Techniques for estimating flood peak discharges for unregulated streams and streams regulated by small floodwater retarding structures in Oklahoma

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Inch-pound units used in this report may be converted to International System of Units (SI) by the following conversion factors:

Multiply inch-pound units	By	To obtain SI units
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre-foot (acre-ft)	1,233	cubic meter
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer

TECHNIQUES FOR ESTIMATING FLOOD PEAK DISCHARGES FOR UNREGULATED STREAMS AND STREAMS REGULATED BY SMALL FLOODWATER RETARDING STRUCTURES IN OKLAHOMA

By Robert L. Tortorelli and DeRoy L. Bergman

ABSTRACT

Statewide regression relations for Oklahoma were determined for estimating peak discharge of floods for selected recurrence intervals from 2 to 500 years. The independent variables required for estimating flood discharge for rural streams are contributing drainage area and mean annual precipitation. Main-channel slope, a variable used in previous reports, was found to contribute very little to the accuracy of the relations and was not used. The regression equations are applicable for watersheds with drainage areas less than 2,500 square miles that are not significantly affected by regulation from manmade works. These relations are presented in graphical form for easy application.

Limitations on the use of the regression relations and the reliability of regression estimates for rural unregulated streams are discussed. Basin and climatic characteristics, log-Pearson Type III statistics and the flood-frequency relations for 226 gaging stations in Oklahoma and adjacent states are presented.

Regression relations are investigated for estimating flood magnitude and frequency for watersheds affected by regulation from small FRS (floodwater retarding structures) built by the U.S. Soil Conservation Service in their watershed protection and flood prevention program. Gaging-station data from nine FRS regulated sites in Oklahoma and one FRS regulated site in Kansas are used. For sites regulated by FRS, an adjustment of the statewide rural regression relations can be used to estimate flood magnitude and frequency. The statewide regression equations are used by substituting the drainage area below the FRS, or drainage area that represents the percent of the basin unregulated, in the contributing drainage area parameter to obtain flood-frequency estimates. Flood-frequency curves and flow-duration curves are presented for five gaged sites to illustrate the effects of FRS regulation on peak discharge.

INTRODUCTION

A knowledge of the magnitude and frequency of floods is required for the safe and economical design of highway bridges, culverts, dams, levees and other structures on and near streams. Flood plain management programs and flood-insurance rates also are based on flood magnitude and frequency information.

Flood peak reduction by U.S. Soil Conservation Service FRS (floodwater retarding structures) affects large areas of Oklahoma. About 2,000 FRS are present in more than 120 drainage basins in Oklahoma. About 2,500 FRS will regulate storm runoff from about 8,500 mi^2 (square miles), or 12-percent of the State, upon completion of the present (1984) SCS (U.S. Soil Conservation Service) watershed protection and flood prevention program. FRS are designed to decrease main-stem flood peaks and regulate the runoff recession of single storm events (Bergman and Huntzinger, 1981). Consideration of the flood peak modification capability of FRS can result in more hydraulically efficient, cost-effective culvert or bridge designs along downstream segments of FRS regulated streams.

The purpose of this report is to provide methods for estimating the peak discharge and frequency of floods for Oklahoma streams with a drainage area less than 2,500 mi^2 and procedures to adjust these estimates for a basin regulated by FRS. Flood-discharge records at 226 gaging stations throughout Oklahoma and bordering portions of Arkansas, Kansas, Missouri, New Mexico, and Texas were used to define the statewide flood-frequency relation. Estimates of selected frequency floods were related to basin and climatic characteristics using multiple-regression techniques. These analyses indicated that contributing drainage area and mean annual precipitation were the most significant variables for estimating flood discharges for rural Oklahoma streams. The regression equations derived in these analyses provide a simple and reliable method for estimating the flood frequency of rural streams. These equations are also presented in a graphical form for ease of use. A technique for adjusting the regression equations for regulation by FRS is presented.

The scope of the study is limited to peak flows and does not consider the shape or volume of the flood hydrograph. This report provides techniques for estimating flood discharges for streams with drainage areas smaller than 2,500 mi^2 and, therefore, Sauer's report (1974a) should be used for estimating flood frequency for streams with larger drainage areas. Procedures for adjusting flood discharges for the effect of urbanizaton were not considered. The procedures outlined by Sauer (1974b), also contained in Thomas and Corley (1977), should be utilized for basins affected by urbanization.

This report should be used in preference to an earlier report by Thomas and Corley (1977) for estimating flood discharges for rural Oklahoma streams with a drainage area less than 2,500 mi^2 because: (1) it is based on five years of additional annual peak data and many additional gaging-station records; (2) it is simpler to use since the regression equations contain one less variable; (3) it uses a skew map developed specifically for Oklahoma in the station flood-frequency analysis; and (4) it is based on annual peak data that were carefully edited to remove all data under the influence of regulation from FRS.

The report is the result of a cooperative agreement between the Oklahoma Department of Transportation and the U.S. Geological Survey. The opinions, findings, and conclusions presented in this report are those of the U.S. Geological Survey and do not necessarily reflect the official views or policies of the Oklahoma Department of Transportation.

Acknowledgments

Oklahoma FRS data were obtained from R. C. Riley, State Hydrologist, U.S. Soil Conservation Service, Stillwater, Oklahoma.

Kansas FRS data were obtained from J. A. Wentz, Assistant State Conservationalist, U.S. Soil Conservation Service, Salina, Kansas.

W. O. Thomas, Jr., of the U.S. Geological Survey provided technical advice and assistance in applying the log-Pearson Type III and regression analyses.

ESTIMATING PROCEDURES FOR FLOOD PEAK DISCHARGES

This section briefly outlines the techniques to use when estimating peak discharge and frequency of floods for an unregulated rural site with a drainage area of less than 2,500 mi^2 in Oklahoma. A technique is presented for adjusting the flood peak discharge for regulation by small floodwater retarding structures.

A detailed discussion of the analytical procedures utilized in this report is presented in subsequent sections for the reader interested in the development of the relations.

At the present time (1984), there are no gaged urban sites in Oklahoma with sufficient record to define a flood-frequency curve for either unregulated or regulated urban sites.

Gaged rural unregulated sites

When estimating flood magnitude and frequency for gaged rural unregulated sites, it is recommended that a weighted flood discharge estimate, $Q_{x(w)}$, for recurrence interval x, be used (Thomas and Corley, 1977; Thomas, W. O., Jr., U.S. Geological Survey, written commun., 1980).

Figure 1 shows the location of the gaging stations with unregulated periods of record used in the study. Use figure 1 to obtain the station number of the station of interest. Using this station number, determine the appropriate station flood discharge value, peak discharge or $Q_{x(s)}$, for recurrence interval x, from table 11 (in back of report). The stations which have unregulated periods of record, but are now regulated, are noted with a dagger in table 11. If the station of interest is still unregulated, then this flood discharge value is used with the regression estimate $Q_{x(r)}$ in a weighting procedure that is explained and illustrated later in the report in the section "Application of Techniques".

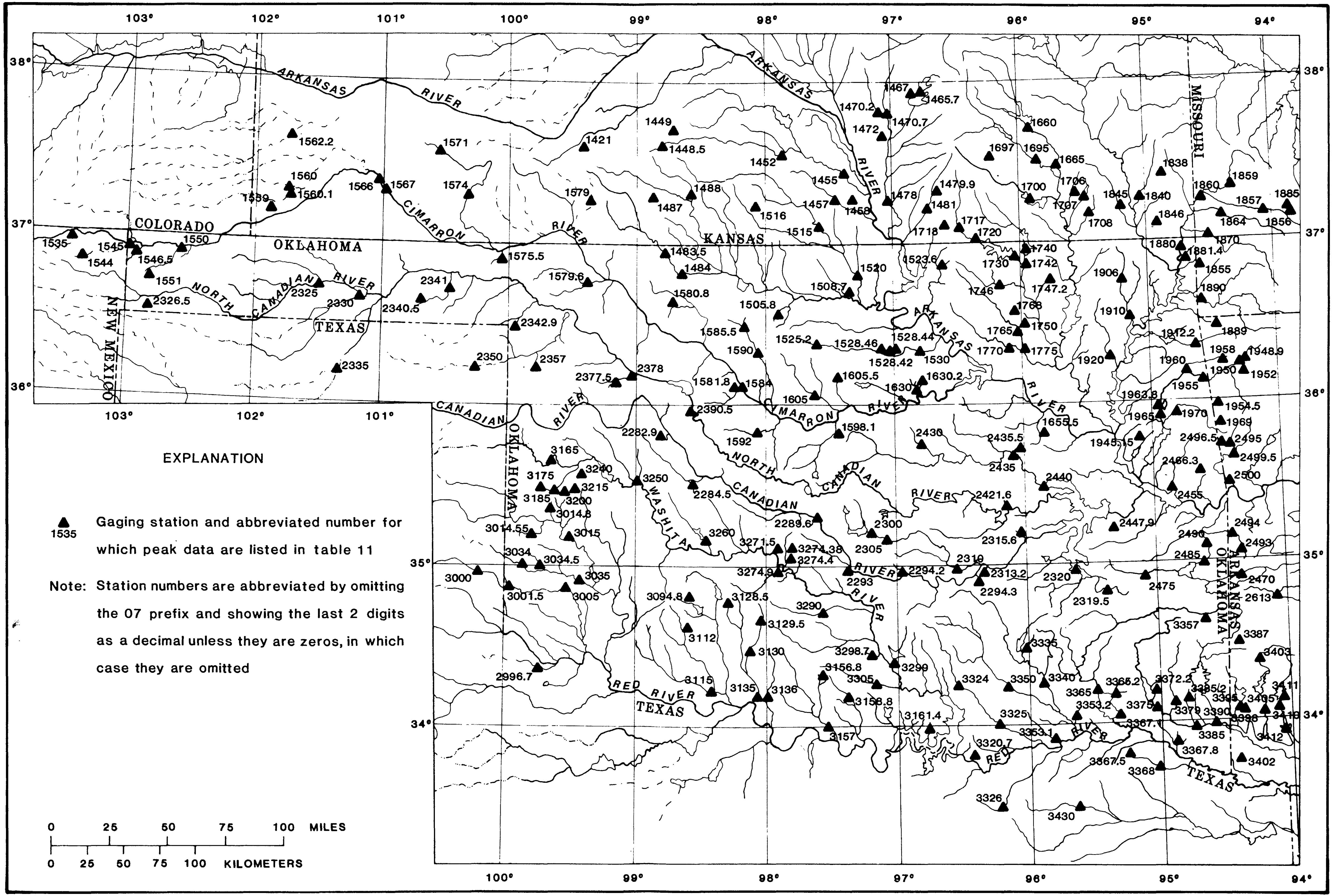


Figure 1.--Location of gaging stations with unregulated periods of record used in study.

Ungaged rural unregulated sites

Multiple regression techniques were used to relate estimates of the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year floods (table 11) to basin and climatic parameters. Of all the parameters investigated, drainage area and mean annual precipitation were the most significant for estimating flood peaks for ungaged rural unregulated sites.

The two parameters used in the regression equations are listed in table 11 for each station used in the analysis and are defined as follows:

1. Drainage area, (A) - the contributing drainage area of the basin, in square miles.
2. Mean annual precipitation, (P) - the mean annual precipitation for the basin, in inches, during the period 1931-60. See figure 2.

The model used in the regression analysis has the following form:

$$Q_{x(r)} = a\ A^{b}\ P^{c}$$

where $Q_{x(r)}$ = peak discharge, in cubic feet per second for recurrence interval x,

a = regression constant,

b, and c = regression coefficients, and

A, and P = basin and climatic parameters as defined above.

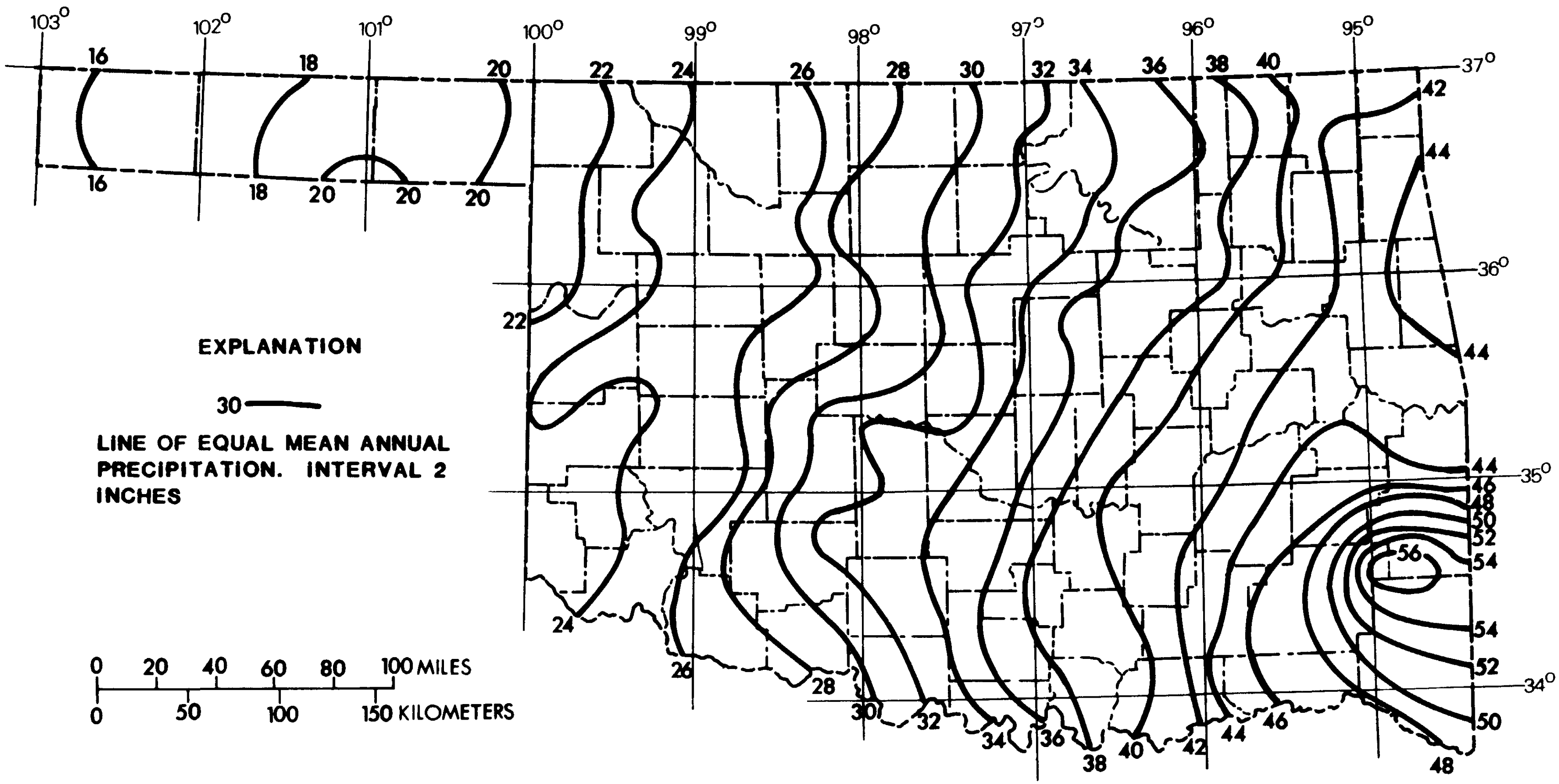


Figure 2.--Mean annual precipitation for the period 1931-60 (National Weather Service Office for State Climatology, 1971).

(no page 10)

The following equations were computed by regression analysis:

$$Q_{2(r)} = 0.368\ A^{0.59}\ P^{1.84} \qquad (2)$$

$$Q_{5(r)} = 4.00\ A^{0.58}\ P^{1.39} \qquad (3)$$

$$Q_{10(r)} = 13.2\ A^{0.57}\ P^{1.17} \qquad (4)$$

$$Q_{25(r)} = 45.3\ A^{0.56}\ P^{0.94} \qquad (5)$$

$$Q_{50(r)} = 98.7\ A^{0.56}\ P^{0.80} \qquad (6)$$

$$Q_{100(r)} = 196\ A^{0.56}\ P^{0.68} \qquad (7)$$

$$Q_{500(r)} = 751\ A^{0.55}\ P^{0.44} \qquad (8)$$

The above equations are based on inch-pound units of measurements. Substitution of metric values for A and P will not provide correct answers. To convert the final answers of discharge from cubic feet per second to the metric equivalent of cubic meters per second, multiply by the factor, 0.02832. Equations 2 through 8 are shown graphically in figures 3 through 9 respectively.

To estimate flood magnitude and frequency for ungaged unregulated rural sites, first determine the drainage area from the best available map or field survey. The mean annual precipitation can be determined from figure 2. Next, enter figures 3-9 with drainage area along the vertical scale, then move horizonally across to the appropriate mean annual precipitation curve and downward vertically to the discharge scale to obtain $Q_{x(r)}$, the regression estimate. Use of figures 3-9 is illustrated in the section on "Application of Techniques".

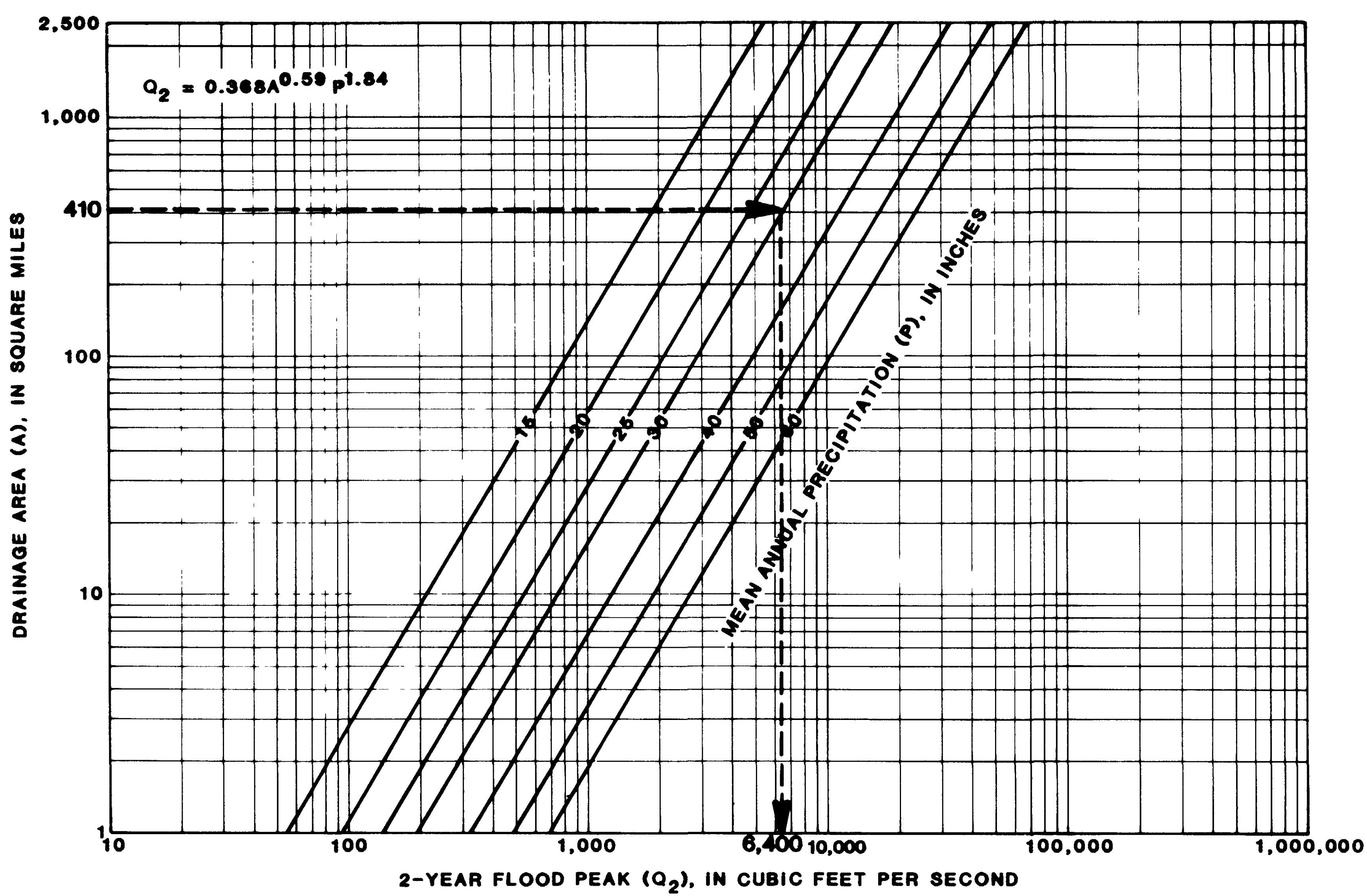


Figure 3.--Relation of 2-year flood peak to drainage area and mean annual precipitation.

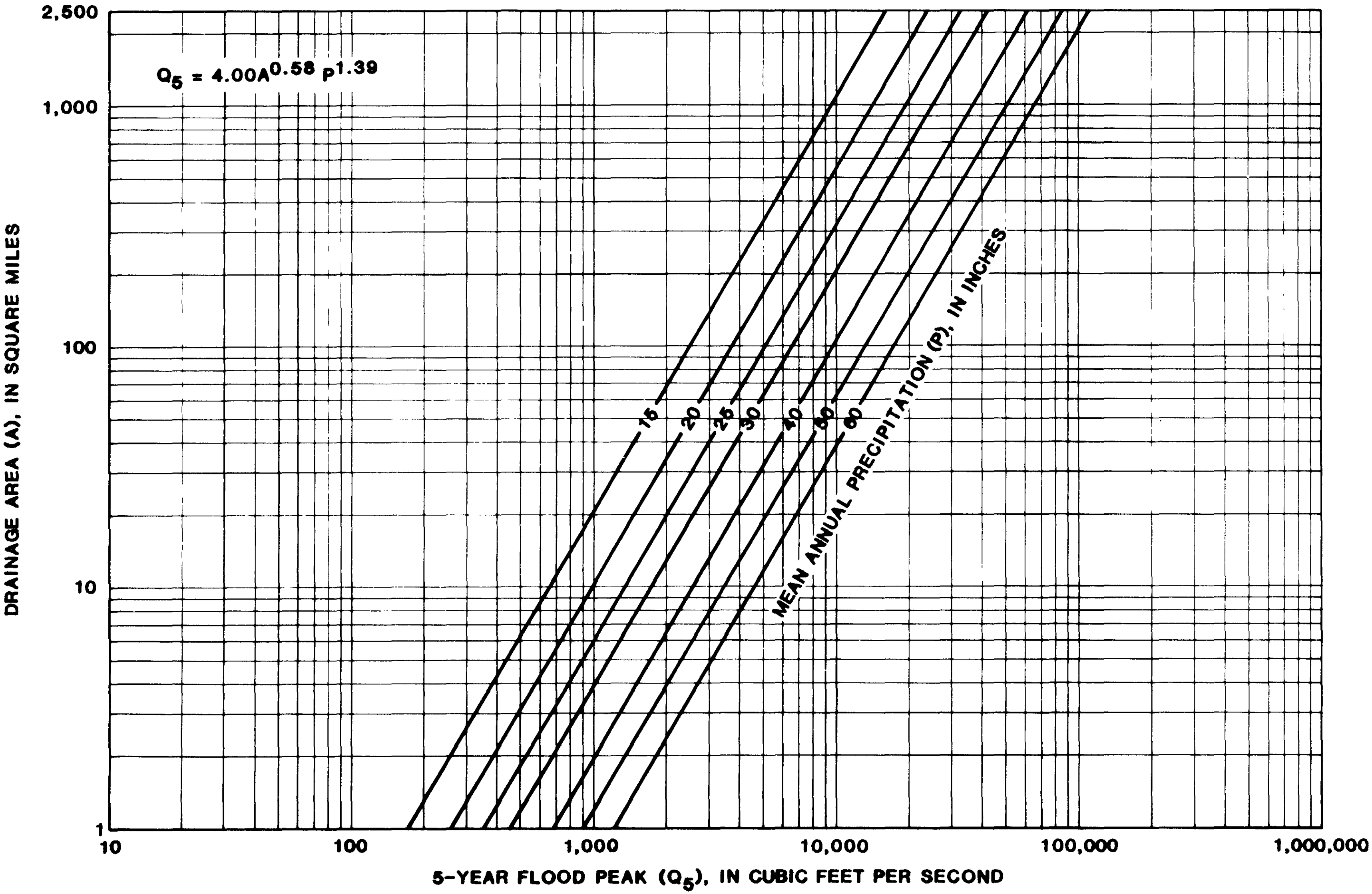


Figure 4.--Relation of 5-year flood peak to drainage area and mean annual precipitation.

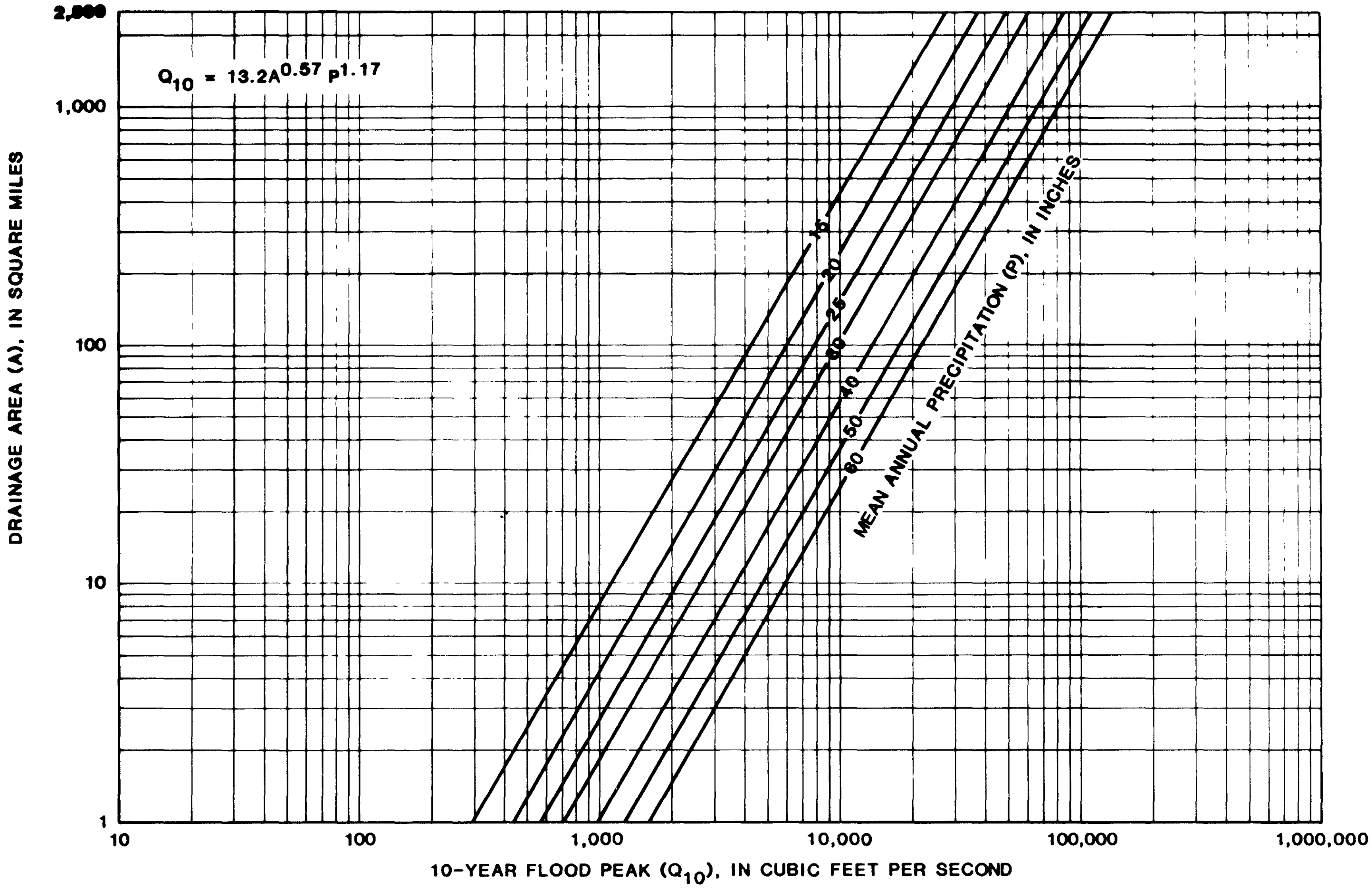


Figure 5.--Relation of 10-year flood peak to drainage area and mean annual precipitation.

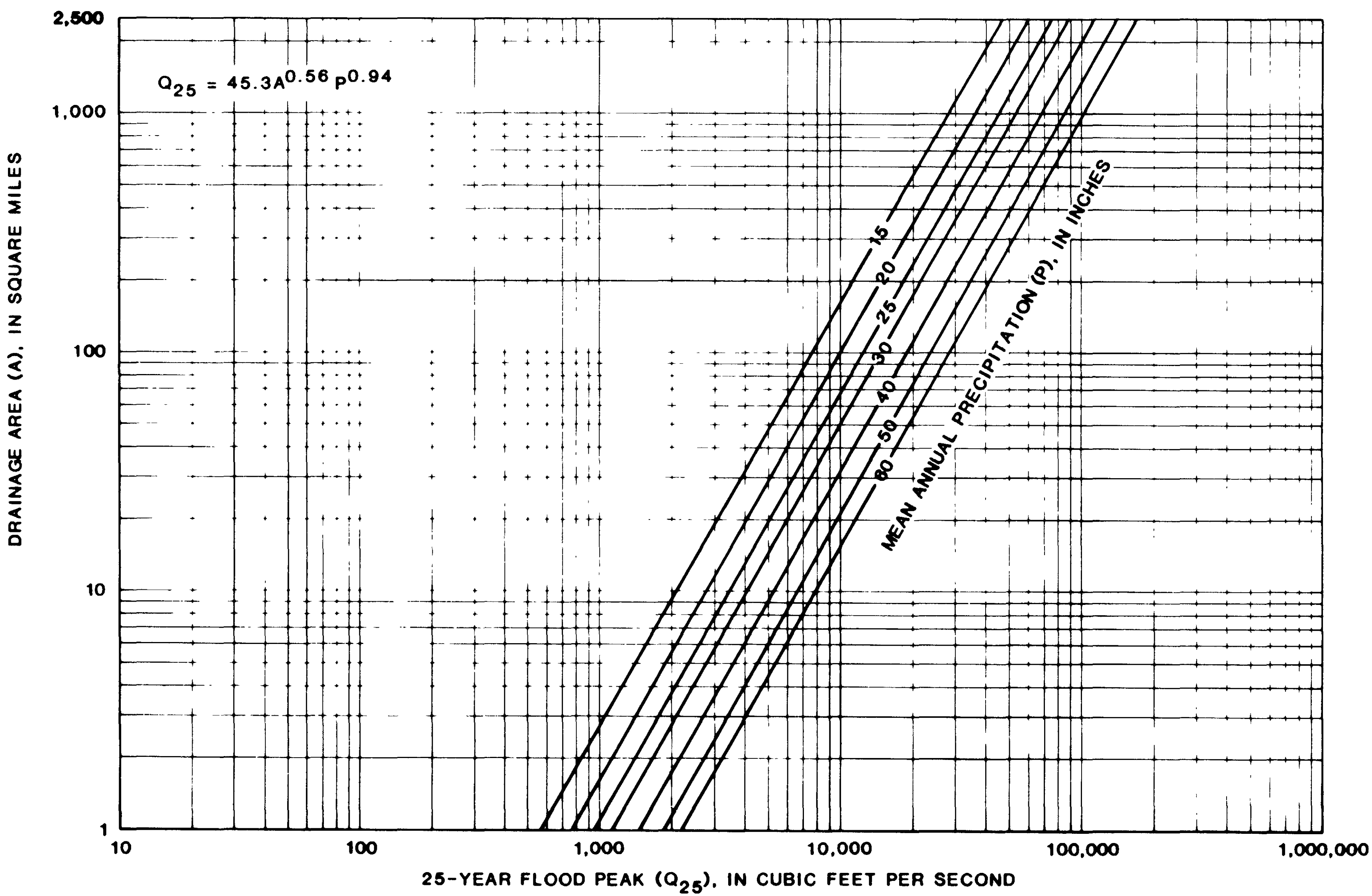


Figure 6.--Relation of 25-year flood peak to drainage area and mean annual precipitation.

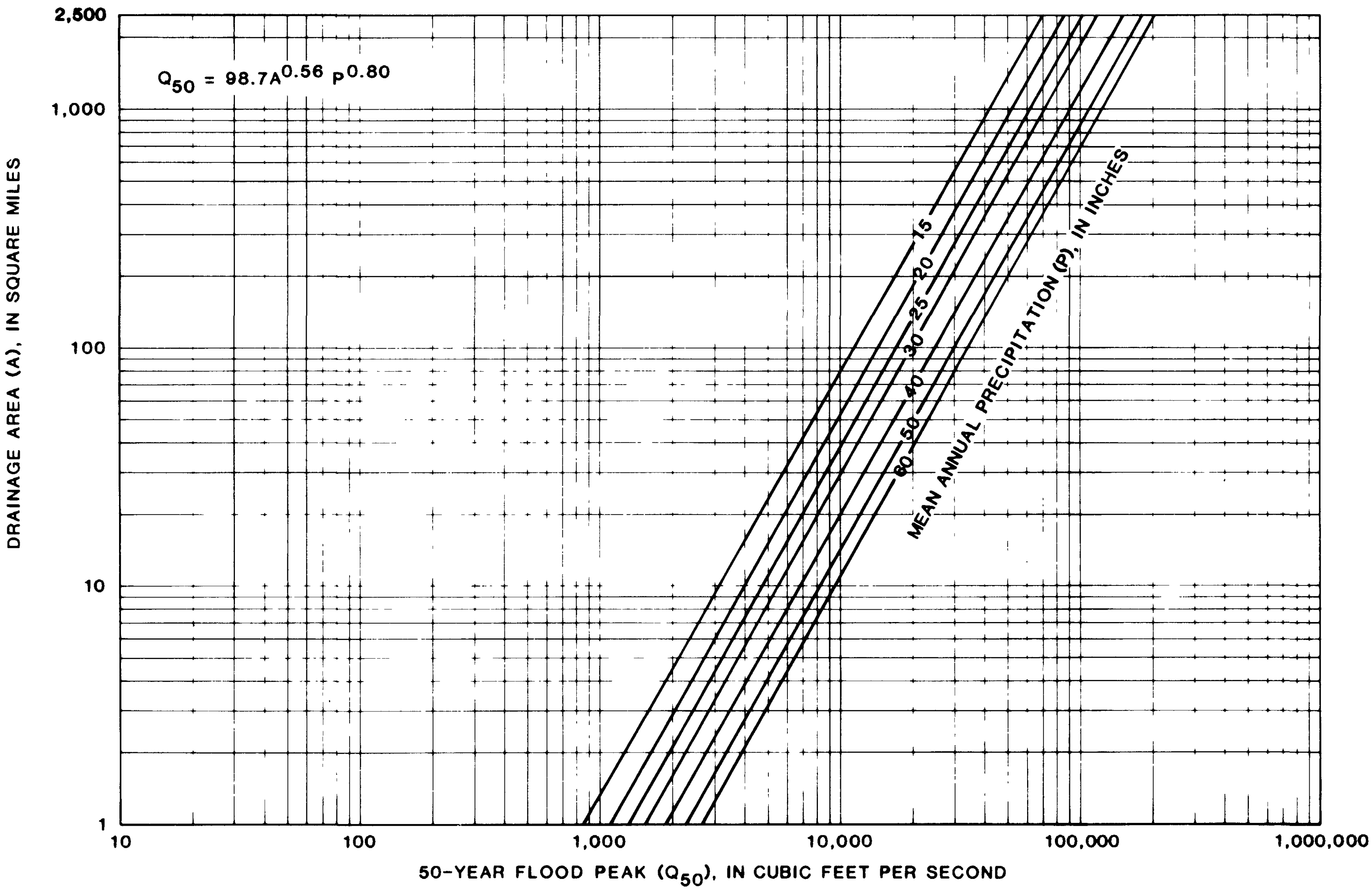


Figure 7.--Relation of 50-year flood peak to drainage area and mean annual precipitation.

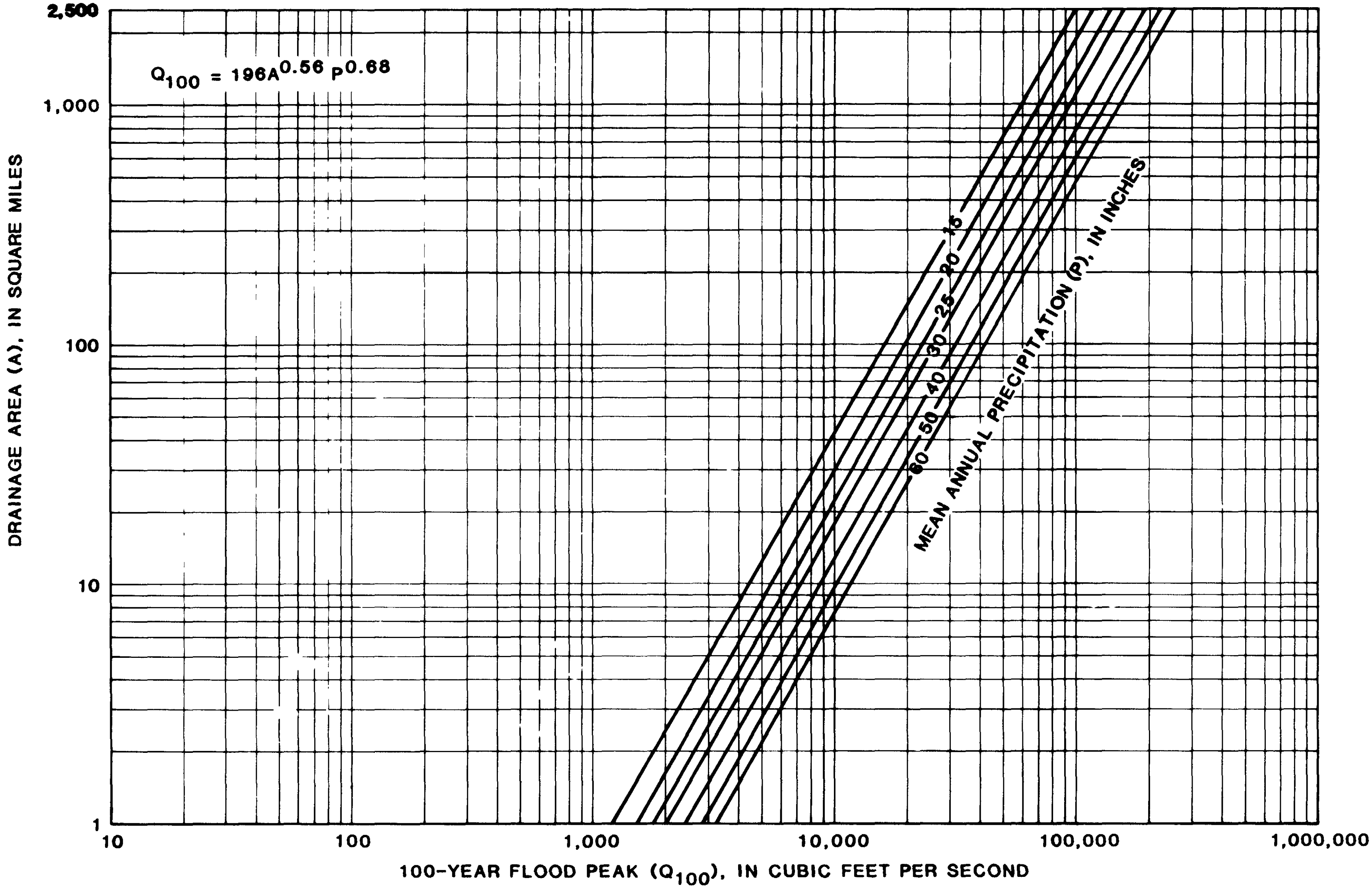


Figure 8.--Relation of 100-year flood peak to drainage area and mean annual precipitation.

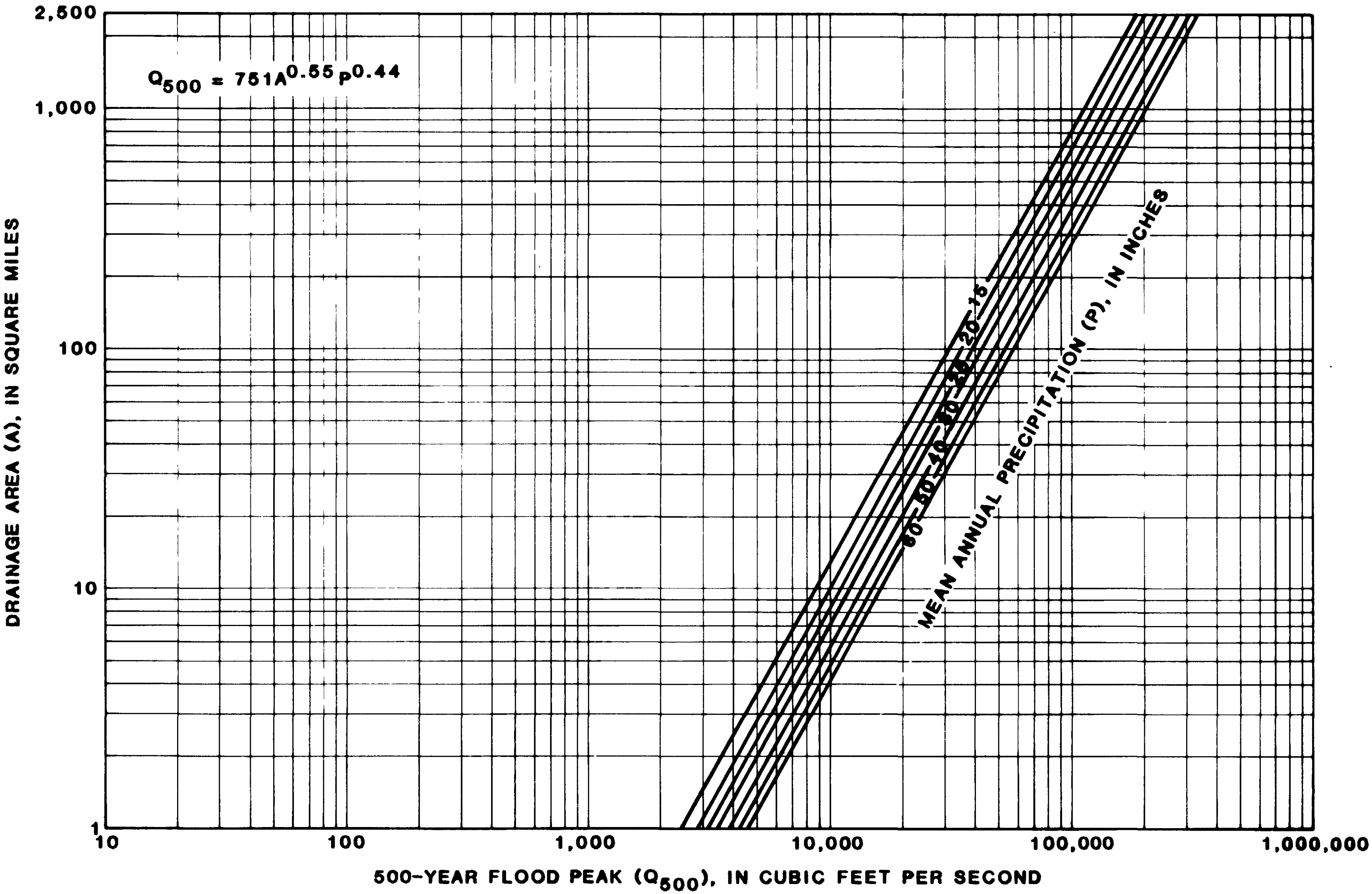


Figure 9.--Relation of 500-year flood peak to drainage area and mean annual precipitation.

Adjustment for regulation from floodwater retarding structures

When estimating flood magnitude and frequency in basins regulated by FRS, an adjustment must be made. The regulated station peak discharges, or $R_{x(s)}$, for recurrence interval x, (table 1) were compared to the discharges obtained from equations 2-8: (1) using for A the unregulated portion of the drainage area or drainage area below the FRS, A_u; and (2) using for A the total drainage area and multiplying the result by the percent of the basin drainage area which is unregulated by FRS, expressed as a decimal. The best fit was obtained using for A the drainage area unregulated by FRS.

The following model will compute the adjusted regression discharge estimate using equations 2-8:

$$R_{x(r)} = a\ A_u^{\ b}\ P^c \qquad (9)$$

where $R_{x(r)}$ = the regression peak discharge estimate adjusted for FRS, cubic feet per second, for recurrence interval x,

a = regression constant,

b, and c = regression coefficients,

A_u, and P = basin and climatic characteristics defined above.

The basin and climatic characteristics for selected regulated basins are shown in table 2.

TABLE 1.--LOG-PEARSON TYPE III STATISTICS AND STATION FLOOD-FREQUENCY RELATIONS FOR SELECTED GAGED STREAMS REGULATED BY U.S. SOIL CONSERVATION SERVICE FLOODWATER RETARDING STRUCTURES

[STD DEV, STANDARD DEVIATION; SKEW, WEIGHTED SKEW COEFFICIENT]

STATION NUMBER	PERIOD OF RECORD, IN WATER YEARS			LOG-PEARSON TYPE III STATISTICS, IN LOGARITHMIC UNITS			PEAK DISCHARGES IN CUBIC FEET PER SECOND FOR INDICATED RECURRENCE INTERVAL IN YEARS						
	TOTAL	UNREGULATED	REGULATED	MEAN	STD DEV	SKEW	2	5	10	25	50	100	500
07172000	1939-81	1939-64		4.0938	0.4192	-0.79	14100	28400	38300	50400	58800	66500	82200
			1967-81	4.0925	0.3085	-0.79	13600	22700	28400	34800	39000	42700	49900
07245500	1943-76	1943-63		4.1105	0.4118	0.11	12700	28500	43900	70200	95400	126000	223000
			1966-76	3.7857	0.1591	-0.12	6150	8330	9720	11400	12700	13900	16600
07247500	1939-80	1939-63		3.8232	0.3889	0.09	6560	14100	21200	32900	43800	56900	97100
			1966-80	3.6305	0.2831	0.15	4200	7350	9950	13800	17200	20900	31500
07316500	1938-81	1938-60		3.7444	0.5304	0.15	5390	15400	27000	50100	75100	109000	233000
			1961-81	3.0726	0.4882	-0.08	1200	3060	4940	8170	11300	15000	26700
07329500	1954-80	1954-64		3.9875	0.3178	0.31	9360	17800	25300	37700	49100	62800	105000
			1967-80	3.7097	0.3593	0.09	5060	10200	14900	22400	29200	37100	60700
07174200	1959-80	1959-64											
			1969-80	3.8615	0.2974	-0.07	7330	13000	17400	23700	28900	34500	49200
07319500	1953-72	NONE											
			1953-72	2.8467	0.4132	0.25	675	1540	2430	4020	5620	7640	14500
07323000	1951-74	NONE											
			1951-74	3.0782	0.3700	-0.05	1210	2460	3550	5230	6720	8400	13100
07324400	1962-80	NONE											
			1962-80	2.9557	0.2459	0.14	891	1450	1880	2500	3020	3580	5080
07328070	1965-80	1965-66											
			1967-80	3.2214	0.3398	0.28	1600	3170	4630	7050	9320	12100	20700

TABLE 2.--BASIN CHARACTERISTICS FOR SELECTED GAGED STREAMS REGULATED BY U.S. SOIL CONSERVATION SERVICE FLOODWATER RETARDING STRUCTURES

[SQ MI, SQUARE MILES; PRECIP, PRECIPITATION; IN, INCHES; I24,2, 24-HOUR RAINFALL, 2-YEAR RECURRENCE INTERVAL; AC-FT/SQ MI, ACRE-FEET PER SQUARE MILE OF TOTAL DRAINAGE AREA]

STATION NUMBER	STATION NAME	DRAINAGE AREA			MEAN ANNUAL PRECIP (IN)	RAINFALL INTENSITY I24,2 (IN)	DETENTION STORAGE (AC-FT/SQ MI)	MEAN ANNUAL RUNOFF (IN)
		TOTAL (SQ MI)	REGULATED (SQ MI)	UNREGULATED (PERCENT)				
07172000	CANEY RIVER NEAR ELGIN, KANS.	445.0	178.0	60	38.0	3.80	161	6.5
07245500	SALLISAW CREEK NEAR SALLISAW, OKLA.	182.0	126.0	31	43.5	4.20	253	13.2
07247500	FOURCHE MALINE NEAR RED OAK, OKLA.	122.0	78.1	36	45.5	4.10	250	14.5
07316500	WASHITA RIVER NEAR CHEYENNE, OKLA.	794.0	508.0	36	22.8	3.10	100	1.3
07329500	RUSH CREEK NEAR MAYSVILLE, OKLA.	206.0	109.0	47	34.5	3.75	155	4.3
07174200	LITTLE CANEY RIVER BELOW COTTON CREEK NEAR COPAN, OKLA.	502.0	223.0	56	37.0	3.80	182	7.1
07319500	SANDSTONE CREEK NEAR BERLIN, OKLA.	44.9	38.7	14	24.0	3.10	285	1.6
07323000	SANDSTONE CREEK NEAR CHEYENNE, OKLA.	87.1	65.8	25	24.0	3.10	242	1.6
07324400	SOLDIER CREEK NEAR FOSS, OKLA. (WASHITA RIVER NEAR FOSS, OKLA.)	51.3	35.6	31	24.5	3.15	163	1.6
07328070	WINTER CREEK NEAR ALEX, OKLA.	33.0	18.5	44	33.0	3.60	183	4.1

Accuracy and limitations

One indication of the accuracy of a flood peak discharge estimate is the standard error of the estimate of the regression equation. The standard errors of the estimate of the regression equations 2-8 can be expressed in two ways, percent or equivalent years of record.

The accuracy in percent is the standard error of the estimate converted to a percent and is the accuracy to be expected, on the average, two-thirds of the time (Hardison, 1971; Tasker, G. D., U.S. Geological Survey, written commun., 1978). That is, the difference between the estimated and actual peak discharge for two-thirds of the estimates will be within plus or minus one standard error of the estimate.

Hardison (1969) and Thomas (U.S. Geological Survey, written commun., 1980) related the standard error of the estimate and streamflow variability to equivalent years of record. When converted to equivalent years of record, the standard error of estimate is expressed as the number of actual years of streamflow records that would be needed at an ungaged site to provide an estimate equal in accuracy to the standard error of estimate. The accuracy of the unregulated regression equations 2-8 is summarized in table 3. The accuracy of the regression equations 2-8 when adjusted for FRS regulation is summarized in table 4.

Table 3.--Accuracy of regression equations for unregulated streams.

Recurrence interval in years	Standard error of estimate, in percent	Equivalent years of record
2	60	3
5	48	6
10	46	8
25	47	11
50	50	12
100	54	12
500	66	12

Table 4.--Accuracy of regression equations adjusted for regulation from floodwater retarding structures.

Recurrence interval in years	Standard error of estimate, in percent	Equivalent years of record
2	63	2
5	50	4
10	50	5
25	52	6
50	58	6
100	66	6
500	80	6

A large part of standard error of estimate is the result of time sampling errors in the actual streamflow record. The increase in the standard error of estimate as the recurrence interval increases indicates that the time-sampling error is larger for the higher recurrence interval floods. Therefore, it is less reliable to estimate the larger floods than the smaller floods with a given number of years of actual streamflow record. The 12 years of equivalent record for $Q_{50(r)}$ (table 3) suggest that the regression estimate is as accurate as a $Q_{50(s)}$ estimate based on 12 years of actual streamflow record. The six years of equivalent record for $R_{50(r)}$ (table 4) suggest that the regression estimate is as accurate as an $R_{50(s)}$ estimate based on six years of actual streamflow record.

The regression equations should not be used to predict flood discharges on drainage basins larger than 2,500 mi^2 or those basins having values of P outside of the range of values used to define the equations, 14.0 - 59.0 in. (inches). Caution should be used when estimating peak flows from drainage areas less than one mi^2. Comparison of observed and predicted peak discharges from those stations less than one mi^2 shows that the equations may over-predict by an average of 50 percent. Equations 2-8 should not be used for those basins significantly affected by urbanization or regulation from large dams with controlled-outlet works.

Estimates from equations 2-8 can be adjusted to account for the effect of regulation from small floodwater retarding structures. The adjusted equations should not be used to predict discharges on drainage basins with a total drainage area greater than 2,500 mi^2 and caution should be used when the unregulated drainage area is less than one mi^2. The adjusted equations can be used when the percent of regulated drainage area is not greater than 86 percent of the basin, which is the upper limit of the range of regulated data used to check the validity of the adjustment. The adjusted equations should only be used on those portions of a watershed regulated by SCS-built floodwater retarding structures and are not applicable to any other type of FRS. The adjusted equations are not meant to replace site-specific information when only one pond is present on the watershed immediately upstream of the point of interest. The technique should be used on watersheds when a system of two or more FRS is present.

Application of techniques

Estimates of flood magnitude and frequency for gaged rural unregulated sites should be combinations of station data and regression estimates. The estimates weighted by years of record are considered more reliable than either the regression or station data when making estimates of flood-frequency relations at gaged sites (Sauer, 1974a; Thomas and Corley, 1977). The equivalent years of record concept is used to combine station estimates with regression estimates of peak flow to obtain weighted estimates at a gaged site. This method was described by Sauer (1974a) and Thomas and Corley (1977) and is expressed in the following equation:

$$Q_{x(w)} = \frac{Q_{x(s)}\,(N) + Q_{x(r)}\,(E)}{N + E} \qquad (10)$$

where $Q_{x(w)}$ = the weighted estimate of peak flow, in cubic feet per second, for recurrence interval x,

$Q_{x(s)}$ = the station estimate of peak flow, in cubic feet per second, for recurrence interval x (table 11),

$Q_{x(r)}$ = the regression estimate of peak flow, in cubic feet per second, for recurrence interval x (equations 2-8, or figures 3-9),

N = number of actual years record at the gaged site (table 11),

E = equivalent years of record for recurrence interval x (table 3).

The following example illustrates how a weighted estimate is calculated for a gaged rural unregulated site and how to apply figures 3-9. The example computation is for Skeleton Creek near Lovell, Okla. (07160500) and the results are presented in table 5.

The columns $Q_{x(s)}$ and N indicate the computed flood-frequency relations derived from the 33 years of record at station 07160500 (table 11). The values in the column labeled $Q_{x(r)}$ were estimated using figures 3-9 and the following basin and climatic characteristics:

$$A = 410 \text{ mi}^2$$

$$P = 29.3 \text{ in.}$$

To use figures 3-9, first enter the contributing drainage area (410 mi^2) along the vertical scale of each figure. Then move horizonally to the mean annual precipitation curves to 29.3 in. Move downward to the discharge scale to obtain the $Q_{x(r)}$ values which are presented in table 5. Dotted lines are plotted on figure 3 as an example. The weighted estimates, $Q_{x(w)}$, were computed from equation 10 using the appropriate values of E from table 3.

The second example illustrates how a weighted estimate is calculated for a gaged rural basin regulated by FRS. The example computation is for Rush Creek near Maysville, Okla., station number 07329500, and the results are presented in table 6.

Table 5.--Computation of a weighted unregulated flood-frequency curve for Skeleton Creek near Lovell, Okla.

[ft³/s, cubic feet per second]

Recurrence interval, x (years)	$Q_{x(s)}$[1] (ft³/s)	N[2] years	$Q_{x(r)}$[3] (ft³/s)	E[4] years	$Q_{x(w)}$[5] (ft³/s)
2	4610	33	6400	3	4760
5	11500	33	14300	6	11900
10	18800	33	21200	8	19300
25	32300	33	31500	11	32100
50	46100	33	42800	12	45200
100	63800	33	56600	12	61900
500	125000	33	90800	12	116000

[1] Station estimate of peak flow, unregulated basin, for recurrence interval x.

[2] Number of actual years of streamflow record at gaged site.

[3] Regression estimate of peak flow, unregulated basin, for recurrence interval x.

[4] Equivalent years of unregulated streamflow record for recurrence interval x.

[5] Weighted estimate of peak flow, unregulated basin, for recurrence interval x

Table 6.--Computation of a weighted regulated flood-frequency curve for Rush Creek near Maysville, Okla.

[ft^3/s, cubic feet per second]

Recurrence interval, x (years)	$R_{x(s)}$ [1] (ft^3/s)	N[2] years	$R_{x(r)}$ [3] (ft^3/s)	E_r[4] years	$R_{x(w)}$ [5] (ft^3/s)
2	5060	14	3700	2	4890
5	10200	14	7800	4	9670
10	14900	14	11300	5	14000
25	22400	14	16400	6	20600
50	29200	14	21700	6	27000
100	37100	14	28200	6	34400
500	60700	14	44200	6	55800

[1] Station estimate of peak flow, regulated basin, for recurrence interval x.

[2] Number of actual years of streamflow record at a gaged site.

[3] Regression estimate of peak flow, regulated basin, for recurrence interval x.

[4] Equivalent years of regulated streamflow record for recurrence interval x.

[5] Weighted estimate of peak flow, regulated basin, for recurrence interval x.

The columns $R_{x(s)}$ and N indicate the computed regulated flood-frequency relations derived from the 14 years of regulated record at station 07329500 (table 1). The column labelled $R_{x(r)}$ was estimated using figures 3-9 and the following basin and climatic characteristics:

$$A = 206 \text{ mi}^2$$

$$A_u = 97.0 \text{ mi}^2$$

$$P = 34.5 \text{ in.}$$

To obtain the regulated regression flood-frequency relations, $R_{x(r)}$, the application of figures 3-9 is modified by using for A the area of the drainage basin unregulated by FRS, A_u. The weighted regulated estimates, $R_{x(w)}$, were then computed from equation 10 using $R_{x(s)}$ instead of $Q_{x(s)}$ and $R_{x(r)}$ instead of $Q_{x(r)}$, and E_r instead of E.

For the third example, assume an estimate of the Q_{100} is needed for an ungaged FRS regulated site on Uncle John Creek in Kingfisher County. The following data are available:

$$A = 155 \text{ mi}^2$$

$$A_u = 65.1 \text{ mi}^2$$

$$P = 28.5 \text{ in.}$$

The following step is required to obtain the needed peak discharge estimate:

$$R_{100(r)} = 19{,}800 \text{ ft}^3/\text{s from figure 8 or equation 7}$$

Therefore, the estimate of the 100-year flood with 58 percent of the basin regulated by FRS is 19,800 ft^3/s.

ANALYTICAL PROCEDURES

This section of the report describes the data utilized and the procedures applied in analyzing these data. The technical details of the analysis are described including the computation of station flood-frequency relations at gaged rural unregulated sites, the regression analysis of these relations, and the testing of assumptions and applicability of the regression analysis. Included is a discussion of the adjustment analysis for regulation by FRS, the computation of station flood-frequency relations at gaged rural regulated sites, regression analysis of these relations and the effects of FRS on peak discharge at regulated sites.

Annual Peak Data

The first step in flood-frequency analysis is to collate and review all pertinent annual peak discharge data. In addition to the Oklahoma stations, the stations in the bordering states of Arkansas, Kansas, Missouri, New Mexico, and Texas in the Arkansas-Red River basin were reviewed.

The flood-frequency analysis for rural unregulated streams of less than 2,500 mi^2 drainage area presented in this report is based on annual peak flow data collected at 226 gaging stations. The data were collected through September 30, 1980, for Missouri, New Mexico, and Oklahoma and through September 30, 1981, for Arkansas, Kansas, and Texas. The location of these gaging stations is shown in figure 1. In this analysis, only those stations with at least 10 years of flood peak data were used in the analysis (U.S. Water Resources Council, 1981). These stations are also free of significant effects from regulation by major dams or FRS and other manmade modification of streamflow. A summary of the distribution of drainage areas, and average observed length of record per station for those stations used in the regression analysis is given in table 7.

The flood-frequency analysis for rural regulated streams presented in this report is based on 10 selected gaging stations with regulated periods of record over 10 years. The location of these gaging stations is shown in figure 10. Five of these stations also have unregulated periods of record over ten years (table 1).

Table 7.--Summary of drainage area distribution and average observed length of record.

Drainage area (square miles)	Number of Stations							Average observed length of record (years)
	Okla.	Border States					Total	
		Ark.	Kans.	Mo.	N. Mex.	Tex.		
Less than 1	12	3	4	1			20	19
1 to 5	19	1	7	1			28	17
5 to 10	17	3	3	1			24	17
10 to 50	24	8	12	1			45	19
50 to 100	2	1	1			3	7	17
100 to 500	32	8	7	3	1	4	55	24
500 to 1000	19		6	1	1		27	25
1000 to 2500	15		3	1		1	20	31
	140	24	43	9	2	8	226	21

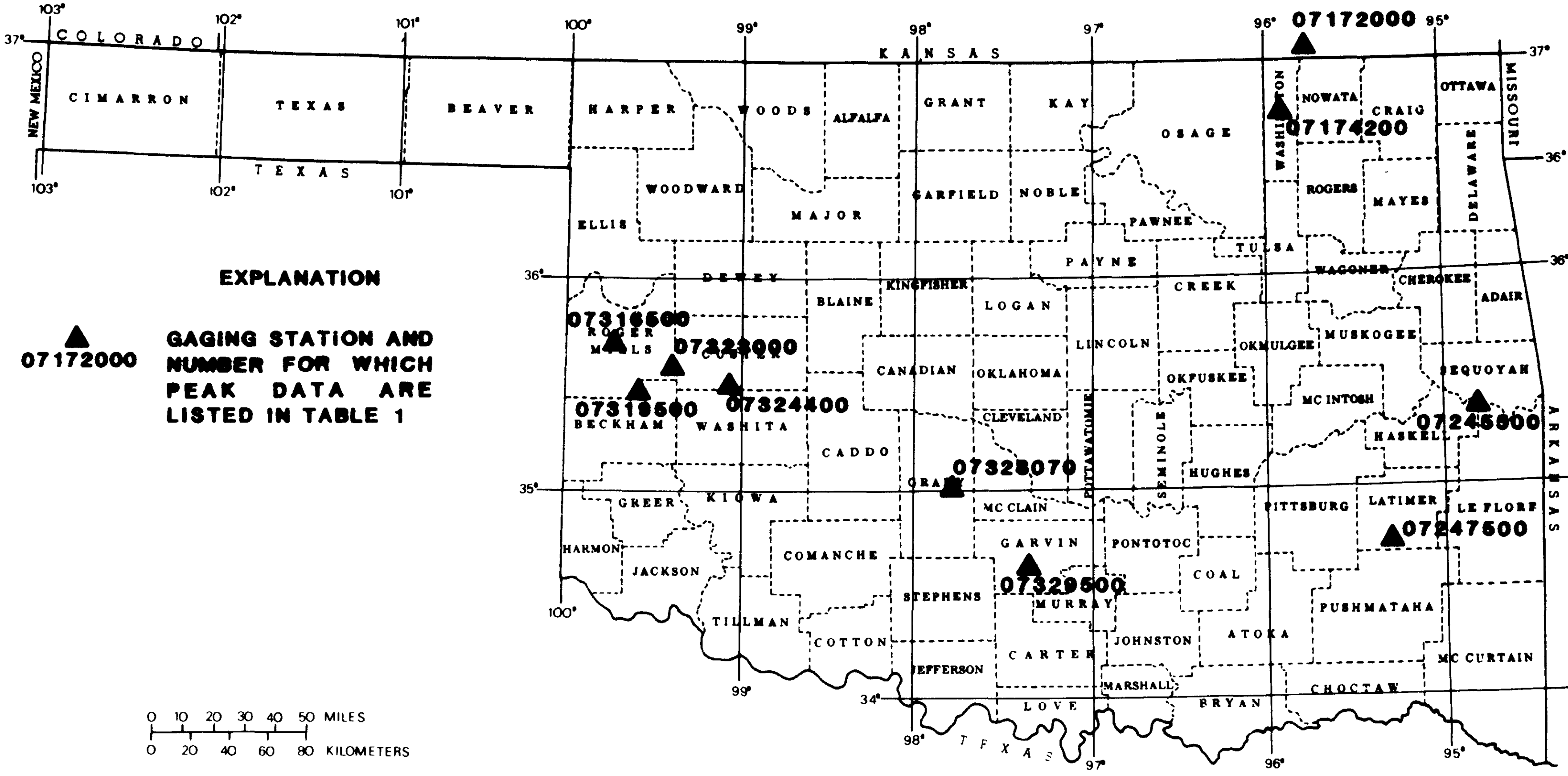


Figure 10.--Location of selected gaging stations regulated by floodwater retarding structures.

Station flood-frequency relations of gaged rural unregulated sites

The relation of flood peak magnitude to probability of exceedance, or recurrence interval, is referred to as a flood-frequency relation or curve. Probability of exceedance is the probability of a given flood magnitude being exceeded in any one year. Recurrence interval is the reciprocal of probability of exceedance times 100, and is the average number of years between exceedances. For instance, a flood having a probability of exceedance of 0.04 has a recurrence interval of 25 years. This does not imply that each 25 years this flood will be exceeded, but only that a 25-year flood will be exceeded on the average of once in 25 years over a very long time period (Thomas and Corley, 1977). In fact, it may be exceeded in successive years, or more than once in the same year. The probability of this happening is called risk. The procedures for making risk estimates are given by the U.S. Water Resources Council (1981).

Flood-frequency relations were defined for selected rural unregulated gaging stations with 10 years or more of record, following the guidelines by U.S. Water Resources Council (1981). Logarithms of annual peak discharges were fitted to the Pearson Type III distribution giving weight to historical peaks and high outliers, omitting low outliers and using a generalized skew map which was developed for Oklahoma and the bordering areas shown in figure 11. The station skew was weighted with the generalized skew map value to give a weighted skew as recommended by U.S. Water Resources Council (1981). Estimates of the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year floods and the log-Pearson Type III statistics for these estimates are given for each station in table 11.

84-435

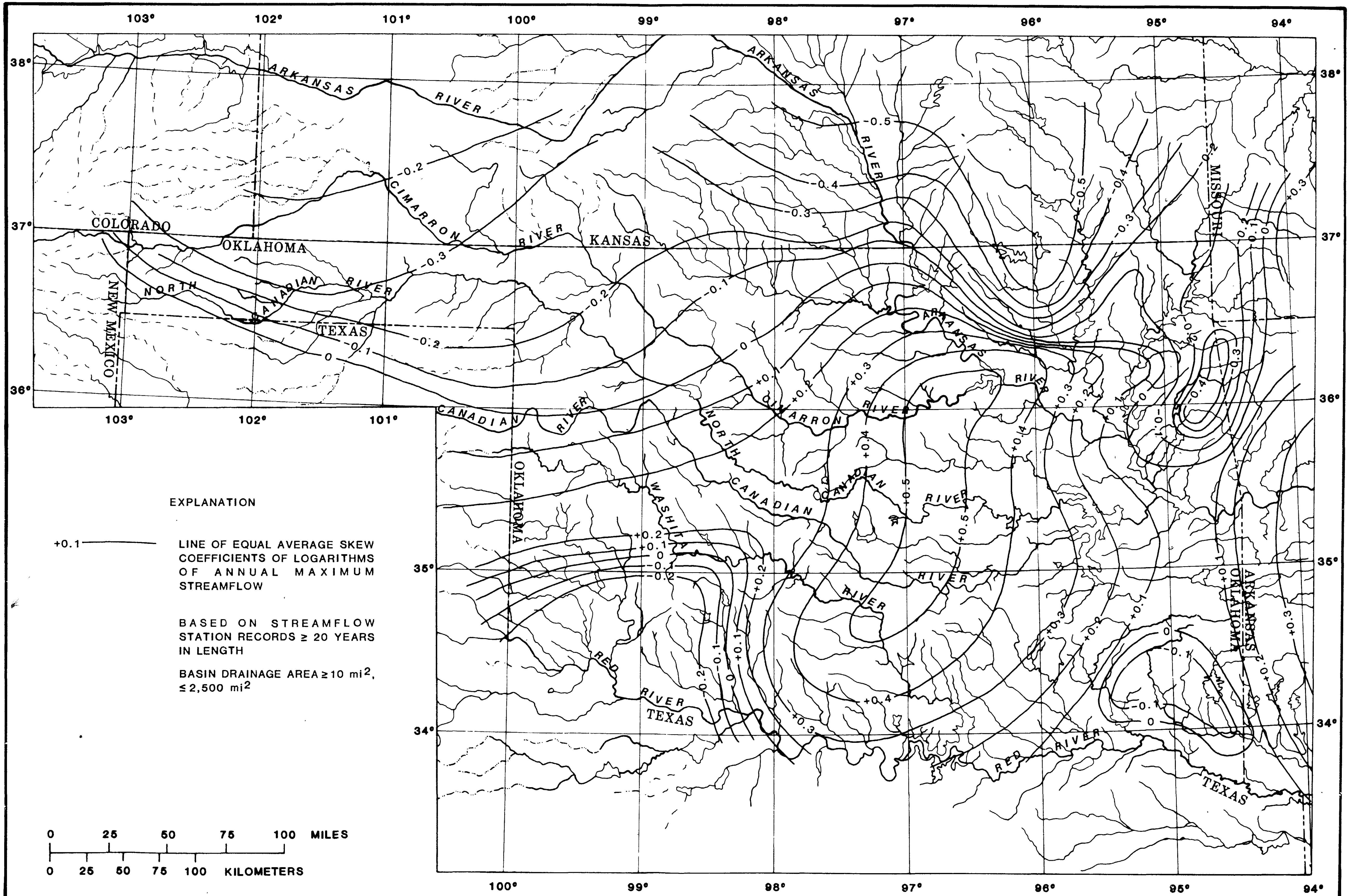


Figure 11.--Generalized skew coefficients of logarithms of annual maximum streamflow for Oklahoma streams less than or equal to 2500 square miles in drainage area.

The generalized skew map published in U.S. Water Resources Council Bulletin No. 17B (1981) was considered inadequate for this study. Therefore, following the guidelines in that publication, an isoline skew map was developed for the area shown in figure 11. Data for stations with 20 or more years of record and drainage areas of 10 mi^2 or more were used. These stations are indicated with an asterisk in table 11. The average of the sum of the squared differences between the observed station skew and isoline values, mean-square error, was computed and utilized in weighting the station and generalized skew map values. This weighted skew coefficient, which was used in the final computation of the flood-frequency relations, is the skew shown in table 11.

The mean-square error, using all 226 stations, between U.S. Water Resources Council (1981) map skews and station skews was 0.251; and between the skews determined from figure 11 and station skews 0.244. The latter mean-square error was used in weighting the station and generalized skew map values. The mean-square error, using only the long term stations that were utilized to develop figure 11, between U.S. Water Resources Council (1981) map skews and station skews was 0.233; and between the skews determined from figure 11 and station skews was 0.108.

Regression analysis of gaged rural unregulated sites

Estimates of flood magnitude and frequency commonly are needed at ungaged sites. Therefore, it is necessary to transfer flood-frequency data from gaged sites to ungaged sites. This can be achieved by defining regression relations between peak discharges of selected frequencies and basin or climatic characteristics measured from maps or taken from readily available reports (Thomas and Corley, 1977). Multiple regression techniques were used to relate estimates of the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year floods (given in table 11) to basin and climatic characteristics.

Many parameters were investigated in the multiple regression analysis in an attempt to find the best relations for estimating flood peak discharges. The parameters investigated as possible predictors of flood discharge are shown in table 8 and are available in a U.S. Geological Survey basin and streamflow characteristics computer file (U.S. Geological Survey, 1983). These parameters were readily available for bordering state gaging stations.

Of all the parameters investigated, the two found most significant were contributing drainage area and mean annual precipitation. A comparison was made of a two-parameter model, using drainage area and mean annual precipitation, and a three-parameter model, using drainage area, mean annual precipitation, and main-channel slope. The average difference between the residuals of the discharge estimates, expressed as a percent of observed station discharge, for all stations and frequencies was less than one-half of one percent. Therefore, the two-parameter regression model was used to define the regression equations.

(no page 40)

Table 8.--Parameters investigated as possible predicators of flood discharge for unregulated rural streams.

Parameter Code Name	Description
AREA	Total drainage area, in square miles, including non-contributing areas.
A	Drainage area, in square miles, that contributes to surface runoff.
SLOPE	Main-channel slope, in feet per mile, average of elevations at 10 and 85 percent of channel length.
LENGTH	Stream length, in miles, measured along channel from gage to basin divide.
ELEV	Mean basin elevation, in feet above mean sea level, measured from topographic maps by transparent grid sampling method (20 to 80 points in basin were sampled).
STORAGE	Area of lakes, ponds, and swamps in percent of contributing drainage area, measured by grid sampling method.
FOREST	Forested area, in percent of contributing drainage area, measured by grid sampling method.
LAT GAGE	Latitude of stream-gaging station in decimal degrees.
LNG GAGE	Longitude of stream-gaging station in decimal degrees.
P	Mean annual precipitation, in inches, from U.S. Weather Bureau series, "Climates of States".
I24,2	Precipitation intensity; 24-hour rainfall, in inches, expected on the average of once each 2 years. (Estimated from U.S. Weather Bureau Technical Paper 40).

The results of a correlation analysis of the possible predictor parameters provided some insight as to why the two parameters used give a good prediction. In Oklahoma, the drainage area is highly correlated with stream length and the mean annual precipitation is highly correlated with mean basin elevation, forested area, longitude of stream-gaging station and precipitation intensity. Main-channel slope is not highly correlated with any of the parameters.

Testing assumptions and applicability of regression equations

Plots of the residuals, the difference between the observed and predicted values of the dependent value in the regression $(Q_{x(s)} - Q_{x(r)})$, were used to check the linearity of the regression relations (Thomas and Corley, 1977). Flood peak discharge residuals for all seven frequencies were plotted against contributing drainage area, mean annual precipitation and years of record. These plots indicated no trend throughout the range of variables used in the analysis. The residuals were also plotted against main-channel slope and also indicated no trend. Therefore, the hypothesis of linearity of the regression relations was accepted.

The regression relations were checked for a possible regionalization effect. The residuals from equations 2-8 were plotted on computer-generated maps to check for regional bias. These computer plots did not indicate any significant regional trends. As an additional check for regional trends, the study area was divided into four regions according to the following range of mean annual precipitation values:

Region 1		<= 24 in.
Region 2	> 24 in.,	<= 33 in.
Region 3	> 33 in.,	<= 44 in.
Region 4	> 44 in.	

Within each region, the Q_{100} residuals, expressed as a percent of the observed station 100-year peak discharge, $Q_{100(s)}$, were sorted by gage latitude. This listing also did not indicate any regional trends. Therefore, equations 2-8 are considered applicable statewide for Oklahoma within the limitations given in an earlier section of this report.

Comparisons were made of the estimates from equations 2-8 with the estimates made by Thomas and Corley (1977). The comparisons of the percent residuals indicate that regression estimates from this study average about 10 percent higher, when averaged through all frequencies, than Thomas and Corley (1977) estimates. A comparison of percent residuals by each frequency shows no difference between the regression estimates of Q_2, with the differences indicated at all the other frequency floods.

A comparison was made of the percent residuals of the discharge estimates from equations 2-8 and from equations 2-8 developed by Thomas and Corley (1977) sorted by drainage area distribution shown in table 7. These comparisons indicate there is little difference when the drainage area is greater than 500 mi^2, with most of the differences when the drainage area is less than 500 mi^2. These differences apparently result because of a greater areal sampling of gaging stations (figure 1) and because most of the stations removed from the analysis in this study due to poor or suspect record were less than 500 mi^2. Also the rainfall-runoff modeling results used by Thomas and Corley (1977) probably account for some of the difference because the synthetic frequency curves tended to have flatter slopes than the observed frequency curves causing the higher interval floods to be underestimated (Thomas, W. O., Jr., U.S. Geological Survey, written commun., 1984).

General description of floodwater retarding structures

This report includes results of a study of the effects of small structures on peak flow. These structures are FRS built by the SCS and used in their watershed protection and flood prevention program.

A typical FRS consists of an earth dam, a valved drain pipe, a drop-inlet principal spillway and an open-channel earthen emergency spillway. The principal spillway is ungated and automatically limits the rate at which water can flow from the reservoir. Most of the structures built in Oklahoma have release rates of 10 to 15 $(ft^3/s)/mi^2$ (cubic feet per second per square mile). The space in the reservoir between the elevation of the principal spillway crest and that of the emergency spillway crest is used for floodwater detention. Structures are designed so that the emergency spillway does not operate on an average of more than once in 25 years to once in 100 years. (See Moore, 1969).

In Oklahoma, most FRS are designed to draw down the floodwater-retarding pool in 10 days or less. The 10-day drawdown requirement serves two principal purposes. First, most vegetation in the floodwater-retarding pool will survive up to 10 days of inundation without destroying the viability of the stand. Secondly, a 10-day drawdown period will significantly reduce the impact from repetitive storms. (Riley, R. C., U.S. Soil Conservation Service, written commun., 1984).

These dams are of small to medium size, with embankment heights ranging generally from 20 to 60 ft (feet) and their drainage areas ranging generally from 1 to 20 mi^2. Their storage capacity is limited to 12,500 acre-ft (acre-feet) for floodwater detention and 25,000 acre-ft total for combined uses, including recreation, municipal and industrial water, and others. (See Moore, 1969).

A cross section of a typical upstream FRS is shown in figure 12.

Emergency spillway design, including storage above the emergency crest and capacity of the emergency spillway, varies depending upon watershed location and size of the FRS. Details of design may be found in the SCS National Engineering Handbook, Section 4 (U.S. Soil Conservation Service, 1972).

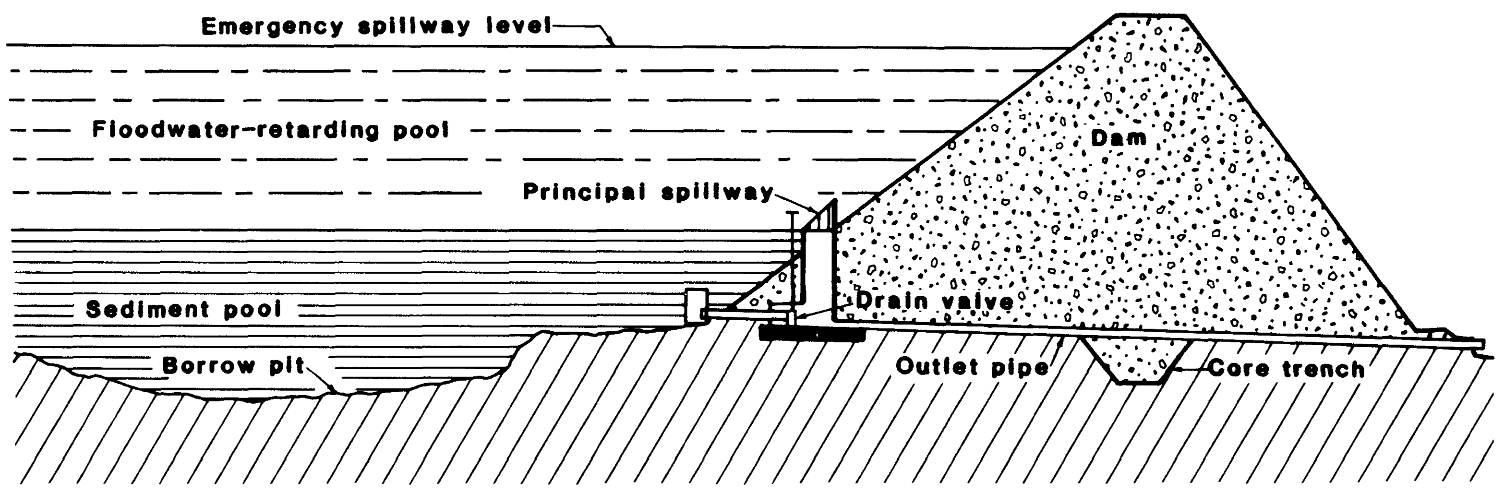


Figure 12.—Cross section of typical floodwater retarding structure (Gilbert and Sauer, 1970).

General effects of floodwater retarding structures

The generalized effects of a system of upstream FRS on a watershed stream flow hydrograph at a point downstream from the FRS is shown in figure 13.

The flood peak discharge is reduced and this reduction is related to the percent of the basin regulated. The slope of the recession segment of the hydrograph will decrease as the number of FRS where the principal spillway is flowing increases. (Coskun and Moore, 1969; DeCoursey, 1975; Hartman and others, 1967; Moore, 1969; Schoof and others, 1980).

Several factors significantly influence the effectiveness of the FRS in reducing peak flow on the main stem downstream from the FRS. Those factors include rainfall distribution over the watershed, contents of the reservoirs before the storm, and distribution of FRS in the watershed. For example, rainfall occurring only on the basin area controlled by FRS will generally result in greater peak reduction. If the structures are empty before the storm, they are more effective in reducing the flood peak. Structures located in the upper end of an elongated basin are less effective than those in a fan-shaped watershed. (Coskun and Moore, 1969; Hartman and others, 1967; Moore, 1969; Schoof and others, 1980).

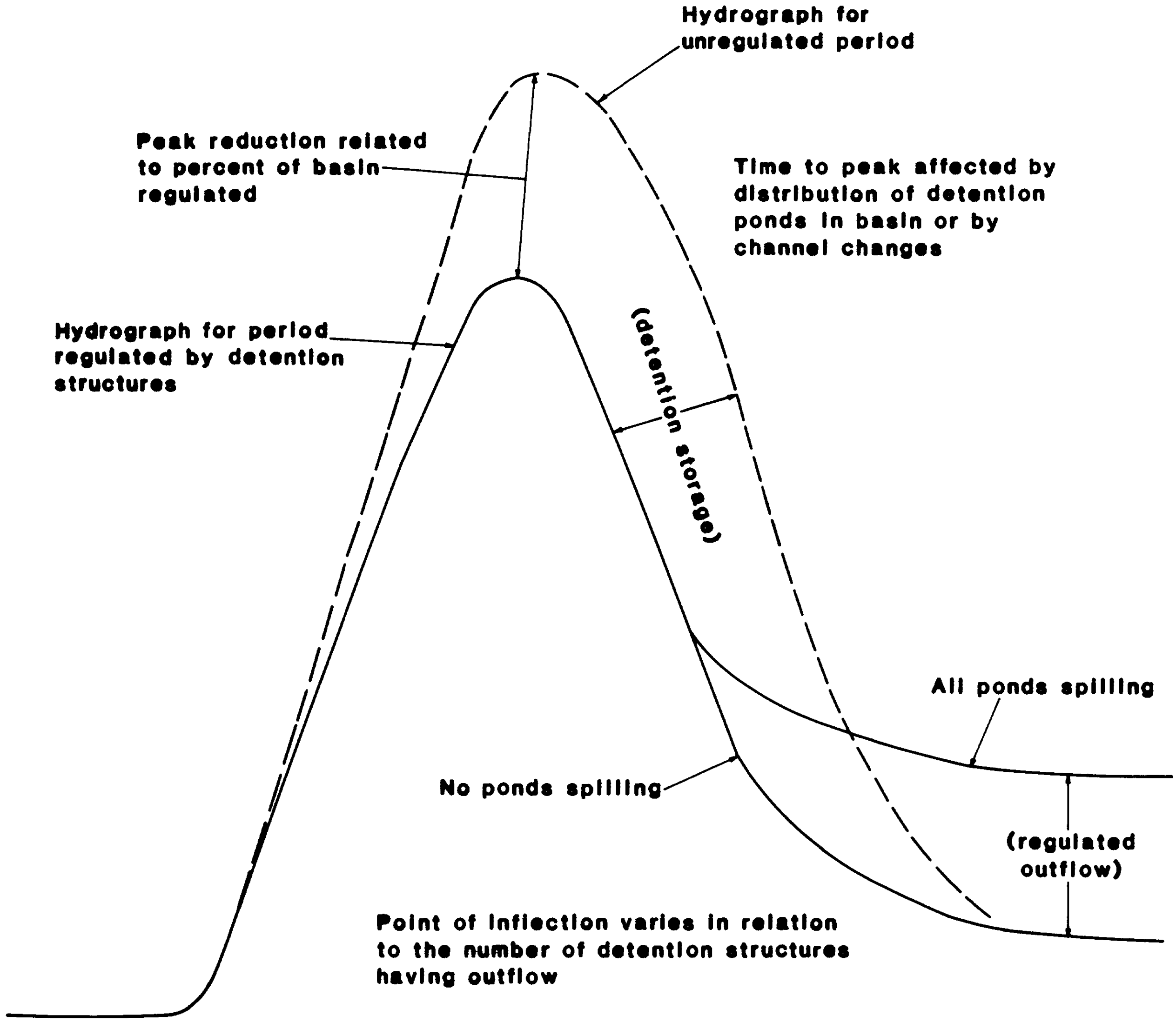


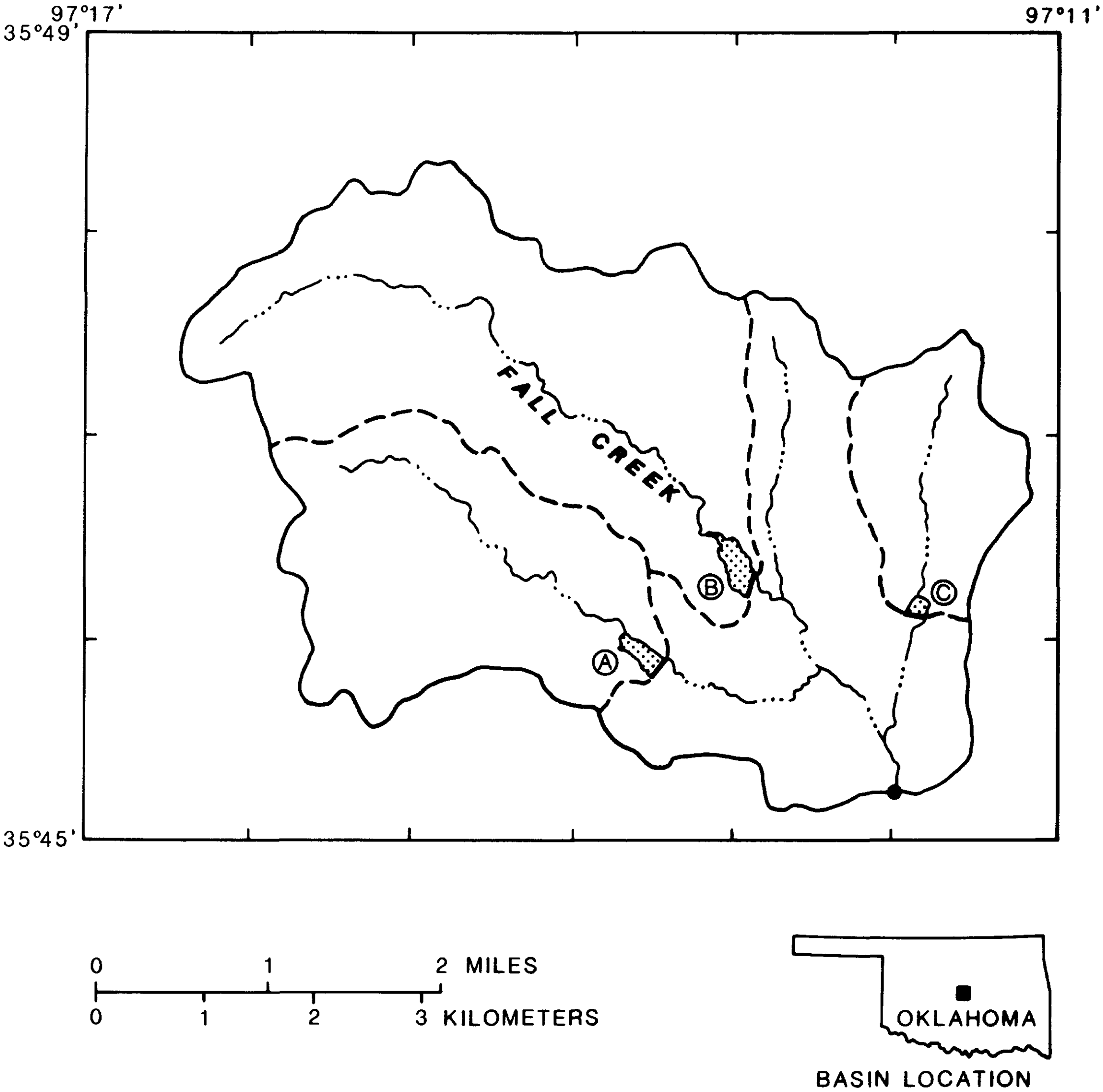
Figure 13.--The generalized effects of runoff retention on the streamflow hydrograph.

An example of a small watershed regulated by three FRS is presented to illustrate the general effects of FRS. In Case 1 the pond water surface was at the principal spillway elevation at the beginning of rainfall, whereas in Case 2 the pond water surface was at half the floodwater-detention-storage-capacity pool elevation at the beginning of rainfall.

The study basin is located on Fall Creek (U.S. Soil Conservation Service, 1957). The regulated drainage area totals 7.94 mi^2 or 74 percent of the watershed, whereas the unregulated drainage area is 2.80 mi^2 or 26 percent of the watershed (figure 14).

The floodwater-detention-storage capacity of each FRS was set equal to the runoff from the 25-year, 6-hour duration rainfall as determined from National Weather Service Technical Paper No. 40 (Hersfield, 1961). This constraint is synonymous with the "worst possible case," because many FRS actually have larger floodwater-detention-storage capacities available and also have part of the sediment-pool-storage capacity available for flood detention.

Four rainfall recurrence intervals for the 6-hour duration rainfall were run for the design storms: (1) 25-year, (2) 50-year, (3) 100-year, and (4) 500-year (table 9). The first three frequency rainfalls were taken from National Weather Service Technical Paper No. 40 (Hersfield, 1961), and the 500-year frequency rainfall was obtained graphically from an extrapolation of a plot of the 25-, 50-, and 100-year frequency rainfalls on log-probability paper. The SCS emergency spillway design storm distribution was used as the temporal storm pattern for all frequencies (U.S. Soil Conservation Service, 1972).



EXPLANATION

Ⓐ FLOODWATER RETARDING STRUCTURE AND LETTER IN TABLE 10

BASIN DIVIDE

SUB-BASIN DIVIDE

STREAM CROSS-SECTION

Figure 14.--Location of Fall Creek study watershed (modified from U.S. Soil Conservation Service, 1957).

Table 9.--Six-hour duration rainfall and resulting runoff for Fall Creek study watershed.

	Rainfall and runoff in inches for indicated recurrence interval in years.			
	25	50	100	500
Rainfall	5.10	5.80	6.25	7.20
Runoff	4.07	4.75	5.19	6.12

The SCS hydrologic computer program Technical Release No. 20 (U.S. Soil Conservation Service, 1965) was used to compute and route runoff hydrographs through the three FRS and to the downstream cross-section. The inflow peak discharges used for the FRS were equal to those that would be computed by using equations 5 through 8. Also the peak discharges used for the unregulated sub-basin were equal to those that would be computed by using equations 5 through 8. The resulting peak discharges below the FRS ponds A through C and at the downstream cross-section in the Fall Creek study watershed are shown in Table 10.

The 100-year hydrograph is typical of the general effects in both cases, except in the Case 1, 25-year hydrograph where the emergency spillways of the FRS did not flow.

The 100-year hydrograph at the stream cross-section, Case 1, is illustrated in figure 15. The unregulated sub-basin contributes practically all of the major peak. A smaller peak occurs later and is a composite of the regulated outflow and the unregulated sub-basin discharge. At all frequencies, the major peaks are the peak discharges of the unregulated sub-basin increased by the FRS principal spillway outflows.

Table 10.--Peak discharges at floodwater retarding structure ponds and downstream cross-section

[FRS, floodwater retarding structure]

LOCATION	Drainage Area Square Miles	Peak Discharge in Cubic Feet per Second For Indicated Recurrence Interval in Years			
		25	50	100	500
FRS POND A	1.00				
Inflow		1210	1630	2100	3430
Outflow-Case 1[a]		7	133	210	360
Outflow-Case 2[b]		290	380	450	660
FRS POND B	4.27				
Inflow		2720	3640	4780	7830
Outflow-Case 1[a]		30	340	600	1090
Outflow-Case 2[b]		930	1260	1480	1920
FRS POND C	2.67				
Inflow		2130	2790	3680	6010
Outflow-Case 1[a]		19	180	340	640
Outflow-Case 2[b]		580	760	890	1180
TOTAL REGULATED OUTFLOW	7.94				
Case 1[a]		56	580	1060	2000
Case 2[b]		1680	2290	2720	3610
UNREGULATED SUB-BASIN	2.80	2150	2920	3740	6200
TOTAL AT CROSS-SECTION	10.74				
Case 1[a]		2210	2970	3790	6250
Case 2[b]		2400	3190	4070	6830

[a] Case 1 - Pond water surface at principal spillway elevation at beginning of rainfall.

[b] Case 2 - Pond water surface at half floodwater-detention-storage-capacity pool elevation at beginning of rainfall.

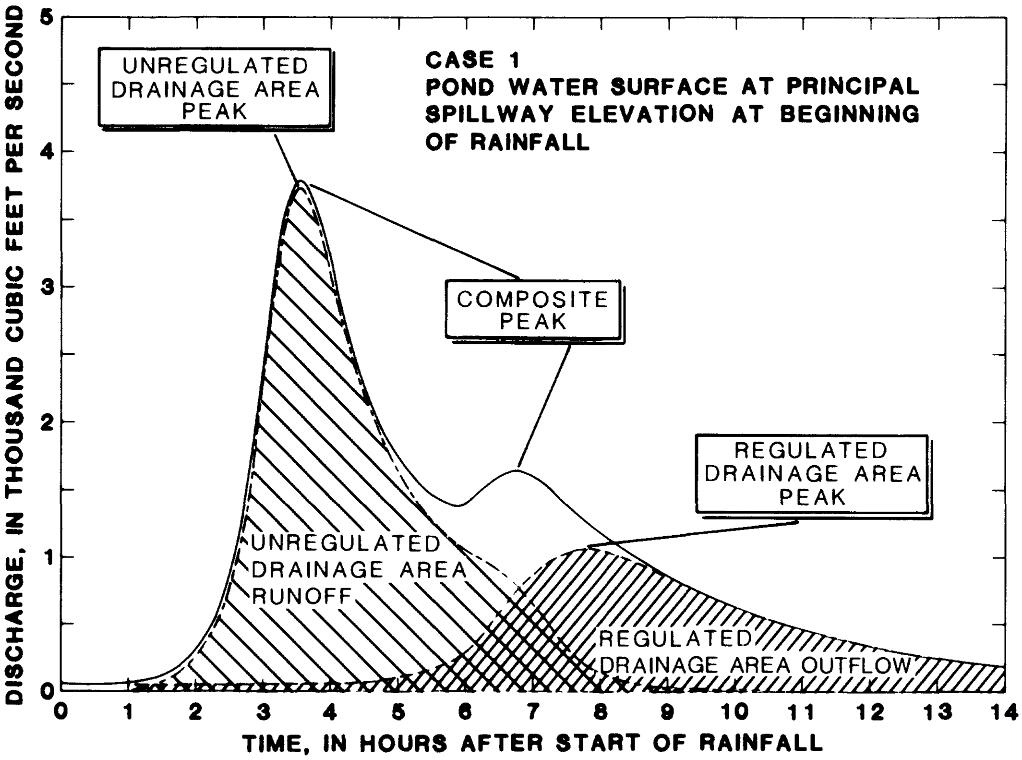


Figure 15.--100-year hydrograph at stream cross-section located downstream from floodwater retarding structures for Case 1.

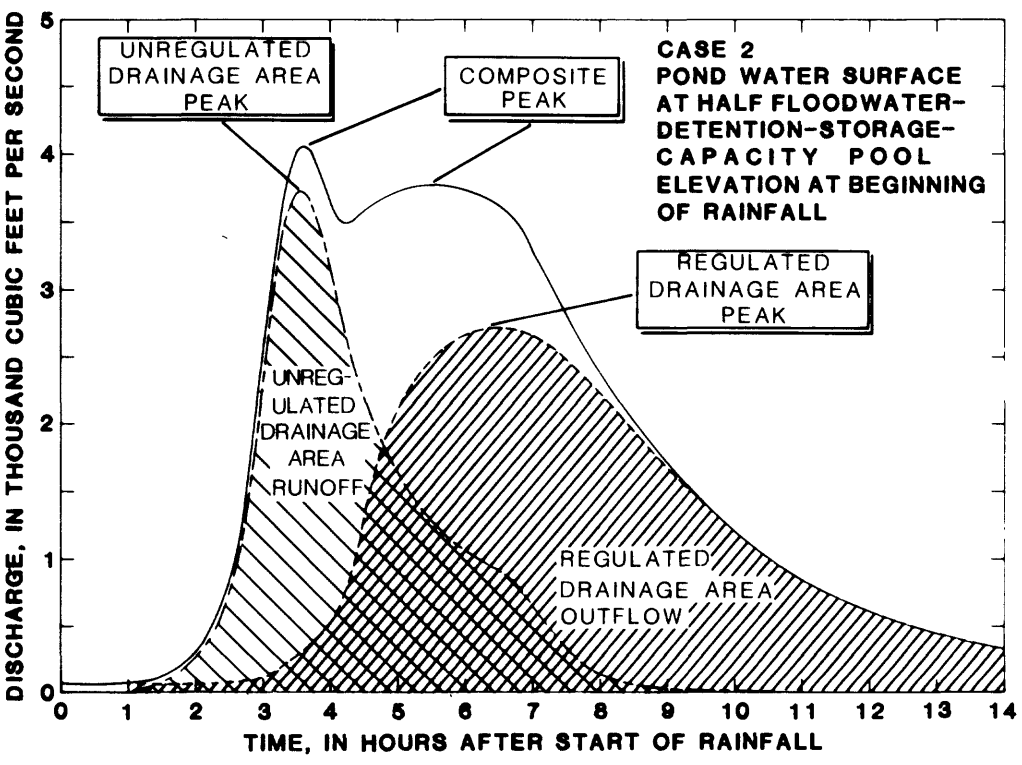


Figure 16.--100-year hydrograph at stream cross-section located downstream from floodwater retarding structures for Case 2.

The 100-year hydrograph at the stream cross-section, Case 2, is illustrated in figure 16. The unregulated sub-basin contributes about 90 percent of the first peak, as compared to about 98 percent in Case 1, because the FRS emergency spillways have started to discharge. The second peak is a composite of the regulated sub-basin outflows and the unregulated sub-basin discharge. The second-peak discharge is approximately the same magnitude as the first-peak discharge in the 25- and 50-year hydrographs, but it is smaller than the first-peak discharges in the 100- and 500-year hydrographs. At all frequencies, the peak discharges of the unregulated sub-basin are increased by about 10 percent -- an amount that is well within the accuracy of the regression equations (table 4).

Therefore, structures in a FRS regulated watershed are effective in reducing the peak flow of the total drainage area to essentially the same magnitude of unregulated portion of the watershed. The flow contribution of the regulated portion of the basin is "retarded" or "lagged" by the FRS. In larger FRS regulated basins, the impact of a large rainfall is further decreased by greater distance, or time of travel, between structures; more channel miles to provide greater channel storage; and an unequal distribution of rainfall.

These examples are a "worst case". Class "a" structures are designed to flow through the emergency spillway an average of once in 25 years. Over 95 percent of all FRS built to date in Oklahoma have been class "a" structures. In Oklahoma, the SCS has recorded an emergency spillway flow on the average of once for every 134 structure-years of record. The principal reasons why emergency spillways have not functioned as often as anticipated are (Riley, R. C., U.S. Soil Conservation Service, written commun., 1984):

1. The water level in the reservoir prior to the storm was below the principal spillway.
2. Antecedent moisture conditions prior to major storms have been more often dry rather than wet.
3. Soil profile storage in the floodwater retarding pool is not counted but may be quite significant for some sites and for certain soils.
4. Additional detention storage is often added where it is relatively economical or where poor emergency spillway conditions exist. Therefore, many class "a" structures have more than 25-year detention storage.

Station flood-frequency relations of gaged regulated sites

Flood-frequency relations were defined for the 10 selected rural gages regulated by FRS. The procedures used to define these relations were the same as utilized in the previous section on unregulated sites. Estimates of the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year floods and log-Pearson statistics for these estimates are given for each station in table 1.

The frequency relations for the FRS regulated sites were computed using weighted skew values, utilizing the regional skew values based on the unregulated sites. This method was used since several of the regulated station skew values were close to the same value as the unregulated station skew or the regionalized skew (for stations with no unregulated record 10 years or greater). The FRS regulated data analysis shows that as the regulated period of record increases, the regulated station skew approaches the value of the unregulated station skew.

Five of these sites also include unregulated periods of record of 10 years or more in length and these data are also listed in table 11. The years missing from the end of the unregulated period to the beginning of the regulated period represent the period during which most of the FRS were constructed on the watershed upstream from the gage. Data from station 07324400, Washita River near Foss, Okla., was used as Soldier Creek near Foss, Okla., because during the period of record 1962-80, all storm runoff flowing by that gage was contributed entirely by Soldier Creek.

Regression analysis of gaged rural regulated sites

Regression relations were defined between peak discharges of selected frequencies and basin and climatic characteristics. The parameters investigated included all those in table 8 except FOREST and STORAGE. A was defined as the drainage area below the influence of the FRS and represents the unregulated portion of the basin. In addition three more parameters were investigated:

PERCUNR percent of the drainage area in the basin unregulated by FRS,

DETSTOR actual detention storage of the FRS, in acre-feet per square mile of the total drainage basin,

MDETSTOR estimated detention storage, in inches

$= (I24,2)(100-PERCUNR)$

At least three parameters are required to obtain reasonable accuracy. Three different sets of three parameters produced equivalent accuracy: (1) AREA, P, and PERCUNR; (2) A, P, and DETSTOR; and (3) AREA, P, and MDETSTOR.

The following three sets of regression relations on the 10 regulated station data set were run: (1) all regulated data; (2) regulated data from those basins that had unregulated periods of record; and (3) regulated data from those basins with regulated periods of record only. Covariance analysis on a 2-variable model using A and P indicated that both sets of regulated data, (2) and (3), were not significantly different and could be pooled together.

Since there was a scarcity of data to define regulated regression relations, it was decided to check if a modification of the unregulated regression relations, which had a large data base, would give a reasonable comparison to the regulated station flood-frequency curves defined by the 10 station records. The station flood-frequency relations were compared to: (1) using the unregulated portion of the drainage area, A_u, as A in equations 2-8 (Livingston, 1981); and (2) using the entire drainage area in equations 2-8 and multiplying the result by the percent drainage area unregulated, **PERCUNR**, expressed as a decimal. The residuals between the observed station peak discharges and the estimates obtained by both modifications of the statewide unregulated regression equations were used to compute standard errors. The method of using the unregulated area as the contributing drainage area had a much smaller standard error at each flood frequency. Therefore, that method is the best adjustment for regulation from FRS.

Effects of floodwater retarding structures

Using the data from the five sites that had both unregulated and regulated periods of record of 10 years or more, the effects of FRS on peak discharge and flow duration curves of these particular sites were investigated. The effect of FRS on peak flood discharge is especially noticeable when the flood-frequency from before and after FRS construction periods is plotted on the same graph (fig. 17-21). In each case, flood peaks are reduced for all recurrence intervals.

The structures should start to lose their flood peak reduction effectiveness at a recurrence interval greater than the 500-year frequency and the regulated frequency curve should start to converge toward the unregulated frequency curve. However, this hypothesis is not supported by the data because there is insufficient length of record at FRS regulated sites.

Flow duration curves for these five stations with the before and after periods plotted on the same graph also indicate a significant effect in that mean daily discharges are reduced at the higher discharges (fig. 22-26).

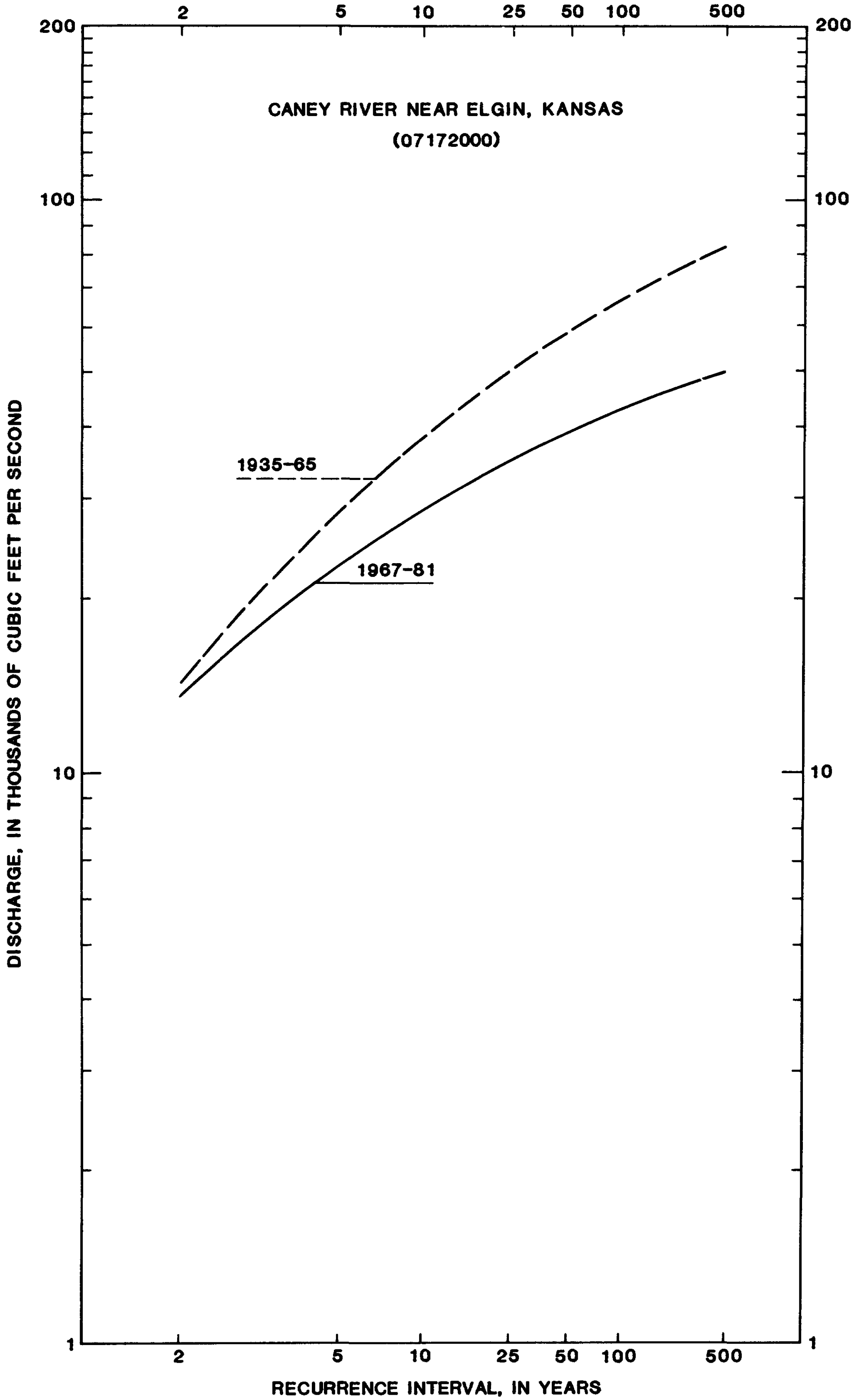


Figure 17.--Comparison of flood-frequency relations before and after regulation by floodwater retarding structures for Caney River near Elgin, Kans.

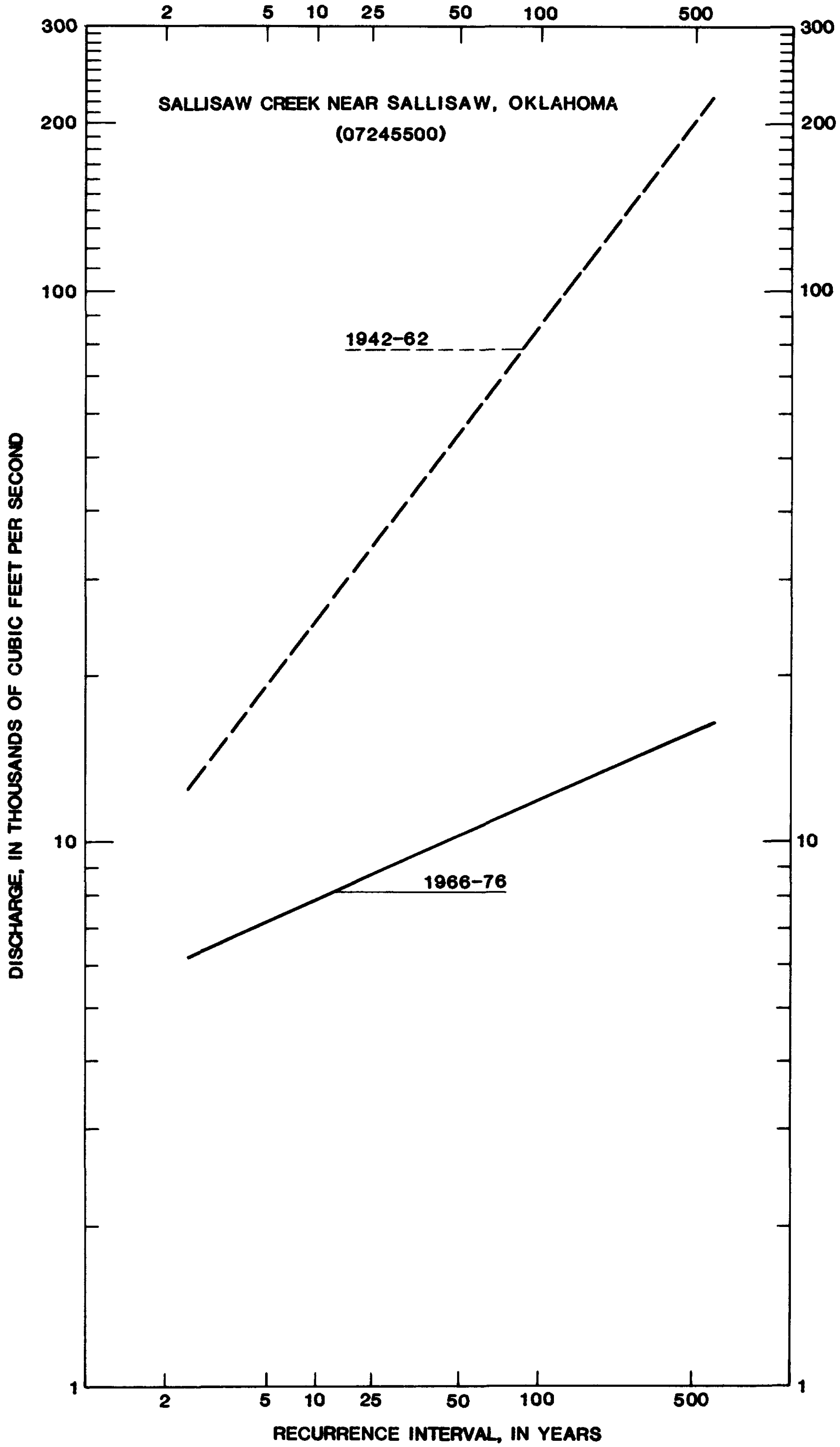


Figure 18.--Comparison of flood-frequency relations before and after regulation by floodwater retarding structures for Sallisaw Creek near Sallisaw, Okla.

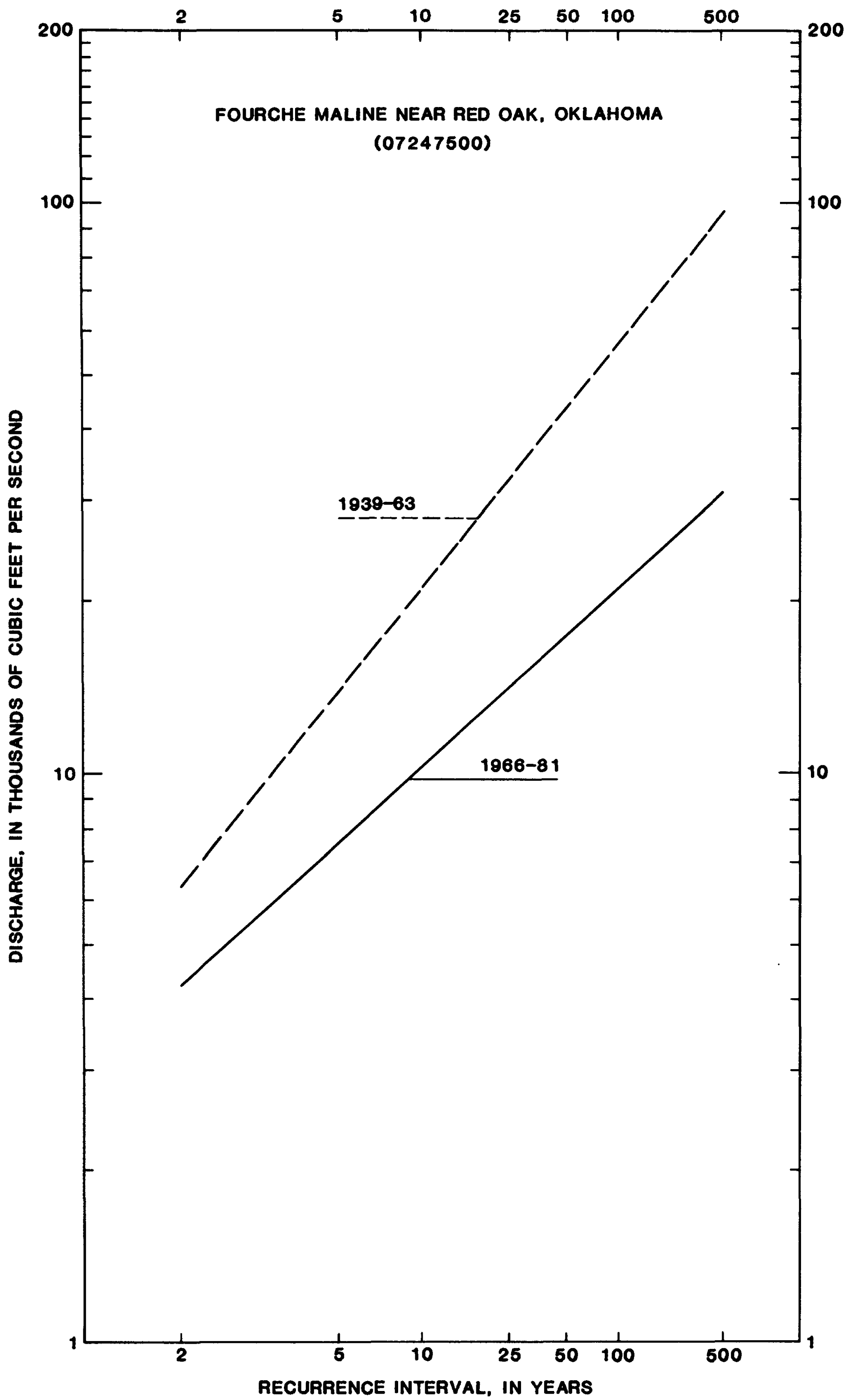


Figure 19.--Comparison of flood-frequency relations before and after regulation by floodwater retarding structures for Fourche Maline near Red Oak, Okla.

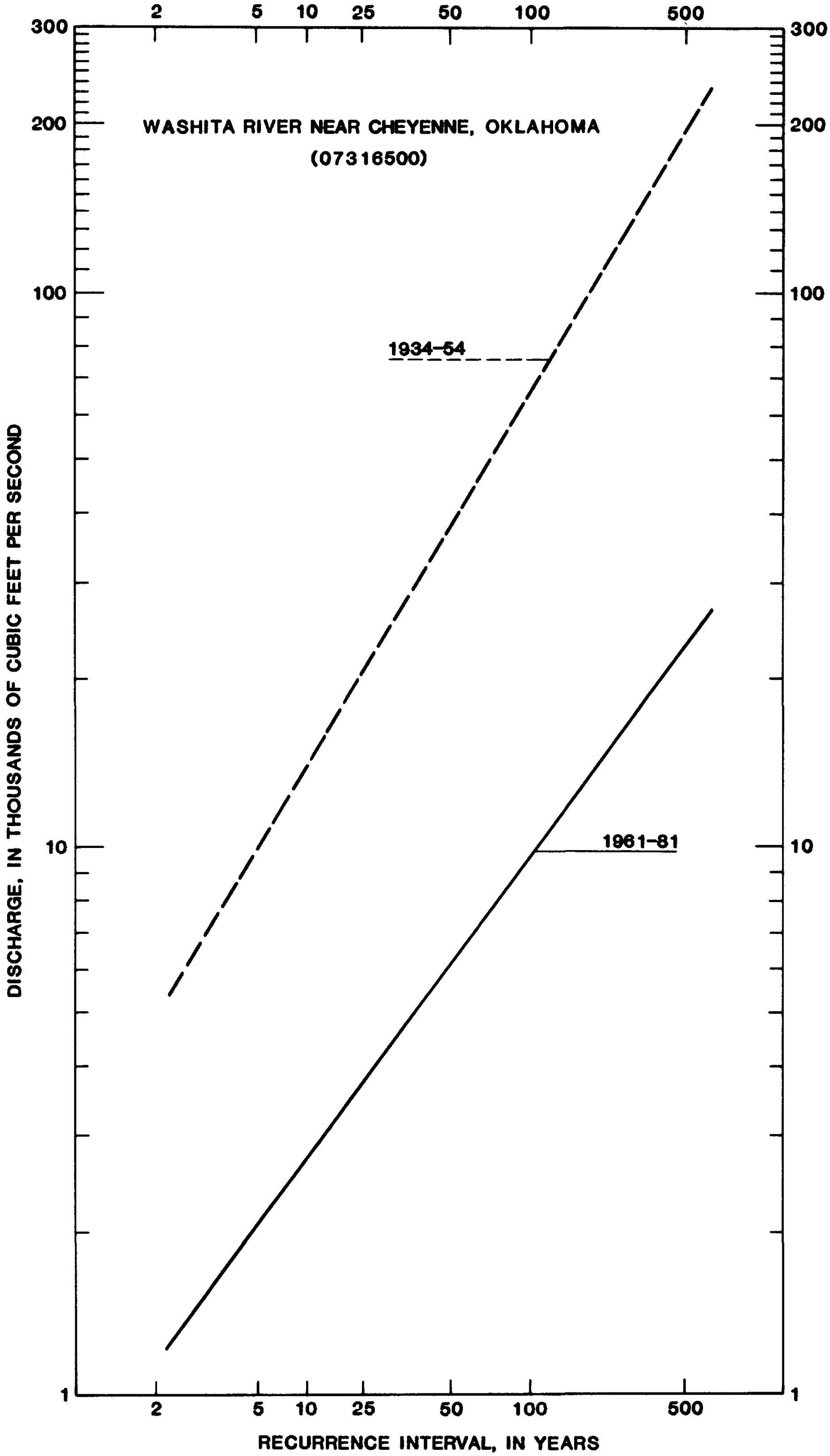


Figure 20.--Comparison of flood-frequency relations before and after regulation by floodwater retarding structures for Washita River near Cheyenne, Okla.

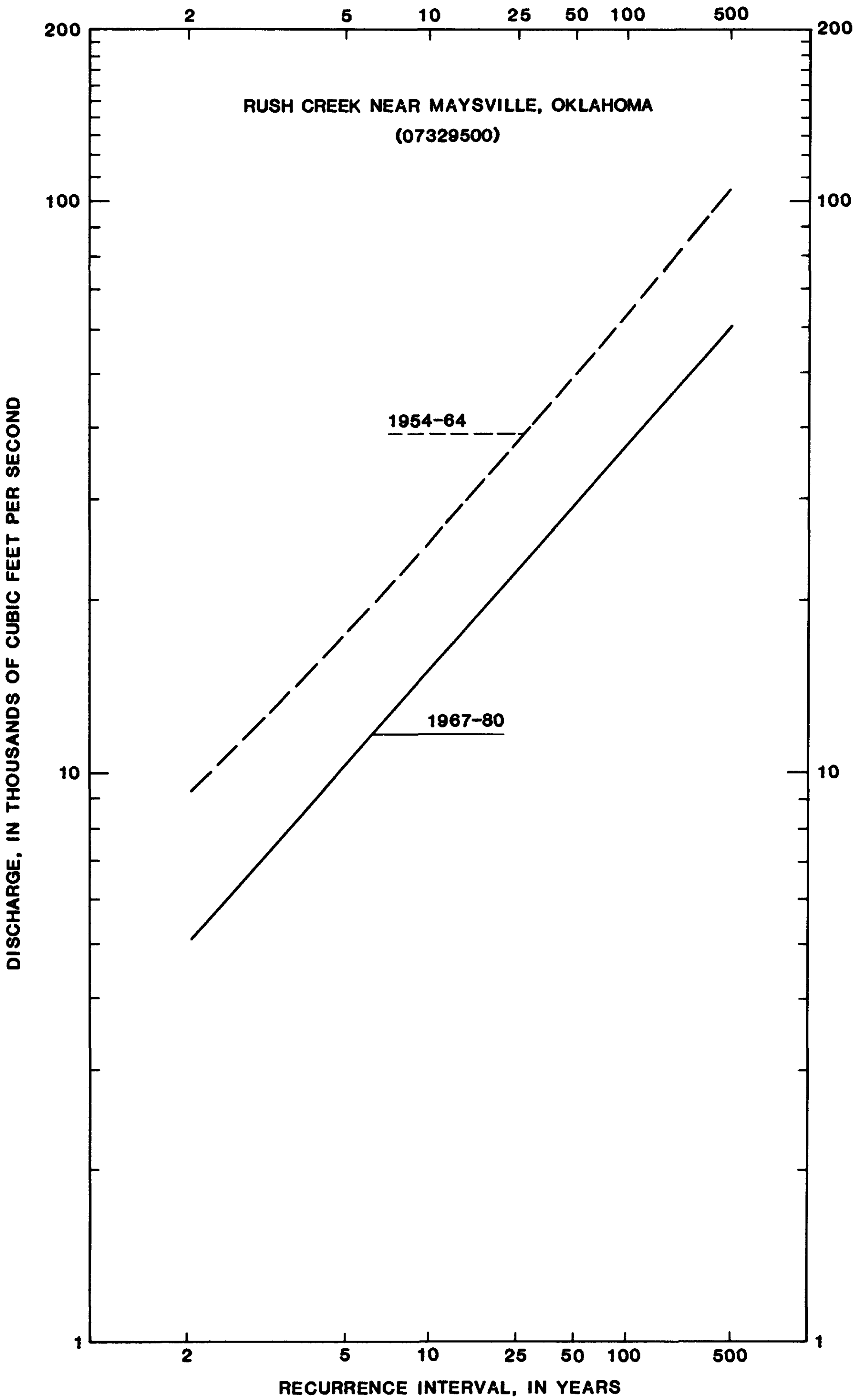


Figure 21.--Comparison of flood-frequency relations before and after regulation by floodwater retarding structures for Rush Creek near Maysville, Okla.

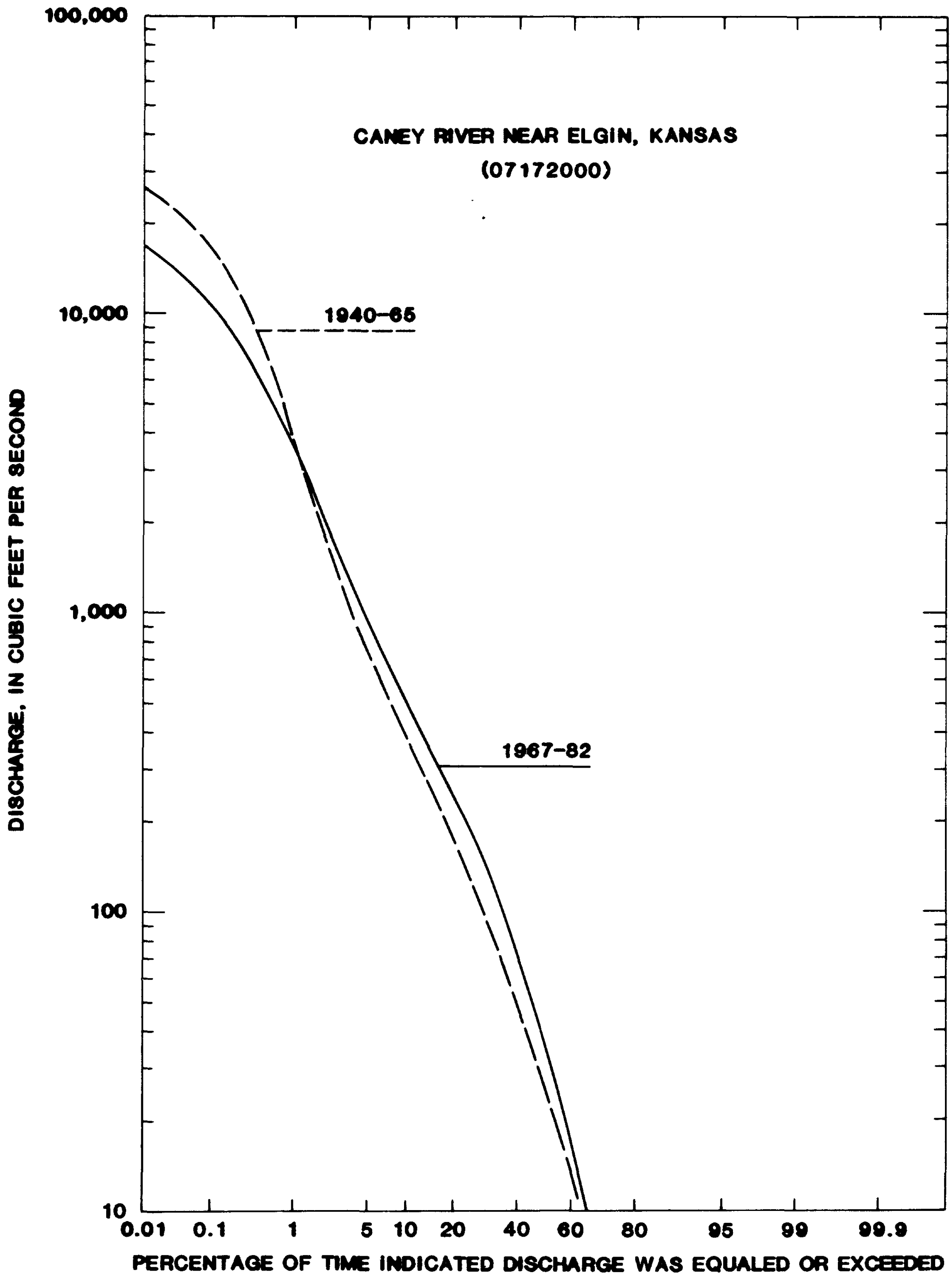


Figure 22.—Flow duration curves for Caney River near Elgin, Kans. showing the effects of floodwater retarding structures on time distribution of streamflow.

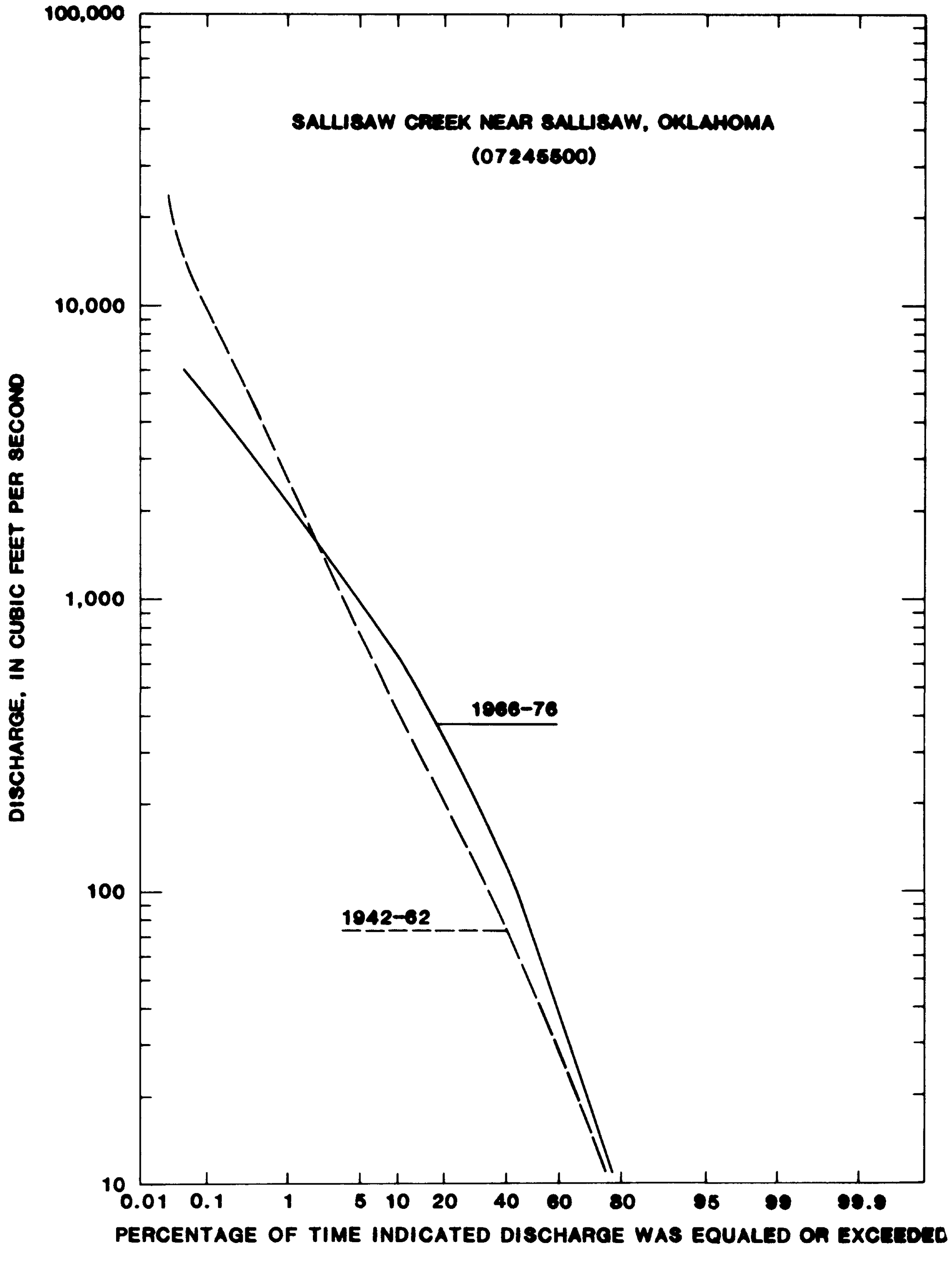


Figure 23.--Flow duration curves for Sallisaw Creek near Sallisaw, Okla. showing the effects of floodwater retarding structures on time distribution of streamflow.

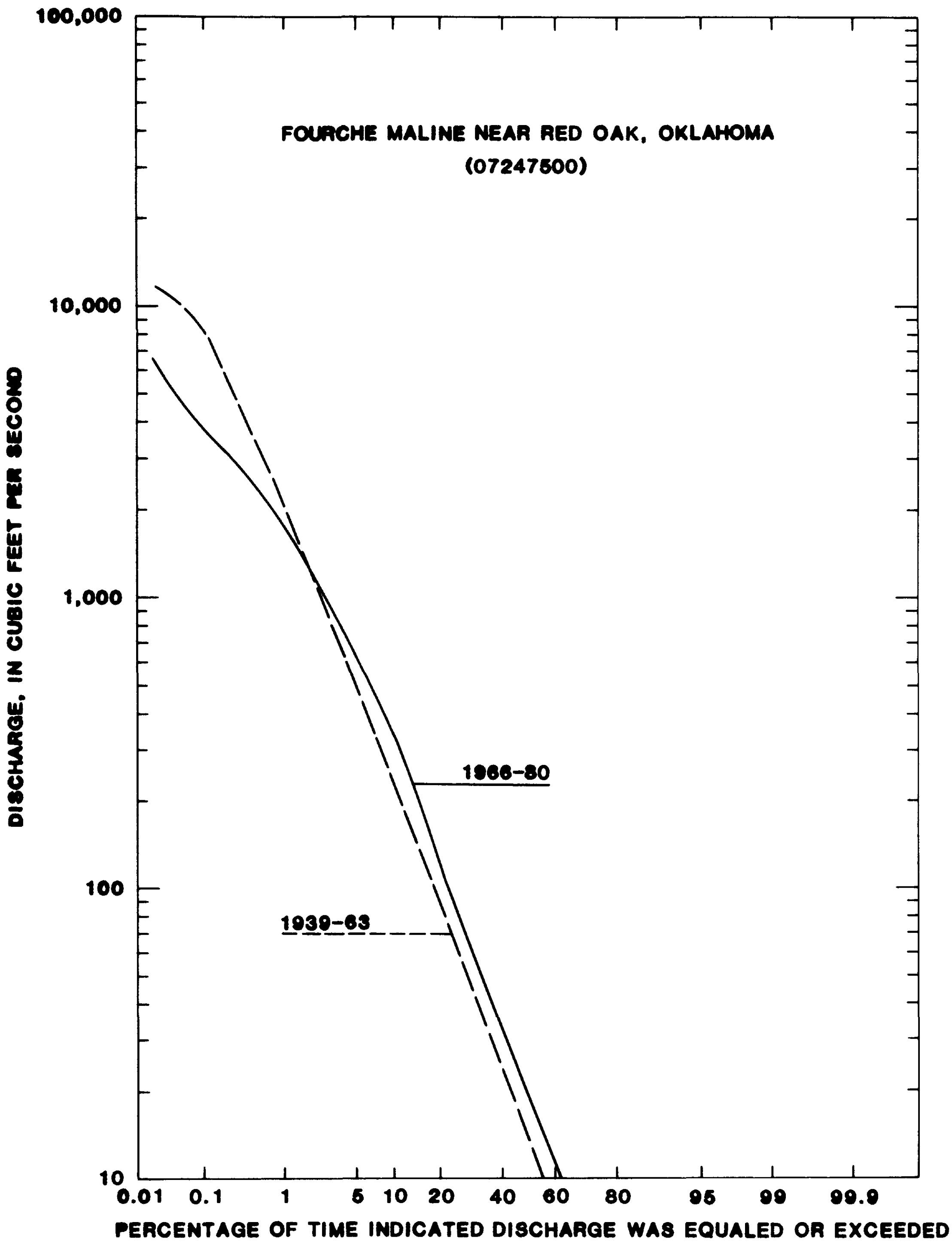


Figure 24.--Flow duration curves for Fourche Maline near Red Oak, Okla. showing the effects of floodwater retarding structures on time distribution of streamflow.

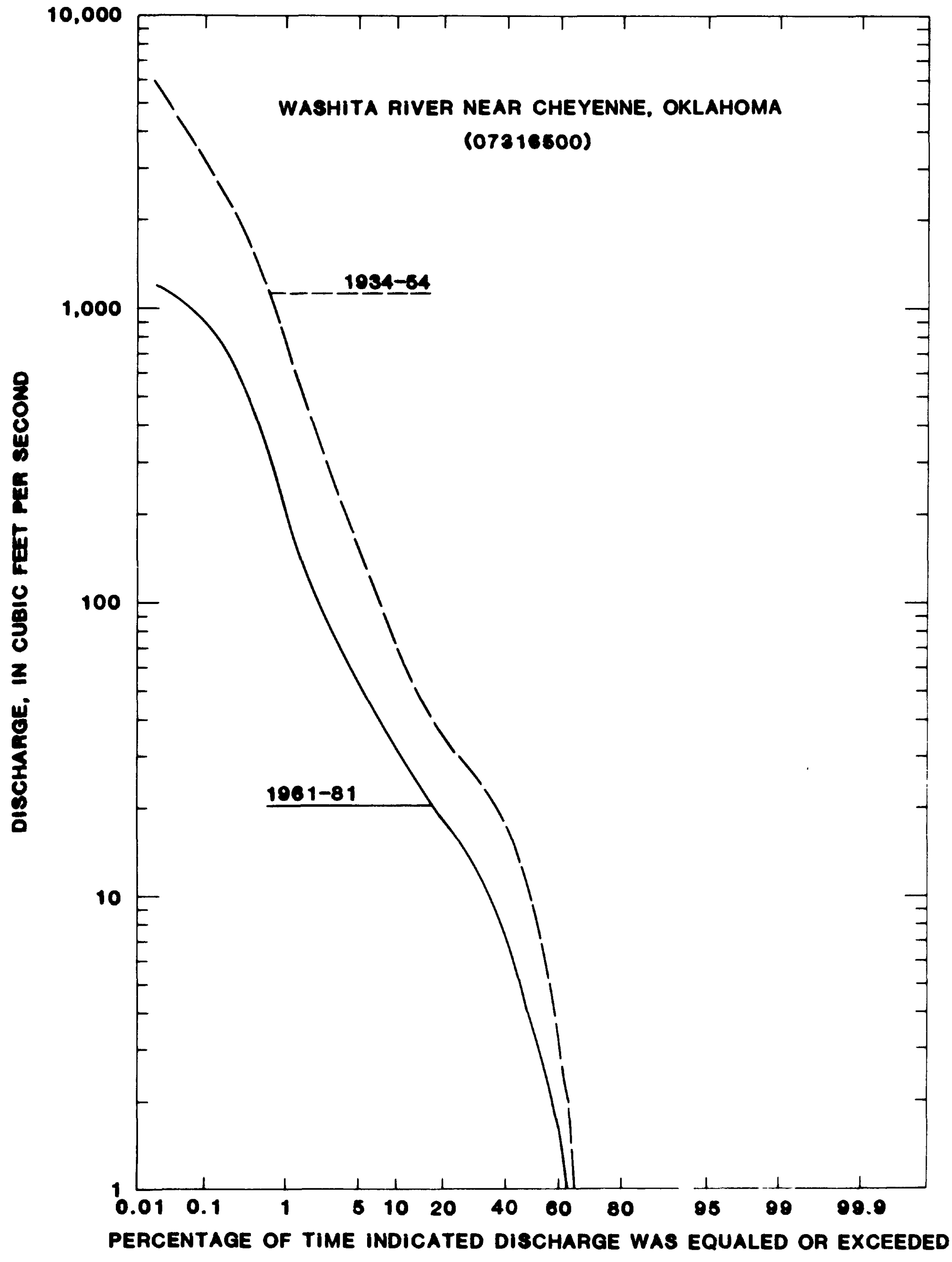


Figure 25.--Flow duration curves for Washita River near Cheyenne, Okla. showing the effects of floodwater retarding structures on time distribution of streamflow.

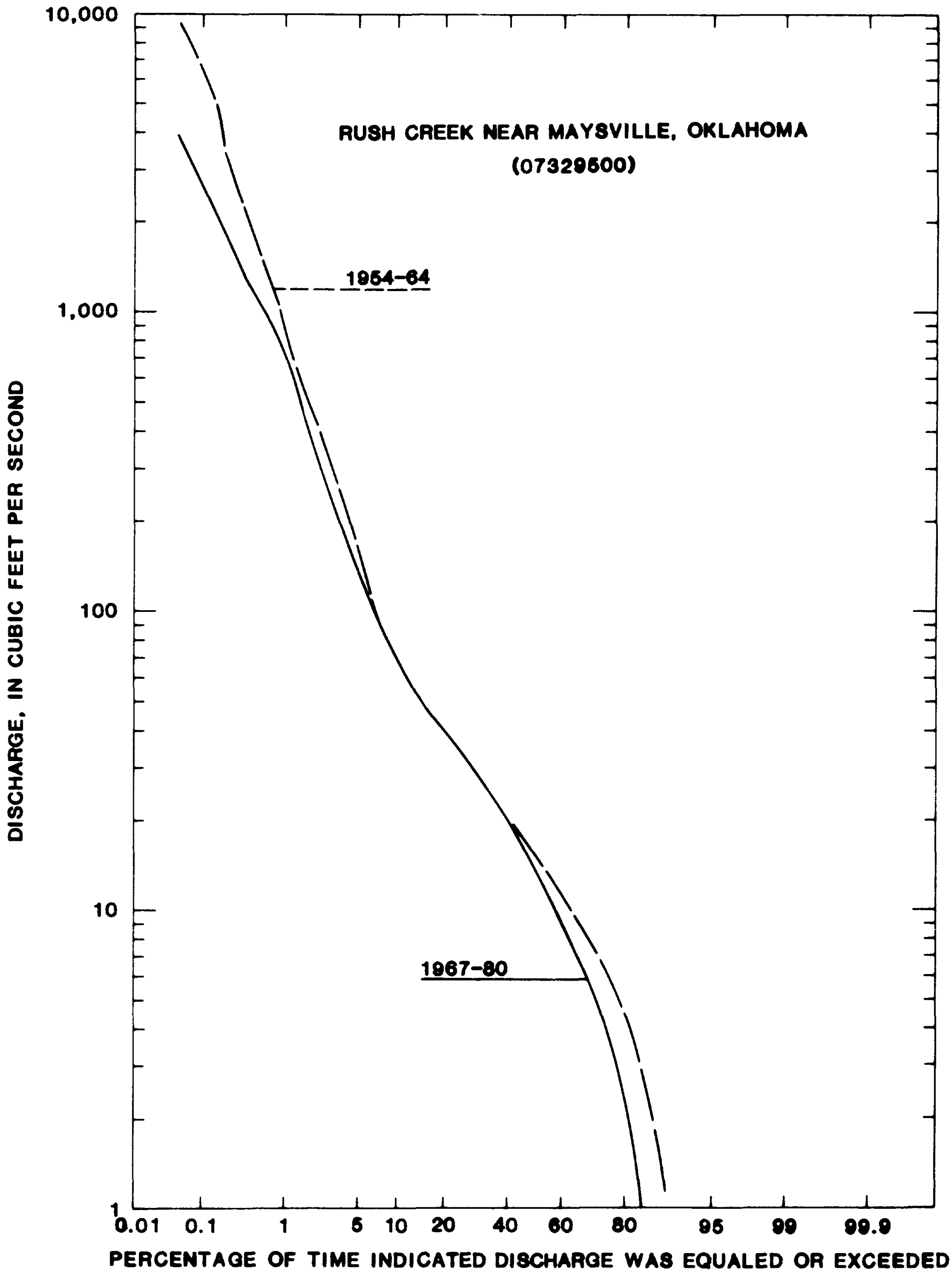


Figure 26.--Flow duration curves for Rush Creek near Maysville, Okla. showing the effects of floodwater retarding structures on time distribution of streamflow.

SUMMARY

Observed flood peak data at 226 unregulated rural sites in Oklahoma and adjacent States were used to compute regression equations defining flood-frequency relations for sites draining less than 2,500 mi^2. A new generalized skew map for Oklahoma was developed for the flood-frequency relations utilized in the regression analysis. These equations are not applicable to basins significantly affected by regulation. Methods for estimating flood discharges for urban areas in Okahoma were not analyzed due to insufficient data. The methods in Sauer (1974b) and Thomas and Corley (1977) should be used for urban areas.

The flood-frequency relations of 10 selected sites regulated by small floodwater retarding structures (FRS) built by U.S. Soil Conservation Service were compared with modifications of the unregulated regression equations. Comparisons indicate that the magnitude and frequency of flooding at ungaged sites where flow is regulated by FRS can best be determined by replacing total drainage area with the unregulated portion of the drainage area (area below the FRS) in the statewide regression equation. The effects of FRS on flood-frequency relations and flow duration curves were shown for five regulated sites that had both unregulated and regulated periods of record.

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TABLE 11.--BASIN AND CLIMATIC CHARACTERISTICS, LOG-PEARSON TYPE III STATISTICS AND STATION FLOOD-FREQUENCY RELATIONS FOR UNREGULATED GAGED STREAMS

[STD DEV, STANDARD DEVIATION; SKEW, WEIGHTED SKEW COEFFICIENT; YR, YEARS; SQ MI, SQUARE MILES; PRECIP, PRECIPITATION; IN, INCHES]

STATION NUMBER	RECORD LENGTH (YR)	DRAINAGE AREA (SQ MI)	MEAN ANNUAL PRECIP (IN)	LOG-PEARSON TYPE III STATISTICS, IN LOGARITHMIC UNITS			PEAK DISCHARGES IN CUBIC FEET PER SECOND FOR INDICATED RECURRENCE INTERVAL IN YEARS						
				MEAN	STD DEV	SKEW	2	5	10	25	50	100	500
07142100*	25	10.30	23.0	2.6103	0.6754	-0.32	443	1540	2820	5200	7580	10500	19800
07144850	19	21.00	24.0	2.7993	0.4699	-0.16	649	1580	2470	3930	5280	6840	11400
07144900	25	1.48	25.0	2.4740	0.3390	-0.50	318	581	770	1010	1190	1370	1770
07145200*	31	543.00	26.0	3.8382	0.3530	-0.33	7210	13800	18900	25900	31500	37300	51600
07145500*†	26	1785.00	27.0	4.0681	0.2839	0.07	11600	20200	27200	37300	45800	55200	80900
07145700*	22	154.00	30.5	3.5354	0.4063	-0.24	3560	7610	11100	16300	20700	25600	38500
07145800	25	0.41	32.5	2.0706	0.3307	-0.25	121	225	305	417	507	601	838
07146570	19	30.00	35.0	3.3084	0.4599	-0.13	2080	4990	7780	12400	16600	21600	36300
07146700*	21	11.00	35.0	3.1079	0.3318	-0.19	1310	2450	3360	4640	5690	6810	9700
07147020	19	0.17	33.5	1.8612	0.4625	-0.46	79	181	267	393	495	603	871
07147070*	20	426.00	33.5	3.8568	0.4921	-0.50	7900	19000	28500	42500	53900	66000	95800
07147200	21	0.90	33.5	2.3426	0.2701	-0.09	222	372	485	641	766	898	1230
07147800*†	47	1872.00	34.5	4.2974	0.3601	-0.14	20200	40100	56600	81300	102000	125000	187000
07147990	21	2.41	35.0	2.5900	0.6672	-0.43	434	1450	2560	4510	6350	8500	14700
07148100*	22	170.00	35.0	3.8636	0.3927	0.21	7080	15500	23700	37900	51700	68700	124000
07148350*	21	856.00	24.0	3.9212	0.4827	-0.14	8560	21400	34100	55300	75200	98800	170000
07148400	16	1009.00	24.2	4.1497	0.1869	0.06	14100	20200	24600	30200	34600	39100	50300
07148700	21	5.31	25.0	2.3928	0.6782	-0.19	260	931	1760	3420	5170	7460	15300
07148800	21	2.04	25.5	2.1372	0.6423	-0.42	152	486	844	1460	2040	2710	4640
07150580	12	7.21	29.0	2.6044	0.3170	0.71	369	715	1060	1690	2340	3180	6180
07150870	17	2.35	29.5	2.4644	0.4259	0.03	290	664	1030	1640	2210	2910	5060
07151500*	22	794.00	27.5	3.9067	0.4292	-0.28	8450	18700	27700	41200	52700	65400	99200
07151600*	25	12.00	27.5	3.0460	0.3759	-0.39	1180	2330	3230	4480	5460	6480	8960
07152000*	45	1859.00	28.5	4.2473	0.3832	0.12	17400	36900	55400	85900	115000	149000	256000
07152360	12	18.20	34.2	3.3364	0.3914	0.13	2130	4600	6970	10900	14700	19200	33500

Table 11.--Continued.

STATION NUMBER	RECORD LENGTH (YR)	DRAINAGE AREA (SQ MI)	MEAN ANNUAL PRECIP (IN)	LOG-PEARSON TYPE III STATISTICS, IN LOGARITHMIC UNITS			PEAK DISCHARGES IN CUBIC FEET PER SECOND FOR INDICATED RECURRENCE INTERVAL IN YEARS						
				MEAN	STD DEV	SKEW	2	5	10	25	50	100	500
07152520	12	0.97	29.8	2.0027	0.6112	0.09	99	327	619	1230	1940	2910	6730
07152842	22	0.32	32.3	2.1262	0.3011	0.14	132	238	328	465	584	719	1100
07152844	25	0.03	32.3	1.3695	0.4244	0.01	23	53	82	130	175	228	393
07152846	25	0.14	32.3	0.4999	0.4999	0.07	69	183	307	538	776	1080	2130
07153000*†	20	576.00	33.5	3.8436	0.2746	0.35	6720	11700	16000	22700	28700	35600	56300
07153500*	33	545.00	16.0	3.4678	0.4351	0.27	2810	6720	10900	18500	26500	36700	72800
07154400*	27	111.00	15.4	3.4596	0.4738	-0.28	3030	7300	11200	17400	22900	29100	46100
07154500*	30	1038.00	14.0	3.8212	0.4464	-0.11	6750	15800	24400	38500	51500	66700	112000
07154650	17	25.40	15.5	3.2627	0.4391	-0.35	1940	4340	6400	9450	12000	14800	21900
07155000	13	1879.00	16.5	3.9232	0.3307	-0.21	8600	16000	21800	30100	36800	43900	62000
07155100	17	11.00	15.8	1.5039	1.1944	-0.22	35	331	1010	3180	6520	12300	42200
07155900*	25	10.00	18.0	2.2882	0.9489	-0.16	206	1240	3060	7840	14200	24000	67700
07156000*	21	58.90	18.0	2.8525	0.6233	-0.19	745	2410	4340	7990	11700	16400	32000
07156010	10	463.00	17.6	2.8310	0.6647	0.18	647	2420	4950	10800	18200	29200	77900
07156220	15	835.00	17.5	2.9510	0.6987	-0.26	958	3520	6680	12900	19400	27700	55400
07156600	25	8.00	18.5	2.7182	0.5923	-0.55	592	1680	2710	4310	5670	7130	10800
07156700	25	2.41	19.0	2.4402	0.3882	-0.03	277	585	864	1310	1700	2160	3490
07157100*	25	44.00	20.0	2.8420	0.5122	-0.19	722	1890	3070	5050	6910	9110	15700
07157400	25	6.57	22.5	2.5522	0.7981	-0.30	391	1710	3510	7290	11400	16900	36100
07157550	16	4.22	20.3	2.1130	0.5000	-0.19	135	345	553	900	1220	1600	2720
07157900*	25	39.00	23.3	2.6795	0.5463	-0.21	499	1390	2320	3940	5490	7340	13000
07157960	15	408.00	23.0	3.0965	0.6975	-0.07	1270	4850	9670	20000	31900	48300	111000
07158080	12	1.61	24.6	2.1322	0.4383	-0.17	140	319	485	747	981	1250	2010
07158180	12	8.23	25.8	2.8530	0.5778	0.04	706	2180	3950	7470	11300	16400	35200
07158400	12	196.00	26.0	3.6691	0.2215	0.27	4560	7110	9090	11900	14300	16900	24000

Table 11.--Continued.

STATION NUMBER	RECORD LENGTH (YR)	DRAINAGE AREA (SQ MI)	MEAN ANNUAL PRECIP (IN)	LOG-PEARSON TYPE III STATISTICS, IN LOGARITHMIC UNITS			PEAK DISCHARGES IN CUBIC FEET PER SECOND FOR INDICATED RECURRENCE INTERVAL IN YEARS						
				MEAN	STD DEV	SKEW	2	5	10	25	50	100	500
07158550	17	5.08	26.0	2.5523	0.5796	-0.01	357	1100	1970	3680	5500	7890	16400
07159000*	28	248.00	28.8	3.4233	0.5164	0.02	2640	7200	12200	21400	30900	43000	83900
07159200	14	157.00	27.8	3.4231	0.5978	0.08	2600	8390	15600	30700	47600	70900	160000
07159810	14	0.15	32.4	1.4962	0.4918	0.15	30	81	136	241	352	497	1010
07160500*	33	410.00	29.3	3.6766	0.4604	0.17	4610	11500	18800	32300	46100	63800	125000
07160550	17	13.90	30.6	2.9885	0.3831	0.04	968	2040	3030	4620	6070	7780	12900
07163000*	48	31.00	33.2	3.3416	0.3754	0.66	2000	4360	6940	11900	17300	24600	52700
07163020	12	2.89	36.5	2.7774	0.2197	0.18	590	912	1160	1500	1780	2070	2870
07165550	15	50.00	38.0	3.5272	0.2853	0.18	3300	5810	7900	11100	1 800	16900	25700
07166000*†	20	747.00	37.0	4.2581	0.4485	-0.26	18900	43700	65900	100000	131000	164000	256000
07166500*†	21	1138.00	37.5	4.2094	0.3663	-0.27	16800	33200	46400	65400	80800	97300	139000
07169500	13	827.00	36.5	4.1721	0.3118	-0.39	15600	27500	36000	47200	55600	64000	83700
07169700	21	1.84	36.5	2.7084	0.3460	-0.12	519	1000	1400	1990	2490	3040	4500
07170000*	33	575.00	36.5	4.1033	0.4698	-0.54	14000	32100	46900	67900	84500	102000	142000
07170600	21	15.00	38.0	3.3844	0.3345	0.05	2410	4630	6530	9450	12000	14900	23200
07170700	23	37.00	38.5	3.5668	0.3303	0.21	3590	6930	9920	14700	19100	24300	39900
07170800	25	4.22	38.5	3.0578	0.2980	0.12	1130	2030	2780	3910	4890	6000	9120
07171700	25	3.10	35.0	2.7997	0.5527	-0.70	731	1880	2840	4190	5230	6270	8610
07171800	25	0.60	35.0	1.9927	0.4961	-0.60	110	262	388	565	703	845	1180
07172000*†	26	445.00	35.0	4.0938	0.4192	-0.79	14100	28400	38300	50400	58800	66500	82200
07173000 †	14	736.00	38.0	4.1492	0.3025	-0.48	14900	25600	32900	42200	48900	55500	70100
07174000	15	424.00	38.1	4.0089	0.3434	-0.47	10900	20100	26800	35600	42200	48800	64000
07174200*†	21	502.00	38.0	4.0943	0.2571	0.05	12400	20400	26600	35400	42600	50300	70700
07174600*	21	139.00	36.4	3.8400	0.2256	-0.24	7060	10800	13300	16400	18800	21100	26600
07174720	16	0.94	38.0	2.5128	0.2260	-0.45	339	509	616	744	833	918	1100

Table 11.--Continued.

STATION NUMBER	RECORD LENGTH (YR)	DRAINAGE AREA (SQ MI)	MEAN ANNUAL PRECIP (IN)	LOG-PEARSON TYPE III STATISTICS, IN LOGARITHMIC UNITS			PEAK DISCHARGES IN CUBIC FEET PER SECOND FOR INDICATED RECURRENCE INTERVAL IN YEARS						
				MEAN	STD DEV	SKEW	2	5	10	25	50	100	500
07175000	14	2.39	36.6	2.9587	0.4947	-0.46	991	2410	3660	5520	7080	8740	13000
07176500*†	32	364.00	35.0	4.0878	0.2376	-0.31	12600	19500	24200	30000	34300	38500	48100
07176800	11	30.60	36.4	3.6996	0.2403	-0.38	5190	8040	9910	12200	13900	15500	19200
07177000*†	38	340.00	36.2	3.9359	0.2128	0.52	8270	12800	16500	22100	26900	32400	48100
07177500*	42	905.00	37.0	4.2015	0.2853	0.58	14900	26900	38000	56700	74500	96500	168000
07183800*	25	12.00	40.5	3.4187	0.4105	-0.31	2750	5870	8500	12400	15600	19000	28000
07184000*	31	197.00	40.5	3.7626	0.3400	0.00	5790	11200	15800	22800	28900	35800	55300
07184500*	29	211.00	39.0	3.8899	0.2571	-0.28	7980	12900	16200	20600	23900	27200	34900
07184600*	21	27.00	40.0	3.6079	0.5118	-0.17	4190	11000	17900	29700	40900	54200	94400
07185500	26	3.86	42.0	2.8250	0.2426	-0.06	672	1070	1360	1760	2070	2390	3200
07185600	27	0.94	42.0	2.3164	0.3376	0.29	200	393	573	871	1150	1490	2560
07185700*	23	306.00	40.0	3.7519	0.3436	0.33	5410	10800	15900	24600	32900	43000	75600
07185900	23	9.67	40.0	3.0630	0.2441	-0.27	1190	1870	2330	2930	3380	3820	4860
07186000*	58	1164.00	40.0	4.2296	0.3005	-0.23	17400	30600	40400	53800	64400	75400	103000
07186400	18	232.00	41.0	3.7112	0.3515	0.23	4980	10100	14800	22600	29900	38700	66300
07187000*	57	427.00	40.0	3.8784	0.3898	-0.07	7630	16100	23700	35600	46200	58300	92900
07188000*	42	2510.00	41.5	4.5139	0.2897	-0.29	33700	57700	75000	98000	116000	134000	177000
07188140	16	4.90	41.8	2.9724	0.2848	0.03	936	1630	2180	2980	3640	4370	6330
07188500*	29	42.00	42.5	2.9425	0.6558	0.07	860	3110	6140	12800	20600	31800	77100
07188900	21	0.96	46.0	1.9685	0.5887	-0.51	104	297	483	775	1030	1300	2030
07189000*	41	872.00	44.0	4.2807	0.3806	-0.15	19500	40100	57800	84500	107000	133000	203000
07190600	15	71.10	40.9	3.6682	0.3068	-0.09	4710	8460	11400	15700	19200	23000	33000
07191000*	41	450.00	40.9	4.1896	0.3142	-0.11	15700	28500	38800	53400	65500	78600	113000
07191220*	21	133.00	44.0	3.4085	0.5494	-0.44	3320	8930	14200	22600	29900	37900	59200
07192000*	21	229.00	40.8	3.7089	0.4215	0.19	4960	11500	18100	29800	41400	56000	105000

Table 11.--Continued.

STATION NUMBER	RECORD LENGTH (YR)	DRAINAGE AREA (SQ MI)	MEAN ANNUAL PRECIP (IN)	LOG-PEARSON TYPE III STATISTICS, IN LOGARITHMIC UNITS			PEAK DISCHARGES IN CUBIC FEET PER SECOND FOR INDICATED RECURRENCE INTERVAL IN YEARS						
				MEAN	STD DEV	SKEW	2	5	10	25	50	100	500
07194515	16	2.57	42.8	2.7173	0.3150	0.09	516	957	1330	1900	2400	2960	4570
07194890	19	40.40	45.0	3.1282	0.5251	-0.11	1370	3740	6230	10600	14900	20200	36800
07195000*	30	130.00	45.0	3.6745	0.3788	-0.07	4770	9870	14400	21300	27500	34400	54100
07195200	21	0.37	41.0	1.7883	0.5030	-0.17	63	164	265	436	596	787	1360
07195450	19	14.60	40.0	3.1320	0.5053	-0.47	1480	3670	5610	8520	10900	13600	20200
07195500*	25	635.00	44.5	4.2205	0.3693	-0.45	17700	34400	47000	64000	77100	90400	122000
07195800*	21	14.20	41.0	2.8190	0.6252	-0.01	660	2220	4170	8170	12600	18600	41100
07196000*	23	110.00	43.8	3.5750	0.5277	-0.28	3980	10600	17100	27900	37800	49200	82000
07196380	11	3.59	43.3	2.7062	0.6355	-0.23	538	1770	3180	5830	8510	11900	22700
07196500*	48	959.00	44.3	4.2740	0.3921	-0.10	19100	40400	59200	88400	114000	143000	226000
07196900*	23	46.00	46.0	3.7533	0.4586	-0.48	6170	14000	20500	29900	37400	45200	64500
07197000*	34	307.00	44.5	4.1346	0.2949	-0.55	14500	24400	31000	39000	44700	50100	61700
07228290	16	10.40	25.7	3.0040	0.4270	-0.08	1020	2320	3530	5500	7300	9400	15600
07228450	12	2.31	27.8	2.4973	0.2848	0.32	303	539	742	1060	1350	1680	2680
07228960	11	3.32	31.3	2.8595	0.2538	0.10	717	1180	1540	2050	2480	2940	4160
07229300	15	202.00	34.5	3.9163	0.2505	0.36	7970	13200	17600	24200	30100	36700	55900
07229420	17	2.28	37.7	2.6773	0.3106	0.38	455	854	1220	1820	2380	3060	5190
07229430	11	2.26	40.6	2.8389	0.2965	0.39	660	1210	1690	2490	3220	4090	6800
07230000 †	13	257.00	34.0	3.7236	0.2410	0.72	4950	8190	11100	15800	20200	25600	42600
07230500*†	22	456.00	35.0	3.9911	0.2837	0.85	8940	16200	23500	36300	49400	66200	126000
07231000 †	19	865.00	36.0	4.1924	0.2857	0.03	15500	27100	36300	49600	60700	72900	106000
07231320	17	0.72	41.0	2.5380	0.3361	0.30	332	653	951	1440	1910	2470	4250
07231560	11	7.40	42.0	3.2332	0.3023	0.26	1660	3040	4250	6150	7860	9860	15800
07231950	17	9.99	47.0	3.6761	0.3035	0.12	4680	8500	11700	16600	20900	25700	39400
07232000*	21	588.00	44.0	4.1126	0.3137	0.49	12200	23300	33700	51400	68500	89500	159000

Table 11.--Continued.

STATION NUMBER	RECORD LENGTH (YR)	DRAINAGE AREA (SQ MI)	MEAN ANNUAL PRECIP (IN)	LOG-PEARSON TYPE III STATISTICS, IN LOGARITHMIC UNITS			PEAK DISCHARGES IN CUBIC FEET PER SECOND FOR INDICATED RECURRENCE INTERVAL IN YEARS						
				MEAN	STD DEV	SKEW	2	5	10	25	50	100	500
07232500*	44	1175.00	17.0	3.7640	0.5577	-0.39	6310	17400	28300	45900	61600	79400	128000
07232650	12	31.00	15.6	2.1116	0.8743	-0.15	136	713	1650	3950	6860	11200	29500
07233000*	26	767.00	20.0	3.4105	0.5471	-0.26	2720	7520	12400	20800	28700	37900	65400
07233500*	36	440.00	20.5	3.3917	0.5061	0.18	2380	6500	11200	20300	30100	43100	90500
07234050	17	4.22	19.7	1.6031	0.9167	-0.26	44	242	561	1320	2250	3590	8890
07234100	14	170.00	19.8	3.1675	0.7069	-0.19	1550	5860	11400	22700	35000	51300	109000
07234290	14	8.57	21.0	2.5126	0.4718	-0.10	331	816	1290	2100	2860	3770	6530
07235000*	27	475.00	20.5	3.4610	0.5024	-0.27	3050	7750	12300	19600	26200	33700	55100
07235700	11	17.60	21.6	2.6879	0.5407	0.03	484	1390	2410	4360	6410	9060	18300
07237750	17	11.80	24.6	2.6101	0.4408	-0.19	421	965	1460	2250	2950	3740	5990
07237800	14	139.00	24.5	3.5429	0.2497	-0.12	3530	5680	7240	9330	11000	12700	16800
07239050	12	0.52	27.7	2.0894	0.3957	0.17	120	262	401	639	868	1150	2050
07242160	13	16.50	40.6	3.3819	0.1841	0.15	2380	3430	4170	5170	5950	6760	8810
07243000	25	69.00	35.0	3.5494	0.2837	0.39	3390	6040	8370	12100	15500	19500	31800
07243500*†	23	2018.00	36.2	4.0820	0.4392	0.17	11700	28000	44900	75200	106000	144000	274000
07243550	16	5.90	38.5	3.0486	0.3621	-0.10	1130	2270	3220	4670	5910	7300	11100
07244000	19	2307.00	37.5	4.1165	0.4077	0.10	12900	28700	44000	69800	94400	124000	218000
07244790	11	5.66	44.0	3.2686	0.3120	-0.06	1870	3400	4640	6430	7940	9570	14000
07245500*†	22	182.00	43.5	4.1105	0.4118	0.11	12700	28500	43900	70200	95400	126000	223000
07246630	17	5.32	43.5	2.9788	0.2677	-0.36	988	1610	2040	2590	2990	3390	4310
07247000*†	35	203.00	45.0	4.0419	0.2992	-0.11	11200	19700	26400	35800	43500	51800	73100
07247500*†	26	122.00	45.5	3.8232	0.3889	0.09	6560	14100	21200	32900	43800	56900	97100
07248500 †	11	993.00	48.0	4.4392	0.3627	0.03	27400	55400	80400	120000	155000	196000	315000
07249000	14	1240.00	48.0	4.3575	0.3657	0.11	22400	46000	67600	103000	135000	173000	288000
07249300	19	44.00	42.0	3.6931	0.3867	0.20	4790	10300	15700	24900	33800	44600	79700

Table 11.--Continued.

STATION NUMBER	RECORD LENGTH (YR)	DRAINAGE AREA (SQ MI)	MEAN ANNUAL PRECIP (IN)	LOG-PEARSON TYPE III STATISTICS, IN LOGARITHMIC UNITS			PEAK DISCHARGES IN CUBIC FEET PER SECOND FOR INDICATED RECURRENCE INTERVAL IN YEARS						
				MEAN	STD DEV	SKEW	2	5	10	25	50	100	500
07249400*	23	147.00	43.0	3.7929	0.3221	0.24	6020	11500	16300	24200	31300	39800	65500
07249500*	31	35.30	48.0	3.7021	0.3532	0.19	4910	9900	14500	22000	29000	37400	63100
07249650	20	8.15	43.0	3.0922	0.3512	-0.15	1260	2450	3440	4880	6100	7430	11000
07249950	20	0.34	42.0	1.4760	0.6525	0.06	29	105	207	429	690	1060	2540
07250000*	38	426.00	47.0	4.3960	0.2881	0.06	24700	43400	58500	80600	99400	120000	177000
07261300	22	2.33	46.0	2.6171	0.4546	0.32	392	979	1630	2890	4240	6040	12700
07299670*	20	303.00	24.0	3.2581	0.4748	0.10	1780	4520	7440	12800	18200	25100	48400
07300000	15	1013.00	21.5	4.2758	0.4782	0.22	18100	47000	79200	140000	205000	291000	600000
07300150	17	7.24	23.0	2.8962	0.4107	-0.15	807	1760	2600	3920	5080	6380	10000
07300500*	43	1357.00	22.5	4.1727	0.3328	-0.07	15000	28400	39500	55800	69600	84900	126000
07301455	13	19.80	23.8	3.0698	0.3333	-0.18	1200	2250	3090	4280	5260	6310	9030
07301480	16	9.12	23.8	2.7151	0.3231	0.35	497	955	1380	2080	2740	3540	6090
07301500*	36	1938.00	23.0	3.8478	0.3561	0.23	6820	13900	20500	31500	42000	54500	94200
07303400*	20	416.00	23.2	3.7513	0.3026	0.08	5590	10100	13900	19500	24300	29800	45000
07303450	12	27.80	23.0	2.9677	0.3006	-0.09	938	1670	2240	3050	3720	4430	6310
07303500*	28	838.00	23.2	3.8967	0.3594	-0.26	8170	16000	22200	31100	38400	46100	66000
07309480	11	3.35	31.0	2.8989	0.4659	-0.51	868	1990	2910	4230	5290	6380	9030
07311200	16	24.60	29.6	3.0763	0.4680	-0.16	1230	2970	4650	7410	9950	12900	21600
07311500*	31	617.00	28.1	3.7496	0.3829	-0.15	5750	11900	17100	25100	31900	39500	60300
07312850	17	6.29	29.9	2.8953	0.4455	-0.19	811	1880	2860	4420	5820	7420	11900
07312950	12	35.40	32.7	2.9313	0.4511	0.27	814	2010	3320	5780	8370	11800	24000
07313000	15	158.00	32.5	4.0219	0.5301	-0.04	10600	29400	50000	87700	126000	174000	334000
07313500*†	24	563.00	31.7	3.6665	0.4969	0.41	4290	11800	20900	40000	62000	93300	221000
07313600 †	12	193.00	31.6	3.3657	0.4731	0.06	2300	5790	9440	16000	22500	30700	57900
07315680	17	1.74	33.4	2.6365	0.4340	0.12	424	997	1580	2600	3600	4850	8940

Table 11.--Continued.

STATION NUMBER	RECORD LENGTH (YR)	DRAINAGE AREA (SQ MI)	MEAN ANNUAL PRECIP (IN)	LOG-PEARSON TYPE III STATISTICS, IN LOGARITHMIC UNITS			PEAK DISCHARGES IN CUBIC FEET PER SECOND FOR INDICATED RECURRENCE INTERVAL IN YEARS						
				MEAN	STD DEV	SKEW	2	5	10	25	50	100	500
07315700*	20	572.00	33.0	3.6465	0.4185	0.38	4170	9750	15700	26900	38700	54200	110000
07315880	10	5.74	34.8	3.2752	0.0718	-0.03	1890	2170	2330	2510	2640	2760	3020
07316140	16	12.00	35.5	3.4373	0.2588	-0.12	2770	4530	5830	7570	8950	10400	13900
07316500*†	22	794.00	22.8	3.7444	0.5304	0.15	5390	15400	27000	50100	75100	109000	233000
07317500	21	5.16	24.0	2.6590	0.4425	0.27	436	1060	1730	2970	4270	5960	12000
07318500	12	1.02	24.0	2.4518	0.4245	0.03	281	643	994	1590	2150	2820	4920
07320000	19	2.87	24.0	2.8573	0.2681	-0.11	728	1210	1580	2070	2470	2880	3920
07321500	14	0.62	24.0	2.5543	0.3676	0.12	352	727	1070	1630	2150	2770	4650
07324000	17	5.33	24.0	3.0099	0.4456	-0.04	1030	2430	3790	6080	8230	10800	18700
07325000*†	20	1977.00	24.2	3.8876	0.4081	0.26	7410	16800	26300	43400	60500	82200	156000
07326000	15	313.00	28.0	3.6915	0.4244	0.44	4570	10900	17800	31300	45700	65200	139000
07327150	11	23.76	32.0	2.8715	0.4147	0.19	722	1650	2570	4200	5820	7820	14500
07327438	12	0.04	32.2	0.9676	0.5207	0.03	9	25	43	77	111	155	305
07327440 †	10	35.20	32.2	3.2484	0.2773	-0.00	1770	3030	4020	5420	6570	7820	11100
07327490*†	20	208.00	32.0	3.4927	0.3686	0.52	2890	6170	9570	15800	22300	30700	61100
07329000	15	145.00	33.0	4.0163	0.2339	0.35	10100	16100	21100	28400	34700	41700	61700
07329870	16	18.70	37.3	3.2570	0.3598	0.07	1790	3620	5260	7870	10200	13000	21100
07329900 †	11	138.00	38.3	3.6811	0.4156	0.33	4550	10500	16800	28400	40300	55800	110000
07330500	14	298.00	38.0	3.9207	0.3233	-0.02	8350	15600	21600	30500	38100	46600	69700
07332070	10	0.72	40.0	2.6082	0.2731	0.33	392	680	926	1310	1650	2040	3200
07332400	15	203.00	39.5	3.9675	0.2817	-0.08	9360	16100	21200	28400	34200	40400	56400
07332500*	44	476.00	39.5	3.9652	0.2920	0.19	9030	16100	22100	31300	39300	48500	74800
07332600*	20	72.00	43.5	3.8880	0.2482	-0.65	8220	12600	15300	18300	20300	22100	25800
07333500	19	32.70	44.5	3.8771	0.1884	0.09	7490	10800	13200	16300	18700	21300	27500
07334000*†	22	1087.00	42.0	4.3385	0.2168	0.29	21300	32900	41900	54800	65500	77300	109000

Table 11.-Continued.

STATION NUMBER	RECORD LENGTH (YR)	DRAINAGE AREA (SQ MI)	MEAN ANNUAL PRECIP (IN)	LOG-PEARSON TYPE III STATISTICS, IN LOGARITHMIC UNITS			PEAK DISCHARGES IN CUBIC FEET PER SECOND FOR INDICATED RECURRENCE INTERVAL IN YEARS						
				MEAN	STD DEV	SKEW	2	5	10	25	50	100	500
07335000*†	20	720.00	40.5	4.1559	0.3615	0.13	14100	28700	42100	63800	83800	107000	179000
07335310	16	0.94	44.8	2.4047	0.2872	-0.27	262	446	580	759	896	1040	1380
07335320	11	16.60	45.4	3.5048	0.2398	-0.26	3270	5120	6380	7990	9190	10400	13200
07335700	15	40.10	54.0	3.8762	0.2327	-0.20	7660	11900	14800	18500	21300	24100	30800
07336500*	47	1423.00	49.0	4.5337	0.1894	-0.12	34500	49400	59400	72000	81300	90600	112000
07336520	16	19.40	49.0	3.4193	0.2772	-0.02	2630	4500	5940	7990	9670	11500	16200
07336710	11	3.39	46.5	2.8988	0.2009	0.06	789	1170	1440	1800	2080	2370	3100
07336750	11	75.40	46.0	3.7212	0.3386	-0.15	5360	10200	14100	19800	24500	29600	43200
07336780	10	7.53	50.0	3.3505	0.1563	0.29	2200	3020	3590	4360	4960	5590	7190
07336800	17	100.00	46.0	3.5844	0.3516	-0.25	3970	7650	10600	14700	18100	21700	30900
07337220	11	1.99	51.0	2.6359	0.3571	-0.01	433	864	1240	1820	2330	2920	4580
07337500*†	26	645.00	52.0	4.4822	0.2542	-0.04	30500	49700	64100	83800	99600	116000	158000
07337900*†	20	315.00	52.0	4.4542	0.2884	0.10	28100	49600	67100	93100	115000	140000	209000
07338500*	39	1226.00	52.0	4.4386	0.2686	-0.04	27600	46300	60500	80400	96500	114000	158000
07338520	17	9.10	51.5	3.1942	0.2933	-0.25	1610	2780	3640	4810	5720	6650	8930
07338700	19	16.10	49.0	3.2926	0.2927	0.32	1890	3410	4750	6860	8770	11000	17800
07339000*†	40	787.00	55.0	4.5916	0.2624	-0.29	40200	65400	82900	106000	123000	140000	180000
07339500*†	26	181.00	52.0	4.2065	0.3458	0.29	15500	31000	45600	70000	93200	121000	211000
07339800	21	6.43	48.0	2.8778	0.4636	-0.11	770	1860	2920	4690	6340	8280	14100
07340200	20	10.60	46.0	3.1607	0.2778	-0.27	1490	2500	3220	4170	4900	5640	7410
07340300	13	89.40	59.0	4.2181	0.3481	-0.28	17200	32700	44900	62100	75800	90300	127000
07340500*†	37	361.00	54.0	4.4566	0.2599	0.19	28100	47100	62300	84700	104000	125000	183000
07341000*†	34	124.00	54.0	3.9889	0.3316	0.09	9640	18500	26100	38000	48500	60600	95400
07341100	21	9.48	51.0	3.3409	0.3104	0.03	2180	4000	5490	7720	9620	11700	17600
07341200	10	260.00	53.0	4.2059	0.3942	0.30	15400	33900	52700	86100	119000	162000	305000
07343000*	34	276.00	45.0	4.5244	0.1541	-0.47	34400	45300	51600	58600	63200	67400	76100

* Stations used in developing generalized skew map.

† Stations which have unregulated periods of record, but are now regulated.