Procedures for Estimating Peak Rates of Runoff in Eastern Colorado and Adjacent Areas

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CORRECTIONS TO CER60RAS30

"PROCEDURES FOR ESTIMATING PEAK RATES OF RUNOFF
IN EASTERN COLORADO AND ADJACENT AREAS"

The following pen and ink changes should be made to Report Number CER60RAS30:

1. Page iii - Revise the caption for Fig. 13 to read "Relations Between Total Channel Length Measured from 1:250,000 Scale U.S. Geological Survey Maps and from Colorado Highway Maps, Scale 1" = 1 mile."

2. Fig. 13 - Revise caption to read "Relations Between Total Channel Length Measured from 1:250,000 Scale U. S. Geological Survey Maps and from Colorado Highway Maps, Scale 1" = 1 mile."

3. Page 4. Revise paragraph one of "Checking results" to read as follows:

   "1. Comparing the estimates of Q_{10} from Fig. 3 and Q_{10} determined from values of unit discharge from Fig. 4 for the area being considered. (CAUTION: See section "Limitations on Use of Fig. 4 on page 12.")"

4. Page 8 - Revise third line to read as follows:

   "1. The estimate of Q_{10} determined from the unit discharge values of Fig. 4 was within $\pm$ 25 oer cent of ..."

Corrections continued -

5. Page 9 - "Checking Results", First paragraph - Revise to read:

   "1. Comparing the estimate of Q_{10} from Fig. 7 with the values of Q_{10} obtained from the <u>unit</u> <u>discharge</u> values shown in Fig. 4. (CAUTION: See section "Limitations on Use of Fig. 4 on page 12.)"

6. Page 11 - Revise line one of first paragraph in "SIGNIFICANCE OF CHECKS" to read as follows:

   "1. The estimate of Q_{10} determined from unit discharge values within $\pm$ 25 per cent..."

7. Page 21 - Line 2 - Change Table 13 to read "Table 1."

8. Pages 31, 32, 33, and 34 - Revise the heading to read "Table 1. **SUMMARY OF ..,**"

FINAL REPORT

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ABSTRACT

A study was made of the factors affecting peak rates of runoff in the semi-arid region of eastern Colorado and adjacent areas. Within this region, annual maximum floods, on watersheds less than 1000 square miles, are usually the result of intense rainfall over a limited area. The investigation reveals that peak rates of runoff from ungaged watersheds can be estimated from parameters of watershed area, channel slope, and a soil infiltration index in the region east of the Rocky Mountain Foothills.

In the Rocky Mountain Foothills, estimates of peak rates of runoff from ungaged watersheds can be made using watershed contributing area, elevation, and location.

Design procedures for estimating peak rates of runoff in these regions are illustrated by examples.

Results of the studies used to develop these design procedures are presented in summary form.

I. INTRODUCTION

Economical design of highway drainage structures requires a knowledge of the magnitude and frequency of peak rates of runoff. In most cases records of peak rates of runoff are not available at the proposed construction site.

For this reason it was desired to develop techniques for estimating the magnitude and frequency of peak rates of runoff from ungaged watersheds.

A study was made of peak rates of runoff in eastern Colorado and adjacent areas for the purpose of developing such techniques.

Results are presented in two reports, "Procedures for Estimating Peak Rates of Runoff in Eastern Colorado and Adjacent Areas," (CER60RAS30), and "Study of Peak Rates of Runoff in Eastern Colorado and Adjacent Areas," (CER60RAS31). In the first report information is presented which is considered necessary for the design engineer in making estimates of peak rates of runoff. The second report includes the same material as the first, plus additional detailed information on the important results of related studies made in the development of the design procedures.

The organization of both reports is similar. Procedures for making estimates of the magnitude and frequency of peak rates of runoff are described and illustrated, after which the results of related studies are presented. The primary difference in the two reports is that the first gives only a brief summary of these related studies.

II. OBJECTIVES

The objectives of the study were:

1. To evaluate the influence of certain hydrologic, physiographic, and meteorologic parameters on peak rates of runoff.
2. To develop techniques for predicting magnitude and frequency of floods in semi-arid areas (as typified by eastern Colorado and adjacent areas) on ungaged watersheds having contributing areas less than 1000 square miles. The criterion for acceptable accuracy for these techniques is that at least two-thirds of the estimates must not depart from observed values by more than 25 per cent of the estimated value.*

*This criterion for accuracy was recommended by the sponsors. "Per cent of error" is defined by

$$\text{Per cent error} = \frac{Q_{\text{estimated}} - Q_{\text{actual}}}{Q_{\text{estimated}}} \times 100$$

III. ESTIMATING PEAK RATES OF RUNOFF

AREAS OF APPLICATION

Procedures are presented for estimating peak rates of runoff in two separate physiographic areas. The first procedure is applicable in an area of the high plains in eastern Colorado and adjacent areas designated "D-13" and "D-20" in Fig. 1. The second procedure is applicable to the Rocky Mountain Foothills region labeled "E-5" in Fig. 1. The second procedure is also applicable to the shaded portion of the "E-8" area in Fig. 1. Design procedures and background studies for the "E-5" area plus the portion of the Southern Rocky Mountains that is shaded in Fig. 1 are identified as the "E-5" area throughout this report.

PEAK RATES OF RUNOFF FROM THE D-13 and D-20 AREAS

Desired result - Q_N Peak rate of runoff to be expected in N Number of Years.

Data required - For the "D-13" and "D-20" areas of Fig. 1, the following basic data are required for estimating peak rates of runoff:

A	watershed contributing area (square miles)
E_{CS}	elevation (feet MSL) at the construction site
L	length of the longest river channel (miles)
$E_{0.9L}$	elevation (feet MSL) at a point 0.9L upstream from the construction site
I	a soil infiltration index.

Procedure - The procedure for making estimates of the peak rates of runoff having recurrence intervals of 10 years (Q_{10}) is as follows:

1. Determine the parameters A, L, E_{CS}, and $E_{0.9L}$ from the appropriate topographic map or site survey.
2. Determine the soil infiltration index, I, from Fig. 2.
3. Compute the slope parameter

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

4. Enter Fig. 3 with A, $S_{0.9L}$, and I and estimate Q_{10}, the required estimate of the peak rate of runoff having a recurrence interval of 10 years (Q_{10}).
5. For estimates of the peak rate of runoff for a recurrence interval greater than 10 years, multiply the estimate of Q_{10} by the appropriate ratio of Q_N/Q_{10} shown in Fig. 3.
6. Check the accuracy of the estimate of Q_{10} by the methods described in the following section.

Checking results - Several methods of checking the estimate of Q_{10} from Fig. 3 are available to the design engineer. They are:

1. Comparing the estimate of Q_{10} from Fig. 3 with the values of unit discharge determined from Fig. 4 for the area being considered. (CAUTION: See section "Limitations on Use of Fig. 4.")
2. Comparing the estimate of Q_{10} from Fig. 3 with the maximum and minimum recommended value of Q_{10} from Fig. 5. The small circles shown in Fig. 5 are the actual values of Q_{10}

for the watersheds that were used in deriving the relation shown in Fig. 3. The maximum curve on Fig. 5 represents the maximum Q_{10} obtained from the parameters used to derive Fig. 3. This does not imply that higher values of these parameters might not be encountered, but rather that these combinations have not occurred for testing on gaged watersheds.

3. Determining whether the ungaged watershed under investigation is similar to the gaged watersheds used to develop Fig. 3 by using the test for representativeness given in the appendix. If the representativeness test indicates that the watershed under investigation is similar to the gaged watersheds used in deriving Fig. 3, then considerable confidence can be placed in the design estimate derived from Fig. 3. If however, the representativeness test indicates (on the basis of area, slope, location, and precipitation) that the ungaged watershed under consideration is not similar to those used in deriving Fig. 3, then less confidence can be placed in the estimate derived from Fig. 3. Details of the representativeness test are given in the appendix.

Degree of accuracy to be expected - Fig. 6 shows the cumulative relative frequency of errors of estimate of the peak rate of runoff having a 10-year recurrence interval (Q_{10}) that can be expected from use of Fig. 3. Fig. 6 shows, for example, that use of Fig. 3 gave errors of estimate exceeding 25 per cent for about 20 per cent of the cases. It also shows that errors of estimate exceeding 50 per cent can be expected about 10 per cent of the time.

Examples - The following example illustrates the design procedure for estimating peak rates of runoff from watersheds in the D-13 and D-20 areas.

Assume that Federal Highway 24 in Colorado is to be a link in the Federal Inter-State System. A new bridge is to be constructed for four-lane divided traffic across Spring Creek two miles west of Stratton, Colorado. Part of the highway design problem is to determine Q_{10}, Q_{25}, and Q_{50}.

SOLUTION: By means of a topographic map (U.S. Geological Survey, Scale 1:250,000)# and the soil map of Fig. 2, the following information is obtained:

A = 144 square miles

$E_{0.9L}$ = 4,980 feet

E_{CS} = 4,345 feet

L = 38 miles

I = 5.3 (If the watershed being considered contains more than one soil type, determine "I" by the method described in Chapter IV of this report "Effect of Soil Type.")

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

$$S_{0.9L} = \frac{E_{0.9L} - E_{CS}}{0.9L} = \frac{635}{34.2} = 18.6 \text{ ft/mi.}$$

For $A = 144$ sq. mi., $S_{0.9L} = 18.6$ ft/mi., and $I = 5.3$ the graph of Fig. 3 gives

$$Q_{10} = 2150 \text{ cfs}$$

#Note that this procedure is applicable only to this map. Refer to Fig. 13 for use of Colorado Highway Department County maps (Scale 1/2" = 1 mile).

Apply the appropriate ratios of Fig. 3 to obtain

$$Q_{25} = (Q_{10})(1.66) = 3560 \text{ cfs}$$

$$Q_{50} = (Q_{10})(2.15) = 4620 \text{ cfs}$$

These are the required <u>design estimates</u> of Q_{10}, Q_{25}, and Q_{50}.

CHECK: The value of Q_{10} may be checked by one or all of the following methods:

1. Regional distribution of unit discharge (Q_{10}/A). At the location of the construction site (Longitude 102° 38', Latitude 39° 18') read from Fig. 4 the value of $Q_{10}/A = 15$. (Interpolated between isolines of $Q_{10}/A = 10$ and 20.)

   Then $Q_{10} = 15A$

   $$Q_{10} = (15)(144) = 2160 \text{ cfs.}$$

   (CAUTION: See section "Limitation on Use of Fig. 4.")

2. Recommended maximum and minimum peak rates of runoff. For $A = 144$ square miles, Fig. 5 gives a recommended maximum value of Q_{10} of 6,500 cfs., and a recommended minimum value of Q_{10} of 210 cfs.

3. Determination of representativeness.

   From the procedure described and illustrated in the appendix, this ungaged watershed is determined to be similar to the gaged watersheds used to derive the relationships of Fig. 3.

SIGNIFICANCE OF CHECKS: The estimate of design discharge for this watershed may be assumed to be of acceptable accuracy for the following reasons:

1. The estimate of Q_{10} from Fig. 4 was within $\pm$ 25 per cent of the estimate of Q_{10} from Fig. 3.
2. The estimate of Q_{10} from Fig. 3 fell within the recommended maximum and minimum discharges shown on Fig. 5.
3. The watershed was determined to be representative.

PEAK RATES OF RUNOFF FROM THE E-5 AREA

Desired result - Q_N , the peak rate of runoff to be expected in "N" number of years.

Data required - For the area marked "E-5" and the shaded portion of E-8 in Fig. 1, the following data are required for estimating peak rates of runoff:

A	watershed contributing area, square miles
$E_{0.5L}$	elevation on the main channel (feet MSL) half-way between the construction site and the headwaters.

Procedure - The procedure for making estimates of the peak rates of runoff having recurrence intervals of ten years (Q_{10}), from watersheds in this area is as follows:

1. Determine the parameters A and $E_{0.5L}$ from the appropriate topographic map or site survey.
2. Note the latitude and longitude of the construction site.
3. Enter Fig. 7 with these parameters to obtain an estimate of Q_{10}.

4. For estimates of the peak rate of runoff for a recurrence interval greater than 10 years, multiply the estimate of Q_{10} by the appropriate ratio of Q_N/Q_{10} shown in Fig. 7.

5. Check the estimate of Q_{10} by the methods described in the following sections.

Checking Results - Two methods of checking the estimate of Q_{10} from Fig. 7 are available to the design engineer. They are:

1. Comparing the estimate of Q_{10} from Fig. 7 with the values of unit discharge shown in Fig. 4. (CAUTION: See section "Limitations on Use of Fig. 4.")

2. Comparing the estimate of Q_{10} from Fig. 7 with the maximum and minimum recommended value of Q_{10} from Fig. 8. The small circles shown in Fig. 8 are the actual values of Q_{10} for the watersheds that were used in deriving the relation shown in Fig. 7. The maximum curve in Fig. 8 represents the maximum Q_{10} obtained from the parameters used to derive Fig. 7. This does not imply that higher values of these parameters might not be encountered, but rather that these combinations have not been tested by gaged watersheds.

Degree of Accuracy to be Expected - Fig. 9 shows the cumulative frequency of errors of estimate of the peak rate of runoff having a 10-year recurrence interval (Q_{10}) that can be expected from use of Fig. 7. Fig. 9 shows, for example, that use of Fig. 7 gave errors of estimate less than $\pm$ 25 per cent for about 78 per cent of the cases. It also shows that errors of estimate exceeding 50 per cent can be expected slightly more than 10 per cent of the time.

Example - The following example illustrates the design procedure for estimating peak rates of runoff from watersheds in the E-5 Area.

U. S. Highway 285 west of Denver is to be relocated along a less sinuous route through the mountains. Approximately a mile north of Tinytown, Colorado, the highway crosses South Turkey Creek. To determine what size of box or large pipe culvert will be adequate, values for Q_{10}, Q_{25}, and Q_{50} are desired.

SOLUTION: By means of a topographical map (U.S. Geological Survey scale 1:250,000),# the following information is obtained.

$A = 48$ square miles

$E_{0.5L} = 7800$ feet msl

Location of construction site: 105° 14'W, 39° 37'N.

Enter Fig. 7 with $A = 48$, $E_{0.5L} = 7800$, and latitude 39° 37'N, and read $Q_{10} = 840$ cfs.

Apply the appropriate ratios in Fig. 7 to obtain

$$Q_{25} = (Q_{10})(1.66) = (840)(1.66) = 1400 \text{ cfs}$$

$$Q_{50} = (Q_{10})(2.15) = (840)(2.15) = 1800 \text{ cfs}$$

These are the required design estimates of Q_{10}, Q_{25}, and Q_{50}.

CHECK: The value of Q_{10} may be checked by either or both of the following methods:

#Note that this procedure is applicable only to this map. Refer to Fig. 13 for use of Colorado Highway Department County maps (Scale 1/2" = 1 mile).

1. Regional distribution of unit discharge, Q_{10}/A . At the location of the construction site (105° 14'W, 39° 37'N), read from Fig. 4 the value of $Q_{10}/A \approx 14$

   Then $Q_{10} = 14A = 14(48) \approx 675$ cfs

   (CAUTION: See section "Limitation on Use of Fig. 4.")

2. Recommended maximum and minimum peak rates of runoff. For $A = 48$ square miles, Fig. 8 gives a recommended maximum value of Q_{10} of 1220 cfs and a recommended minimum of Q_{10} of 420 cfs.

SIGNIFICANCE OF CHECKS: Both methods of checking indicate that the estimates of design discharge are reasonable, because:

1. The estimate of Q_{10} from Fig. 4 was within $\pm$ 25 per cent of the estimate of Q_{10} from Fig. 7.
2. The estimate of Q_{10} from Fig. 7 fell within the recommended limits of maximum and minimum discharge shown on Fig. 8.

LIMITATIONS AND PRECAUTIONS

Limitations in Basic Data - In the D-13 and D-20 areas runoff records had the following limitations:

1. Only a few runoff records for watershed areas less than 100 square miles were available, and
2. Only a few of all the runoff records were for a period of time greater than 20 years.

Therefore, a primary need in obtaining improved estimates of peak rates of runoff from small watersheds is the establishment of additional gaging stations--recording and non-recording--on watersheds having contributing areas less than 100 square miles.

Limitations of Extrapolation Techniques for Floods having a Recurrence Interval Greater than 40 Years - From flood frequency studies of watersheds in and near the study area, it was determined that the peak rates of runoff from floods 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 Q_N/Q_{10} shown on Figs. 3 and 7 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 extrapolation of the straight line.

The possible inaccuracy that may result from such an extrapolation technique should be recognized, since the basic data used to derive Figs. 3 and 7 were mostly derived from records less than 40 years in length.

Limitations on Watershed Size - Design procedures presented in this report are valid for watersheds having a drainage area of 1000 square miles or less. Since the basic data used in developing the design charts for the D-13 and D-20 areas were mostly larger than 100 square miles, the portions of Fig. 3 for areas less than 100 square miles are shown in dashed lines to indicate reduced confidence in the estimates of Q_{10} from watersheds of this size.

Limitations on Use of Fig. 4 - Although the isolines on Fig. 4 were drawn after a qualitative consideration of slope, elevation, soil type, and precipitation, no consideration could be given to the effect of area on unit discharge. THEREFORE, FIG. 4 SHOULD NOT BE USED AS A DESIGN CHART, IT SHOULD BE USED ONLY AS A QUALITATIVE CHECK OF THE RESULTS FROM FIGS. 3 AND 7.

It has not been possible to establish any consistent relationship between unit discharge and watershed size in the study area.

IV. SUMMARY OF RELATED STUDIES

In this section brief summaries of related studies are presented. More detailed information on these studies is given in the report "Study of Peak Rates of Runoff in Eastern Colorado and Adjacent Areas" (CER60RAS31).

Seasonal Distribution of Annual Maximum Flood Events - A study was made to determine the effects of watershed contributing area and elevation on the seasonal distribution of annual maximum flood events for 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 becomes later with an increase in watershed size.

For watersheds having a minimum elevation less than 7,680 ft, the date of occurrence of 67 per cent of the annual maximum floods becomes later with decreasing elevation of the watershed.

These results can be interpreted in terms of summer-time 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.

Characteristics of Precipitation Associated with Annual Maximum Floods - 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, more than two-thirds of the annual maximum floods were probably caused by rains covering the entire watershed, while for watersheds smaller than about 50 square miles, less than one-third of the annual maximum floods were produced by such rains.

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

Use of Weather Radar Data to Provide Increased Areal Coverage of Precipitation 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.

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

Precipitation Maps Showing 24-hour Precipitation Amounts Having Recurrence Intervals of 2, 5, 10, 25, and 50 years - Precipitation data were analyzed to obtain the maximum annual 24-hour precipitation amounts having recurrence intervals of 2, 5, 10, 25, and 50 years. Maps of eastern Colorado and adjacent areas were prepared showing isolines of these values. There is relatively little variation in the 24-hour precipitation amounts having a 2-year recurrence interval, but as the recurrence interval increases to 25 and 50 years, there are marked differences between adjacent areas. The variation is such that regions of high elevations show higher values of precipitation than regions of low elevation. The isohyetal map of 24-hour rainfall having a 10-year recurrence interval is shown in Fig. 10.

Regional Distribution of Unit Discharge (Q_{10}/A)

Values of unit discharge (Q_{10}/A) for all available stream-gaging records were plotted on a map of the study area at the location of the gaging station. The results are presented in Fig. 4. Isolines on Fig. 4 were drawn after consideration of slope, elevation, soil type, and precipitation. (CAUTION: See section "Limitations on use of Fig. 4.")

Unit Peak Flow (Q_{10}/A) as a Function of Watershed Size - Records of runoff in and near the study area were analyzed to obtain the 10-year recurrence interval unit discharge (Q_{10}/A), in order to study the relation between unit discharge and contributing area. The results of this study indicate that the 10-year recurrence interval unit discharge increases with increase in watershed size up to about 400-800 square miles and decreases thereafter for larger watersheds. This is in contrast to the maximum observed floods for which unit discharge increases with decreasing size.

Relations Between Short- and Long-term Peak Rates of Runoff - Since long-term records of runoff were not available within the study area, a study was made of the relations between the 10-year and the 40-year recurrence interval discharge for runoff records in adjacent areas. These studies indicate that the discharge having a 40-year recurrence interval is approximately 2.0 times as large as the discharge having a 10-year recurrence interval. This fact was used in deriving the relations between the discharge having a 10-year recurrence interval and discharges having longer recurrence intervals as shown in Figs. 3 and 7.

Physical Factors Causing Breaks or "Dog-legs" on Gumbel Plots of Peak Rates of Runoff - A study was made to investigate the causes for nonlinearity in plotting annual maximum peak rates of runoff on Gumbel plotting paper for those cases in which there was nonlinearity. All of the plotted points that departed from a straight line were examined and compared with the highest values of discharge that fell on the upper limits of the straight line. Such comparisons were made on the basis of geographic distribution, base stream flow, precipitation amounts, and precipitation intensity. Of these factors, the only significant differences that could be detected were caused by differences in precipitation intensities. Higher precipitation intensities were associated with those discharges that were plotted above the lower limb of the dog-leg.

Effect of Diversion on Peak Rates of Runoff - A study was made to determine whether diversions for irrigation had an effect on magnitude and frequency of peak rates of runoff from selected small watersheds in Colorado. A study of seven watersheds smaller than 1000 square miles indicates that the effect of such diversion on peak rates of runoff is probably negligible for those watersheds for which peak rates of runoff are caused by rainstorms. On the other hand, evidence indicates that such diversions probably become significant as the size of the watershed increases to 1000 square miles or more for watersheds for which snow melt is an important contributing factor in producing peak rates of flow.

Effect of Soil Type - A study was made to determine the effect of soil type on peak rates of runoff. An arbitrary index system was assigned to various soil types classified under the SCS soil classification scheme. The index numbers range from 16 for a sandy soil having a high infiltration rate, to a low of unity for a clay soil having a low infiltration rate.

If a watershed under investigation falls into regions of more than one soil index value as shown in Fig. 2, a weighted soil index should be determined. This weighted soil index can be computed by weighting each of the index values shown in Fig. 2 in proportion to the area of the watershed that falls within each value of the soil index. The weighted soil index was found to be related significantly to runoff in the D-13 and D-20 areas, and was incorporated into the design chart presented in Fig. 3. (In the E-5 area, soil type could not be related significantly to runoff.)

Effect of Watershed Slope - A study was made of a number of different techniques for measurement of watershed slope as related to peak rates of runoff. From results of the study, it was determined that channel slope was better related to runoff than overland slope. The best correlation with runoff was obtained for a channel slope measured between the construction site and a point lying between 5/10 and 9/10 of the total length of the channel from the construction site (Note, however, that the slope measured at the 9/10 point is used in the design procedure presented in this report. No substitutions of parameters should be made in the design procedures presented herein.)

Effect of Watershed Characteristics - A study was made in which the objective was to determine whether or not a particular watershed was similar to other gaged watersheds that had been used in deriving relations for estimating peak rates of runoff. From this study, it was found that the physiographic factors of area, drainage density (as determined by total channel length), an infiltration index, a location parameter, and a precipitation index could be used. The preliminary study, based on a limited number of available data, indicates that this method provides a technique for determining whether or not a particular watershed is representative of other watersheds which were used to derive relations for making estimates of runoff.

DEVELOPMENT OF DESIGN CHARTS FROM SIGNIFICANT FACTORS AND ESTIMATE OF ERROR CURVES

The procedures used for estimating peak flows utilize relationships established between peak flows and certain physical parameters on gaged watershed for which past records are available. It is then assumed that these relationships hold for ungaged watersheds having similar characteristics and that relationships which existed in the past will also hold in the future.

Graphical correlation techniques were utilized to establish the relationship between 10 year peak flows and parameters by which they are influenced.

The parameters most strongly affecting peak flows and utilized in the graphical correlation for D-13, D-20 are area, slope as measured between the gaging station and the 0.9 channel length, and an infiltration index. Parameters used for the E-5 area are area, elevation, and latitudinal location.

Attempts were made to include a precipitation parameter in the graphical correlation procedure for estimating Q_{10}. These attempts failed. The reason for this failure probably is due to the relative homogeniety of extreme precipitation events throughout the region studied. (See Fig. 10).

Distribution of error curves for estimates obtained from these graphical correlations are shown in Fig. 6 for the D-13, D-20 areas, and in Fig. 9 for the E-5 area. The curves show the per cent of time that errors of certain amounts have occurred in the sample tested. These curves were prepared by accumulating the errors to be expected as the number of cases with increasing amounts of error are added.

It can be noted that the per cent of error to be expected is not excessive (Greater than about 25 per cent) in about 90 per cent of the cases for the D-13, D-20 area and in about 80 per cent of the cases for the E-5 area.

It must be borne in mind that the excessive errors in about 10 per cent of the cases for D-13, D-20; and in about 20 per cent of the cases for E-5 could, and in some cases, probably are the result of non-representative samples in the test data and not necessarily real errors of such magnitude from the design graphs. The cases giving large errors in the D-13, D-20 areas, for example, are both for cases in which the watershed area was greater than the 1000 miles for which the design chart is recommended. For the largest error, the value of Q_{10} from frequency analysis is in doubt since the total length of record was only eight years.

V. ADDITIONAL INFORMATION

A summary of the basic data used in deriving the design charts for estimating peak rates of runoff is given in the appended Table 13.

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

VI. ACKNOWLEDGMENTS

The authors wish to acknowledge with thanks the assistance given by Mr. Carl F. Izzard and Mr. W. D. Potter of the U. S. Bureau of Public Roads, and by Mr. Mark U. Watrous and Mr. Adolph Zulian of the Colorado Department of Highways. Mr. Robert Bond and Mr. Hugh Berger of the Denver Regional office of the U. S. Bureau of Public Roads, and Mr. W. T. Miller of the U. S. Geological Survey in Denver were very helpful throughout the study.

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VII. APPENDIX

WATERSHED CHARACTERISTICS AS A REPRESENTATIVENESS TEST FOR CHECKING DESIGN ESTIMATES OF PEAK RATES OF RUNOFF

WATERSHED CHARACTERISTICS AS A REPRESENTATIVENESS TEST FOR CHECKING DESIGN ESTIMATES OF PEAK RATES OF RUNOFF

In the early part of the study it was determined from multiple correlation techniques that peak rates of runoff having a 10-year recurrence interval (Q_{10}) could be estimated from either of the following:

1. A combination of the parameters of contributing area, in square miles; drainage density, in miles per square mile; and location (longitude minus latitude).
2. A combination of the parameters of contributing area, in square miles and slope, $S_{0.9L}$, in feet per mile. (The slope measured between the construction site and a point 9/10 of the length from the construction site to the headwaters.)

A method was sought to determine whether a particular ungaged watershed under consideration could be considered similar to the gaged watersheds used in deriving the relations used for estimating Q_{10}. The ideal procedure to follow would be to relate various physical characteristics of watersheds to discharge. However, because only limited discharge data were available, it was necessary to relate the physical characteristics to a parameter that was related to discharge which could be obtained from a large number of watersheds in the region studied. As noted above, $S_{0.9L}$ was such a parameter, hence, the procedure followed was to select a large sample of ungaged watersheds and search for typical relationships of physical characteristics that could be related to $S_{0.9L}$, which in turn could reasonably be expected to be related to Q_{10}. This procedure permitted examination and analysis of a much larger sample of data than would have been possible from analysis of gaged watersheds only.

An attempt was made to relate the slope parameter $S_{0.9L}$ to the following independent variables:

A , Contributing area, square miles.

ΣL , Total length of channel including tributaries in the watershed, obtained by measuring the total length of the blue lines in the watershed on the 1:250,000 scale maps# of the area prepared by the U. S. Geological Survey.

L_L , Difference in degrees between the longitude and the latitude at the construction site.

I , A soil infiltration index, ranging from unity for a clay soil to 16 for a sandy soil. (See Fig. 2).

P_{10} , The 24-hour amount of precipitation having a recurrence interval of 10 years. (See Fig. 10).

A zone of environment was also used in the graphical correlation analysis. The zones were:

1. The Upper Republican River Basin
2. The Arkansas River Basin
3. The South Platte River Basin

Fifty-two (52) ungaged watersheds in certain portions of the D-13 and D-20 areas in eastern Colorado were used as the dependent sample to

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For consistent results only this map or the Colorado Highway Department County Maps (Scale 1/2" = 1 mile) should be used. See Fig. 13.

derive the relation for estimating $S_{0.9L}$ from A, ΣL, L_L, and P_{10} as shown in Fig. 11. An independent sample of 18 ungaged watersheds was used to check the accuracy of estimate of $S_{0.9L}$ from Fig. 11.

Fig. 12 shows the cumulative relative frequency of error of estimate for Fig. 11. It will be noted that approximately 67 per cent of the cases gave errors less than about 22 per cent for the dependent sample, and 67 per cent of the cases in the independent sample gave errors less than 18 per cent.

These results indicate that the parameter $S_{0.9L}$ can be estimated with acceptable accuracy from the given watershed characteristics. Furthermore, success in estimating $S_{0.9L}$ from the watershed characteristics suggests that the relation shown in Fig. 11 can serve as a test for determining whether or not the runoff characteristics of a particular watershed under investigation is similar to the watersheds in the region from which the design chart (Fig. 3) was derived. This assumption is supported by the fact that the factors used to estimate $S_{0.9L}$ from Fig. 11 (Area, drainage density, location, soil infiltration characteristics, and precipitation) are all factors which reasonably could be expected to influence peak rates of runoff. Hence if a given ungaged watershed under consideration is found to be similar (on the basis of the aforementioned characteristics) to the gaged watersheds for which Fig. 3 was developed, it is reasonable to expect that runoff characteristics would also be similar. Unfortunately it was not possible to test this assumption with an adequate sample of data from gaged watersheds.

It should be noted, however, that for ten (10) out of twelve (12) watersheds in eastern Colorado, the departure of the measured value of $S_{0.9L}$ from the value of $S_{0.9L}$ estimated from Fig. 11 did not exceed 25 per cent of the estimated value. For two watersheds the error of estimate of $S_{0.9L}$ from Fig. 11 exceeded 25 per cent.

This leads to the criterion for determining whether or not a particular watershed is representative of those from which **Fig. 3** was developed: IF THE ESTIMATED $S_{0.9L}$ FROM FIG. 11 DOES NOT DEPART FROM THE MEASURED VALUE OF $S_{0.9L}$ BY MORE THAN 25 PER CENT OF THE ESTIMATED VALUE, THE WATERSHED MAY BE REGARDED AS REPRESENTATIVE. Greater confidence can be placed in the results of use of Fig. 3 when a watershed is determined to be representative.

The procedure for determining the representativeness of a watershed is as follows:

1. Determine if the watershed falls in the area of application - the procedure is applicable in the D-13 and D-20 areas only as shown in Fig. 1.
2. Determine from topographic maps (scale 1:250,000) prepared by the U. S. Geological Survey, the following:

   A , Contributing area, square miles.

   ΣL , Total length of channel, including tributaries in the watershed, miles, represented by the blue lines on the U.S.G.S. maps of scale 1:250,000.

   L_L , Location, longitude minus latitude of the construction site.

NOTE: Total channel length can also be obtained from the county highway maps, (Scale 1/2" = 1 mile) prepared by the Colorado Department of Highways. The relation between the total channel length as determined from these maps and the 1:250,000 U.S.G.S. maps is shown in Fig. 13.

3. Determine the soil infiltration index, I , from Fig. 2.

4. Determine the precipitation parameter, P_{10} , from Fig. 10.

5. With these parameters, enter Fig. 11 and obtain an estimate of $S_{0.9L}$. If the watershed is in the South Platte Basin and the estimate of $S_{0.9L}$ exceeds 22 feet per mile, determine an adjusted value of the estimate, $S_{0.9L}^*$, by the relation#,

$$S_{0.9L}^* = 2.3 \ S_{0.9L} - 28.8$$

6. Measure the actual $S_{0.9L}$ from topographic maps or from a site survey.

7. Compute the per cent of error.

$$\text{Per cent error} = \frac{S_{0.9L} \text{ est.} - S_{0.9L} \text{ actual}}{S_{0.9L} \text{ est.}} \times 100$$

8. Accept the watershed as representative if the per cent of error of estimate does not exceed 25 per cent.

The following examples illustrate this procedure.

See insert in Fig. 11.

EXAMPLE OF CHECKING FOR REPRESENTATIVENESS

From the example given in Chapter III (D-13 and D-20 Areas), we have given the following:

$$A = 144 \text{ square miles.}$$

$$E_{0,9L} = 4{,}980 \text{ ft.}$$

$$E_{CS} = 4{,}345 \text{ ft.}$$

$$L = 38 \text{ miles.}$$

$$I = 5.3$$

$$S_{0.9L} = 18.6 \text{ ft/mile.}$$

By means of topographical map (U.S. Geological Survey, scale 1:250,000) the following additional information is obtained:

$$\Sigma L = 104 \text{ miles}$$

$$L_L = 102^{\circ}38' - 39^{\circ}18' = 63^{\circ}20'$$

From Fig. 10, obtain

$$P_{10} = 3.13 \text{ inches.}$$

For $A = 144$ square miles, $\Sigma L = 104$ miles, $I = 5.3$,

$L_L = 63^{\circ}20'$, and $P_{10} = 3.13$ inches

one obtains from Fig. 11 the estimate $S_{0.9L} = 21$ ft/mile.

The per cent of error between the measured $S_{0.9L}$ and the estimated $S_{0.9L}$ obtained from Fig. 11 is

$$\text{Per cent of error} = \frac{21 - 18.6}{21} \times 100 = \frac{240}{21} = 11.4 \text{ per cent.}$$

Since 11.4 per cent $<$ 25 per cent, the watershed is representative.

Since this watershed is accepted as being representative, one can place more confidence in the estimate of Q_{10} from Fig. 3 than would have been the case had the watershed not been representative. Conversely, if the per cent of error between the measured $S_{0.9L}$ and the estimate of $S_{0.9L}$ from Fig. 11 would have exceeded 25 per cent, one should be cautious in accepting the estimate of Q_{10} from Fig. 3.

TABLE 13 SUMMARY OF BASIC DATA - D-13 and D-20 AREAS

Ser. No.	Name of Watershed	Location		Contrib. Area	$S_{0.9L}$	Infiltration Index	Q_{10}		
		Longitude	Latitude				Est. from Fig. 3	From Freq. Anal.	Error
		(Degree°	Min.')	Sq. mi.	Ft/mi.	I	cfs	cfs	%
1	Fountain Creek at Pueblo, Colo.	104°-35'	38°-16'	926	35.2	5.7	18,200	16,300	+ 10.4
3	Apishapa River near Fowler, Colo.	103 -59	38 -05	1125	35.5	7.2	12,300	15,000	- 22.0
4	Timpas Creek near Rocky Ford, Colo.	103 -43	37 -57	451	24.3	6.3	7,800	9,500	- 21.8
10	Blue Creek near Lewellen, Nebr.	102 -10	41 -20	267	13.7	12.8	850	600	+ 29.4
11	Birdwood Creek near Hershey, Nebr.	101 -04	41 -13	286	10.7	8.4	980	1,100	- 12.2
12	Cherry Creek near Franktown, Colo.	104 -45	39 -21	172	53.3	6.0	6,800	6,400	+ 5.9
13	Cherry Creek near Melvin, Colo.	104 -49	39 -36	369	42.3	6.0	11,600	11,600	0.0
16	Lodgepole Creek at Bushnell, Nebr.	103 -51	41 -14	1090	27.3	7.8	7,800	5,900	+ 24.4
18	N. Fork Republican River at Colo. - Nebr. State Line	102 -03	40 -04	130	18.5	11.3	1,150	1,400	- 20.8
19	Bufallo Creek near Haigler, Nebr.	101 -52	40 -02	21	27.9	16.0	115	112	+ 2.6

TABLE 13 SUMMARY OF BASIC DATA - D-13 and D-20 AREAS (cont'd)

Ser. No.	Name of Watershed	Location: Longitude	Location: Latitude	Contrib. Area	$S_{0.9L}$	Infiltration Index	Q10: Est. from Fig. 3	Q10: From Freq. Anal.	Q10: Error
		(Degree°	Min.')	Sq. Mi.	Ft/mi.	I	cfs	cfs	%
20	Rock Creek near Parks, Nebr.	101°-43'	40°-02'	14	19.0	16.0	66	68	- 3.0
22	Frenchman Creek below Champion, Nebr.	101 -43	40 -28	570	13.1	11.5	1,350	1,660	- 23.0
25	Niobrara River above Box Butte Reservoir, Nebr.	103 -10	42 -27	980	10.6	6.3	1,450	1,100	+ 24.2
31	Pumpkin Creek near Bridgeport, Nebr.	103 -02	41 -38	1080	13.8	10.4	1,820	740	+ 59.4
33	Landsman Creek near Hale, Colo.	102 -14	39 -34	450	17.7	5.6	5,200	5,050	+ 2.9
34	S. Fork Republican River near Idalia, Colo.	102 -14	39 -37	1300	19.3	7.1	6,800	17,000	-150.00

TABLE 13. SUMMARY OF BASIC DATA - E - 5 AREA

Ser. No.	Name of Watershed	Location: Longitude	Location: Latitude	Contributing Area	Elevation $E_{0.5L}$	Q_{10}: Est. From Fig.7	Q_{10}: From Freq. Anal.	Q_{10}: Error
		(Degree°	Min.')	Square Mile	Ft/Mi.	cfs	cfs	%
200	Illinois Creek near Rand, Colo.	106° 11'	40° 27'	71	8,950	620	690	-11.3
205	Deer Creek at Glenrock, Wyo.	105° 52'	42° 52'	216	6,500	2,000	1,900	5.0
206	La Prele Creek near Douglas, Wyo.	105° 36'	42° 40'	146	6,400	1,100	980	10.9
213	N. Fork South Platte below Geneva Creek at Grant, Colo.	105° 39'	39° 27'	127	9,400	670	825	-23.1
214	N. Fork South Platte River at South Platte, Colo.	105° 11'	39° 25'	484	7,900	2,750	1,580	42.6
215	Bear Creek at Morrison, Colo.	105° 12'	39° 39'	165	7,200	3,500	3,400	2.9
216	Turkey Creek near Morrison, Colo.	105° 10'	39° 38'	49.4	7,300	960	880	8.3
217	Cherry Creek near Franktown, Colo.	104° 46'	39° 22'	172	6,900	5,200	6,200	-19.2
218	St. Vrain Creek at Lyons, Colo.	105° 16'	40° 13'	226	7,800	2,400	2,700	-12.5
221	Middle Crow Creek near Hecla, Wyo.	105° 15'	41° 11'	23	7,950	131	163	-24.4
222	South Crow Creek near Hecla, Wyo.	105° 12'	41° 08'	16	7,550	121	66	45.5

TABLE 13. SUMMARY OF BASIC DATA - E - 5 AREA (Cont'd)

Ser. No.	Name of Watershed	Location		Contributing Area	Elevation $E_{0.5L}$	Q_{10}		
		Longitude	Latitude			Est. From Fig.7	From Freq. Anal.	Error
		(Degree° Min.')		Square Mile	Ft/Mi.	cfs	cfs	%
224	Hverfano River at Manzanares Crossing near Redwing, Colo.	105° 21'	37° 44'	73	9,300	480	1,240	-158.5
225	Cucharas River at Boyd Ranch near Le Veta, Colo.	105° 03'	37° 25'	56	8,800	490	442	9.8
226	Apishapa River near Aguilar, Colo.	104° 40'	37° 23'	126	7,300	2,600	4,750	82.7
227	Purgatoire River at Trinidad, Colo.	104° 31'	37° 10'	795	6,900	23,400	23,400	0
228	Vermejo River near Dawson, N. Mex.	104° 47'	36° 41'	301	7,200	6,200	5,540	10.6
229	Six Mile Creek near Eagle Nest N. Mex.	105° 16'	36° 31'	11	8,700	127	112	11.8
230	Ponil Creek near Cimarron, N. Mex.	104° 57'	36° 35'	171	7,800	1,950	1,735	11.0
231	Mora Creek near Golondrinas, N. Mexico	105° 10'	35° 54'	273	7,500	3,800	3,550	6.6

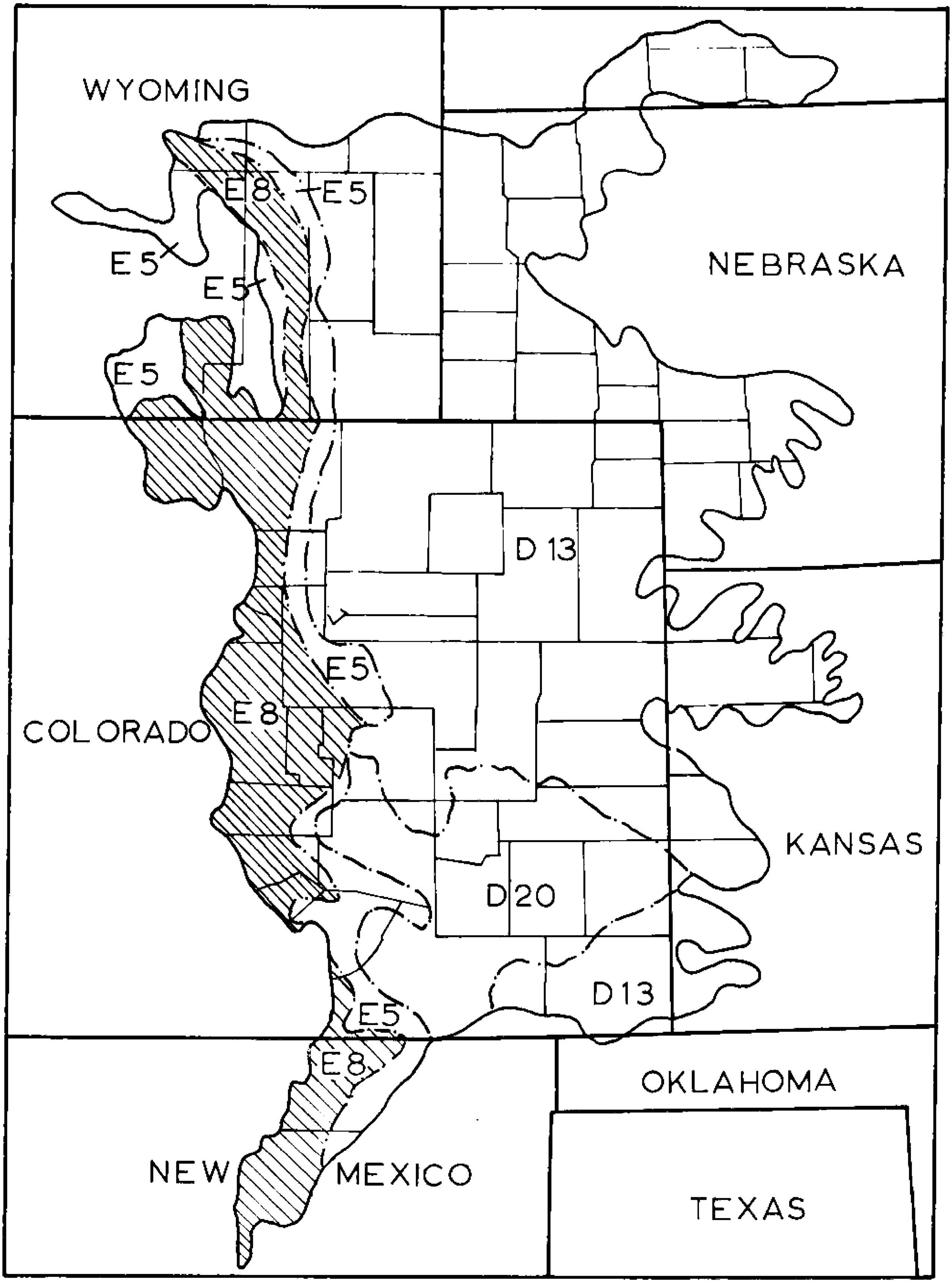

Fig. 1 Area of application of methods for estimating flood flows. (Design procedures and background studies for the combination of the E-5 areas plus the shaded part of the E-8 area are identified throughout the report as the "E-5" Area.)

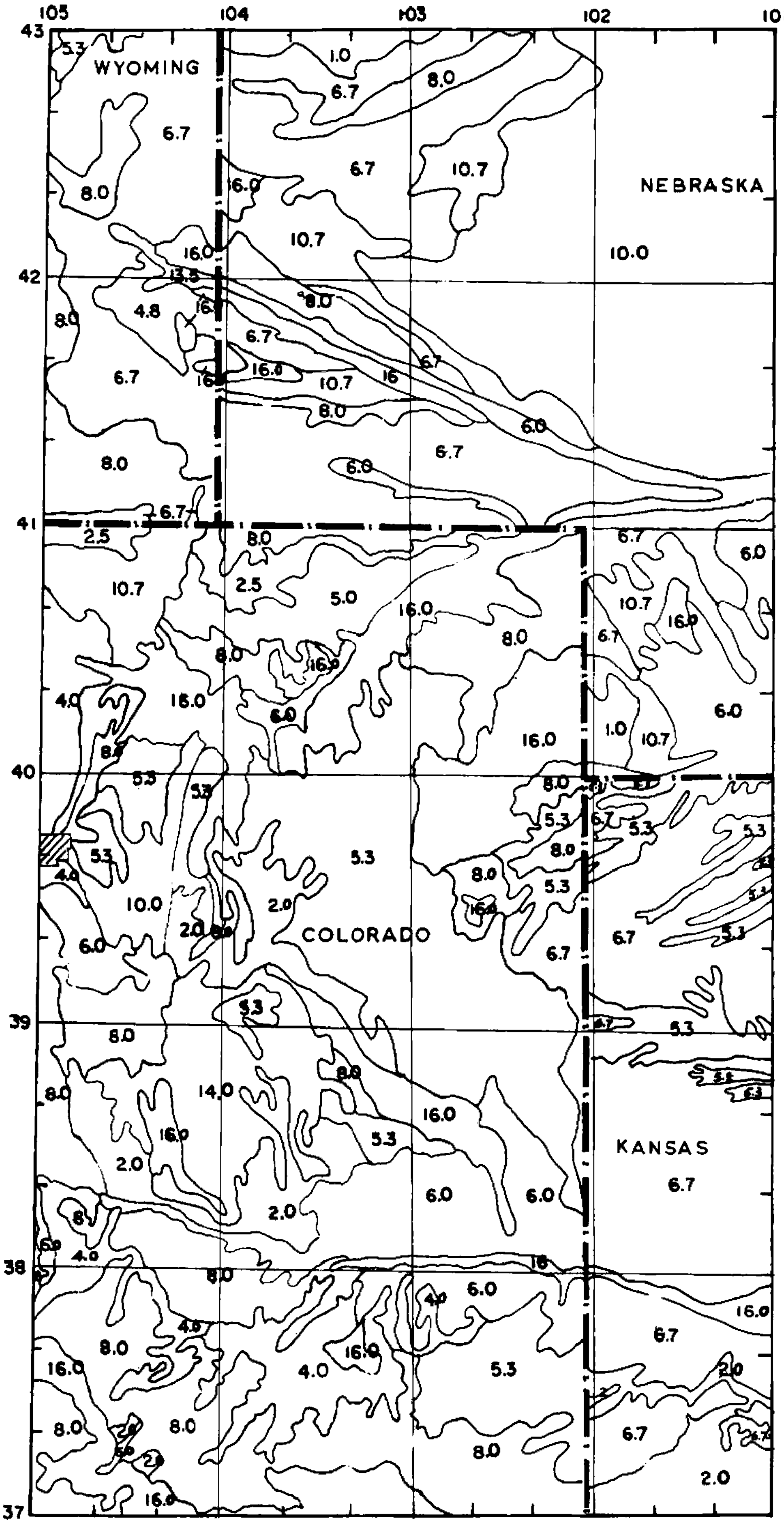

Fig. 2. Soil infiltration indicies for study area based on an arbitrary numbering scale of 16 for high infiltration rates (sandy soils) and unity for low infiltration rates (clay soils).

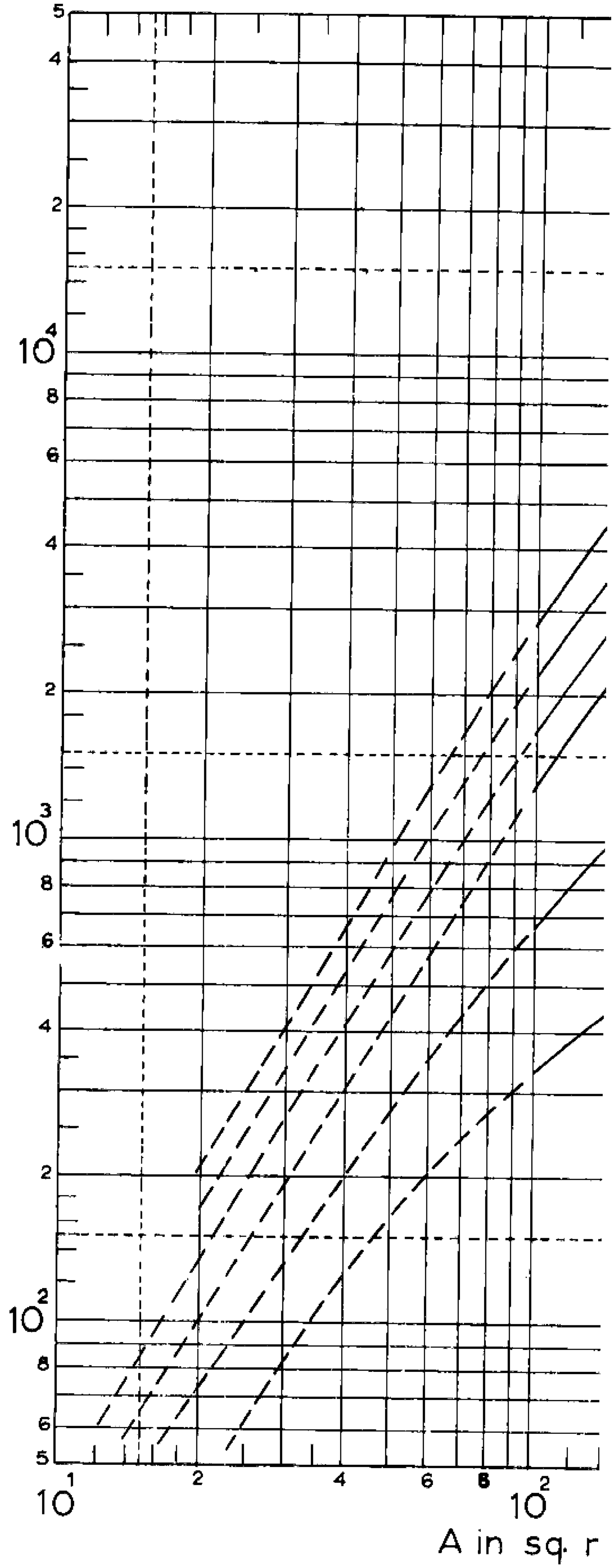

Fig 3 Peak rates of runoff dete

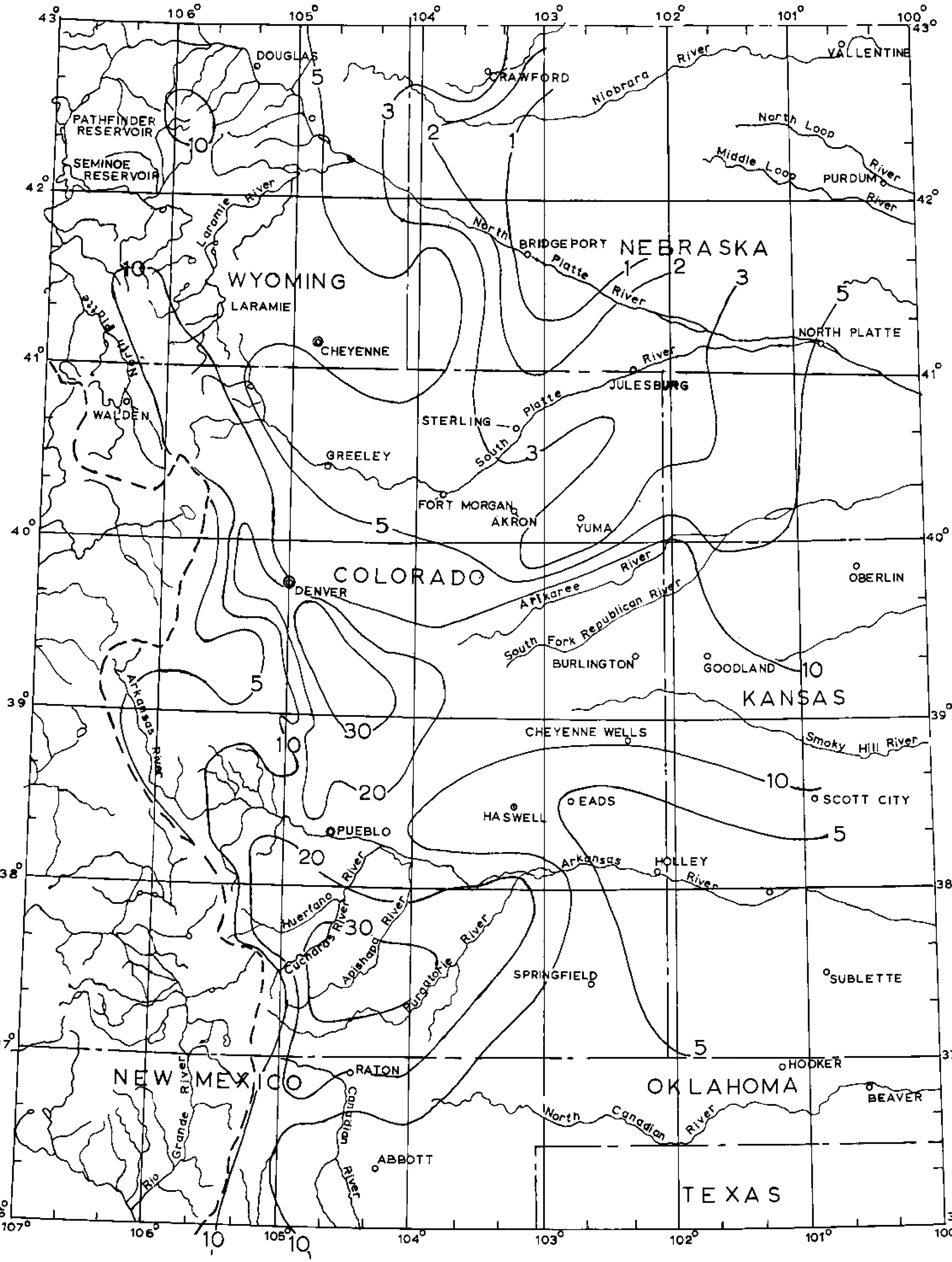

Fig. 4. Regional distribution of unit discharge values (Q_{10}/A) within the study area. Values shown are cfs per square mile.

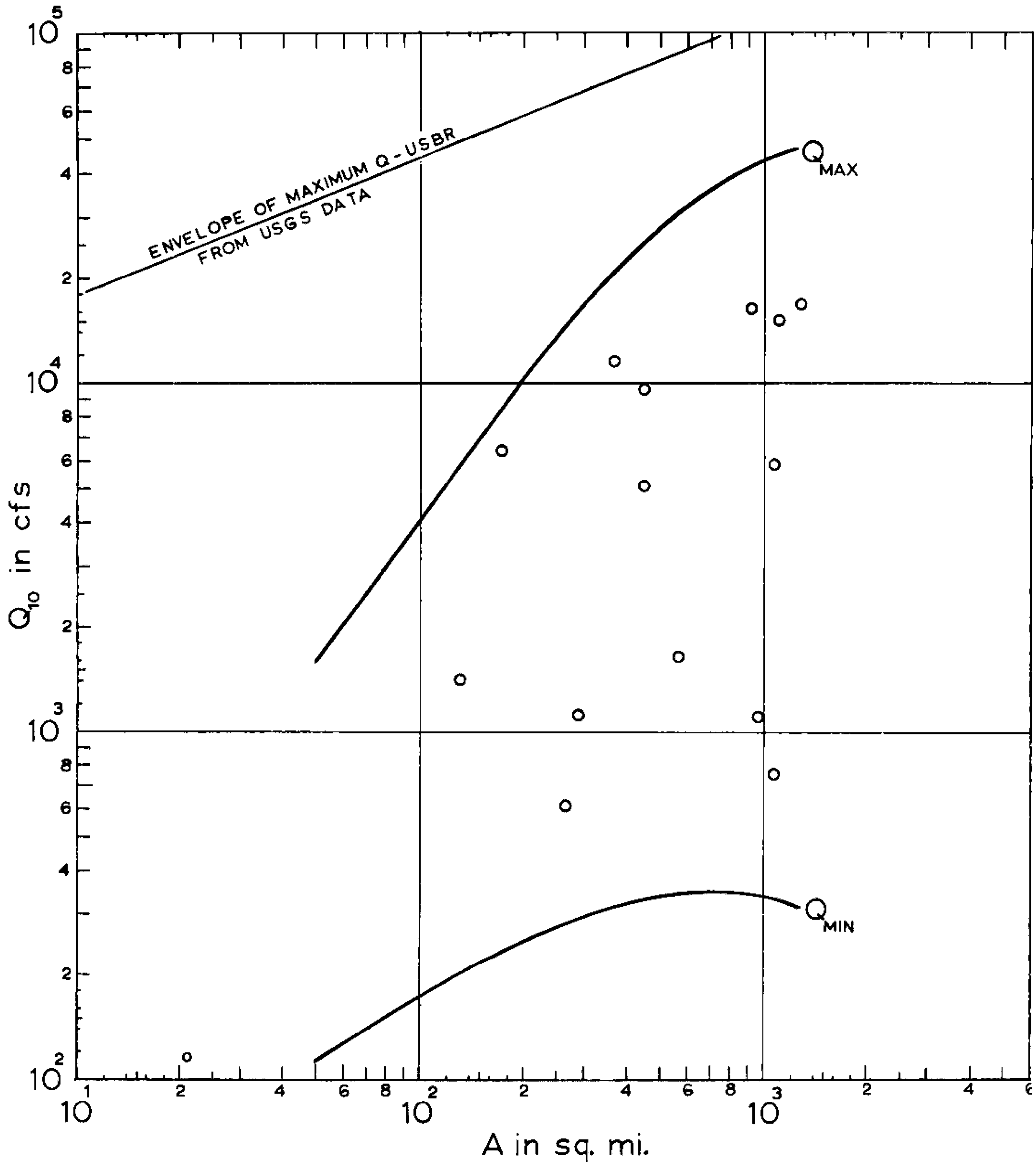

Fig. 5. Recommended maximum and minimum values of Q_{10} of watershed contributing area (D-13 and D-20).

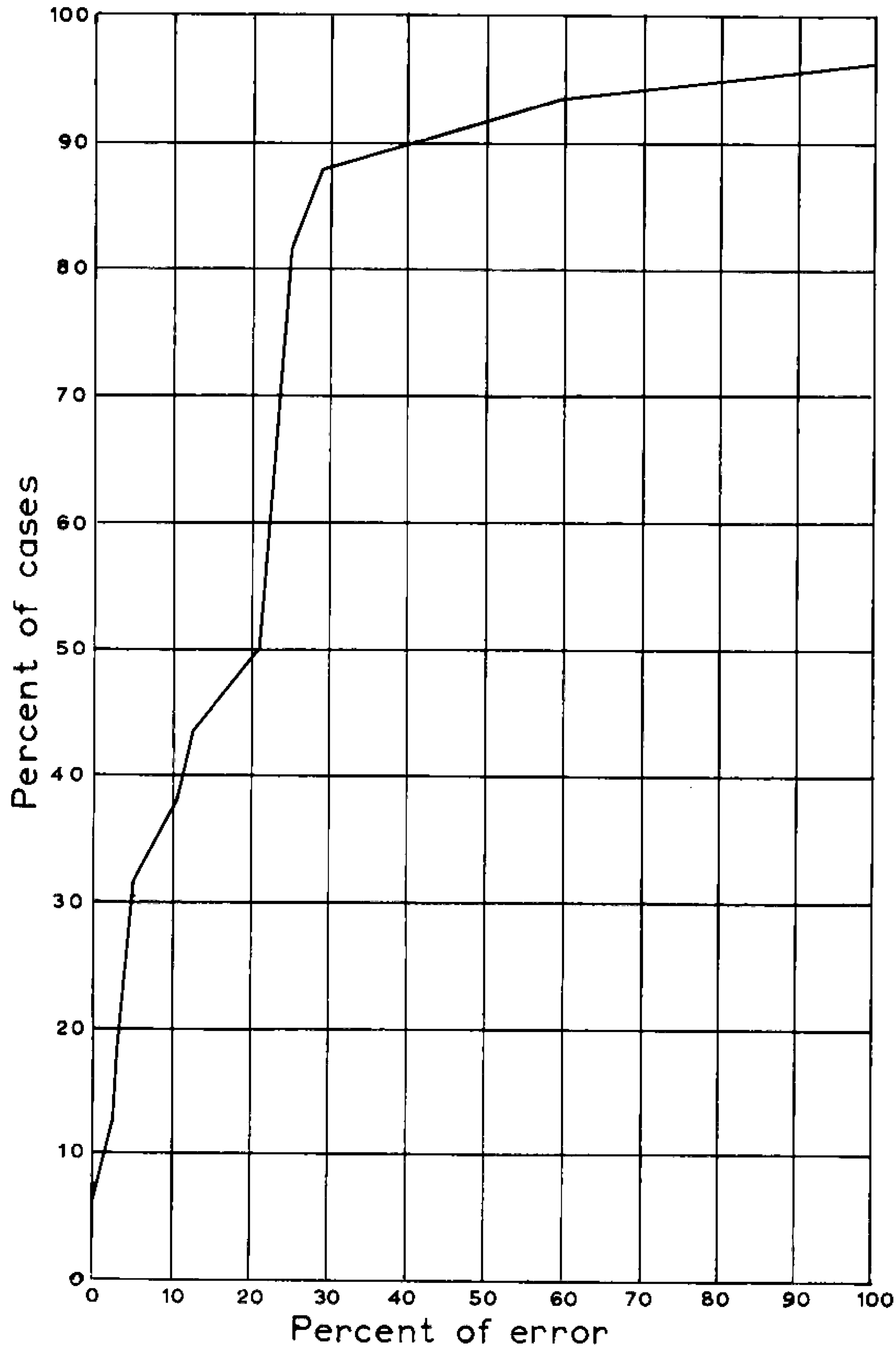

Fig. 6. Cumulative relative frequency of errors of estimate of Q_{10} from Fig. 3.

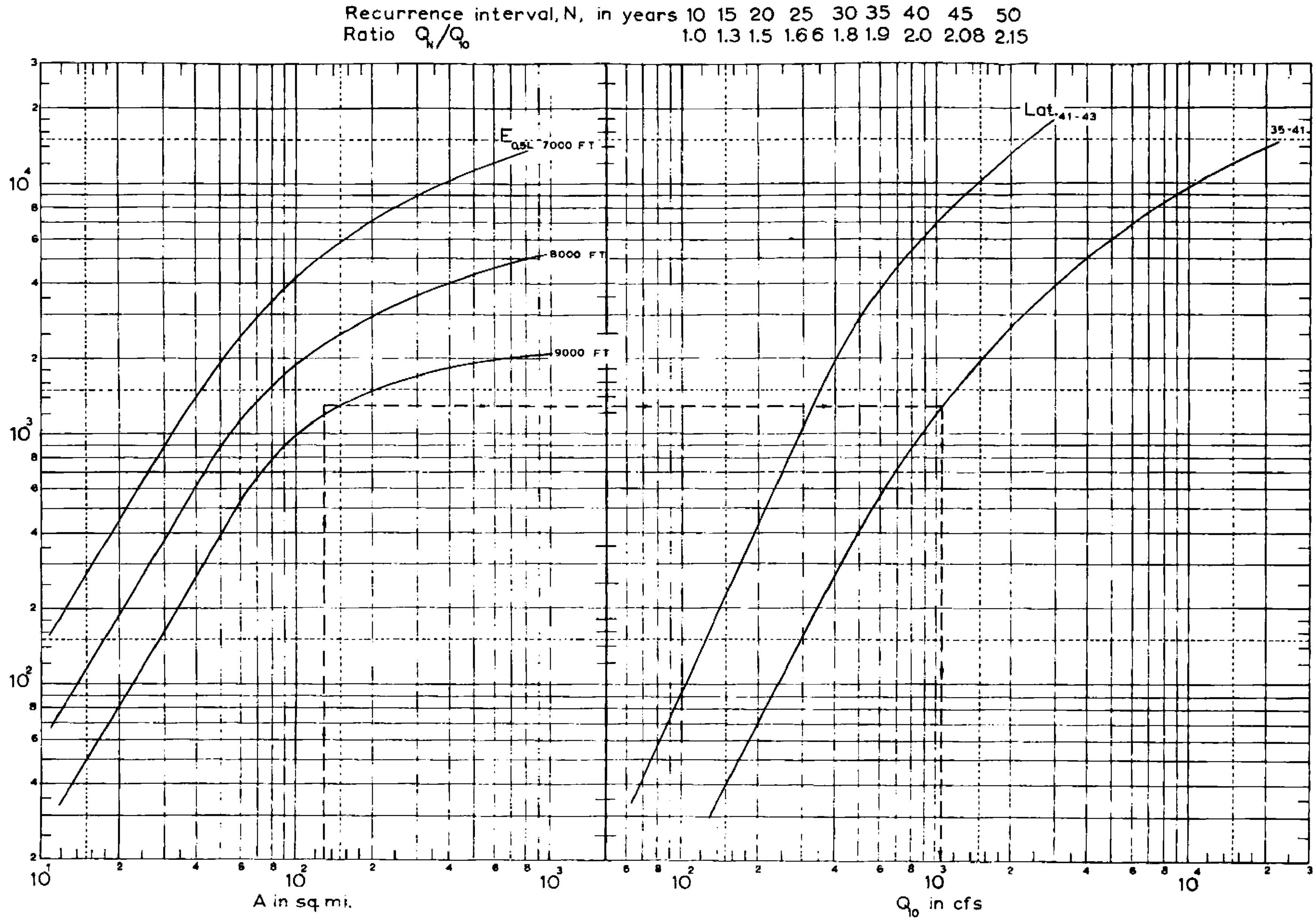

Fig.7 Peak rates of runoff determined from watershed contributing area, elevation and location (E-5 area).

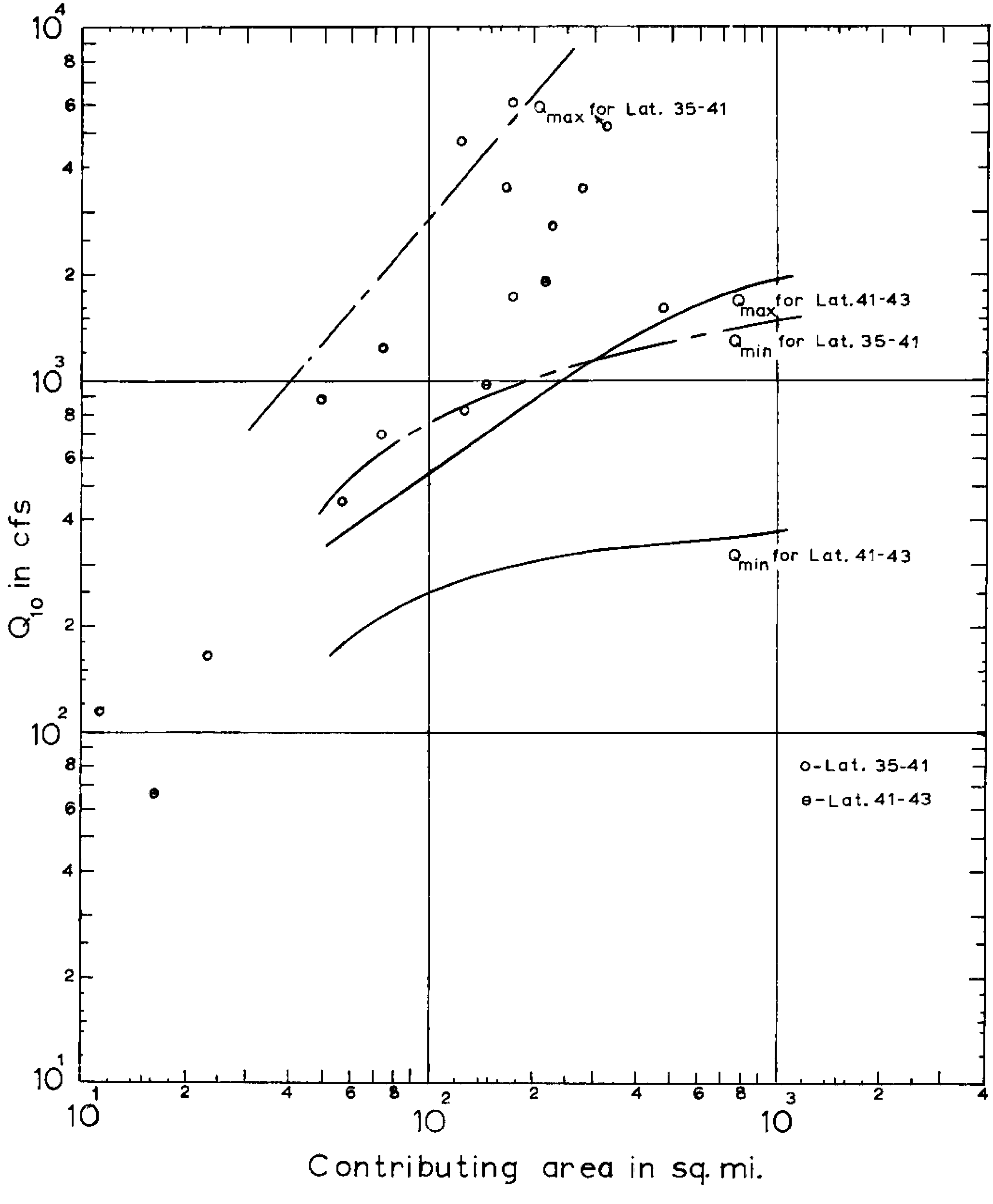

Fig. 8. Recommended maximum and minimum values of Q_{10} as a function of watershed size (E-5 area).

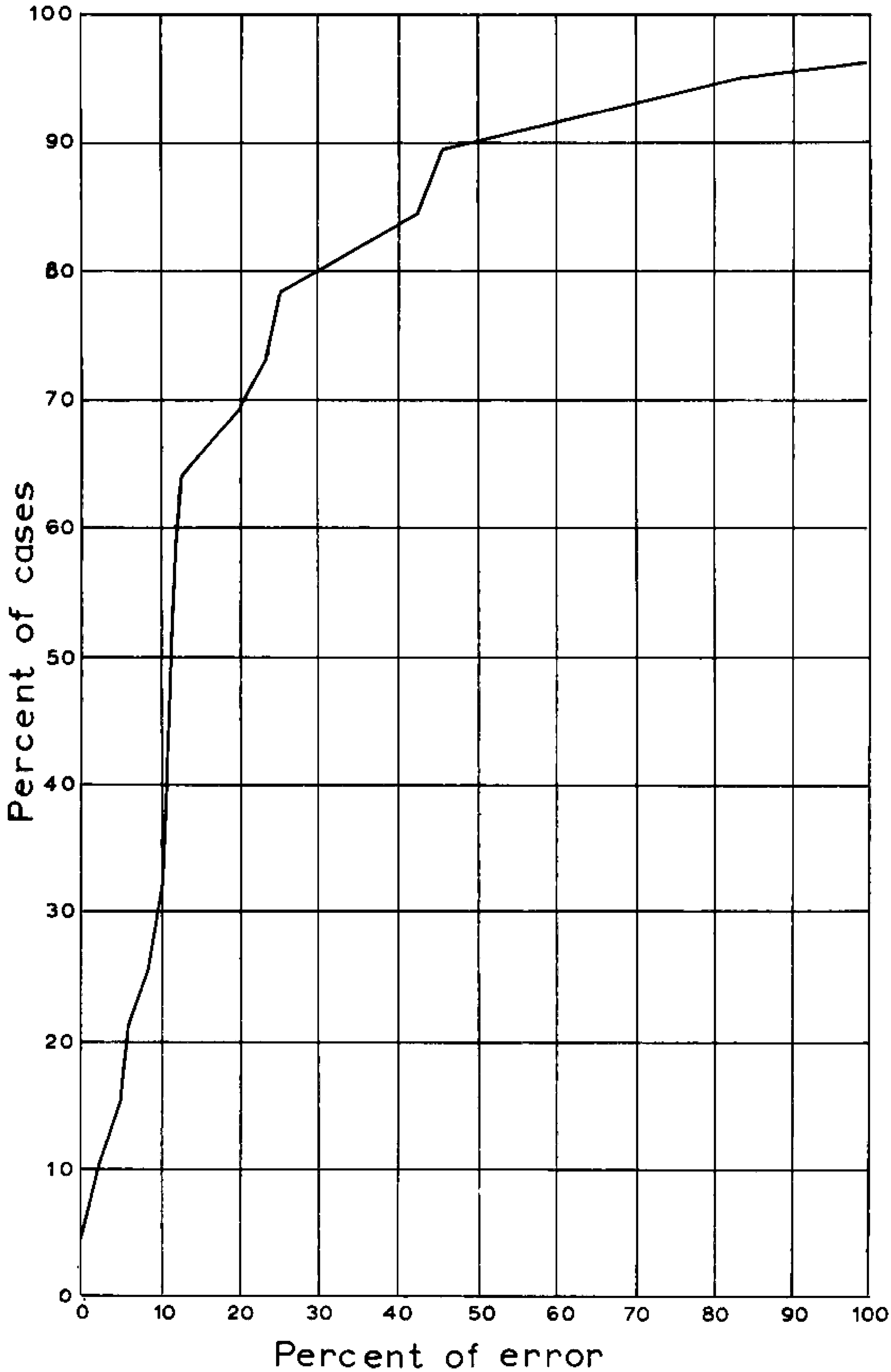

Fig. 9. Cumulative relative frequency of error of estimate of Q_{10} from Fig. 7.

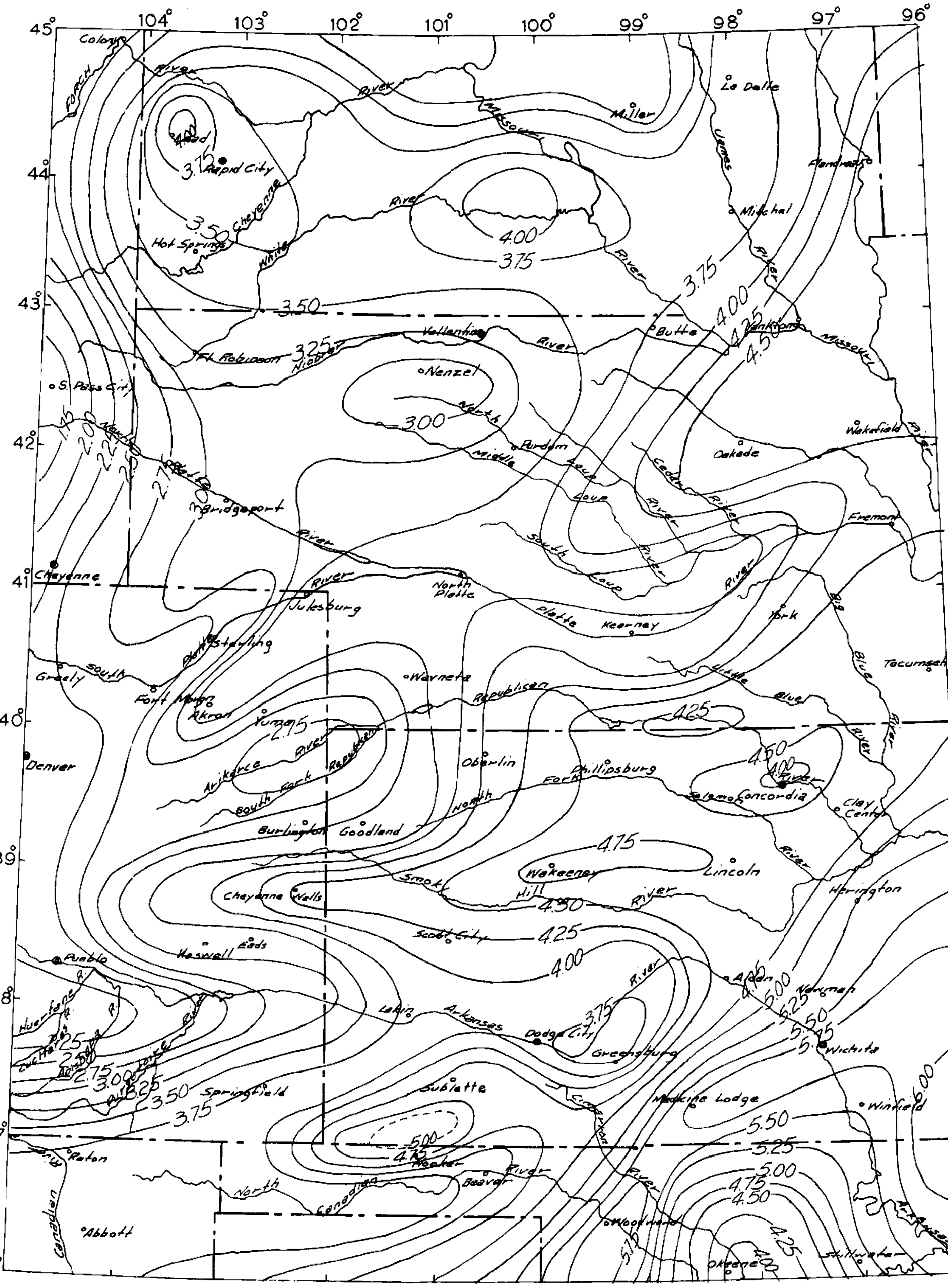

Fig. 10 Isohyetal map of 24 hour precipitation having a 10-year recurrence interval.

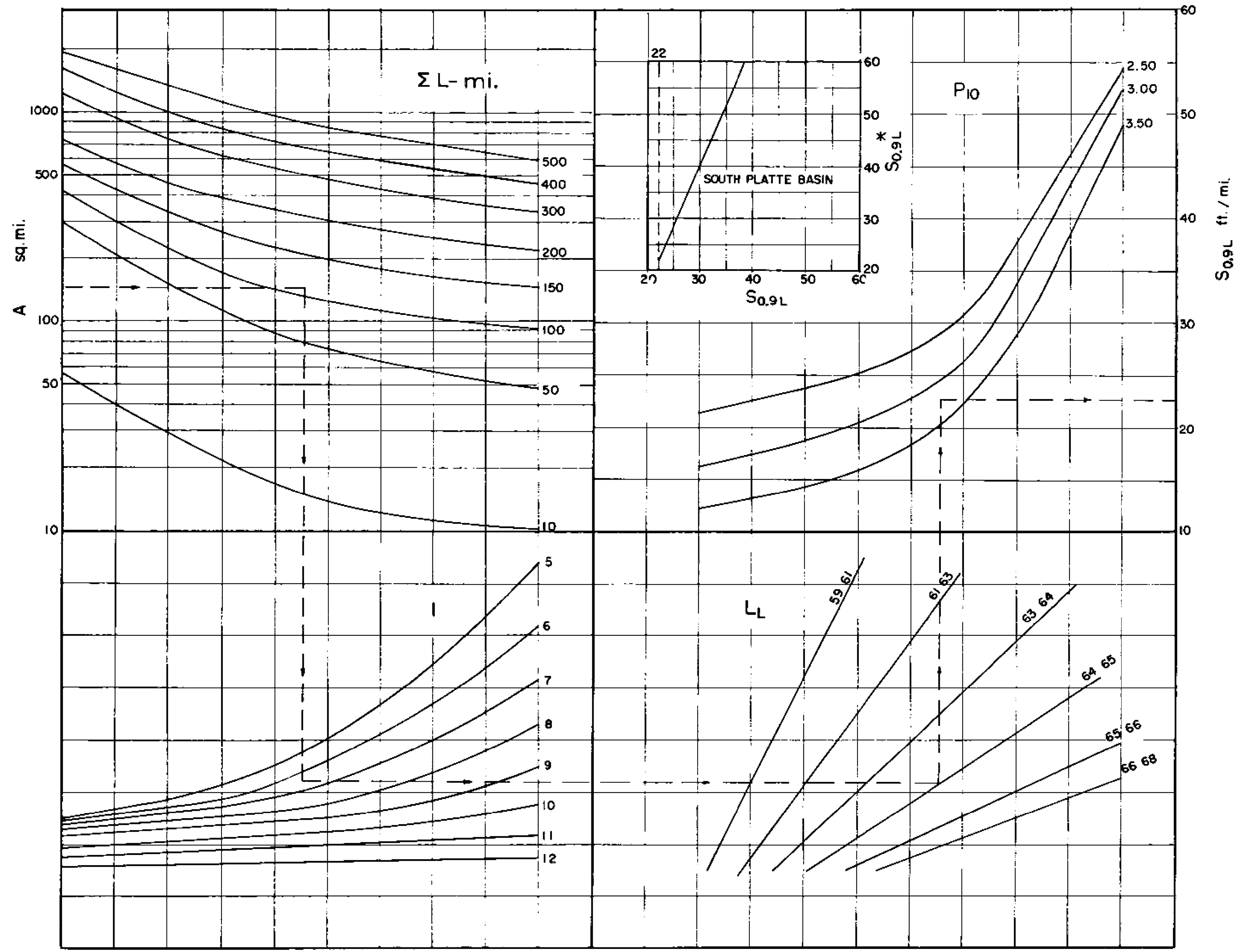

Fig.11 Relations for estimating S from A, ΣL, I, L_L, and P_{10}

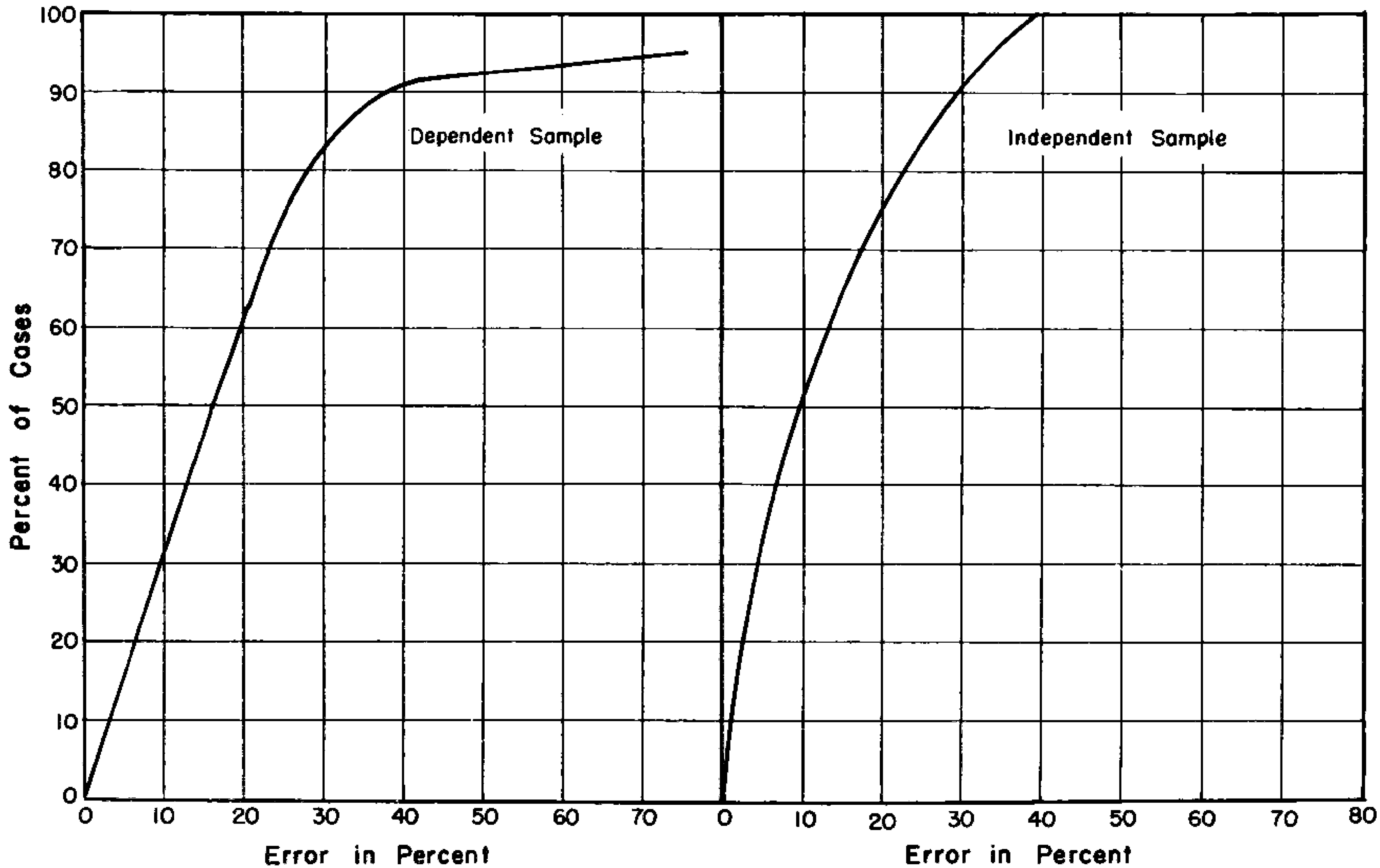

Fig. 12 Cumulative relative frequency of errors of estimate from Fig. 11.

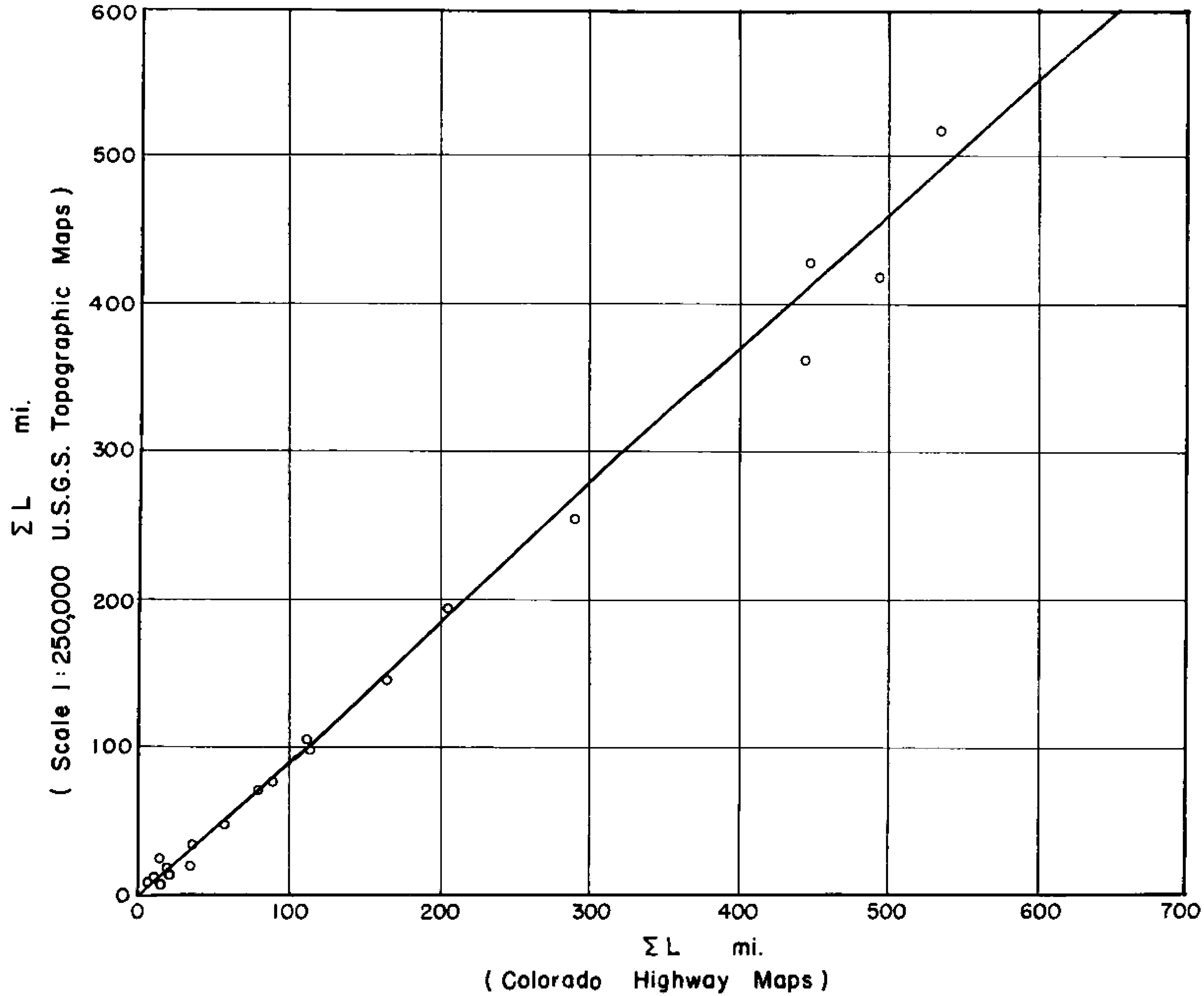

Fig. 13 Relations between the total channel length measured from 1:250,000 scale topographic maps and from Colorado Highway maps.