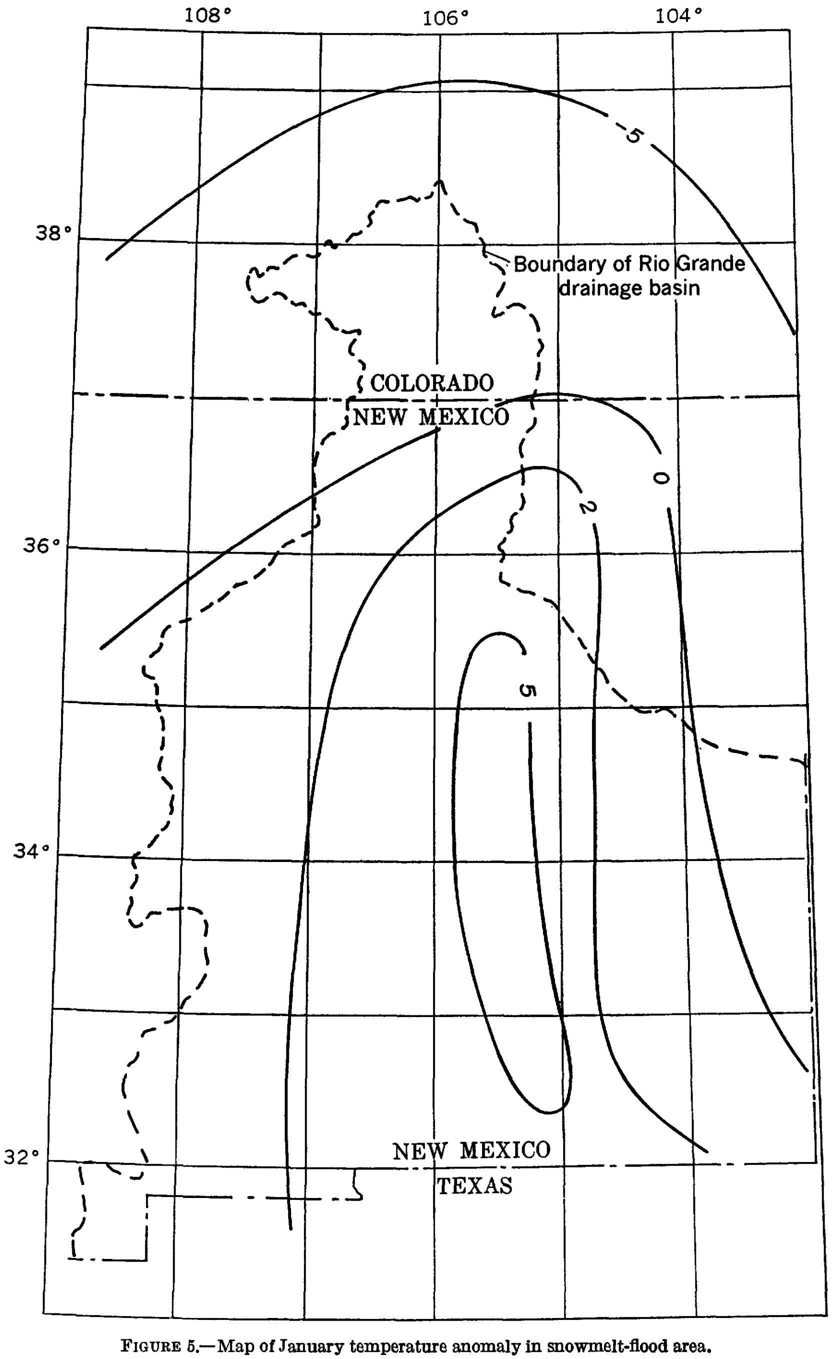

FIGURE 5.—Map of January temperature anomaly in snowmelt-flood area.

adjusted temperature from 32°; the difference was restricted to a minimum value of +1.0° below freezing.

The January temperature index was not found to be a significant variable in relation to peak discharges.

SPRING TEMPERATURE

At any point within a basin the rate at which snow melts in the spring is a function of temperature, among other things. The mean June temperature was used as the index. Data for weather stations were obtained from the U.S. Weather Bureau publications "Climates of the States." The same procedures were followed as in determining basin values of mean January temperatures. A well-defined straight-line relation was found between mean June temperature and altitude. Temperatures from this relation are adjusted by values from the anomaly map of figure 6. The June temperature gradient represents a decrease of 4.35° for each 1,000 feet of rise in altitude, which is very close to the January gradient of 4.45° per 1,000 feet. The relation between June temperature and altitude is:

$$t_6=91.5-\frac{4.35E}{1,000}.$$

The June temperature index, used within the snowmelt-flood area, was not found to be significantly related to peak discharges.

WIND

In addition to the equivalent water content and the melting temperatures of the snow, the prevailing direction and intensity of winds may be expected to influence the rate of snowmelt in the area where snowmelt floods occur. However, insufficient data on prevailing winds in the snowmelt area were available to permit reliable conclusions to be drawn. What little evidence there was indicated no relation between wind direction and intensity and peak discharge rates.

EVAPORATION

Although it was not expected that the annual rate of evaporation over land surfaces would have much effect on annual peak discharge rates, this factor was investigated. Average basinwide annual pan evaporation (Kohler, Nordenson, and Baker, 1959) was computed for those basins for which peak discharges had extremely large or small residual errors after all significant variables had been used. There was no apparent relation between evaporation rates and peak discharges.

RUNOFF AND RUNOFF/PRECIPITATION RATIOS

Soil and geologic characteristics probably have an important effect on both volume and rate of runoff. No objective procedure is known

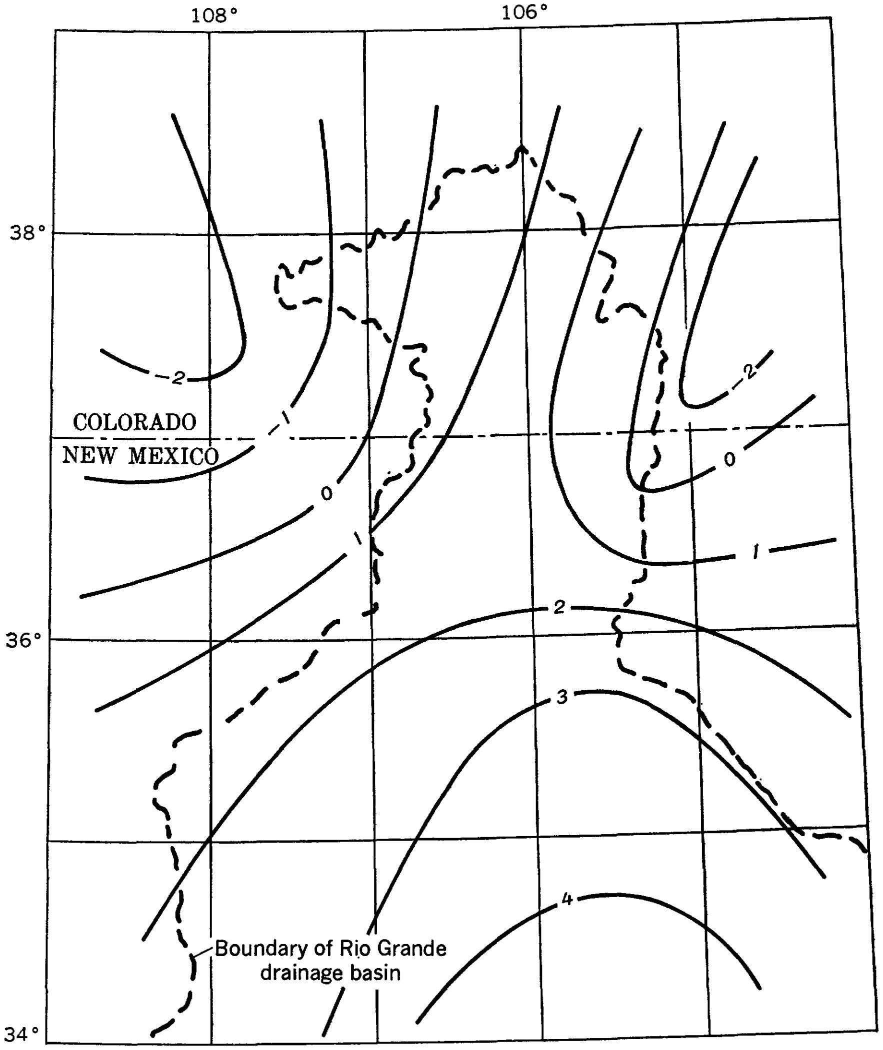

FIGURE 6.—Map of June temperature anomaly in snowmelt-flood area.

for numerical evaluation of the effect of subsurface geology. In addition, the only available index of soils effect, the hydrologic soils complex, could not be used with full efficiency because of lack of detailed data of land use and condition. Therefore, an attempt was made to use runoff or runoff/rainfall ratio as an index of the effect of soils and geology. Actually, runoff is strongly dependent on the quantity of rainfall available, and the runoff/rainfall ratio is influenced by other factors than soil and geology, such as slope, storage, evaporation, average antecedent soil moisture, and so forth. However, because of the strong influence of soil and geology on the runoff characteristics, it was considered that the runoff characteristics might act at least in part as indices of the ground characteristics and might explain some of the variations in peak discharge.

MEAN ANNUAL RUNOFF

Mean annual runoff has been used successfully in some studies that correlate annual peak discharges with hydrologic characteristics (Ellis and Edelen, 1960; Bodhaine and Thomas, 1964). In these studies mean annual runoff has served as an index of water supply. Its utility for this purpose is understandable because mean runoff represents the precipitation minus the abstractions, or the precipitation that actually reaches the stream channels, provided the losses within the channel are small.

In a semiarid region, the annual runoff is a small proportion (5 percent or less) of the annual precipitation. Figure 7 shows the variation in the annual runoff/precipitation ratio. As McDonald (1960) has shown, runoff is more variable than precipitation in

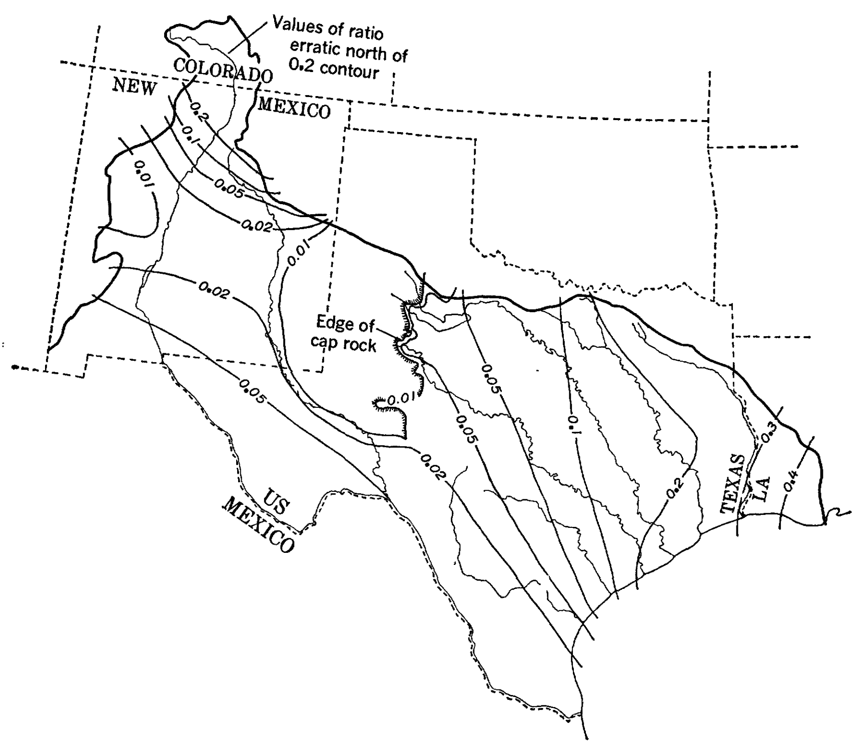

FIGURE 7.—Map of annual runoff/precipitation ratio.

mountainous regions of the arid southwest. Runoff in itself is a poor index of losses to soil because it is a small and highly variable residual that remains after losses have been deducted from rainfall. Another factor unfavorable for its use are the large and variable diversions for irrigation in the study area that may reduce the annual runoff by a large percentage. This reduction is particularly true in the more arid parts of the area where there is less water and more of what gets to the channels is utilized for irrigation. Although the irrigated acreage is known approximately for most basins, the quantities of water diverted are not known. The lack of data of diversions for irrigation made it impracticable to attempt to use mean runoff as a variable.

ANNUAL RUNOFF RATIO

If diversions for irrigation were known, the ratio of annual runoff to annual precipitation would be a fairly good index of total losses, of which losses to the soil are probably the major part. However, as was true of annual runoff, the diversions have a large but unknown effect on the annual runoff ratios. Figure 7 provides a generalized picture of the ratio of runoff to precipitation, but this ratio should be used with caution for local areas or small basins. The annual runoff ratios were not used as a variable.

MONTHLY RUNOFF RATIO

A runoff ratio was sought as an index that would not be appreciably affected by diversions for irrigation and that would represent more closely than the annual runoff ratio the losses to the soil at the time of the annual peak discharge. The ratio of the runoff to the rainfall during each month when an annual peak discharge occurred was used as a variable. For each basin the month of occurrence of each annual peak discharge was noted. To stabilize the median only those years were used in which the peak discharge was a 5-year peak or larger; where many low floods were involved, ratios were very low and the median was erratic. For each qualifying year, the appropriate monthly discharge was obtained from the streamflow reports of the U.S. Geological Survey, and the corresponding monthly mean rainfall over the basin was computed by using rainfall stations within and close to the basin. The ratio of runoff to rainfall was computed for each such month. The basin runoff ratio was computed as the median of all ratios for each basin. The median ratios for all stations were used as the basis for the map of figure 8.

The monthly runoff ratio was found to be a significant variable in relation to peak discharges within the rain-flood area.

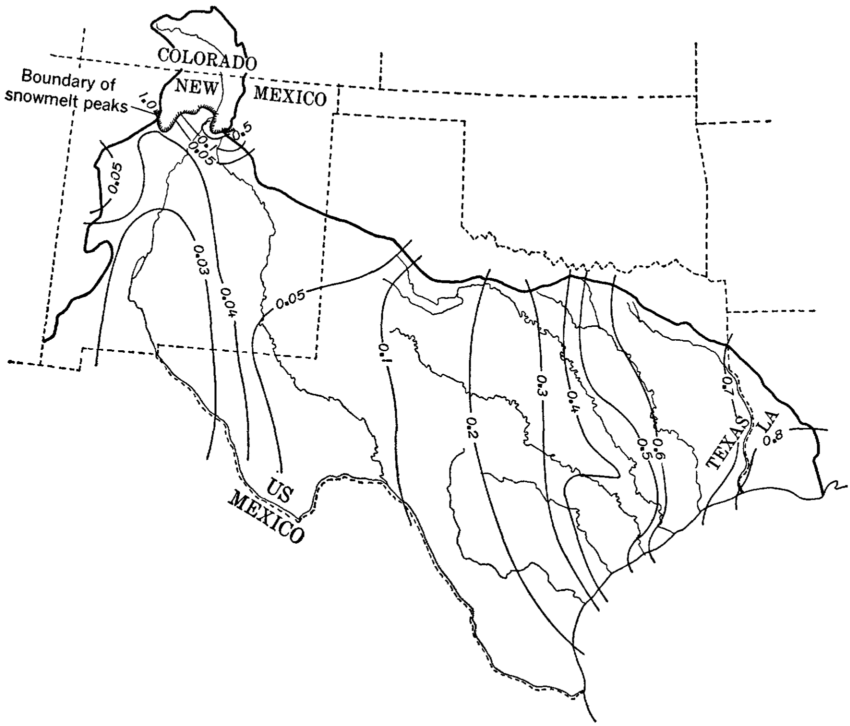

Figure 8.—Map of runoff/precipitation ratio for months of occurrence of annual peak discharges.

ANALYTICAL PROCEDURES

DETERMINATION OF *T*-YEAR PEAKS

The annual peaks for each station were listed and ranked in order of magnitude. Probabilities for each peak were computed by the formula:

$$p=\frac{m}{n+1},$$

where p represents the probability of recurrence, n represents the number of years of record, and m is the rank of the peak starting with the highest as 1. For historical floods or floods within a recent period of record whose rank relative to long periods of time was known, the long period of time was used as n in the above formula. The computed probability represents the chance of an annual peak of that magnitude or higher occurring within any year. For each gaging station used in this report, a frequency curve was drawn to average graphically the trend of the plotted points.

Each curve was extended only as high as it could be drawn with confidence on the basis of the plotted points, and aided to some extent by comparison with curves for nearby stations. No curves were extended beyond the data available for the individual gaging stations except where historical data may have been based on information at adjoining stations. For example, at some stations the highest floods are known to have recurrence intervals far greater than the period of record, yet local information that might be used to extend the recurrence intervals is lacking. Where such information is available for the same floods at nearby sites, that information was used to improve the plotting positions.

Values of the peak discharge were selected from each frequency curve at probabilities of 0.833, 0.429, 0.200, 0.100, 0.040, 0.020, and 0.010. These discharges (shown in table 1, upper line for each station) represent, respectively, the flood peaks having recurrence intervals of 1.2, 2.33, 5, 10, 25, 50, and 100 years. The following number of peaks of each size of flood were then available for further study, and they represented the dependent variables whose relations with pertinent hydrologic factors were to be studied.

Recurrence interval (years)	*Annual peaks*
1.2	219
2.33	219
5.0	217
10.0	212
25.0	178
50.0	112
100.0	55

MULTIPLE-REGRESSION PROCEDURES

Past experience in many hydrologic studies has shown that peak discharges are linearly related to most hydrologic variables if the logarithms of each are used. The plotting of logarithms of peak discharge against logarithms of each of the independent variables in the present study showed a large scatter, but indicated linear relations.

The peak discharges at several recurrence intervals (1.2, 2.33, 5, 10, 25, 50, and 100 years) were related to many hydrologic variables by standard multiple-regression techniques. Computations were made by automatic digital computer. The first trials included the data from all 219 gaging stations throughout the study area. These trials revealed that stations in northern New Mexico and Colorado (the area in which snowmelt floods occur) showed consistent deviations from the general pattern.

The snowmelt-flood area was then separated from the entire area and, thereafter, the snowmelt- and rain flood-area data were treated separately. The boundary between the two areas was fixed by studying the dates of the annual peak discharges and finally by computing the ratios of the momentary to the daily discharges. The snowmelt-flood peaks consistently showed low ratios, and the rain-flood peaks high ratios. The boundary between the two types of peaks ran roughly through a line slightly north of Santa Fe, N. Mex. (see pl. 1). There were 46 stations within the snowmelt-flood area and 173 stations within the rain-flood area.

Further analysis of the rain-flood area disclosed a part north and south of the western end of the Balcones fault zone that showed consistent large deviations from the general pattern regardless of what variables were used. The probable reasons for these deviations are discussed on page 63. This area, as shown in figure 9, contains 18 stations. These stations were not used in formulating the relations for the rain-flood area; hence 155 stations in all were used for that purpose.

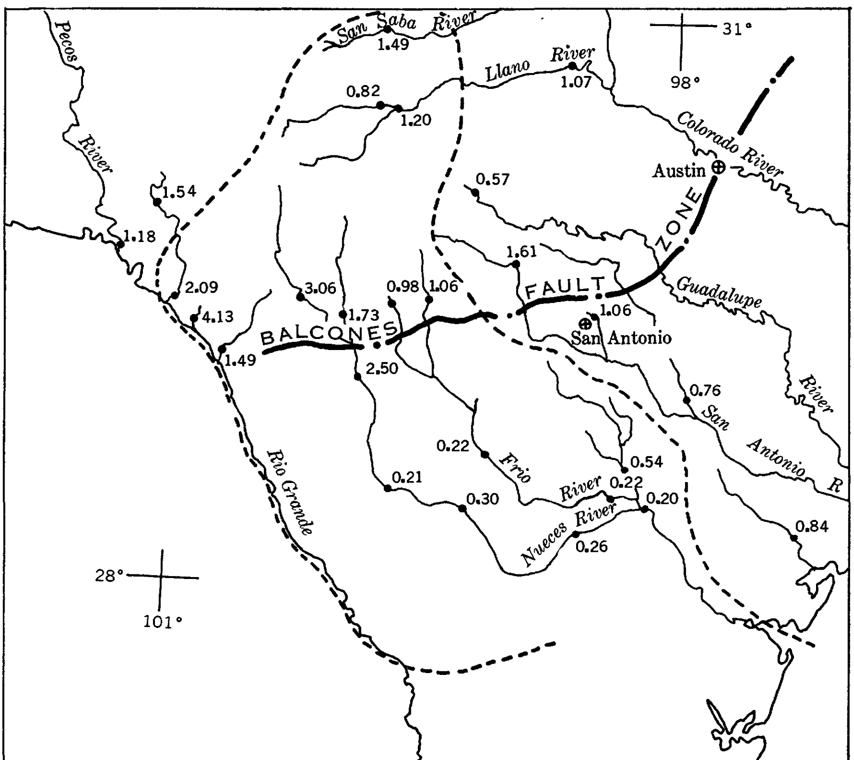

FIGURE 9.—Balcones fault zone area, showing median departures from standard regression relations.

There is some relation between flood peaks and each of the many variables that might be selected on the basis of hydrologic knowledge. Such a relation may, statistically, be expressed as the simple regression between two variables. The relation will be stronger, that is, it will explain more of the variation in flood peaks, for some variables than for others. The strength of the relation is measured by the standard error, which represents the degree to which the variation in flood peaks may be explained. For example, if only one independent variable is considered, a regression of flood peaks with drainage-area size would have a smaller standard error than a regression with channel slope, and would thus show the stronger influence of drainage-area size. However, a large number of such simple regressions, each indicating the relation of flood peaks to a single hydrologic factor, would not express the combined effect of hydrologic variables on the variation in flood peaks from one place to another.

The logical step forward is to find the two hydrologic variables that in combination are most efficient in explaining the variations in flood peaks. The relation thus formulated is known as a multiple regression. The process of adding variables can be carried on further until a relation is found having a series of hydrologic variables that represent the most efficient possible combination, that is, a minimum-variance combination that utilizes the least number of statistically significant variables.

After the most efficient combinations had been determined for both the snowmelt-flood and the rain-flood areas, discharges and residual errors were computed by using the regression equations for all flood levels at all stations (see table 1). The residuals (median ratios of actual to computed discharges) at each station were tested graphically against variables previously eliminated and against several variables not previously used in the formal computations. No apparent relationships were found at this stage. As a final step, the residuals were plotted on a map and were nearly randomly distributed. Some local evidences of nonrandomness are discussed on pages 63, 64. Residuals for small-area stations showed a random pattern geographically and were distributed randomly about a value of 1.0. Discharges for the anomalous Balcones fault-zone area were computed using the standard relation, and the pattern was studied for probable causes; these are discussed on page 63.

RESULTS

RAIN-FLOOD AREA

Regression relations in the rain-flood area were calculated with a digital computer. The simple correlation matrix is obtained as part of the regression computations. The correlation matrix is informative, for it reveals the degree of correlation between any pair of the so-called "independent variables," and between the dependent variable and each of the independent variables. Table 6 shows the simple correlation matrix of the 2.33-year peak discharge ($Q_{2.33}$) and the independent variables.

TABLE 6.—*Simple correlation matrix with* $Q_{2.33}$ *in rain-flood area (155 stations)*

[Coefficients with absolute values exceeding 0.16 are significant at the 5 percent level. Independent variables include; Drainage area, *A*, in square miles; main-channel slope, *S*, in feet per mile; surface storage area, *St*, in lakes and ponds, as percent of total drainage area, increased by 1.0 percent; intensity of rainfall, *I*, in inches, for 10-year, 24-hour expectancy; main-channel length, *L*, in miles; mean annual precipitation, *P*, in inches; altitude index, *E*, in feet above mean sea level; basin rise, *H*, in feet; ratio of runoff to precipitation, *R*, during month of annual peak discharge; mean annual number of thunderstorm days, *N*]

	$Q_{2.33}$	*A*	*S*	*St*	*I*	*L*	*P*	*E*	*H*	*R*	*N*
$Q_{2.33}$	1.00										
A	.77	1.00									
S	−.64	−.56	1.00								
St	.11	.27	−.36	1.00							
I	.43	.04	−.74	.10	1.00						
L	.69	.97	−.57	.27	.06	1.00					
P	.30	−.07	−.61	.12	.88	−.06	1.00				
E	−.35	.01	.74	−.18	−.91	.01	.91	1.00			
H	−.06	.31	.59	−.16	−.78	.33	−.76	.84	1.00		
R	.34	−.03	−.57	.17	.79	−.01	.83	−.79	−.66	1.00	
N	−.08	−.19	−.24	.19	.30	−.19	.60	−.54	−.47	.54	1.00

The general minimum-variance equation that includes all statistically significant variables is in the form:

$$Q_T = aA^bS^cSt^dI^eL^fR^gN^h$$

or its equivalent in linear form,

$$\log Q_T = \log a + b \log A + c \log S + d \log St + e \log I + f \log L + g \log R + h \log N,$$

where T is the recurrence interval, a is the regression constant, and b, c, d, e, f, g, and h are the regression coefficients.

A summary of results (table 7) shows the values of the regression constant, regression coefficients, multiple-correlation coefficients, and standard errors for seven values of T, for independent variables from 1 to 7 in total number listed generally in order of decreasing importance; the change in standard error as each variable is added is also shown. The level of significance of the regression coefficients is indicated.

TABLE 7.—*Summary of regression equations, rain-flood area,* $Q_T = aA^bS^cSt^dI^eL^fR^gN^h$

Independent variables included: *A*, contributing drainage area, in square miles; *I*, 10-year, 24-hour rainfall intensity, in inches; *L*, basin length (total length of main channel), in miles; *N*, mean annual number of thunderstorm days; *R*, ratio of runoff to precipitation during months when annual peak discharges occur; *S*, main-channel slope (85 to 10 percent points), in feet per mile; *St*, percentage of area in lakes and ponds, increased by 1 percent.
Asterisk [*], statistically significant at the 5 percent level.
Double asterisk [**], statistically significant at the 1 percent level.
x, logarithm of standard deviation of dependent variable; *y*, ΔS.E., the decrease in standard error caused by adding the variable shown in the last column.

Recurrence interval, *T*, in years	Number of Stations	Independent variables included	Log a	a	b	c	d	e	f	g	h	Standard error		*y* ΔS.E. percent	Variable added
												Log units	Percent		
1.2	155											*x*0.770	284.4		
		A	1.21327	16.3	0.73**							.520	150.7	133.7	*A*
		A, R	1.60020	39.8	.74**					0.67**		.438	118.9	31.8	*R*
		A, L, R	1.91794	82.8	1.53**				−1.39**	.69**		.407	108.1	10.8	*L*
		A, St, L, R	1.91161	81.6	1.56**		−1.07*		−1.40**	.72**		.403	106.7	1.4	*St*
		A, St, L, R, N	2.99654	992	1.55**		−.93		−1.42**	.79**	−0.60	.402	106.4	.6	*N*
		A, St, I, L, R, N	2.51228	325	1.56**		−.90	0.36	−1.44**	.66**	−.50	.401	105.8	.3	*I*
		A, S, St, I, L, R, N	2.57426	375	1.56**	−0.01	−.91	.33	−1.44**	.67**	−.51	.403	106.7	0	*S*
2.33	155											*x*.608	190.4		
		A	2.17569	150	.59**							.392	103.1	87.3	*A*
		A, I	1.16413	14.6	.58**			1.50**				.312	78.2	24.9	*I*
		A, I, L	1.35960	22.9	1.20**			1.57**	−1.10**			.284	70.1	8.1	*L*
		A, St, I, L	1.29339	19.7	1.24**		−1.42**	1.62**	−1.10**			.271	66.5	3.6	*St*
		A, St, I, L, R	1.81162	64.8	1.24**		−1.62**	1.07**	−1.09**	.27**		.263	64.3	2.2	*R*
		A, St, I, L, R, N	3.42484	2,660	1.24**		−1.45**	.93**	−1.12**	.40**	−.83**	.256	62.4	1.9	*N*
		A, S, St, I, L, R, N	2.60132	399	1.27**	.15	−1.29**	1.31**	−1.07**	.38**	−.69**	.255	62.2	.2	*S*
5	155											*x*.558	166.8		
		A	2.57598	377	.55**							.353	90.6	76.2	*A*
		A, I	1.64909	44.6	.54**			1.38**				.277	68.2	22.4	*I*
		A, St, I	1.56413	36.7	.58**		−1.80**	1.44**				.254	61.9	6.3	*St*
		A, St, I, L	1.71139	51.5	1.05**		−1.81**	1.49**	−.83**			.234	56.5	5.4	*L*
		A, St, I, L, N	2.52848	338	1.05**		−1.64**	1.58**	−.85**		−.50*	.231	55.7	.8	*N*
		A, St, I, L, R, N	3.75966	5,750	1.05**		−1.72**	1.07**	−.85**	.28**	−.92**	.223	53.6	2.1	*R*
		A, S, St, I, L, R, N	2.73180	539	1.08**	.18*	−1.52**	1.54**	−.80**	.25**	−.75**	.221	53.1	.5	*S*
10	153											*x*.537	157.8		
		A	2.81469	653	.53**							.339	86.2	71.6	*A*
		A, I	1.93948	87.0	.52**			1.28**				.273	67.0	19.2	*I*
		A, S, I	−.14520	.716	.73**	.57**		2.65**				.241	58.4	8.6	*S*
		A, S, St, I	.31734	2.08	.71**	.43**	−1.45**	2.36**				.226	54.4	4.0	*St*
		A, S, St, I, L	.60762	4.05	1.05**	.38**	−1.53**	2.28**	−.63**			.215	51.5	2.9	*L*
		A, S, St, I, L, R	.82346	6.66	1.05**	.38**	−1.61**	2.05**	−.63**	.11		.213	51.0	.5	*R*
		A, S, St, I, L, R, N	2.42936	269	1.03**	.29**	−1.58**	1.75**	−.67**	.22**	−.67**	.209	49.9	1.1	*N*

TABLE 7.—*Summary of regression equations, rain-flood area,* $Q_T = aA^bS^cSt^dI^eL^fR^gN^h$—Continued

Recurrence interval, *T*, in years	Stations	Independent variables included	Log a	a	b	c	d	e	f	g	h	Standard error: Log units	Standard error: Percent	y AS.E. percent	Variable added
25	126											x0.513	147.8		
		A	3.00985	1,020	0.52**							.325	82.0	65.8	*A*
		A, I	2.26031	182	.51**			1.14**				.271	66.5	15.5	*I*
		A, S, I	−.11378	.770	.73**	0.65**		2.71**				.228	54.9	11.6	*S*
		A, S, I, L	.04589	1.11	.97**	.63**		2.68**	−0.43*			.223	53.6	1.3	*L*
		A, S, I, L, R	.27587	1.89	.98**	.67**		2.40**	−.43*	0.17*		.221	53.1	.5	*R*
		A, S, I, L, R, N	1.95782	90.7	.96**	.58**		2.08**	−.47**	.28**	−0.70*	.216	51.8	1.3	*N*
		A, S, St, I, L, R, N	2.25953	182	.97**	.48**	−0.95*	1.89**	−.51**	.28**	−.70**	.212	50.7	1.1	*St*
50	87											x.391	102.8		
		A	3.47307	2,970	.42**							.272	66.8	36.0	*A*
		A, I	2.95354	899	.42**			.73**				.251	61.1	5.7	*I*
		A, S, I	.38695	2.44	.68**	.67**		2.39**				.217	52.0	9.1	*S*
		A, S, I, L	.65256	4.49	.95**	.61**		2.28**	−.49*			.210	50.2	1.8	*L*
		A, S, I, L, N	1.98517	96.6	.92**	.49**		2.09**	−.52**		−.56	.208	49.7	.5	*N*
		A, S, I, L, R, N	3.20028	1,590	.88**	.51**		1.64**	−.48*	.28*	−.99**	.203	48.4	1.3	*R*
		A, S, St, I, L, R, N	3.56522	3,670	.91**	.40**	−1.06	1.42**	−.53**	.28*	−1.03**	.200	47.6	.8	*St*
100	44											x.389	102.2		
		A	3.75029	5,630	.38**							.295	73.2	29.0	*A*
		A, I	3.20933	1,620	.40**			.66**				.283	69.8	3.4	*I*
		A, S, I	−.90441	.125	.82**	1.09**		3.32**				.182	43.1	26.7	*S*
		A, S, I, L	−.58945	.257	1.07**	1.01**		3.17**	−.47			.176	41.6	1.5	*L*
		A, S, I, L, R	−.55241	.280	1.13**	1.09**		3.09**	−.53*	.15		.177	41.8	0	*R*
		A, S, I, L, R, N	.30930	2.04	1.14**	1.06**		2.87**	−.57**	.25	−.35	.179	42.4	0	*N*
		A, S, St, I, L, R, N	.60835	4.06	1.15**	1.01**	−.49	2.75**	−.59**	.28	−.43	.180	42.6	0	*St*

SNOWMELT-FLOOD AREA

Regression relations in the snowmelt-flood area were computed including the independent variables shown in table 8. Table 8 shows the simple correlation matrix of the 2.33-year peak discharge ($Q_{2.33}$) and the independent variables.

The general minimum-variance equation that includes all statistically significant variables is in the form

$$Q_T = aA^b S^c St^d P^e E^f N^g$$

or its equivalent in linear form

$\log Q_T = \log a + b \log A + c \log S + d \log St + e \log P + f \log E + g \log N$, where T is the recurrence interval, a is the regression constant, and b, c, d, e, f, and g are the regression coefficients.

A summary of results (table 9) shows the values of the regression constant, regression coefficients, multiple-correlation coefficients, and standard errors for six values of T, for independent variables from 1 to 6 in total number, listed generally in order of decreasing importance; it also shows the change in standard error as each variable is added. The level of significance of the regression coefficients is indicated.

TABLE 8.—*Simple correlation matrix with* $Q_{2.33}$ *in snowmelt-flood area (46 stations)*

[Coefficients with absolute values exceeding 0.29 are significant at the 5 percent level. Independent variables included: drainage area, *A*, in square miles; main-channel slope, *S*, in feet per mile; surface storage area, *St*, in lakes and ponds as percent of total drainage area, increased by 1.0 percent; mean annual precipitation, *P*, in inches; mean June temperature, t_6, in degrees Fahrenheit; main-channel length, *L*, in miles; basin rise, *H*, in feet; mean January degrees below freezing, t_1, in degrees Fahrenheit; altitude index, *E*, in feet above mean sea level; mean annual number of thunderstorm days, *N*; intensity of rainfall, *I*, in inches, for 10-year 24-hour expectancy; mean annual snowfall, *Sn*, in inches; equivalent water content of snow, *W*, in inches]

	$Q_{2.33}$	*A*	*S*	*St*	*P*	t_6	*L*	*H*	t_1	*E*	*N*	*I*	*Sn*	*W*
$Q_{2.33}$	1.00													
A	.92	1.00												
S	−.91	−.95	1.00											
St	−.21	−.20	.11	1.00										
P	−.52	−.69	.68	.34	1.00									
t_6	.62	.71	−.68	−.29	−.75	1.00								
L	.91	.98	−.97	−.15	−.72	.72	1.00							
H	.03	.18	.07	−.17	−.18	.19	.18	1.00						
t_1	−.55	−.64	.59	.20	.62	−.96	−.65	−.26	1.00					
E	−.76	−.85	.78	.21	.68	−.88	−.85	−.31	.88	1.00				
N	−.40	−.29	.37	.13	.29	.03	−.30	.26	−.21	.03	1.00			
I	−.64	−.54	.63	.30	.61	−.54	−.57	.21	.34	.45	.65	1.00		
Sn	−.49	−.65	.60	.29	.74	−.95	−.66	−.25	.92	.84	−.10	.43	1.00	
W	−.46	−.61	.46	.21	.48	−.77	−.57	−.45	.80	.77	−.10	.23	.77	1.00

TABLE 9.—*Summary of regression equations, snowmelt-flood area,* $Q_T = a\ A^b\ S^c\ St^d\ P^e\ E^f\ N^g$

Independent variables included: *A*, contributing drainage area, in square miles; *E*, altitude index (mean of 85 and 10 percent points), in feet above mean sea level; *N*, mean annual number of thunderstorm days; *P*, mean annual precipitation, in inches; S, main-channel slope (85 to 10 percent points), in feet per mile; *St*, percentage of area in lakes and ponds, increased by 1 percent.
Asterisk [*], statistically significant at the 5 percent level.
Double asterisk [**], statistically significant at the 1 percent level.
x, log of standard deviation of dependent variable.
*y*Δ S.E. is the decrease in standard error caused by adding the variable in the last column.

Recurrence interval, *T*, in years	Number of stations	Independent variables include	Log *a*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	Standard error: Log units	Standard error: Percent	*y* ΔS.E. percent	Variable added
1.2	46										*x*0.733	261.2		
		S	5.1056	1.28×10^{5}		−1.32**					.366	94.8	166.4	*S*
		S, P	17.0478	1.12×10^{17}		−1.61**		3.06**			.336	85.3	9.5	*P*
		S, P, E	13.0508	1.13×10^{13}		−1.41**		3.79**	−3.22*		.324	81.7	3.6	*E*
		S, P, E, N	29.9545	9.01×10^{29}		−1.12**		4.57**	−5.86**	−4.70**	.289	71.5	10.2	*N*
		S, P, E, N, St	27.0168	1.04×10^{27}		−1.20**	−1.02*	5.13**	−5.42**	−4.30**	.280	69.0	2.5	*St*
		S, P, E, N, St, A	21.0156	1.04×10^{21}	0.24	−.88**	−.86	5.01**	−4.21*	−4.20**	.277	68.2	.8	*A*
2.33	46										*x*.704	243.0		
		A	1.1523	1.42×10^{1}	.73**						.285	70.4	172.6	*A*
		A, P	−1.8764	7.52×10^{-1}	.85**			2.12*			.268	65.7	4.7	*P*
		A, P, N	3.0838	1.21×10^{3}	.82**			2.41**		−3.06**	.244	59.2	6.5	*N*
		A, P, N, S	3.4362	2.73×10^{3}	.56**	−.54*		2.55**		−2.39*	.232	55.9	3.3	*S*
		A, P, N, S, St	2.8542	7.15×10^{2}	.48**	−.71**	−.90*	3.04**		−2.10*	.222	53.3	2.6	*St*
		A, P, N, S, St, E	15.1942	1.56×10^{15}	.34*	−.74**	−.90*	3.55**	−2.77*	−3.07**	.214	51.2	2.1	*E*
5	44										*x*.698	239.4		
		A	1.3610	2.30×10^{1}	.72**						.262	64.0	175.4	*A*
		A, N	6.3700	2.34×10^{6}	.68**					−2.85**	.244	59.2	4.8	*N*
		A, N, P	3.3451	2.21×10^{3}	.80**			2.06**		−2.81**	.227	54.6	4.6	*P*
		A, N, P, E	15.5260	3.36×10^{15}	.67**			2.64**	−2.79	−3.77**	.219	52.5	2.1	*E*
		A, N, P, E, S	16.8176	6.57×10^{16}	.44**	−.46*		2.87**	−3.05*	−3.24*	.209	49.9	2.6	*S*
		A, N, P, E, S, St	16.3258	2.12×10^{16}	.37**	−.62**	−.83*	3.31**	−3.05*	−2.98**	.199	47.4	2.5	*St*
10	41										*x*.712	247.9		
		A	1.4909	3.10×10^{1}	.71**						.269	65.9	182.0	*A*
		A, N	6.6698	4.68×10^{6}	.68**					−2.96*	.251	61.1	4.8	*N*
		A, N, P	3.6168	4.14×10^{3}	.80**			2.22**		−3.04**	.231	55.7	5.4	*P*
		A, N, P, E	17.3758	2.38×10^{17}	.65**			2.84**	−3.17*	−4.04**	.220	52.8	2.9	*E*
		A, N, P, E, S	18.6045	4.02×10^{18}	.43**	−.45*		3.06**	−3.42*	−3.52**	.210	50.2	2.6	*S*
		A, N, P, E, S, St	18.2182	1.65×10^{18}	.35*	−.62	−.90*	3.54**	−3.48*	−3.18**	.197	46.8	3.4	*St*
25	36										*x*.737	263.7		
		S	5.7576	5.72×10^{5}		−1.26**					.297	73.8	189.9	*S*
		S, St	5.7826	6.06×10^{5}		−1.23**	−1.35**				.270	66.2	7.6	*St*
		S, St, P	3.4423	2.77×10^{3}		−1.43**	−1.65**	2.12*			.254	61.9	4.3	*P*
		S, St, P, E	18.9420	8.75×10^{18}		−1.18**	−1.56**	3.40**	−4.48**		.210	50.2	11.7	*E*
		S, St, P, E, N	27.0409	1.10×10^{27}		−1.03**	−1.44**	3.47**	−5.58**	−2.43*	.199	47.4	2.8	*N*
		S, St, P, E, N, A	21.9216	8.35×10^{21}	.22	−.73**	−1.25**	3.38**	−4.49**	−2.53*	.193	45.8	1.6	*A*

DISCUSSION OF RESULTS

VARIABLES IN FINAL EQUATION

The variables that appear in the final equations are not the only ones that affect flood peaks. However, they represent the most efficient combination found for explaining peak flow. For example, in the rain-flood area, mean annual precipitation might have been retained in the final equation instead of rainfall intensity, and would have been statistically significant. However, the standard error would have been larger than when intensity is used. When intensity is used, mean annual precipitation no longer adds any significant contribution towards explaining the variation in peak flow. The same is true of other alternative variables that are highly interrelated.

SIMPLE CORRELATION COEFFICIENTS

Tables 6 and 8 show the simple correlation coefficients between the mean annual (2.33-year) peak and many independent variables and between the independent variables. These coefficients are highly informative and yet may be misleading. The interrelations described by the simple correlation coefficients do not take into account the fact that other important variables are affecting the simple two-way relations beside the pair being considered.

For example, in table 6 any correlation coefficient larger than 0.16 (sign disregarded) is statistically significant at the 5-percent level. The simple relation between $Q_{2.33}$ and S, slope, indicates a negative correlation, which means that as slope increases the mean annual flood decreases. Hydrologically, such a relation is nonsense, and it appears to exist only because the effect of drainage-area size is being disregarded. Large drainage areas tend to have small slopes, and vice versa; therefore the larger mean annual floods that occur on larger drainage areas accompany the smaller slopes. However, if the effect of drainage-area size is nullified, a negative relation will apply. For the same size of drainage area, larger slopes will produce larger floods. This fact is shown by the positive exponents of slope in the multiple-regression equation (table 7), as found in this and other studies (Benson, 1962b). Similarly, the relation of $Q_{2.33}$ and L, length, is positive, because both are large for larger drainage areas. Yet, for drainage areas of equal size, the longer the basin length, the smaller will be the mean annual or any other flood. This relation is shown by the negative exponents of L in the multiple-regression equation. If, instead of a simple relation, a multiple relation is considered, the partial correlation coefficient will reveal the true direction of the relation.

The simple correlation table shows the high degree of interrelation between precipitation factors P and I, altitude indices E and H, and the runoff ratio, R. These are all meaningful hydrologic relations.

A large degree of correlation exists between drainage area, A, and basin length, L, as is to be expected. Geomorphologists have been interested in the interrelations between drainage area, channel slope, and channel length. The following relations were found for the 155 basins in the rain-flood part of the study area:

$$L=1.66A^{.57},$$

$$S=153L^{-.67},$$

$$S=113A^{-.38},$$

where L is in feet, A in square miles, and S, slope, in feet per mile. Hack (1957) found, for streams in Virginia and Maryland, the relation

$$L=1.4A^{.6},$$

Brush (1961) found, for streams in Pennsylvania, the relation

$$L=1.43A^{.59},$$

and Gray (1961) found, for small streams in the midwest and east, that

$$L=1.40A^{.57}.$$

If the ratio of meander length to straight-line stream length remained the same as drainage area increased, the exponent of A should be 0.5 in the relation of L with A. However, the disproportionate increase of meandering as drainage area grows larger and, simultaneously, slopes grow smaller, is believed to explain the exponent of 0.6 instead of 0.5. The constant of 1.66 in the southwest as contrasted to about 1.4 in the northeast is believed attributable to the fact that, for equal drainage sizes, slopes are ordinarily flatter in the southwest than in the northeast and that in the southwest, therefore, the degree of meandering is higher and streams longer by about 16 percent.

The relations involving slope are somewhat dependent on the method of computing slope. The investigations of Hack (1957) and Brush (1961), and to some extent those of Gray (1961), show that the slope-area and the slope-length relations vary with the lithology and that composite relations represent only a generalized picture of trend. The scatter of the data for the relations shown by this study is indicated by the correlation coefficients of −0.57 for the slope-length relation and −0.56 for the slope-area relation (see table 6). These coefficients may be compared with the correlation coefficient of 0.97 for the length-area relation, which shows little scatter and apparently does not vary with lithology.

RELATIVE IMPORTANCE OF SIGNIFICANT INDEPENDENT VARIABLES

The relative importance of the independent variables in the final multiple-regression equations may be judged by the percent reduction in the standard error of estimate as each is included in turn. The reductions are shown in tables 7 and 9.

In the rain-flood area, the size of drainage area, *A*, is by far the most important variable. The use of drainage area as the first independent variable reduces the standard deviations of the dependent variables by an amount ranging from 29 to 134 percent. The next variable in order of importance is rainfall intensity, *I*, which reduces the standard error by an average of 15 percent where it is significant. Main-channel slope reduces the error by an average of 6 percent where it is significant. Main-channel length, *L*, reduces the standard error an average of 5 percent. The area of lakes and ponds, *St*, is responsible for an average reduction of 4 percent where it is significant.

The runoff ratio, *R*, reduces the standard error by an average of 6 percent where significant, although most of the reduction occurs at the 1.2-year flood level, whereas the reduction is 2 percent through most of the range. The number of thunderstorm days, *N*, causes an average reduction of 1 percent where statistically significant.

In the snowmelt-flood area, drainage-area size and main-channel slope are highly correlated ($r=-0.95$, table 8). Drainage area is the most important variable related to the 2.33-, 5-, and 10-year peak discharges and is responsible for most of the variability. Main-channel slope is most important in explaining the 1.2- and 25-year peaks, and for these, drainage-area size is not significant. A hydrologic interpretation for the interchange of the importance of drainage-area size and main-channel slope is not apparent. It is known that a high degree of correlation between two variables in a multiple-regression computation will lead to difficulties, sometimes to an indeterminate solution. One of the two variables—for example, slope—could be eliminated altogether. However, it will be seen (table 9) that for the 2.33-, 5-, and 10-year peaks, slope is significant even where drainage area is highly significant and that slope reduces the variance by 2 to 3 percent for those peaks.

In the snowmelt-flood area, in addition to drainage-area size and slope, mean annual precipitation, *P*, altitude, *E*, the number of thunderstorm days, *N*, and storage, *St*, each reduce the standard error by an average of 4 to 6 percent.

GRAPH OF REGRESSION COEFFICIENTS

Figure 10 shows how the regression coefficients vary with recurrence interval in the rain-flood area. The values graphed are those for the multiple relations in which all seven of the independent variables are used. The values of each coefficient vary uniformly with recurrence interval except at 100 years. Values at 100 years are erratic and are not graphed. The sudden change in most of the coefficients at 100 years could be caused by either (1) a change in flood characteristics there or (2) inaccuracies attributable to the smaller number of stations (44) and uncertainties in establishing the values of the 100-year floods. The latter cause is believed to be more probable. The extrapolated values at 100 years, as shown on the graph of figure 10, are probably more realistic than the values computed.

The variation among the coefficients is not consistent with time; that is, one may increase as another decreases. For this reason, a single general formula incorporating recurrence interval, *T*, as an additional variable cannot be used.

Figure 11 shows the variation of regression coefficients with recurrence interval in the snowmelt-flood area. The graphs of figure 11 reveal a general consistency in the values of the regression coefficients for relations in that area.

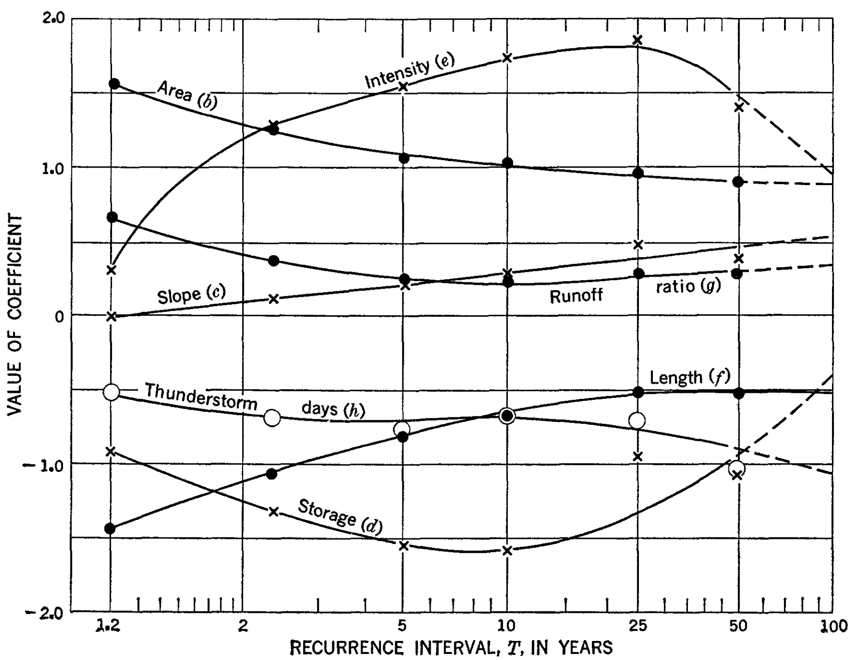

FIGURE 10.—Variation of regression coefficients with recurrence interval, rain-flood area.

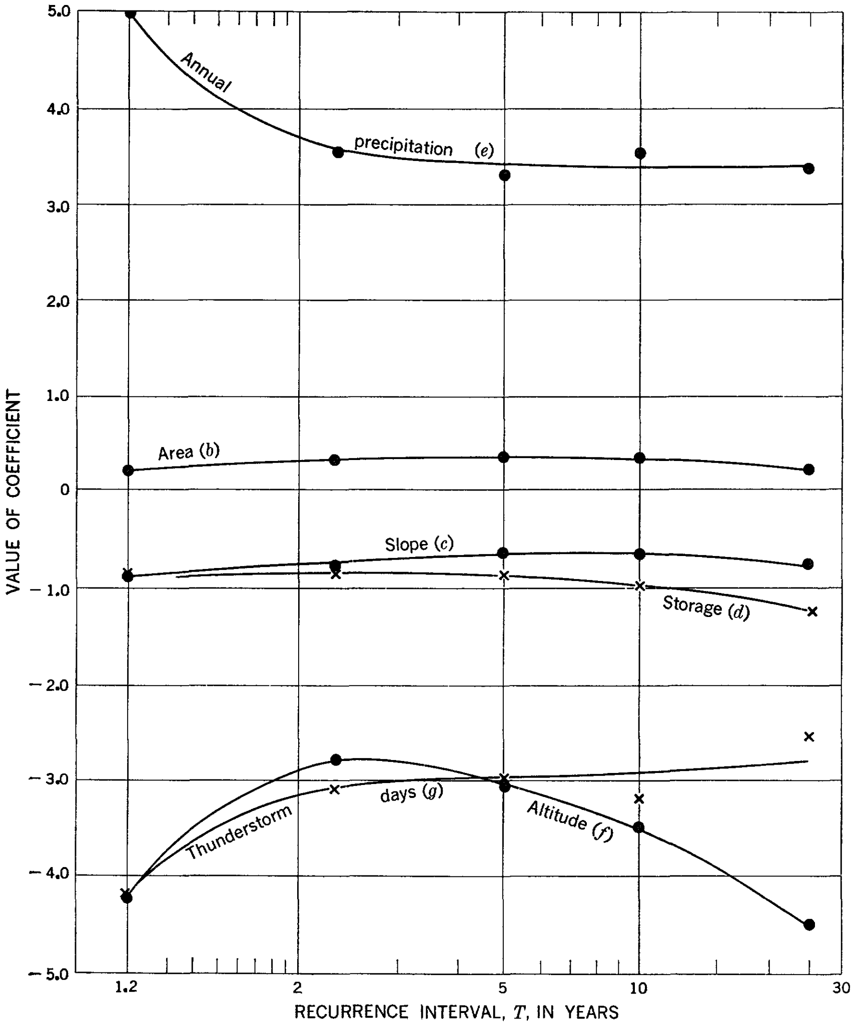

FIGURE 11.—Variation of regression coefficients with recurrence interval, snowmelt-flood area.

CONSISTENCY OF EQUATIONS

The uniformity of the variation of each of the regression coefficients gives reason for confidence in the relations found, at least through the 25-year peaks. However, the number of stations used in the analysis decreased progressively, of necessity, as the recurrence interval increased. This decrease may mean a different range of values of the independent variables as the recurrence interval increases. For example, the longer records are likely to be for the larger streams having larger drainage areas, and hence the stations at which 50-year peak discharges have been defined may not include the smaller drainage areas. In the mountain areas, stations having longer records are not likely to be at the higher altitudes. For these reasons the formulas may not be entirely consistent. It was considered that there was more to be gained by use of all possible data at each level than by a drastic decrease to attain an equal number of stations at all levels.

Peak discharges were computed, by means of the formulas, for all stations used in the report. These discharges are shown in table 1 as the lower line for each station. The computed flood magnitudes at any station, when plotted on a frequency graph, usually line up to define a smooth curve. Occasionally they plot somewhat erratically, particularly at the upper end. A smooth curve that averages all the points would be the best representation of the computed magnitude-frequency relation.

REGRESSION COEFFICIENTS, RAIN-FLOOD AREA

The regression coefficients for various combinations of variables are listed in table 7. The level of statistical significance is indicated there.

The coefficient, b, for drainage area, has a value of 0.59 at 2.33 years when only area, A, is considered in relation to Q_T. This value for the study area may be compared with the value for b of 0.85 found in New England by Benson (1962b), which is typical of values in humid areas. When other significant, and effective, variables are included in the relation with Q_T, the coefficient becomes closer to 1.0. As in the New England study, the coefficient of area, where all significant variables have been included, is above 1.0 at the lowest recurrence interval and decreases progressively to a value slightly below 1.0 as the recurrence interval decreases (disregarding the value at 100 years, for which all coefficients are erratic). The hydrologic significance of the decrease in the coefficient of A with recurrence interval is not known, but the tendency is consistent in studies made to date. The coefficient is positive throughout and shows the direct relation of discharge with drainage area.

Drainage area is significant at the 1-percent level throughout the range of recurrence interval. As has been shown previously, drainage area is by far the most important variable, in spite of uncertainties in the amount of noncontributing area to be deducted and despite the fact that most storms cover only part of the larger drainage basins. The larger basin does have the opportunity of experiencing more of the smaller storms than does a small basin, and, contrary to general belief, basinwide storms are fairly frequent. Data tabulated by Lowry (1934) indicates that once every 3 to 4 years, on the average, a storm occurs that covers at least half the State of Texas with at least 3 inches of rain. Such storms provide the highest peaks on most drainage basins.

The slope of the main channel is an important factor in New England (Benson, 1962b) and is also important in the Southwest. Except at the 1.2-year level, where it is not significant, the coefficient *c*, for slope, is positive throughout and shows the direct relation of peak discharge with slope. The coefficient is statistically significant above 2.33 years. The lack of significance at the lowest flood levels may be due to the fact that in this part of the United States the smaller floods do not in general extend entirely over a drainage basin, and hence the slope of the entire basin may not have meaning except for the higher floods.

The coefficient, *d*, for *St*, surface storage area of lakes and ponds, is negative throughout; the expected inverse relation between peak discharge and storage is thus borne out. The coefficient is significant between the 2.33- and 25-year flood levels, in spite of the small amount of such storage area in most streams in this region. This significance suggests that perhaps the variable may be representative of some other factors, such as channel storage, that are related to the area of lakes and ponds, that are not included directly, and that may be effective in reducing peak flows.

The coefficient, *e*, of *I*, rainfall intensity, is positive throughout and highly significant through most of the range of recurrence interval. The coefficient, *f*, of *L*, basin length, is negative, a relation to be expected in view of the flattening and diminution of the peak discharge attributable to increased channel storage and increased loss of water through the channel bed with increase of length. The coefficient is highly significant (that is, at the 1-percent level) throughout the range of recurrence interval.

The coefficient, *g*, of *R*, the runoff/rainfall ratio during the months of annual peak discharge, is positive throughout, according to expectation. The coefficient is significant for recurrence intervals of as much as 50 years. Its effect is much larger at the 1.2-year flood than anywhere else; this effect is consistent with the role of the runoff ratio as an index of the effect of soil abstractions on flood runoff, because soil abstractions are expected to have more effect on the smaller floods.

The coefficient, *h*, of *N*, the annual number of thunderstorm days, is highly significant between 2.33 and 50 years. The coefficient is negative throughout, and an inverse relation to peak discharge is indicated. This inverse relation was not expected in view of its originally intended role as a measure of rainfall intensity. The reason for the inverse relation is speculative. Peak discharge depends not only on the intensity of rainfall, but on its volume. Given the same potential precipitation in the atmosphere, a larger number of thunderstorms would mean a lesser volume in each storm. Conditions in which many small storms are generated rather than a few large ones may result in smaller peak discharges.

REGRESSION COEFFICIENTS, SNOWMELT-FLOOD AREA

The regression coefficients for flood-peak relations in the snowmelt-flood area are listed in table 9 for various combination of variables. The level of statistical significance is indicated there.

The coefficients *b*, for drainage area, and *e*, the mean annual precipitation, are positive; a direct relation to peak discharge is indicated, as expected. The coefficient, *d*, for storage in lakes and ponds, is negative, according to expectation.

The negative coefficients *c* and *f*, for slope and altitude, are believed attributable to the snowmelt characteristics of this region. The higher the mean altitude, the slower the rate of snowmelt will be because of the decrease in temperature with altitude, and therefore the smaller the peak discharge will be. The negative coefficient for slope is contrary to what has been found in New England (Benson, 1962b) and in the rain-flood area of this study. This difference in the effect of slope is attributed to the association of high slopes with large altitude differences within a basin and to the variation in snowmelt with altitude. According to Linsley, Kohler, and Paulhus (1949), "* * * in basins having a wide range of elevation, only a portion of the basin (the melting zone) contributes to snowmelt at any time." As a consequence of the differential melting of snow that starts at the lower altitude and progresses to the higher, a large basin rise means a protracted melting period and, hence, a decrease in the peak. This effect outweights the hydraulic effect of slope in increasing the peak, and the result is a negative coefficient for slope.

The coefficient, *g*, for the annual number of thunderstorm days, *N*, is negative, as in the rainflood area. The coefficient is significant at the 1-percent level through most of the range in recurrence interval. It is not readily apparent why the number of thunderstorm days should be a related variable where the peak discharges are the result of snowmelt rather than thunderstorm activity. When a relation with all the significant variables except thunderstorm days was computed and when the peak discharges and departures were computed for each station, the departures appeared to indicate a pattern related to the orographic pattern of this mountainous region, similar to what was found in the New England study (Benson 1962b), but not as sharply defined. The contours of annual thunderstorm days (U.S. Weather Bureau, 1952) followed this same pattern to a large degree.

It is therefore possible that the number of thunderstorm days is acting as an index of the orographic effect on snowmelt characteristics.

RESIDUAL ERRORS AT GAGING STATIONS

By use of the relations in tables 7 and 9 for seven and six variables in the rain-flood and snowmelt-flood areas, respectively, discharges and residual errors were computed for all flood levels at all stations. The residual errors were expressed as the ratio of actual to computed discharges, which, in log units, is the same as the departure. At each station, the median of these ratios was obtained, and the medians were plotted on a map (not presented). These residuals were almost randomly distributed, except for several local areas to be discussed.

Discharge for stations at the western end of the Balcones fault zone were computed using the standard rainflood-area multiple-regression formula; the residual errors were computed and are shown on figure 9. The 18 stations within the dashed line were not used to develop the standard formula. The residuals show the discharges north of the fault zone in this locality to be higher than computed and those below the line to be much lower than computed. At the western end of the Balcones fault there is a very steep and high escarpment at right angles to the general direction of storm winds. Dorroh (1946, p. 6) mentions the lift-convective type of storm that occurs in association with abrupt topographic barriers, and says, "It is in fact not unlikely that at or near sudden changes in topography the characteristic rainfall intensities will far exceed those normally experienced in the vicinity." Precipitation maps do not show this phenomenon here, but the experience of several people whom the author has spoken to confirms the occurrence of such storms.

The low flows may be attributable to heavy losses through the fault zone or may perhaps be caused by losses to flat and permeable pervious areas below the fault. The latter phenomenon is mentioned by Dorroh (1946, p. 23), who says, "The possibility of natural spreading within a given watershed should also be considered. Rough estimates * * * indicate that a relatively flat and reasonably pervious spreading area of one tenth the size of the more sloping and rough tributary watershed may absorb a major portion of the runoff from the tributary area, or at times all the runoff."

A group of 10 Louisiana stations, 100, 120, 130, 135, 145, 150, 155, 164, 166, and 275 (pl. 1), indicates residuals that are somewhat high (average, 1.50). The reason for these high residuals is not certain. Perhaps the widespread swamp areas and rice fields within this locality have the effect that little or no precipitation is lost by infiltration at the start of a storm, contrary to what occurs in the remainder of this study area.

The only two stations, 795 and 807, within the high plains area of Texas show low residuals (0.28 and 0.54, respectively). Whether these low residuals are a result of high soil absorption there or the very uncertain estimates of contributing area is not known.

Upper Pecos River stations 3795, 3830, and 3835 and western tributaries of the Pecos, stations 3945, 4055, and 4085, that are adjacent to one another show high residuals (average, 1.78). It is not known whether these high residuals are due to orographic causes or whether they represent simply the chance occurrence of several high floods within the two areas.

Several adjacent tributaries to the Rio Grande just south of the assigned boundary of the snowmelt-flood area, stations 2910, 2920, 2950, 3025, and 3160, have low residuals (average, 0.39). These low values may be due to the fact that these streams have some annual floods caused by snowmelt and hence their characteristics are somewhere between those of the rain-flood and the snowmelt areas, although they have been assigned to the rain-flood area.

UNIT FLOOD-PEAK DISCHARGES

The general level of peak flood discharges of all recurrence intervals in humid and semiarid areas may be compared by noting the flood-peak data (expressed as average discharge per square mile) of the New England study (Benson, 1962b) and of this study. Figure 12 is a graph of the average logarithm of unit peak discharge in both regions throughout the range of recurrence intervals defined for each

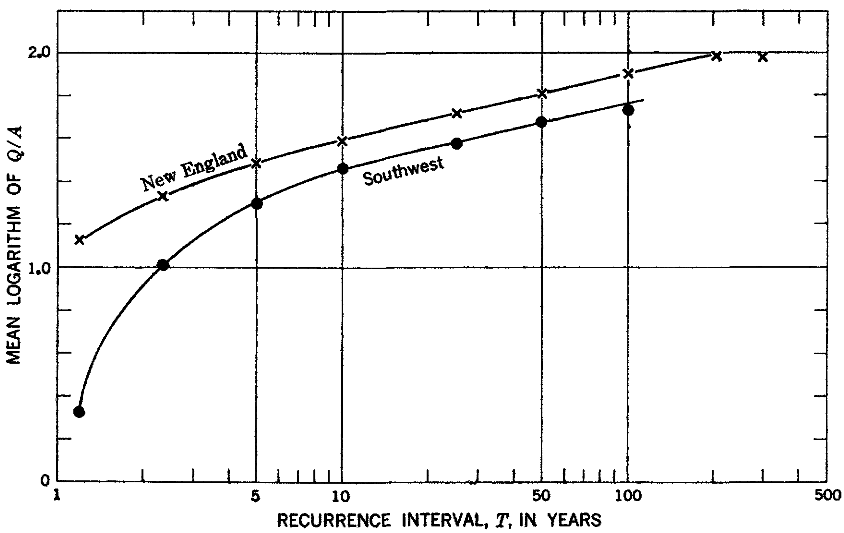

FIGURE 12.—Graph of logarithm of unit peak discharge versus recurrence interval in New England and in the Southwest.

region. It may be noted that the unit discharge is higher for New England throughout the range of recurrence interval, that above a recurrence interval of about 10 years a straight-line variation is defined for each region, and that the lines for the two regions are parallel.

In the rain-flood area the standard deviation of the flood peaks in percent, which is equivalent to the coefficient of variation, decreases as the recurrence interval increases (see table 7). The same tendency in apparent in New England data and means that, in general, there is less variation in 100-year floods than there is in 5-year floods. The basin characteristics (including drainage-area size) have an increasingly small effect at the higher recurrence intervals. It may be surmised that during extremely rare floods (1,000- or 10,000-year events) the magnitude of the peak discharge may have little relation to basin characteristics and may depend almost entirely on the volume and intensity of rainfall of comparable frequency that can occur during a single storm.

STANDARD ERROR OF RESULTS

In this study, the standard error of prediction is a measure of the aggregate departures of the actual flood peaks experienced from the flood peaks computed by the relation established. The standard error is, then, a means of judging the success of a study such as this. The standard error expresses the unexplained variation remaining after all the explainable variation has been taken into account.

In the snowmelt-flood area (see table 9), the standard error varies from 68 to 46 percent as the recurrence interval increases from 1.2 to 25 years. In the rain-flood area (see table 7), the standard error is 107 percent at 1.2 years and varies from 62 to 43 percent as the recurrence interval increases from 2.33 to 100 years.

The numerical value of the standard error signifies the percentage within which two-thirds of predictions made by using the established relations will lie. We would like to believe that we can predict floods of given recurrence intervals within closer limits than are represented by the standard errors that have resulted from this study. However, our present state of knowledge and conditions within this area now preclude any appreciable improvement of the results and may continue to preclude such improvement for a long time to come. The following discussion presents some reasons for this limitation:

1. Some factors known to be highly influential in affecting peak discharges are not adequately taken into account. The chief of these are probably the effects of geologic and soil characteristics. These two factors have so far not been evaluated precisely

enough for demonstration of their relation to peak discharges. The lack of factors to represent adequately the effects of geology and soils is probably one reason for the larger standard errors for the smaller floods, because the smaller floods are much more influenced by these characteristics. The complex effects of orography also are not included fully in the factors used. The anomalies of the Balcones fault area as discussed on page 63 probably illustrate both types of missing factors.

2. Conditions within a semiarid area are such that the highest peak flood discharges cannot now be measured either directly or indirectly with the precision possible for lower discharges. This difficulty is brought about by the characteristically rapid rises and the uncertainties in the indirect measurement of alluvial channels, such as are found in large number within this area. Any errors in the original data on flood discharges will increase the standard error of prediction based on use of these data.
3. Many of the basins within this study region contain large areas that do not contribute directly to surface runoff. The extent of noncontributing area in a drainage basin is known to vary with the size of flood, but the manner of this variation is not known precisely. Thus, uncertainties are introduced that increase the standard error of prediction. The errors from this source may also be expected to be largest for the smaller floods.
4. The erratic chance occurrence of storm within a semiarid region probably accounts for a large part of the unexplainable deviation still present after all known physical and climatic factors are taken into account. To the extent that this is true, the average flood experience within the region will be a better basis for the establishment of hydrologic relations than the local flood experience at any one point.

Figures 13 and 14 summarize the results of the entire study. Figure 13 is a graph showing the original, explained, and unexplained variations in flood-peak data in terms of percent standard error. The percent standard error (otherwise known as the coefficient of variation) is easily comprehended as the percentage deviation from the mean (for original data) or from the formula value (for computed data); however, the variations are not shown in proper proportions in this manner. Figure 14 shows the variations in their true proportions by expressing them in terms of the variance (square of the standard error) in log units. These graphs indicate the initial stage of ignorance, the contribution of this study, and the remaining area of presently unexplainable variation in flood peaks that affords a challenge for future research.

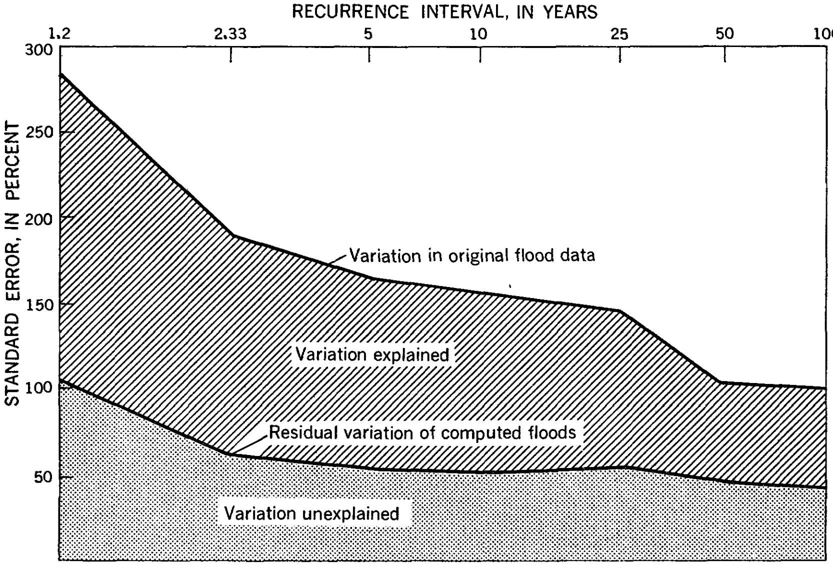

FIGURE 13.—Original and residual standard error in percent.

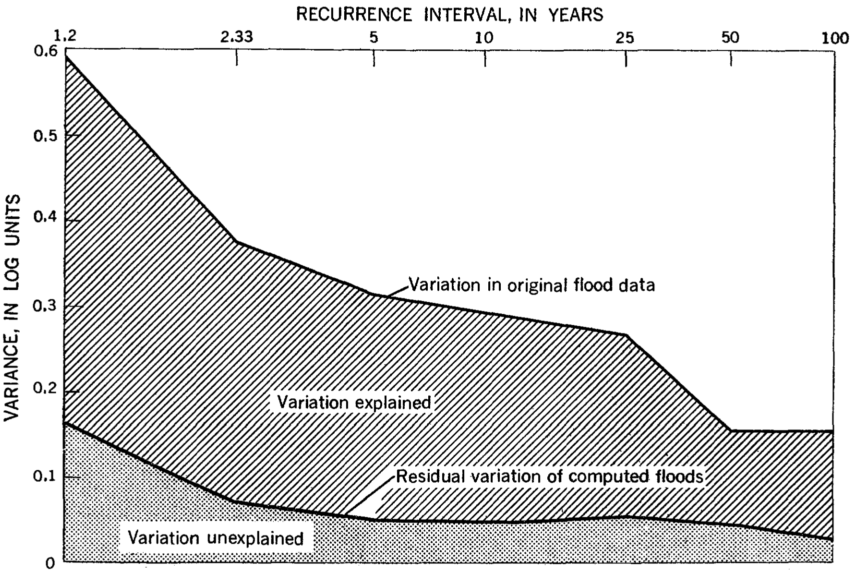

FIGURE 14.—Original and residual variance in log units.

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