Estimates of Runoff from Small Water Sheds In Eastern Colorado, Western Kansas and Nebraska, And Southeastern Wyoming

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Prepared under the Sponsorship of the Hydraulics Division,
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ABSTRACT

This report presents a method for predicting peak rates of runoff from ungaged watersheds in eastern Colorado, western Kansas, and Nebraska, and southeastern Wyoming, using watershed area and a slope parameter. An estimate of the accuracy of the method, and recommended maximum and minimum design discharges for a 10-year recurrence interval are given.

A summary of results of related studies is presented.

The investigation is being continued to refine the techniques presented herein, and to extend the study to adjacent areas.

INTRODUCTION

This paper presents a method for estimating peak rates of runoff from ungaged watersheds, using watershed contributing area and a slope parameter. Relations presented herein were developed from a study of a large number of factors that affect peak rates of runoff, and from consideration of the history of flood events on gaged watersheds in the study area.

ESTIMAGES OF PEAK RATES OF RUNOFF FROM UNGAGED WATERSHEDS

Area of Application - Results of this study are applicable in the shaded area of Fig. 1. Attempts should not be made to apply these results outside of this region.

Estimates of Peak Rates of Runoff from Physiographic Parameters - Fig. 2 gives estimates of flood flows having a recurrence interval of 10 years (Q_{10}) as a function of watershed contributing area in square miles and a slope parameter. The slope parameter $S_{0.9L}$ may be computed as follows:

$$S_{0.9L} = \frac{E_{0.9L} - E_{CS}}{0.9L}$$

where E_{CS} = elevation (feet MSL) at the construction site

L = length of the main river channel and its major tributary in miles

$E_{0.9L}$ = elevation (feet MSL) at a point $0.9L$ upstream from the construction site.

From flood frequency studies of watersheds in and near the study area it was determined that the peak rates of runoff from floods

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having a 40-year recurrence interval (Q_{40}) were approximately twice as big as floods having a 10-year recurrence interval (Q_{10}). The ratios of Q_n/Q_{10} shown on Fig. 2 were determined by plotting the ratios of Q_n/Q_{10} for n=10 and 40 on extremal probability paper and connecting the points with a straight line. Intermediate points were determined by interpolation. Values of Q_n/Q_{10} for recurrence intervals of 45 and 50 years were determined by an extrapolation of the straight line. It should be emphasized that considerable inaccuracy may result from such an extrapolation technique, since the basic data used to derive Fig. 2 were limited to records less than 40 years.

Limitation on Size of Contributing Watershed - Fig. 2 is applicable for watersheds having a contributing area of about 1000 square miles or less. The basic data that were used in the preparation of Fig. 2 included very few watersheds less than 100 square miles. Therefore, the portion of Fig. 2 for contributing areas less than 100 square miles is shown in dashed lines to indicate a degree of uncertainty associated with estimates of peak rates of runoff for contributing areas smaller than 100 square miles.

Degree of Accuracy to be Expected From Fig. 2 - Fig. 3 shows the cumulative relative frequency of errors of estimate of the flood flow having a 10-year recurrence interval (Q_{10}) that can be expected from use of Fig. 2. Fig. 3 shows, for example, that use of Fig. 2 gave errors of estimate of Q_{10} of less than 20 per cent for about 58 per cent of the cases. It also shows that errors of estimate exceeding 50 per cent can be expected slightly more than 20 per cent of the time. "Percent of error" is defined by:

$$\text{Per cent of error} = \frac{Q_{10}(\text{Estimated}) - Q_{10}(\text{Actual})}{Q_{10}(\text{Estimated})}$$

Examples of Use of Fig. 2 for Estimating Peak Rates of Runoff - The following examples illustrate the use of Fig. 2 for estimating peak rates of runoff from ungaged watersheds in the region shown in Fig. 1.

EXAMPLE 1. (D-13 Area)

Assume that in order to provide for more efficient control of the traffic to and from the Martin Company Plant near Littleton, Colo., a four-lane highway approximately 2.5 miles long is to be constructed from the Plant to Highway 87. The highway will cross Plum Creek and will join Highway 87 just north of its present junction with Highline canal. Part of the highway design problem is to determine Q_{10}, Q_{25}, and Q_{50} (the discharges having recurrence intervals of 10, 25, and 50 years, respectively for Plum Creek at the place of crossing.)

By means of a topographical map the following information is obtained:

$$A = 400 \text{ sq. mi.}$$

$$E_{0.9L} = 6340 \text{ ft.}$$

$$E_{CS} = 5425 \text{ ft.}$$

$$L = 24 \text{ miles.}$$

On the basis of these factors compute the slope, $S_{0.9L}$, expressed by

$$S_{0.9L} = \frac{E_{0.9L} - E_{CS}}{0.9L} = \frac{915}{21.6} = 42.3 \text{ ft./mi.}$$

For $A = 400$ sq. mi. and $S_{0.9L} = 42.3$ ft./mi. the graph of Fig. 2 gives

$$Q_{10} = 13,900 \text{ cfs}$$

By applying the appropriate ratios shown at the top of the graph it is seen that

$$Q_{25} = (Q_{10})(1.66) = 23,100 \text{ cfs}$$

$$Q_{50} = (Q_{10})(2.15) = 29,900 \text{ cfs}$$

These are the required design estimates.

EXAMPLE 2. (D-20 Area)

To relieve traffic congestion in the business district of Pueblo, Colorado, it is decided to relocate Highway 6 north of the city. Relocating the highway will require crossing Fountain Creek. Part of the highway design problem is to determine Q_{10}, Q_{25} and Q_{50} at the place of crossing.

By means of a topographical map the following information is obtained:

$$A = 920 \text{ sq. mi.}$$

$$E_{0.9L} = 5900$$

$$E_{CS} = 4700$$

$$L = 53 \text{ mi.}$$

Computing the slope, $S_{0.9L}$, by

$$S_{0.9L} = \frac{E_{0.9L} - E_{CS}}{0.9L} = \frac{1200}{47.6} = 25.2 \text{ ft./mi.}$$

For $A = 920$ sq. mi. and $S_{0.9L} = 25.2$ ft./mi. the graph of Fig. 2 gives:

$$Q_{10} = 11{,}900 \text{ cfs.}$$

By applying the appropriate ratios shown at the top of the graph it is seen that

$$Q_{25} = (Q_{10})(1.66) = 19{,}800 \text{ cfs.}$$

$$Q_{50} = (Q_{10})(2.15) = 25{,}600 \text{ cfs.}$$

These are the required design estimates.

EXAMPLE 3. (D-13 Area)

A contract is to be let for widening and surfacing of Highway 86 between Castle Rock, Colorado, and Frankton, Colorado. Part of the contract calls for relocation of the highway across Cherry Creek. To determine if the size of flow control structures now used would be adequate for the new crossing, values for Q_{10}, and Q_{25}, and Q_{50} are to be obtained.

By means of a topographical map the following information is obtained:

$$A = 170 \text{ sq. mi.}$$

$$E_{0.9L} = 7120 \text{ ft.}$$

$$E_{CS} = 6150 \text{ ft.}$$

$$L = 27 \text{ miles}$$

Computing the slope, $S_{0.9L}$, by

$$S_{0.9L} = \frac{E_{0.9L} - E_{CS}}{0.9L} = \frac{970}{24.3} = 40.0 \text{ ft./mi.}$$

For $A = 170$ sq. mi. and $S_{0.9L} = 40.0$ ft./mi. the graph of of Fig. 2 gives

$$Q_{10} = 5100 \text{ cfs.}$$

By applying the appropriate ratios shown at the top of the graph it is seen that

$$Q_{25} = (Q_{10})(1.66) = 8500 \text{ cfs.}$$

$$Q_{50} = (Q_{10})(2.15) = 11{,}000 \text{ cfs.}$$

These are the required design estimates.

Recommended Maximum and Minimum Values of Q_{10} as a Function of Watershed Size - Fig. 4 shows recommended limiting values of discharge as a function of watershed size. The recommended values shown in Fig. 4 are intended to assist the designer in making a sound judgment in selection of a design discharge. The small circles shown in Fig. 4 are the actual values of Q_{10} for the watersheds that were used in deriving the relation shown in Fig. 2.

The maximum curve on Fig. 4 represents the upper limits of Q_{10} obtained from values of $S_{0.9L}$ for watersheds used in developing Fig. 2. This does not imply that higher values may not be encountered, but that these combinations have not been tested by gaged watersheds. In such cases the user must exercise his own judgment as to whether or not he should use the higher Q_{10} value as his estimate.

LIMITATIONS AND PRECAUTIONS

Limitations in Basic Data - Because of the limited basic data that were available for this study, particularly for watersheds having a contributing area of less than 100 square miles, the results presented in this study must be considered as tentative and subject to revision as new data become available.

Judgment Required - The information presented herein can not be considered as a substitute for judgment on the part of the designer, but are intended as a tool to assist him in the selection of a design discharge. While the results of this study are believed to be applicable to the entire area as shown in Fig. 1, the sample of watersheds used to develop Fig. 2 was limited in number. Therefore, the designer must exercise judgment in use of Fig. 2. For example, it is possible that Fig. 2 would give a design estimate that might be too high for an area of very sandy soils, or an area underlain with gravel.

SUMMARY OF RELATED STUDIES

Characteristics of Precipitation Associated with Annual Maximum Flood Events - From a study of precipitation amounts associated with annual maximum flood events from nine watersheds in Colorado in the foothills of the Rocky Mountains, it was concluded that for watersheds equal to or greater than about 900 square miles, two-thirds or more of the annual maximum floods were probably caused by rains covering the entire watershed; while for watersheds smaller than about 50 square miles, one-third or less are produced by such rains.

Estimates of Clock-Hourly Precipitation from Precipitation Amounts of Longer Duration - A study was made to determine the interrelations among precipitation amounts for various time periods for a given recurrence interval for precipitation records for stations located in eastern Colorado. Preliminary studies show that estimates of clock-hourly precipitation can be made with satisfactory accuracy from records of precipitation amounts of longer duration.

Utilization of Weather Radar Data to Provide Increased Areal - Coverage of Rainfall Events - Attempts were made to utilize weather radar data to extend the areal coverage for individual rainfall events. It was concluded that the available data were not suitable for the intended purpose.

Correlation of Precipitation Factors with Physiographic Parameters - Some success was obtained in correlating mean monthly precipitation for May with position (latitude, longitude, and elevation) for 48 stations in eastern Colorado.

Seasonal Distribution of Annual Maximum Flood Events - A study was made to determine the effect of watershed contributing area and elevation on the seasonal distribution of annual maximum flood events from sixty-two (62) stations drawn from all parts of Colorado except the San Luis Valley.

Results indicate that the average date of occurrence of 67 per cent of the annual maximum floods advances with increase in watershed size.

For watersheds having an elevation less than 7683 feet, the date of occurrence of 67 per cent of the annual maximum floods advances with decreasing elevation.

These results can be interpreted in terms of summertime rains as a cause of flood events on the plains, as compared to snow melt, or a combination of snow melt and rain as a cause of flood events in the mountain areas.

ADDITIONAL INFORMATION

A summary of the basic data used in deriving Fig. 2 is given in Table 1.

A complete report on the development of the relations presented in this report, plus more complete information on the related studies summarized above, is available from the authors. Copies of the complete report may be obtained on a loan basis on request.

The study is being continued to improve the accuracy of the techniques presented, and to extend the study to adjacent areas.

TABLE I SUMMARY OF BASIC DATA

Serial Number	Name of Watersheds	Location		Contributing Drainage Area	$S_{0.9L}$	Q_{10}		
		Longitude	Latitude			Estimate from Fig. 2	Obtained by Freq. Analysis	Error in %
		(Degree° Min.' Sec.")		Sq. mi.			cfs	
1	Fountain Creek at Pueblo, Colo.	104°-35'-40"	38°-16'-20"	926	35.2	17,400	16,300	+ 6.3
3	Apishapa River near Fowler, Colo.	103 -59 -00	38 -05 -00	1125	35.5	18,000	15,000	+16.7
4	Timpas Creek near Rocky Ford, Colo.	103 -43 -20	37 -57 -20	451	24.3	8,000	9,500	-18.8
10	Blue Creek near Lewellen, Nebr.	102 -10 -00	41 -20 -00	267	13.7	1,320	600	+54.5
11	Birdwood Creek near Hershey, Nebr.	101 -04 -00	41 -13 -00	286	10.7	860	1,100	-27.9
12	Cherry Creek near Franktown, Colo.	104 -45 -50	39 -21 -30	172	53.3	7,650	6,400	+16.4
13	Cherry Creek near Melvin, Colo.	104 -49 -15	39 -36 -20	369	42.3	13,000	11,600	+10.8
16	Lodgepole Creek at Bushnell, Nebr.	103 -51 -00	41 -14 -00	1090	27.3	13,400	5,900	+55.9
18	N. Fork Republican River at Colo. - Nebr. State Line	102 -03 -05	40 -04 -10	130	18.5	1,520	1,400	+ 7.9
19	Buffalo Creek near Haigler, Nebr.	101 -52 -15	40 -02 -45	21	27.9	190	112	+41.0
20	Rock Creek near Parks, Nebr.	101 -43 -40	40 -02 -30	14	19.0	68	68	0.0

TABLE I SUMMARY OF BASIC DATA (Continued)

Serial Number	Name of Watersheds	Location		Contributing Drainage Area	$S_{0.9L}$	Q_{10}		
		Longitude	Latitude			Estimate from Fig. 2	Obtained by Freq. Analysis	Error in %
		(Degree° Min.' Sec.")		Sq. mi.			cfs	
22	Frenchman Creek below Champion Nebr.	101°-43'-10"	40°-28'-00"	570	13.1	1,970	1,660	+15.7
25	Niobrara River above Box Butte Reservoir, Nebr.	103 -10 -15	42 -27 -35	980	10.6	1,440	1,100	+23.6
31	Pumpkin Creek near Bridgeport, Nebr.	103 -02 -00	41 -38 -00	1080	13.8	2,960	740	+75.0
33	Landsman Creek near Hale, Colo.	102 -14 -50	39 -34 -40	450	17.7	4,300	5,050	-17.4
34	S. Fork Republican River near Idalia, Colo.	102 -14 -30	39 -37 -00	1300	19.3	8,750	17,000	-94.4

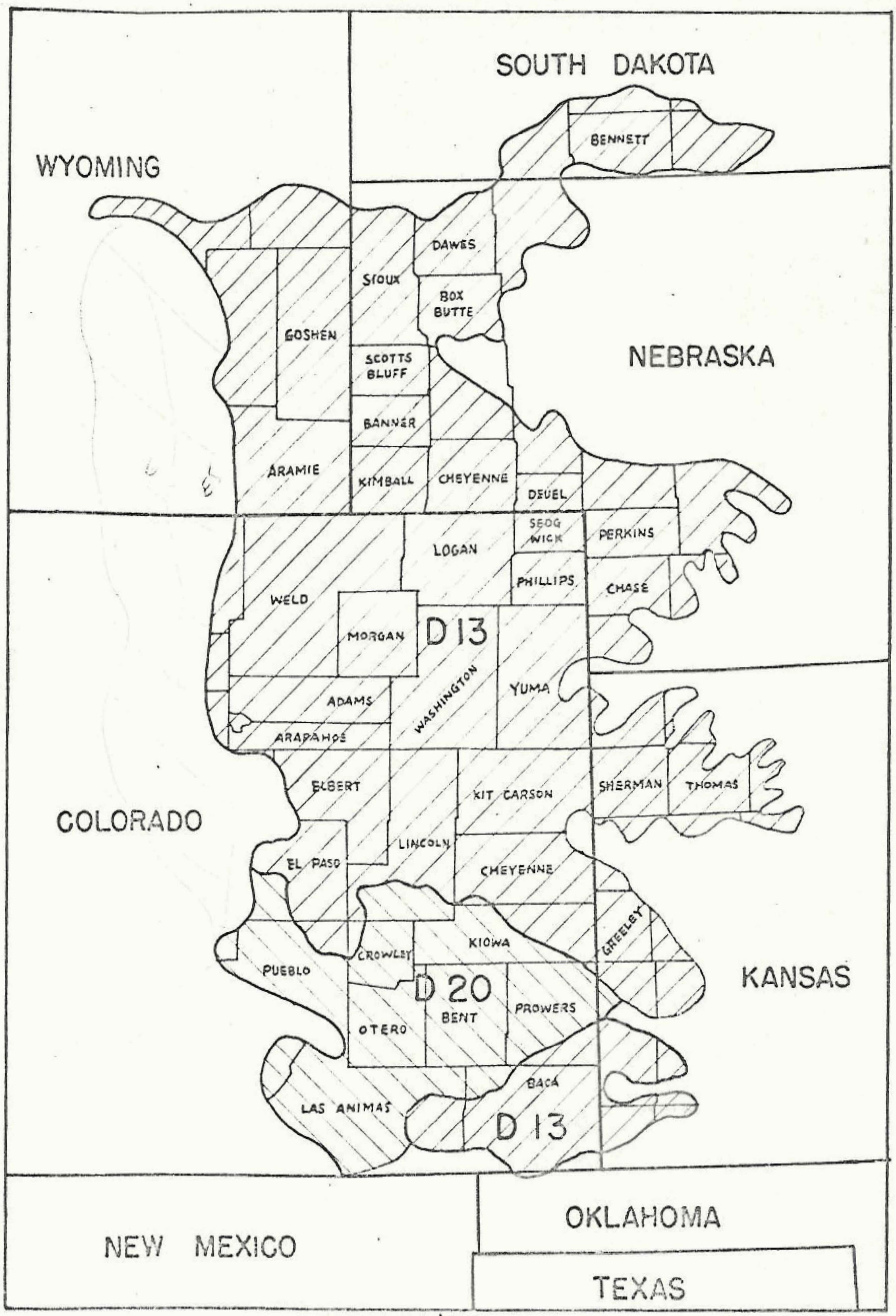

Fig. 1 Area of Application of Method for Estimating Flood Flows.

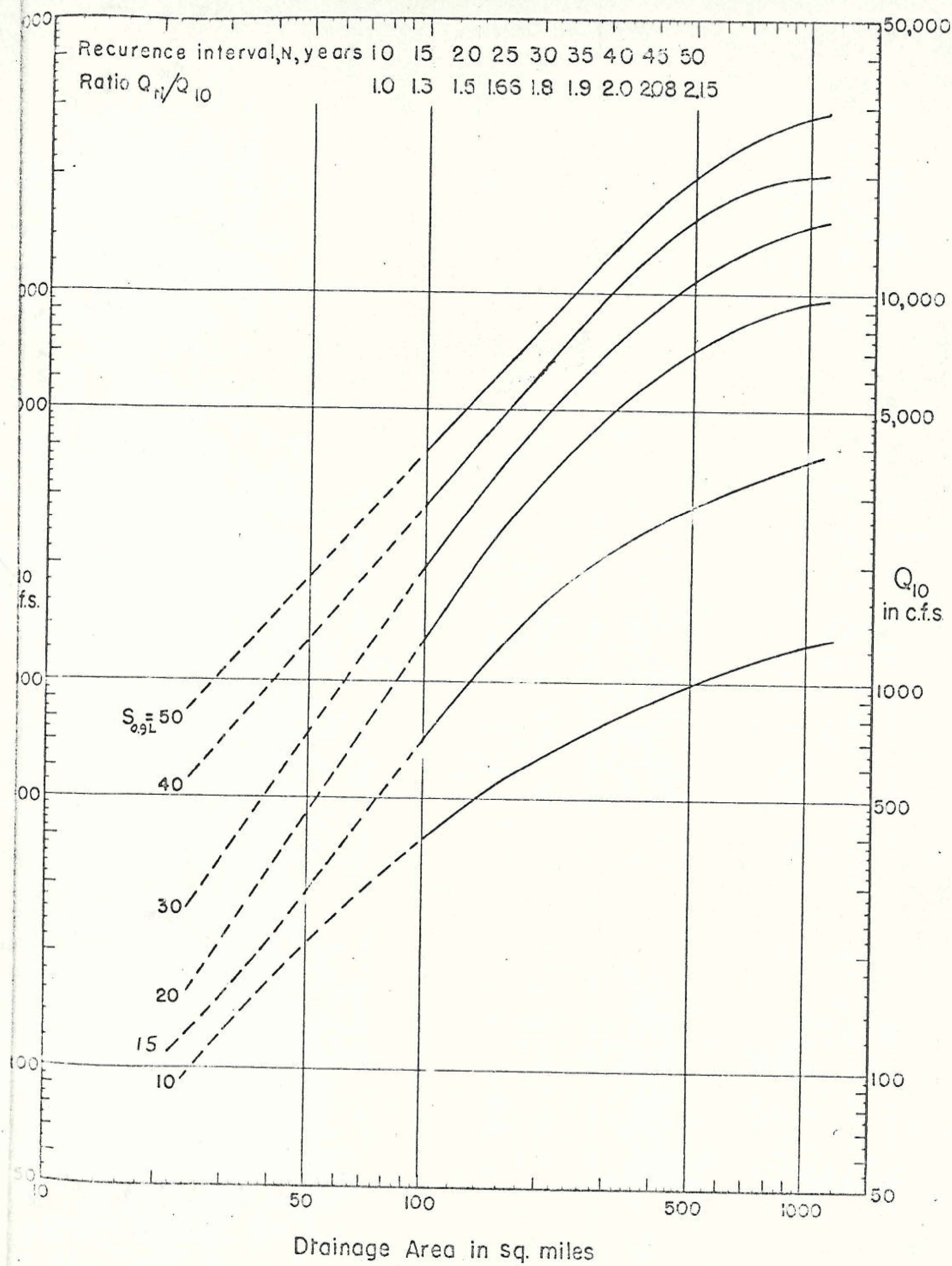

Fig. 2 Flood Flows Determined from Watershed Contributing Area and a Slope Factor $S_{0.9L}$.

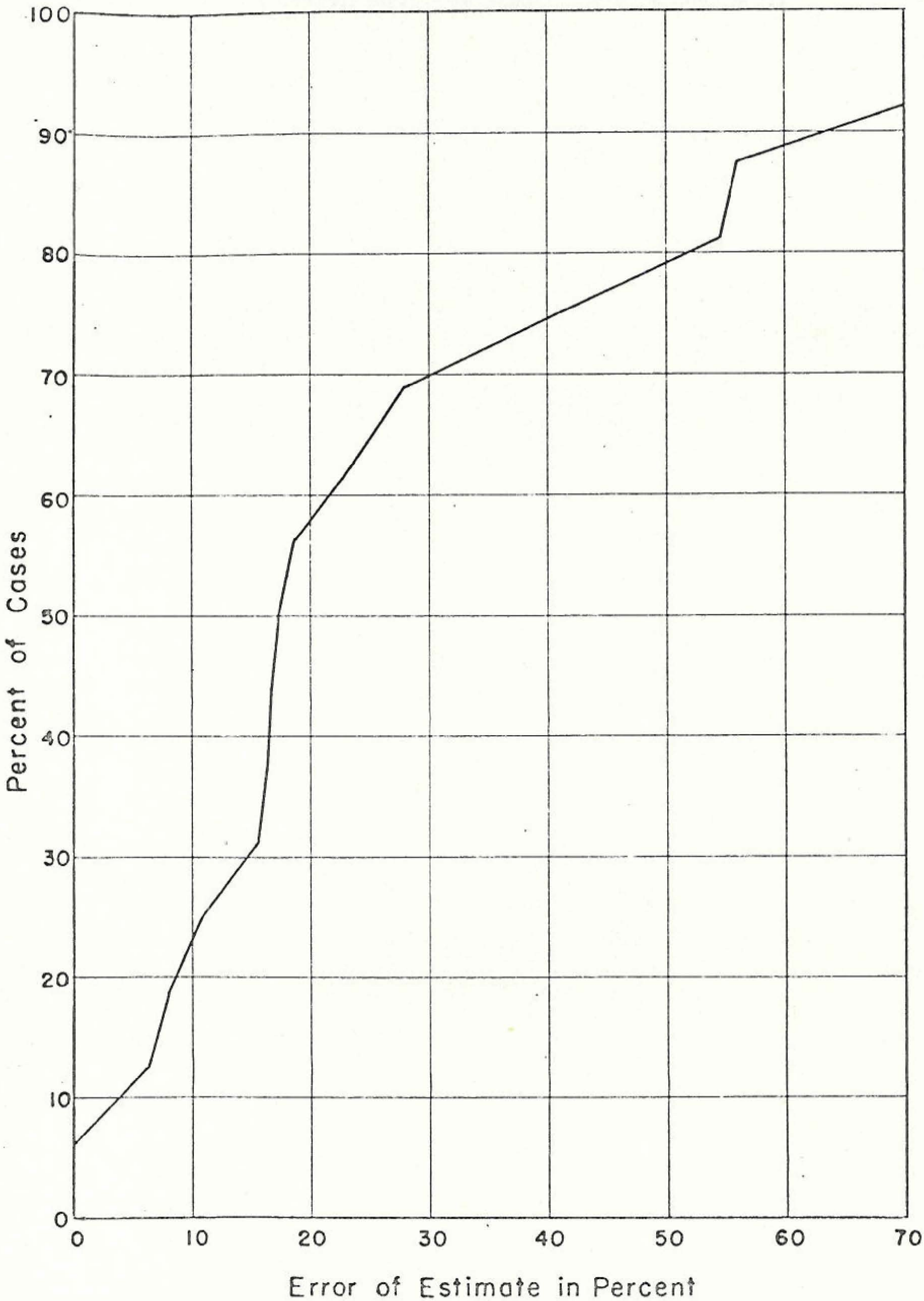

Fig. 3 Cumulative Relative Frequency of Errors of Estimate of Q_{10} from Fig. 2.

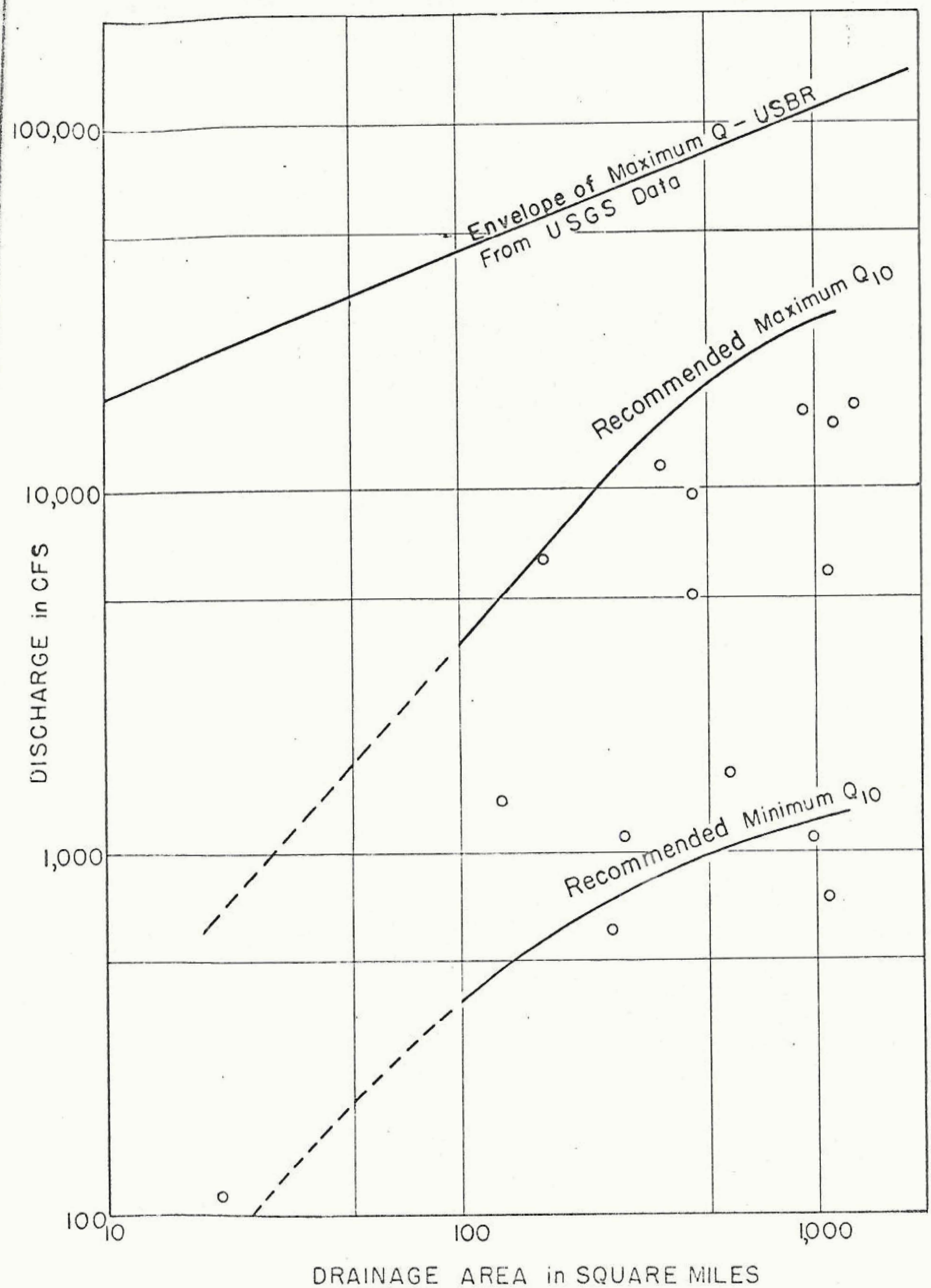

Fig. 4. Recommended Maximum and Minimum Q_{10} as a Function of Watershed Contributing Area.