Preliminary Report

On

Magnitude and Frequency of Floods From Small Watersheds In Semi-Arid Areas

To

U.S. Bureau of Public Roads

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PRELIMINARY REPORT

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TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

TABLE OF CONTENTS - Continued

LIST OF FIGURES

Figure

LIST OF FIGURES (Continued)

Figures

ABSTRACT

This is a report of an investigation into meteorological and hydrologic records which established that watershed area and a slope parameter could be utilized for prediction of the peak rates of runoff having a ten-year recurrence interval in a part of the High Plains in eastern Colorado, western Kansas and Nebraska, and southeastern Wyoming.

Tentative relations were developed for peak rates of runoff having a ten-year and forty-year recurrence interval. Peak rates of runoff can be predicted from ungaged watersheds within the study area by using these relations.

Because limited data were available for this study from watersheds having a contributing area less than 100 square miles, results from this study must be considered as tentative and subject to revision as more data become available.

Results from related studies are presented.

The investigation is being continued to refine the techniques developed and to extend the study to adjacent areas.

I. INTRODUCTION

OBJECTIVES

The objectives of the investigation were:

1. To develop techniques for predicting magnitude and frequency of floods in semi-arid regions on watersheds having a contributing area less than 1000 square miles and lying within a region having similar lithologic and physiographic characteristics.
2. To evaluate the influence of certain physiographic parameters on peak rates of runoff.
3. To investigate the possibility of utilizing weather radar data to provide more adequate areal coverage of precipitation events for use in making estimates of runoff.

HISTORY

This investigation, initiated in July, 1958, is a research project sponsored by the United States Bureau of Public Roads.

II. ESTIMATES OF RUNOFF FROM PHYSIOGRAPHIC PARAMETERS

PRELIMINARY STUDIES

Collection of Data - Preliminary studies were confined to parts of eastern Colorado, western Nebraska and Kansas, southeastern Wyoming, and a part of southern South Dakota, as shown in Fig. 1. The "D-13" and "D-20" problem areas shown in Fig. 1 were established by the Soil Conservation Service on the basis of having similar physiographic features and similar problems in soil conservation. The D-13 area is called the "Northern Brown Plains." The D-20 area is called the "Plains of the Upper Arkansas and Purgatorie Rivers." Brief descriptions of the area in an unpublished manuscript of the Soil Conservation Service follow:

D-13 Northern Brown Plains

"The Northern Brown Plains occupy a total area of 48,938,000 acres located in northeastern Colorado, northwestern Kansas, southeastern Wyoming, western Nebraska, and a small area extends into south central South Dakota... It has a relief that is characterized by nearly level to gently rolling tableland areas that break off into steeply rolling valley slopes. In the eastern part of Colorado and southwestern Nebraska there are several relatively large areas of sandhills...

"The average annual precipitation is about 14 to 18 inches ... Rainfall is quite variable .. (with) the greater portion of the precipitation falling (at high rates) with high runoff and erosion rates..

"In the area as a whole 42 per cent of the land is in cultivation and 54 per cent is in range....

"Soils of the area are.. of four types and all of them can be found in each of the four states. They are: (1) deep medium textured soils on nearly level tableland areas; (2) medium depth, medium textured soils on upland ...; (3) shallow medium textured soils and gravel; and (4) sandy soils on aeolian sand deposits."

D-20 Plains of Upper Arkansas and Purgatorie Rivers

"This area is located in southeastern Colorado and covers an area of 6,795,000 acres. The relief is undulating to rolling, 4,000 to 5,000 feet elevation above sea level. Rainfall variable, 11 to 14 inches (annually). Shallow to moderately deep, medium to moderately heavy textured soils on range land.

"...Erosion - - slight sheet erosion on much of the area. Severe in local areas having poor cover...

"Seven per cent cultivated ... 90 per cent grassland classed as semi-arid grazing land ... , 3 per cent miscellaneous, no forest."

Records of maximum annual rates of runoff from stations within these areas were collected if the following criteria were satisfied:

1. The length of record was equal to or greater than 7 years.
2. No significant artificial flow control existed for high flows.
3. The watershed contributing area was not more than 1500 square miles.
4. More than 50 per cent of the contributing area of each watershed must lie within the boundary of the D-13 or D-20 problem areas.

Analysis - All available records of peak rates of runoff from stations within the D-13 and D-20 areas that met these criteria were plotted on Gumbel's Extreme-Value probability paper and analyzed on the basis of techniques developed by Potter (1)* and by Benson (2). Discharges having a recurrence interval of 10 years (Q_{10}) were determined by Benson's technique for further study for seventeen watersheds in the D-13 and D-20 problem areas. Values of Q_2, Q_5, and Q_{15} were determined for the same stations by the same method. An estimate of Q_{25} was made by extension of the curve drawn by Benson's technique.

Relations Between Short-Term and Long-Term Floods - Attempts were made to relate short-term discharge values (Q_2, Q_5, Q_{10}) to longer-term discharge values (Q_{15}, Q_{25}) for stations with records of suitable length. Logarithmic plots were made of Q_2 vs Q_5, Q_5 vs Q_{10}, Q_5 vs Q_{15}, Q_5 vs Q_{25}, and Q_{10} vs Q_{25}. Of these combinations, Q_5 vs Q_{25} and Q_{10} vs Q_{25} were considered to have the greatest potential usefulness. The departures from the fitted regressions of Q_{25} on Q_5 and Q_{25} on Q_{10} was such that more than 67 per cent of the sample had an error of less than ±25 per cent, the criterion of

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* Numbers refer to appended references.

suitable accuracy followed in this study.

In order to make estimates of peak rates of discharge for recurrence intervals greater than 25 years, it was considered necessary to utilize records having longer records than those which were available in the D-13 and D-20 areas. The success in relating Q_{10} to Q_{25} as described above suggested that a sample of longer records from outside the study area could yield usable relations between floods of short and long-term frequencies that would be applicable to the study area. This approach is described in Chapter II.

Parameters Used in Multiple Correlation - Graphical multiple correlation techniques (3) were used in evaluating the relationship of Q_{10} with the following parameters:

1. The contributing area of the watershed, as listed in the U. S. Geological Survey Water Supply Papers.
2. A location factor, defined as the difference in degrees between the mean longitude and the mean latitude at the centroid of the watershed as determined by eye.
3. A drainage density factor, defined as the total length of channels in miles as indicated by the blue lines on 1:250,000 scale maps of the area prepared by the U. S. Geological Survey, divided by the contributing area in square miles as defined in item 1.
4. An orientation factor with respect to an east-northeast axis.
5. The mean elevation of the watershed, an average of the highest and lowest elevations.
6. The mean longitude in degrees at the centroid of the watershed as determined by eye.
7. The mean latitude in degrees at the centroid of the watershed as determined by eye.

8. The ratio of width of the watershed divided by its length. The length of the watershed was the distance from the gaging station to the furthest point. The width was defined as the contributing area divided by this length.
9. A compactness ratio, defined as the circumference of the circle having the same area as the watershed, divided by the total perimeter of the watershed.
10. A precipitation parameter which was the 2-year, 1-day point rainfall in inches, at the station nearest the centroid of the watershed.
11. A precipitation parameter which was the 5-year, 1-day point rainfall in inches, at the station nearest the centroid of the watershed.
12. A precipitation parameter which was a 5-year, 1-day point rainfall in inches, expressed as an average of stations in and near the watershed.
13. A precipitation parameter which was a 5-year, 1-day point rainfall in inches, expressed as area rainfall with an appropriate reduction from point-rainfall.
14. The overall slope of the watershed in feet per mile, determined by dividing the elevation difference between gaging station and headwater (in feet) by the distance (in miles) between these two points.
15. A slope parameter for the upper and lower halves of the watershed, determined as for item 14.

Of these parameters, the first three listed gave errors of estimate within acceptable limits of accuracy, using the dependent sample. The graphical relationship that was derived is shown in Fig. 2. It was not possible to develop a graphical correlation that gave acceptable accuracy using combinations of the other parameters.

REFINED ESTIMATES

Collection of Basic Data - The general requirements considered in the collection of basic data for refined estimates of rates of runoff included the following criteria in addition to those described previously:

1. Records of annual maximum stream flow had to be derived from recording gages only; those records derived from staff gage readings were discarded.
2. Records were not used if there were more than four years break in records.
3. No record was utilized where there had been a change in location of site greater than two miles up or down stream.

Records of rates of runoff from stations outside of the D-13 and D-20 problem areas were compiled in order to relate short-term to long-term floods. For these stations, the additional requirement of a minimum length of record of 23 years was established and a watershed size of not more than 2000 square miles.

Records of rates of runoff were also collected from stations inside the D-13 and D-20 problem areas. For these stations, the contributing watershed areas were all less than 1500 square miles with most stations having a contributing area less than 1000 square miles. The minimum acceptable length of records for stations in these areas was limited to seven years.

Relations Between Floods of Short-Term and Long-Term Frequency - A comparison was made between two techniques currently used in the analysis of data plotted on Gumbel paper. Potter's method (1) approximates an array of points on Gumbel paper by two straight lines, giving a "dog-leg". Benson's method (2) consists of drawing a curved line that best fits the array of plotted points. A frequency plot of the annual maximum runoff from each of the stations was made on Gumbel plotting paper. Each of the stations used in the study is identified in Appendix No. 1. Gumbel plots from the individual stations are included in Appendix No. 2. Stations included in the study that were located outside of problem areas D-13 and D-20 fell into four general geographic locations: northwest, east, southeast and southwest of the problem areas D-13 and D-20, defined respectively by the following locations:

Northwest: 45 to 49 degrees north by 106 to 113 degrees west.
East: 37 to 43 degrees north by 94 to 100 degrees west.
Southeast: 29 to 35 degrees north by 94 to 101 degrees west.
Southwest: 34 to 38 degrees north by 102 to 107 degrees west.

Curves were drawn on the Gumbel plots by the two methods described previously. Using the Potter approximation, two straight lines were drawn to best fit the data, and using Benson's method a curved line was drawn that best fit the plotted points.

Approximately 58 separate records were available in the geographic locations mentioned previously outside the problem areas D-13 and D-20. A sample was selected, using the following criteria:

1. Equal numbers of stations were desired from each location.
2. Equal numbers of stations were desired from watersheds less than 500 square miles from watersheds larger than 500 square miles.
3. Equal numbers of stations were desired from different lithologic areas having the following classifications:
    a. Sandstone and shale.
    b. Glacial drift and loess.
    c. Unclassified.

Using these criteria, a total sample of 22 stations was selected from the 58 records available. Of these 22 stations, 19 were suitable for the Benson method of analysis; three stations being discarded because of extreme irregularities in the plotted curve on the Gumbel paper. The same 3 stations were discarded in utilizing the Potter method because the upper and lower frequency curves were nearly parallel. This gave a discontinuous curve utilizing the Potter method. In addition, two other stations were discarded for utilization by the Potter method because of an excess error in approximating the plotted points with the two straight lines by the "dog-leg" method. For these two stations, the accumulated percentage error in representing the data with the "dog-leg" was greater than ± 25 per cent for 2/3 of all plotted points having a recurrence interval of 10 years or more.

The next procedure was to compare the errors resulting from each of the two methods of curve fitting. Using the 17 stations that remained, the accumulated error curve was plotted for both methods. The distribution of error curve is shown in Fig. 3. It will be noted that both methods gave a good representation of the plotted points having a recurrence interval greater than 10 years. Approximately 95 per cent of the sample was within ±17 per cent error for both methods.

An attempt was made to group the data from the regions outside of D-13 and D-20 problem areas by geographic areas and by geological parent material classifications. Variations in the relation between Q_{10} vs Q_{40} (Benson's method) and Q_{10U} vs Q_{40U} (Determined from the upper frequency curve by Potter's method) were considered to be sufficiently small to permit grouping together the data from northwest, southwest, and east of the problem area. Data from these locations were grouped together. A plot of Q_{10} vs Q_{40} (Benson method) is given in Fig. 4. Plots of Q_{10L} vs Q_{40U} and Q_{10U} vs Q_{40U} are given in Fig. 5. (Q_{10L} was determined from Potter's lower frequency curve.) Fig. 6 shows the distribution of error curves for both methods. Examination of Fig. 6 shows that a smaller error results from use of the Benson method, which gives 94 per cent of the sample having ± 25 per cent error.

The relations shown if Fig. 4 and Fig. 5 were derived from geographic locations outside of the D-13 and D-20 problem areas. The problem remained to compare this type of relation from outside the D-13 and D-20 areas with that inside the same area. Fig. 7 shows the relation between Q_{10} vs Q_{25} for points inside and outside the D-13 and D-20 problem areas. Since the points from inside the study area appear to be consistant with those northwest, east, and southwest of the study area, the assumption was made that the relation between Q_{10} and Q_{40} as shown in Fig. 4 also applied inside the D-13 and D-20 areas. This is in agreement with the tentative conclusion reached in the preliminary studies.

It should be noted that the apparent better fit for the "Benson" curve on Fig. 6 is not adequate justification for acceptance and use of the method described herein. Drawing a curved line on Gumbel paper departs significantly from the straight line that theoretically should represent extreme values. Acceptance of a curved line on Gumbel paper implies the existence of a limiting discharge for a curve that is concave downward or of a limiting recurrence interval for a curve that is concave upward. While a limitation on the maximum possible discharge may be possible on physical reasoning, a more common occurrence in the area studied was a curve that was concave upward.

The method of Potter in fitting two straight lines to the plotted points on Gumbel paper does not suffer these limitations, although for some records difficulty was experienced in obtaining a suitable fit for the data with two straight lines. Fig. 6 shows that this method approaches acceptable accuracy of "two-thirds of the sample having less than 25 per cent error."

A comparison of values of Q_{10} and Q_{10U} for stations inside and outside of the D-13 and D-20 problem areas is shown in Fig. 8. Based on this comparison it was concluded that differences between Q_{10} and Q_{10U} as used in this study were not significant.

Comparison of Figs. 4 and 5b show that for a given estimate of Q_{10} (or Q_{10U}), the difference between the resulting estimate of Q_{40} and Q_{40U} is less than 25 per cent for nearly all the range of values shown on Fig. 8.

For these reasons the estimate of Q_{10} and Q_{40}, obtained as described above, are considered to be consistent with estimates of Q_{10U} and Q_{40U}. In view of the length of records used to derive the relationship of Fig. 11, it was not considered feasible to extend the relationship shown in Fig. 14, beyond a frequency of 40 years. The relation shown in Fig. 4 was used to develop the relation between Q_{10} and Q_{40} as shown in Fig. 14.

Graphical Correlation - The preliminary studies described previously indicated that watershed contributing area, geographic location, and stream density were factors that could be used for making estimates of peak rates of runoff for ungaged watersheds. While it was believed possible to utilize these physiographic parameters in the final graphical correlation, several disadvantages in use of these parameters were evident. Computation of the drainage density factor was time consuming and laborious. The location parameter (longitude minus latitude), while probably directly related to the frequency of thunderstorm occurrence, is not a parameter that is directly involved in the runoff process. Consequently other suitable parameters were sought.

Work by Benson (5) indicated that channel slope showed considerable promise as a factor for explaining variations in peak rates of runoff from New England watersheds. Watersheds from inside the study area were examined and dimensional and dimensionless plots were made of the channel profiles. These profiles are shown in Figs. 9 and 10.

Each of three slope parameters were used in conjunction with contributing area in a graphical correlation process to derive a relation suitable for use in estimating Q_{10}. Following Benson's work (5) a slope parameter $S_{.9L}$ was defined by

$$S_{.9L} = \frac{E_{0.9L} - E_{CS}}{D}$$

where $E_{0.9L}$ = elevation in feet 9/10ths of the length of the watercourse upstream from the construction site.

E_{CS} = elevation in feet at the construction site.

D = distance in miles along the watercourse between these locations.

The second slope parameter utilized was the "T" factor, suggested in conversations with Mr. W. D. Potter. The "T" factor (indicating a measure of "time of travel,") is defined as follows:

$$T = T_1 + T_2 = \frac{0.3L}{\sqrt{S_1}} + \frac{0.7L}{\sqrt{S_2}}$$

where $\sqrt{S_1} = \sqrt{\frac{E_{HW} - E_{0.7}}{0.3L}}$

and $\sqrt{S_2} = \sqrt{\frac{E_{0.7L} - E_{CS}}{0.7L}}$

where the symbols have the following meanings:

E_{HW} = elevation (feet msl) at the headwaters of the watershed

$E_{0.7L}$ = elevation (feet msl) at a point 0.7 of the distance from the construction site to the headwaters, measured along the watercourse.

E_{CS} = elevation (feet msl) at the construction site.

L = distance (in miles) between construction site and headwaters.

A third slope parameter was defined by

$$S_{0.5L} = \frac{E_{0.5L} - E_{CS}}{0.5L}$$

where $E_{0.5L}$ and E_{CS} are the elevations in feet at the point 0.5 the length of the watercourse and at the construction site, respectively, and L has the same meaning as above.

These slope parameters were used in conjunction with contributing area "A" (in square miles) in a graphical correlation process to estimate Q_{10}. It was found that use of $A^{1/2}$ provided some improvement over $A^{1.0}$ in some cases. The correlations were repeated, using $A^{0.75}$ and $A^{0.90}$. It was found that $A^{0.90}$ vs Q_{10} with the slope parameter $S_{0.9L}$ gave the best results. Fig. 11 shows the relation between these variables, and forms the basis of Fig. 14 which is presented in Chapter IV.

The parameters used in Fig. 11 and Fig. 14 are probably not the only ones suitable for use; in fact they may not be the best ones for the intended purpose. However, they are believed to be suitable for use because they satisfy the following criteria:

1. They are relatively simple to determine.

2. The accuracy of estimate of Q_{10} is consistent with the accuracy of the basic data on contributing area and measured discharge that went into the study.

For these reasons, further refinements in Figs. 11 and 14 were not attempted. Additional records of peak rates of runoff having a high degree of accuracy are desirable for making further refinements in the relations shown in Figs. 11 and 14. It will be noted that five stations in Fig. 11 (Nos. 4, 20, 25, 33, and 34) have 12 years' record or less. For this reason their estimated Q_{10} in Fig. 11 may be subject to some revision. In view of this fact and because of the scarcity of data from drainage areas of less than 100 square miles, the correlation charts in Fig. 11 and Fig. 14 were modified from a consideration of unit discharges (cfs/mi^{-2}) as a function of area. (Details are not presented in this report.)

A description of the use of Fig. 14 and some of the limitations and precautions to be observed, are given in Chapter IV, "SUMMARY OF RESULTS."

III. BACKGROUND STUDIES

OUTSIDE CONTACTS

A survey of all sources of information was first made with the following objectives:

1. Prevention of duplication in methodology and data analysis.
2. Obtaining only data essential to the proposed study.

Agencies contacted were (a) those making studies of runoff on small watersheds, (b) those making studies of severe storms in eastern Colorado, and (c) those responsible for flood and erosion control on small watersheds.

A list of persons and agencies contacted during the course of the study is given in Appendix 3.

CONFERENCES

A general description of the objectives of the project and some of the details of procedure being followed were presented at two separate conferences. The first presentation was given to meeting of the Committee on Surface Drainage of the Highway Research Board which met at Fort Collins on 15 September 1958.

The second presentation was given to a Highway Drainage Conference sponsored jointly by the U.S. Bureau of Public Roads and the Colorado Department of Highways on 3 March 1959 in Denver.

PRECIPITATION STUDIES

Because runoff in semi-arid regions is a direct function of such parameters as the amount of precipitation, and precipitation pattern on the watershed, the rainfall distribution associated with annual floods in eastern Colorado was studied. The objective of the study was to define the size of watershed that gives floods from "random" thunderstorm activity, as opposed to general precipitation over a wider area. Using climatological data, this study was confined to nine stations in eastern Colorado.

Annual maximum peak flows from contributing watersheds of not more than 1000 square miles were recorded for the period 1930-1950. For each flood event the amount of precipitation at raingage stations--recording or non-recording--on or near the basin was determined. The precipitation data were then given a weight, as follows: If 0.1 inch per day fell at a raingage station, a weight of 1 was given; if less than 0.1 inch were recorded, a weight of 0.5 was given; and zero rainfall was given a weight of zero.

The drainage basin was divided into sub-areas by the Thiessen method using the foregoing weighted values to compute the per cent of basin area covered by precipitation for the given flood event. A weight of "one" was used when the entire sub-area received rainfall. The ratio of the number of the annual maximum floods associated with 100 per cent coverage of watershed to the total number of flood events was then expressed as a per cent. This value was then plotted against basin area, as shown in Fig. 12 . Fig. 12 shows that for watersheds with contributing areas larger than about 900 square miles, two-thirds or more of the annual maximum flood events are associated with rains which cover the entire basin. For watersheds with contributing areas less than about 50 square miles, one-third or less of the annual maximum floods are caused by such rainfalls.

A factor related to flood runoff from small, intense storms is clock-hourly precipitation amounts. Because of the paucity of such data at non-recording rain gage stations in eastern Colorado, an investigation was made to determine if daily or monthly values of rainfall could be used to make estimates of clock-hourly precipitation values.

The investigation was confined to the analysis of precipitation amounts having a two-year recurrence interval. The data collected included daily, monthly, seasonal and annual precipitation amounts having a two-year recurrence interval. Through interrelationships termed "relative wetness," estimates were made of clock-hourly precipitation amounts for the two-year recurrence interval from precipitation amounts of longer duration. Preliminary results show that these estimates are acceptable as a substitute for recorded clock-hourly precipitation amounts. Details of this study are given in Appendix 4.

The use of weather radar echo data received from rainstorm patterns was also investigated as a possible means of obtaining more adequate areal coverage of rainfall events. Two sources were considered (a) hand-drawn sketches of the PPI scope of the United Air Lines 5.5 cm radar set, and (b) reconstructed records of CPS-9 data (a 3.0 cm set) from Lowry Air Force Base. Both radar units were located in Denver, Colorado and have a range of approximately 200 miles.

To test the suitability of these data as a means of providing more adequate areal coverage of rainstorm events, attempts were made to correlate echo intensity with clock-hourly rainfall amounts concurrent with the time of echo occurrence.

No satisfactory correlation was obtained for either the United Air Lines data or the CPS-9 data.

Details of these studies are given in Appendix 5 and Appendix 6.

Attempts were made to correlate certain physiographic parameters with precipitation parameters, as had been done by Spreen (4) for western Colorado, where mean seasonal and annual precipitation was correlated to factors of elevation, exposure, and zone. Results indicated that a statistically significant correlation could be obtained between mean monthly rainfall (the month of May was used in the study) and simple parameters of location (latitude, longitude and elevation.) Detailed results of these correlation analysis for a number of stations in eastern Colorado are given in Chapter IV.

These precipitation studies were undertaken in an attempt to find a precipitation parameter suitable for reducing some of the observed variation in rate of runoff from watersheds of comparable size. As noted previously, several precipitation parameters (2 and 5-year) 24-hour precipitation amounts, both for point and areal rainfall) were tried unsuccessfully for this purpose. The reason for this failure is not clear. It is possible that the entire region under study may have precipation characteristics sufficiently homogeneous that explanations for variations in rate of runoff cannot be explained by precipitation parameters.

A further limitation in the precipitation parameter using clock-hourly data is the relative shortness of record for many stations. This may have caused difficulty, for example, in attempts to relate a precipitation parameter having a 2-year or a 5-year recurrence interval to a 10-year rate of runoff. The relative wetness study described previously indicates that there is a close relation between daily and clock-hourly precipitation amounts. Hence, use of daily rainfall amounts from stations having long records can help to overcome this difficulty.

RUNOFF STUDY

The Seasonal Distribution of Annual Maximum Flood Events - A study was made to determine the effect of elevation and contributing area on the seasonal distribution of annual maximum flood events for sixty-two stations in the North Platte, South Platte, Republican, Arkansas, and Colorado River watersheds covering all of Colorado, except the San Luis Valley.

The stations were first divided into three nearly equal groups according to elevation. These groups were then divided into three more groups according to watershed area, making a total of nine classes with varying numbers of cases in each class. Each class was then plotted using accumulated frequency of annual maximum flood events in per cent vs month of occurrence of the maximum flood event.

Results of this study indicate that the average date of occurrence of 67 per cent of annual maximum floods advances with increase in watershed size, and that for watersheds below 7683 feet elevation, the date of occurrence of 67 per cent of annual maximum floods advances with decreasing elevation.

Details of this study are given in Appendix 7.

IV. SUMMARY OF RESULTS

PRESENTATION OF RESULTS

Area of Application - A map showing the area of application of these results is shown in Fig. 13.

Estimates of Q_{10} and Q_{40} from Physiographic Parameters - Fig. 14 shows the relations among area (A), slope factor $(S_{0.9L})$, Q_{10} and Q_{40}.

USE OF FIG. 14 FOR ESTIMATES OF PEAK RATES OF RUNOFF

Geographical Limitations - Use of Fig. 14 should be limited to the confines of problem areas D-13 and D-20, shown in Fig. 13.

Limitation on Size of Contributing Watershed - Fig 14 is applicable for watersheds having a contributing area less than 1000 square miles.

Example of Use - The following example illustrates the use of Fig. 14 for making estimates of magnitude and frequency of peak rates of runoff. Assume a watershed within the region shown in Fig. 13, having the following characteristics:

Contributing area: 400 square miles.

Length of watercourse (measured from appropriate map or aerial photograph): 45 miles.

Elevation at construction site: 5608 feet.

Elevation at 9/10ths of the distance from the construction site to the headwaters: 7320 feet.

From these values, the following parameters are determined:

$A = 400$ square miles.

$$S_{0.9L} = \frac{E_{0.9L} - E_{CS}}{0.9L} = \frac{7320 - 5608}{40.5} = 42.3$$

Enter Fig. 14 with $A = 400$, $S_{0.9L} = 42.3$,

and read

$Q_{10} = 14{,}000$ cfs

$Q_{40} = 20{,}500$ cfs

These values of Q_{10} and Q_{40} are the desired estimates of peak rates of runoff having a recurrence interval of 10, and 40 years, respectively.

LIMITATIONS AND PRECAUTIONS

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

Errors of Estimate - The distribution of error curve for estimates of Q_{10} from Fig. 11, from which Fig. 14 was derived, are given in Fig. 15. This shows that approximately 76 per cent of the dependent sample has an error of estimate less than 25 per cent. This is considered as acceptable accuracy for field design purposes, since it complies with the basic accuracy requirement of at least 67 per cent of the sample having a departure of less than ± 25 percent from the fitted regression.

Recommended Maximum and Minimum Values of Q_{10} as a Function of Area - Maximum recorded peak rates of flow as a function of watershed size are shown in Fig. 16 as an envelope curve. (Source: U.S. Bureau of Reclamation, compiled largely from U.S. Geological Survey records.) Observed values of Q_{10} at 15 stations in D-13 and D-20 areas are plotted on Fig. 16 with small circles. The curves giving maximum and minimum recommended values of Q_{10} were computed on the basis of the graphical correlation in Fig. 11. These two curves serve as envelopes for estimation of Q_{10} for the streams with $S_{.9L} = 10 - 50$ ft/mi in the study area. The upper curve corresponds to $S_{.9L} = 50$ ft/mi, and the lower curve to $S_{.9L} = 10$ ft/mile.

SUMMARY OF RESULTS 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 two types of weather radar data to extend the areal coverage for individual rainfall events. Hand-drawn sketches of the Plan-Position Indicator (PPI) scope from a 5.5 cm set used by United Air Lines in Denver, and sketches of a PPI scope reconstructed from coded descriptions of radar echo data from a 3.0 cm set at Lowry Air Force Base in Denver were studied. It was concluded that the data in this form were not suitable for the intended purpose.

Correlation of precipitation factors with physiographic parameters- Mean monthly precipitation for May was correlated with position (latitude, longitude, and elevation) for 48 stations in eastern Colorado.

Details of this correlation follow:

Independent variable (Y) = mean monthly precipitation for May, inches

Independent variables

X_1 = latitude, less 30 degrees.

X_2 = longitude, less 100 degrees.

X_3 = elevation, in 10 thousands of feet.

Station groupings

Group 1: Nineteen (19) stations in Colorado in the Arkansas River drainage.

Group 2: Twenty-nine (29) stations in the Platte and Kansas drainage in Colorado.

Results included the regression equation, the correlation coefficient $\bar{R}$, the standard error of estimate $\bar{S}$, and the standard deviation (σ) of the individual coefficients.

Results

Group 1:

$Y = 2.99 - 0.045X_1 - 0.55X_2 + 2.95X_3$

$\bar{R} = .72$ (Significant at 99 per cent level)

$\bar{S} = .38$

$\sigma_1 = .17$

$\sigma_2 = .12$

$\sigma_3 = .73$

Group 2:

$Y = 3.33 + 0.03X_1 + 0.15X_2 - 3.43X_3$

$\bar{R} = 0.67$ (Significant at 99 per cent level)

$\bar{S} = 0.37$

$\sigma_1 = .13$

$\sigma_2 = .09$

$\sigma_3 = .90$

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.

V. DISCUSSION

RESEARCH NEEDS

Need for additional records from small watersheds - Throughout the course of this study it was evident that there was an acute shortage of suitable records of runoff from small watersheds in the study area. This scarcity of adequate records of runoff was probably the most severe limitation in the statistical sampling procedure for determining relations suitable for prediction of magnitude and frequency of runoff from small watersheds.

One of the most valuable contributions to knowledge in the field of small watershed hydrology in this region would be the establishment of additional records of runoff for watersheds having a contributing area less than 100 square miles.

Such re-examination should have the objective of determination of a distribution that would produce the characteristic of linearity when applied to peak flood flows from small watersheds in semi-arid regions.

PLANS FOR FUTURE STUDIES

The similarity in relations between Q_{10} and Q_{40} for stations over a broad region (See Fig. 7) suggests that an analysis of the type presented in this study could also produce usable results in the areas adjacent to the D-13 and D-20 problem areas. Adjacent areas wherein records of peak rates of runoff were compiled in this study include the following (See Fig. 1 for locations.)

South: D21, D22, D29.
East: D14, D16, D18, D19.
North: D6, D7, D8, D9.

In addition to these areas, the Rocky Mountain Foothills region (E-5) contains a considerable number of records of runoff suitable for analysis.

Plans for future studies include the analysis of records collected from these areas, with the objective of developing suitable relations for estimates of peak rates of runoff from ungaged watersheds. Priority of endeavor will be determined in consultation with the sponsor of the work.

In addition, work is underway on certain of the items mentioned previously in the section "RESEARCH NEEDS." Specific items include the following:

Study of the effects of diversions for irrigation on peak rates of runoff.

A better delimitation of precipitation characteristics as they affect runoff from small watersheds.

Study of methods of representing frequency distribution of peak rates of runoff with linearity in semi-arid regions.

ACKNOWLEDGMENTS

Throughout this study, a large number of persons have contributed suggestions and comments from their experience which have been of considerable help in the study.

Particular thanks are due Mr. W. T. Miller of the Denver office of the U. S. Geological Survey for his assistance in collection of the basic data included herein. Thanks are also due the U. S. Geological Survey offices in Lincoln, Nebraska and Topeka, Kansas for their assistance in collection of basic data.

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The authors wish to thank Mr. Carl Izzard and Mr. W. D. Potter for their helpful suggestions made during the study, and to thank the U. S. Bureau of Public Roads for sponsoring the study.

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APPENDIX NO. 1.

IDENTIFICATION OF STATIONS USED IN THE STUDY

Appendix No. 1, Part a-1

Identification of Caging Stations Used In The Study
(Includes every station for which frequency plot was made)

Stations Inside D-13 & D-20 Problem Areas, Including Fringes

Serial Number	Name	Refer to U.S.G.S. Water Supply Paper
1	Fountain Creek at Pueblo, Colo.	159-1311
3	Apishapa River near Fowler, Colo.	184-1311
4	Timpas Creek near Rocky Ford, Colo.	186-1311
5	Horse Creek near Sugar City, Colo.	191-1311
9	Rawhide Creek near Lingle, Wyo.	126-1310
10	Blue Creek near Lewellen, Nebr.	155-1310
11	Birdwood Creek near Hershey, Nebr.	165-1310
12	Cherry Creek near Franktown, Colo.	201-1310
13	Cherry Creek near Melvin, Colo.	202-1310
14	Cherry Creek below Cherry Creek Dam, Colo.	203-1310
15	Cherry Creek at Denver, Colorado	204-1310
16	Lodgepole Creek at Bushnell, Nebr.	288-1310
18	North Fork Republican River at Colorado-Nebraska State Line	387-1310
19	Buffalo Creek near Haigler, Nebr.	388-1310
20	Rock Creek near Parks, Nebr.	389-1310
22	Frenchman Creek below Champion, Nebr.	400-1310
23	Sappa Creek near Oberlin, Kansas	420-1310
24	White River at Crawford, Nebr.	332-1439
25	Niobrara River above Box Butte Reservoir, Nebr.	343-1439
31	Pumpkin Creek near Bridgeport, Nebr.	151-1310
33	Landsman Creek near Hale, Colo.	392-1310
34	South Fork Republican River near Idalia, Colo.	391-1310
35	Cottonwood Creek at Wendover, Wyo.	99-1310
36	Frenchman Creek near Hamlet, Nebr.	403-1310
37	Purgatoire River at Trinidad, Colo.	193-1311
38	Vermejo River near Dawson, New Mexico	323-1311
40	Sheep Creek near Morrill, Nebr.	137-1310
41	Dry Spotted Tail Creek at Mitchell, Nebr.	139-1310
42	Tub Spring near Scottsbluff, Nebr.	141-1310
43	Winter Creek near Scottsbluff, Nebr.	143-1310
44	Ninemile Drain near Mcgrew, Nebr.	146-1310
45	Bayard Sugar Factory Drain near Bayard, Nebr.	147-1310
46	Red Willow Creek near Bayard, Nebr.	149-1310
47	Bijou Creek near Wiggins, Colo.	282-1310
48	Buffalo Creek near Darr, Nebr.	300-1310
49	Buffalo Creek near Overton, Nebr.	301-1310
50	Elm Creek near Overton, Nebr.	302-1310
51	Wood River near Riverdale, Nebr.	305-1310
52	Wood River near Gibbon, Nebr.	306-1310
53	Middle Loup River at Dunning, Nebr.	312-1310
54	Middle Loup River at Arcadia, Nebr.	318-1310

Location		Drainage Area in Sq. Mile		Period of Record in Years	Problem Area
Longitude	Latitude	Nominal	Contributing		
104-35-40	38-16-20	926	------	17	D-20
103-59	38-05	1125	------	20	D-20
103-43-20	37-57-20	451	------	9	D-20
103-37-40	38-14-10	1080	------	8	D-20
104-19-20	42-07-30	510	------	23	D-13
102-10	41-20	267	------	24	D-13
101-05	41-13	286	------	23	D-13
104-45-50	39-21-30	172	------	19	D-13
104-49-15	39-36-20	369	------	19	D-13
104-51-[illegible]	39-39-10	386	------	9	D-13
105-00-00	39-44-58	420	------	16	D-13
103-[illegible]	41-14	1090	------	20	D-13
102-03-05	40-04-10	320	------	24	D-13
101-58-15	40-02-45	180	20	18	D-13
101-43-40	40-02-30	180	14	12	D-13
101-[illegible]	40-28-00	940	[illegible]	22	D-13
100-32-[illegible]	39-48-45	1040	unknown	1[illegible]	D-13
103-25-[illegible]	42-41	313	------	1[illegible]	D-13
103-10-[illegible]	42-27-35	1400	960	[illegible]	D-13
103-0[illegible]	41-38	1080	------	2[illegible]	D-13
102-1[illegible]	39-34-40	450	------	[illegible]	D-13
102-1[illegible]	39-37-00	1300	------	[illegible]	D-13
104-[illegible]	42-19-37	159[illegible]	------	23	D-13
10[illegible]	40-22-30	1480	960	2[illegible]	D-13
104-[illegible]	37-10-15	795	------	37	D-20
104-[illegible]	36-40-50	301	------	30	D-20
103-[illegible]	41-58	?	------	18	
103-[illegible]	41-57	?	------	16	
103-[illegible]	41-55	?	------	16	
103-[illegible]	41-52	?	------	20	
103-2[illegible]	41-46	?	------	20	
103-1[illegible]	41-44	?	------	20	
103-[illegible]	41-43	?	------	20	
104-02-[illegible]	40-14-53	1420	------	7	
99-50-00	40-54-00	63	------	10	
99-3[illegible]	40-44	179	------	9	
99-3[illegible]	40-50-40	31	------	12	
99-1[illegible]	40-47-50	379	------	12	
98-4[illegible]	40-46-10	572	------	10	
100-0[illegible]-20	41-49-50	1760	80	9	
99-08-10	41-25-20	4730	820	19	

	Main Channel Slope Factor		
L in Miles	$E_{0.9L}$ in Ft.	E_{GS} in Ft.	$S_{0.9L}$
71.4	6920	4663	35.2
100.3	7530	4317	35.5
48.0	5270	4220	24.3
31.6	3700	3309	13.7
29.0	3200	2920	10.7
25.7	7380	6150	53.3
44.9	7320	5608	42.3
93.9	7120	4812	27.3
25.5	3760	3336	18.5
10.2	3460	3204	27.9
9.2	3250	3093	19.0
80.6	4190	3240	13.1
122.0	5180	4012	10.6
55.9	4330	3636	13.8
56.1	4615	3720	17.7
88.1	5210	3680	19.3

(Remark)

1. L - Main Channel Length from Gaging Station to Headwater

2. $E_{0.9L}$ - Elevation of Channel Bed at 90% of L upstream from Gaging Station

3. E_{GS} - Elevation of Channel Bed at Gaging Station

4. $S_{0.9L} = \dfrac{E_{0.9L} - E_{GS}}{0.9L}$

Appendix No. 1, Part a-1 (continued)

Identification of Gaging Stations Used In The Study
(Includes every station for which frequency plot was made)

Stations Inside D-13 & D-20 Problem Areas, Including Fringes

Serial Number	Name	Refer to U.S.G.S. Water Supply Paper
55	South Loup River at Ravenna, Nebr.	322-1310
56	Mud Creek near Sweetwater, Nebr.	324-1310
57	Oak Creek near Dannebrog, Nebr.	326-1310
58	Arikaree River at Haigler, Nebr.	385-1310
59	South Fork Republican River near Hale, Colo.	393-1310
60	Frenchman Creek near Imperial, Nebr.	401-1310
61	Frenchman Creek near Enders, Nebr.	402-1310
62	Frenchman Creek at Palisade, Nebr.	404-1310
63	Stinking Water Creek near Wauneta, Nebr.	405-1310
64	Stinking Water Creek near Palisade, Nebr.	406-1310
65	Blackwood Creek near Culbertson, Nebr.	408-1310
66	Driftwood Creek near McCook, Nebr.	409-1310
67	Red Willow Creek near McCook, Nebr.	411-1310
68	Red Willow Creek near Red Willow, Nebr.	412-1310
69	Medicine Creek at Maywood, Nebr.	290-1440
70	Fox Creek at Curtis, Nebr.	292-1440
71	Dry Creek near Curtis, Nebr.	293-1440
72	Medicine Creek above Harry Strunk Lake, Nebr.	413-1310
73	Mitchell Creek above Harry Strunk Lake, Nebr.	414-1310
74	Medicine Creek at Cambridge, Nebr.	417-1310
75	Muddy Creek at Arapahoe, Nebr.	300-1440
76	Prairie Dog Creek at Norton, Kans.	426-1310
77	Cottonwood Creek near Bloomington, Nebr.	311-1440
78	Rose Creek near Wallace, Kans.	441-1310
79	North Fork Smoky Hill River near McAllaster, Kans.	442-1310
80	Big Creek near Hays, Kans.	448-1310
81	Bow Creek near Stockton, Kans.	351-1440
82	North Fork Solomon River at Kirwin, Kans.	461-1310
83	Fountain Creek near Fountain, Colo.	158-1311
84	St. Charles River near Pueblo, Colo.	163-1311
85	Apishapa River near Aguilar, Colo.	181-1311
86	Purgatoire River near Alfalfa, Colo.	194-1311
87	Cimarron River near Guy, New Mexico	240-1311
88	Canadian River near Hebron, New Mexico	316-1311
89	White River below Cottonwood Creek near Whitney, Nebr.	333-1439

. (continued)

ıs Used In The Study
'equency plot was made)

.reas, Including Fringes

Location		Drainage Area in Sq. Mile		Period of Record in Years	Problem Area
Longitude	Latitude	Nominal	Contributing		
98-54-45	41-00-35	1660	890	14	
98-59-45	41-02-05	678	------	11	
98-38-30	41-07-00	122	------	8	
101-57-25	40-01-30	1460	------	19	
102-09-45	39-37-25	?	------	9	
101-37-30	40-25-20	1220	760	17	
101-30-35	40-25-05	1300	820	12	
101-07-40	40-20-50	1500	980	8	
101-19-50	40-29-20	1260	340	10	
101-06-50	40-22-10	1390	430	9	
100-48-25	40-14-05	290	------	12	
100-39-40	40-08-50	360	------	13	
100-39	40-21	600	300	7	
100-30-00	40-14-10	710	400	18	
100-36-40	40-39-20	207	------	8	
100-29-20	40-38-00	77	------	8	
100-26-40	40-38-05	20	------	8	
100-19-20	40-30-10	?	------	9	
100-15-25	40-28-20	53	------	9	
100-10-35	40-17-55	1070	680	20	
99-54-40	40-18-20	243	------	8	
99-53	39-50	721	------	15	
99-03-55	40-05-10	17	------	7	
101-38	38-53	28	------	7	
101-22	39-01	670	------	7	
99-19	38-51	594	------	13	
99-17	39-34	337	------	8	
99-07	39-40	1360	------	11	
104-40-13	38-36-08	676	------	16	
104-31-40	38-12-20	468	------	12	
104-39-50	37-22-50	126	------	11	
104-07-30	37-11-30	1320	------	7	
103-25-25	36-59-15	545	------	17	
104-27-45	36-47-10	229	------	12	
103-10-05	42-48-35	676	------	8	

Appendix No. 1, Part a-2

Identification of Gaging Stations Used In The Study
(Includes every station for which frequency plot was made)

Stations Outside D-13 & D-20 Problem Areas

Serial Number	Name	Refer to U.S.G.S. Water Supply Paper
101	Floyd River at James, Iowa	3-1310
102	Elkhorn River at Neligh, Nebr.	352-1310
103	Tarkio River at Fairfax, Mo.	371-1310
104	Nodaway River near Burlington Junction, Mo.	377-1310
105	Little Blue River near Endicott, Nebr.	478-1310
106	Soldier Creek near Topeka, Kans.	484-1310
107	Delaware River at Valley Falls, Kans.	485-1310
108	Wakarusa River near Lawrence, Kans.	487-1310
109	Stranger Creek near Tonganoxia, Kans.	488-1310
110	Marais des Cygnes River near Ottawa, Kans.	524-1310
111	Pawnee River near Larned, Kans.	219-1311
112	Little Arkansas River at Valley Center, Kansas	224-1311
113	Walnut River at Winfield, Kans.	229-1311
114	Spring River near Waco, Mo.	296-1311
115	Rayado Creek at Sauble Ranch, near Cimarron, New Mexico	333-1311
116	Cimarron River at Springer, New Mexico	338-1311
117	Mora River near Golondrinas, New Mexico	346-1311
118	Coyote Creek near Golondrinas, New Mexico	348-1311
119	Mora River near Shoemaker, New Mexico	351-1311
120	Mountain Fork River near Eagletown, Okla.	533-1311
121	Kiamichi River near Belzoni, Okla.	528-1311
122	Judith River near Utica, Mont.	67-1439
123	Musselshell River at Harlowton, Mont.	75-1439
124	Flatwillow Creek near Flatwillow, Mont.	81-1439
125	South Fork Milk River near International Boundary	86-1439
126	North Fork Milk River above St. Mary Canal near Browning, Mont.	87-1439
127	North Fork Milk River near International Boundary	88-1439
128	Battle Creek at International Boundary	99-1439
129	Woodpile Coulee near International Boundary	100-1439
130	East Fork Battle Creek near International Boundary	101-1439
131	Whitewater Creek near International Boundary	104-1439
132	Clarks Fork at Chance, Mont.	143-1439
133	Bull Lake Creek near Lenore, Wyo.	154-1439
134	Greybull River at Meeteetse, Wyo.	181-1439
135	Goose Creek near Sheridan, Wyo.	205-1439

t a-2

s Used In The Study
equency plot was made)

Problem Areas

Location		Drainage Area in Sq. Mile		Period of Records in Years	Problem Area
Longitude	Latitude	Nominal	Contributing		
96-18-45	42-34-30	882	------	22	
98-01-40	42-07-20	2200	1800	25	
95-24-20	40-20-20	508	------	34	
95-05-20	40-26-40	1240	------	34	
97-08-10	40-05-10	2340	------	28	
95-43	39-06	268	------	25	
95-27	39-21	922	------	35	
95-16	38-55	458	------	28	
95-01-08	39-06-06	406	------	28	
95-15	38-37	1250	------	38	
99-20	38-11	2148	2010	32	
97-23	37-50	1327	1250	34	
97-00	37-14	1840	------	35	
94-33-55	37-14-45	1164	------	26	
104-58	36-22	65	------	33	
104-35-50	36-21-30	1032	------	27	
105-09-30	35-53-40	273	------	26	
105-09-50	35-54-40	257	------	28	
104-47	35-48	1104	1033	39	
94-37	34-03	787	------	27	
95-29	34-12	1423	------	31	
110-14	46-54	331	------	36	
109-51	46-26	1130	------	42	
108-37	46-47	195	------	34	
112-32-20	49-00	433	------	43	
113-03	48-59	62	------	36	
112-58	49-02	101	------	42	
109-25-20	49-00-10	726	------	39	
109-31-50	48-59-00	70	------	27	
109-08	48-58	95	------	26	
107-51	48-57	300	------	29	
109-05	45-00	1140	------	22	
109-01-20	43-14-33	222	------	39	
108-52-35	44-09-20	690	------	36	
107-11	44-42	120	------	27	

Appendix No. 1, Part a-2 (continued)

Identification of Gaging Stations Used In The Study
(Includes every station for which frequency plot was made)

Stations Outside D-13 & D-20 Problem Areas

Serial Number	Name	Refer to U.S.G.S. Water Supply Paper
136	Clear Fork Trinity River at Fort Worth, Texas	75-1442
137	Middle Concho River near Tankersly, Texas	172-1442
138	North Concho River near Carlsbad, Texas	175-1442
139	Pecan Bayou At Brownwood, Texas	188-1442
140	North Llano River near Junction, Texas	195-1442
141	Llano River near Junction, Texas	196-1442
142	Guadalupe River near Spring Branch, Tex.	213-1442
143	Guadalupe River above Comal River at New Braunfels, Tex.	214-1442
144	Blanco River at Wimberley, Tex.	216-1442
145	Plum Creek near Luling, Tex.	219-1442
146	Cibolo Creek near Falls City, Tex.	229-1442
147	Nueces River at Laguna, Tex.	234-1442
148	Frio River at Concan, Tex.	239-1442
149	Rio Grande near Del Norte, Colo.	259-1442
150	Conejos River near Mogote, Colo.	278-1442
151	Red River near Questa, New Mexico	298-1442
152	Santa Fe River near Santa Fe, New Mexico	318-1442
153	Blue Water Creek near Bluewater, New Mexico	333-1442
154	Pecos River near Pecos, New Mexico	352-1442
155	Pecos River near Anton Chico, New Mexico	353-1442
156	Gallinas River near Montezuma, New Mexico	354-1442
157	Gallinas River at Montezuma, New Mexico	355-1442
158	Mimbres River near Mimbres, New Mexico	403-1442

(continued)

s Used In The Study
equency plot was made)

Problem Areas

Location		Drainage Area in Sq. Mile		Period of Records in Years	Problem Area
Longitude	Latitude	Nominal	Contributing		
97-21	32-44	526	---------	24	
100-36-50	31-22-35	1280	1128	26	
100-39	31-36	1533	1410	26	
98-58-30	31-44-10	1614	---------	26	
99-47	30-30	914	---------	31	
99-44	30-30	1874	---------	24	
98-23	29-51-40	1282	---------	30	
98-06-40	29-42-55	1516	---------	28	
98-04	29-59	364	---------	27	
97-37	29-42	356	---------	26	
97-56	29-01	831	---------	24	
99-59-50	29-25-45	764	---------	29	
99-42	29-29	405	---------	23	
106-27-30	37-41-20	1320	---------	46	
106-11-20	37-03-20	282	---------	44	
105-34	36-42-10	112	---------	25	
105-50-35	35-41-10	20	---------	25	
108-01-40	35-17-50	235	---------	25	
105-41	35-42-25	---	189	25	
105-06-20	35-10-50	---	1050	23	
105-19-10	35-39	84	---------	24	
105-16-30	35-39-15	87	---------	23	
107-59	32-52-20	152	---------	25	

APPENDIX No. 1. Part b. Gaging Stations in Alphabetical Order.

Name	Serial Number	Refer. to USGS Water Supply Paper
Apishapa River near Aguilar, Colo.	85	181-1311
Apishapa River near Fowler, Colo.	3	184-1311
Arikaree River at Haigler, Nebr.	58	385-1310
Battle Creek at International Boundary	128	99-1439
Bayard Sugar Factory Drain near Bayard, Nebr.	45	147-1310
Big Creek near Hays, Kans.	80	448-1310
Bijou Creek near Wiggins, Colo.	47	282-1310
Birdwood Creek near Hershey, Nebr.	11	165-1310
Blackwood Creek near Culbertson, Nebr.	65	408-1310
Blanco River at Wimberley, Tex.	144	216-1442
Blue Creek near Lewellen, Nebr.	10	155-1310
Bluewater Creek near Bluewater, N. M.	153	333-1442
Bow Creek near Stockton, Kans.	81	351-1440
Buffalo Creek near Darr, Nebr.	48	300-1310
Buffalo Creek near Haigler, Nebr.	19	388-1310
Buffalo Creek near Overton, Nebr.	49	301-1310
Bull Lake Creek near Lenore, Wyo.	133	154-1439
Canadian River near Hebron, N. M.	88	316-1311
Cherry Creek below Cherry Creek Dam, Colo.	14	203-1310
Cherry Creek at Denver, Colo.	15	204-1310
Cherry Creek near Franktown, Colo.	12	201-1310
Cherry Creek near Melvin, Colo.	13	202-1310
Cibolo Creek near Falls City, Tex.	146	229-1442
Cimarron River near Guy, N. M.	87	240-1311
Cimarron River at Springer, N. M.	116	338-1311
Clarks Folk at Chance, Mont.	132	143-1439
Clear Fork Trinity River at Fort Worth, Tex.	136	75-1442
Cottonwood Creek near Bloomington, Nebr.	77	311-1440
Cottonwood Creek at Wendover, Wyo.	35	99-1310
Coyote Creek near Golondrinas, N. M.	118	348-1311
Cunejo River near Mogote, Colo.	150	278-1442
Deleware River at Valley Falls, Kans.	107	485-1310
Driftwood Creek near McCook, Nebr.	66	409-1310
Dry Creek near Curtis, Nebr.	71	293-1440
Dry Spotted Tail Creek at Mitchell, Nebr.	41	139-1310
East Fork Battle Creek near International Boundary	130	101-1439
Elkhorn River at Neligh, Nebr.	102	352-1310
Elm Creek near Overton, Nebr.	50	302-1310
Flatwillow Creek near Flatwillow, Mont.	124	81-1439
Floyd River at James, Iowa.	101	3-1310
Fountain Creek near Fountain, Colo.	83	158-1311
Fountain Creek at Pueblo, Colo.	1	159-1311
Fox Creek at Curtis, Nebr.	70	292-1440
Frenchman Creek below Champion, Nebr.	22	400-1310

APPENDIX No. 1. Part b. Gaging Stations in Alphabetical Order (Cont'd)

Frenchman Creek near Enders, Nebr.	61	402-1310
Frenchman Creek near Hamlet, Nebr.	36	403-1310
Frenchman Creek near Imperial, Nebr.	60	401-1310
Frenchman Creek at Palisade, Nebr.	62	404-1310
Frio River at Concan, Tex.	148	239-1442
Gallinas River at Montezuma, N. M.	157	355-1442
Gallinas River near Montezuma, N. M.	156	354-1442
Goose Creek near Sheridan, Wyo.	135	205-1439
Greybull River at Meeteetse, Wyo.	134	181-1439
Guadalupe River above Comal River at New Braunfels, Tex.	143	214-1442
Guadalupe River near Spring Branch, Tex.	142	213-1442
Horse Creek near Sugar City, Colo.	5	191-1311
Judith River near Utica, Mont.	122	67-1439
Kiamichi River near Belzoni, Okla.	121	528-1311
Landsman Creek near Hale, Colo.	33	392-1310
Little Arkansas River at Valley Center, Kans.	112	224-1311
Little Blue near Endicott, Nebr.	105	478-1310
Llano River near Junction, Tex.	141	196-1442
Lodgepole Creek at Bushnell, Nebr.	16	288-1310
Marais des Cygnes River near Ottowa, Kans.	110	524-1310
Medicine Creek at Cambridge, Nebr.	74	417-1310
Medicine Creek above Harry Strunk Lake, Nebr.	72	413-1310
Medicine Creek at Maywood, Nebr.	69	290-1440
Middle Concho River near Tankersly, Tex.	137	172-1442
Middle Loup River at Arcadia, Nebr.	54	318-1310
Middle Loup River at Dunning, Nebr.	53	312-1310
Mimbres River near Mimbres, N. M.	158	403-1442
Mitchell Creek above Harry Strunk Lake, Nebr.	73	414-1310
Mora River near Golondrinas, N. M.	117	346-1311
Mora River near Shoemaker, N. M.	119	351-1311
Mountain Fork River near Eagletown, Okla.	120	533-1311
Mud Creek near Sweetwater, Nebr.	56	324-1310
Muddy Creek at Arapahoe, Nebr.	75	300-1440
Musselshell River at Harlowton, Mont.	123	75-1439
Ninemile Drain near Mcgrew, Nebr.	44	146-1310
Niobrara River above Box Butte Reservoir, Nebr.	25	343-1439
Nodaway River near Burlington Junction, Mo.	104	377-1310
North Concho River near Carlsbad, Tex.	138	175-1442
North Fork Milk River near International Boundary	127	88-1439
North Fork Milk River above St. Mary Canal near Browning, Mont.	126	87-1439
N.F. Republican River at Colorado-Nebraska State Line	18	387-1310
North Fork Smoky Hill River near McAllaster, Kans.	79	442-1310
North Fork Solomon River at Kirwin, Kans.	82	461-1310
North Llano River near Junction, Tex.	140	195-1442
Nueces River at Laguna, Tex.	147	234-1442
Oak Creek near Dannebrog, Nebr.	57	326-1310
Pawnee River near Larned, Kans.	111	219-1311
Pecan Bayou at Brownwood, Tex.	139	188-1442

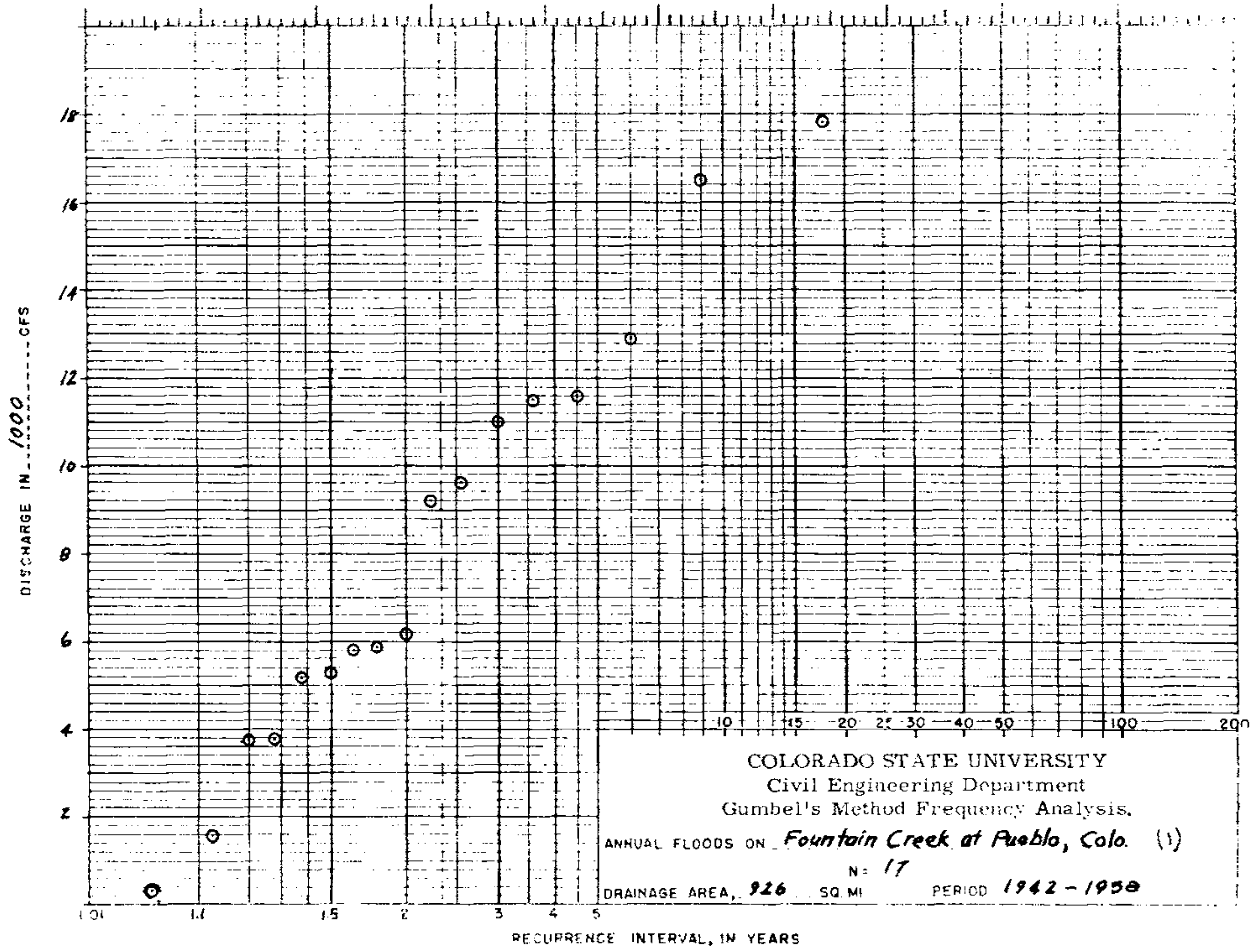
APPENDIX No. 1. Part b. Gaging Stations in Alphabetical Order (Cont'd)

Pecos River near Anton Chico, N. M.	155	353-1442
Pecos River near Pecos, N. M.	154	352-1442
Plum Creek near Luling, Tex.	145	219-1442
Prairie Dog Creek at Norton, Kans.	76	426-1310
Pumpkin Creek near Bridgeport, Nebr.	31	151-1310
Purgatoire River near Alfalfa, Colo.	86	194-1311
Purgatoire River at Trinidad, Colo.	37	193-1311
Rawhide Creek near Lingle, Wyo.	9	126-1310
Rayado Creek at Sauble Ranch, near Cimarron, N. M.	115	333-1311
Red River near Questa, N. M.	151	298-1442
Red Willow Creek near Bayard, Nebr.	46	149-1310
Red Willow Creek near McCook, Nebr.	67	411-1310
Red Willow Creek near Red Willow, Nebr.	68	412-1310
Rio Grande near Del Norte, Colo.	149	259-1442
Rock Creek near Parks, Nebr.	20	389-1310
Rose Creek near Wallace, Kans.	78	441-1310
Santa Fe River near Santa Fe, N. M.	152	318-1442
Sappa Creek near Oberlin, Kans.	23	420-1310
Soldier Creek near Topeka, Kans.	106	484-1310
South Fork Milk River near International Boundary	125	86-1439
South Fork Republican River near Hale, Colo.	59	393-1310
South Fork Republican River near Idalia, Colo.	34	391-1310
South Loup River at Ravenna, Nebr.	55	322-1310
Sheep Creek near Morrill, Nebr.	40	137-1310
Spring River near Waco, Mo.	114	296-1311
St. Charles River near Pueblo, Colo.	84	163-1311
Stinking Water Creek near Palisade, Nebr.	64	406-1310
Stinking Water Creek near Wauneta, Nebr.	63	405-1310
Stranger Creek near Tonganoxia, Kans.	109	488-1310
Tarkio River at Fairfax, Mo.	103	371-1310
Timpas Creek near Rocky Ford, Colo.	4	186-1311
Tub Spring near Scottsbluff, Nebr.	42	141-1310
Vermejo River near Dawson, N. M.	38	323-1311
Wakarusa River near Lawrence, Kans.	108	487-1310
Walnut River at Winfield, Kans.	113	229-1311
White River below Cottonwood Creek near Whitney, Nebr.	89	333-1439
White River at Crawford, Nebr.	24	332-1439
Whitewater Creek near International Boundary	131	104-1439
Winter Creek near Scottsbluff, Nebr.	43	143-1310
Wood River near Gibbon, Nebr.	52	306-1310
Wood River near Riverdale, Nebr.	51	305-1310
Woodpile Coulee near International Boundary	129	100-1439

APPENDIX NO. 2

GUMBEL PLOTS FROM INDIVIDUAL STATIONS

(Arranged in the Order
Given in Appendix 1-a)



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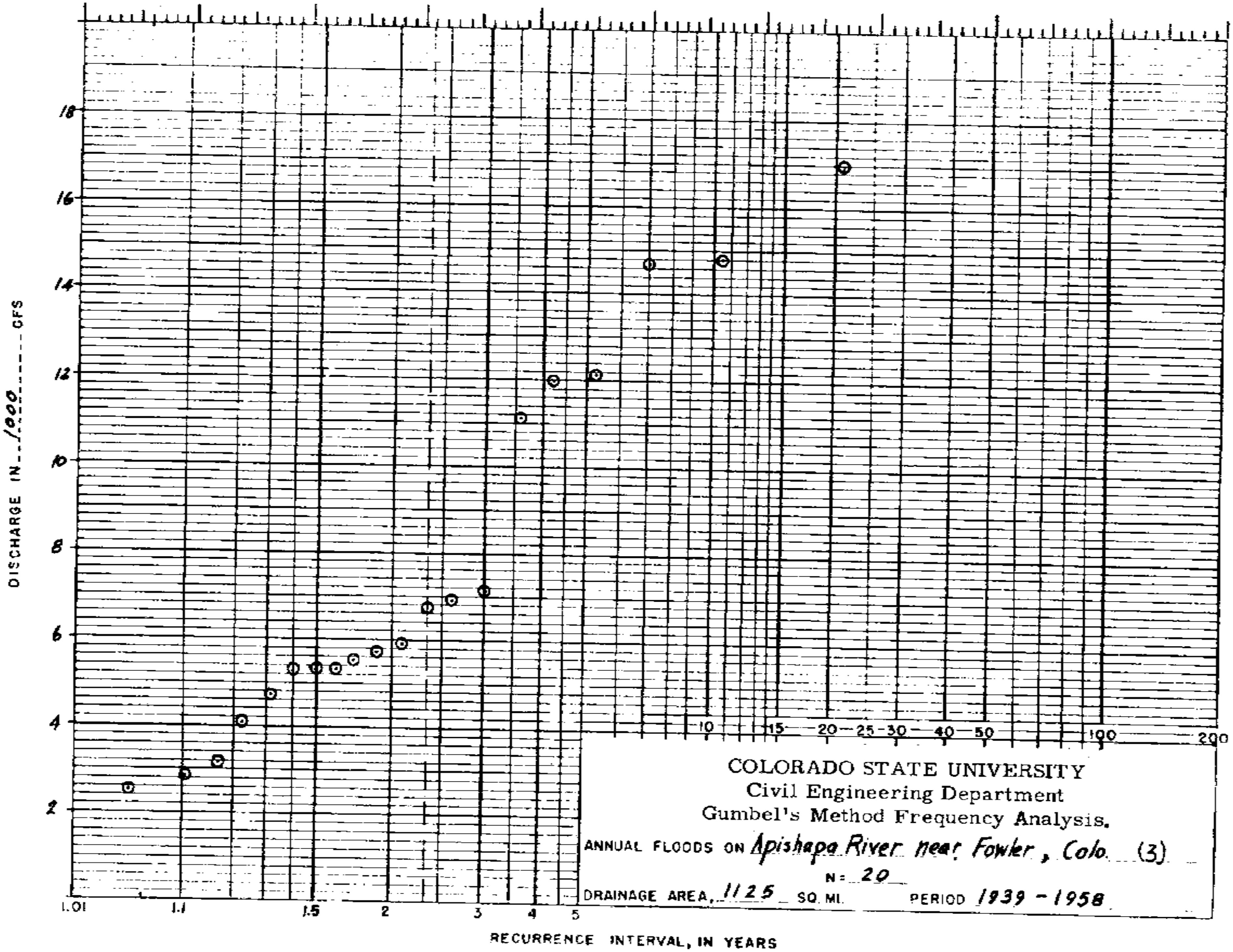
ANNUAL FLOODS ON Fountain Creek at Pueblo, Colo. (1)

N= 17

DRAINAGE AREA, 926 SQ. MI PERIOD 1942 - 1958



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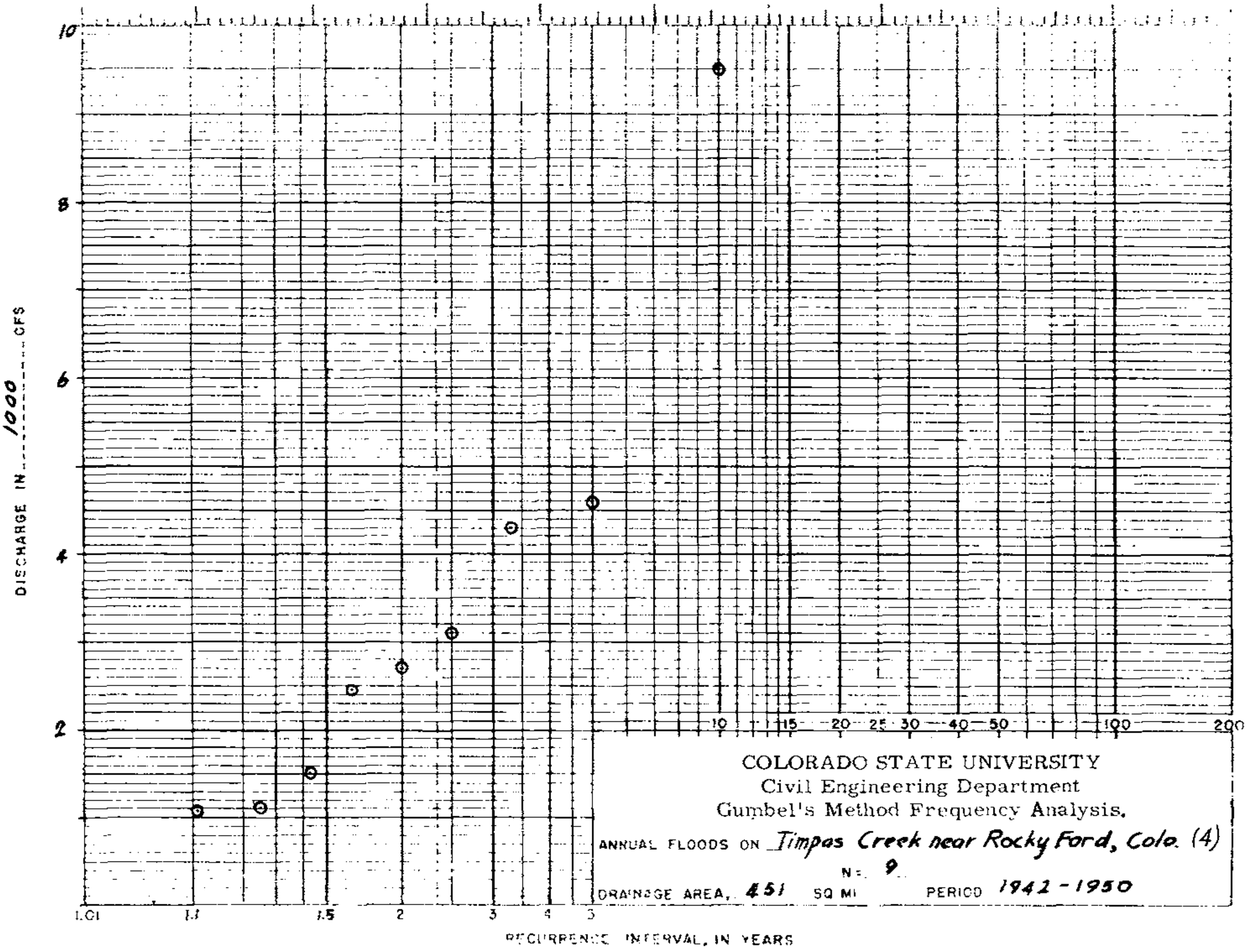
ANNUAL FLOODS ON Apishapa River near Fowler, Colo. (3)
N= 20
DRAINAGE AREA, 1125 SQ. MI. PERIOD 1939 - 1958



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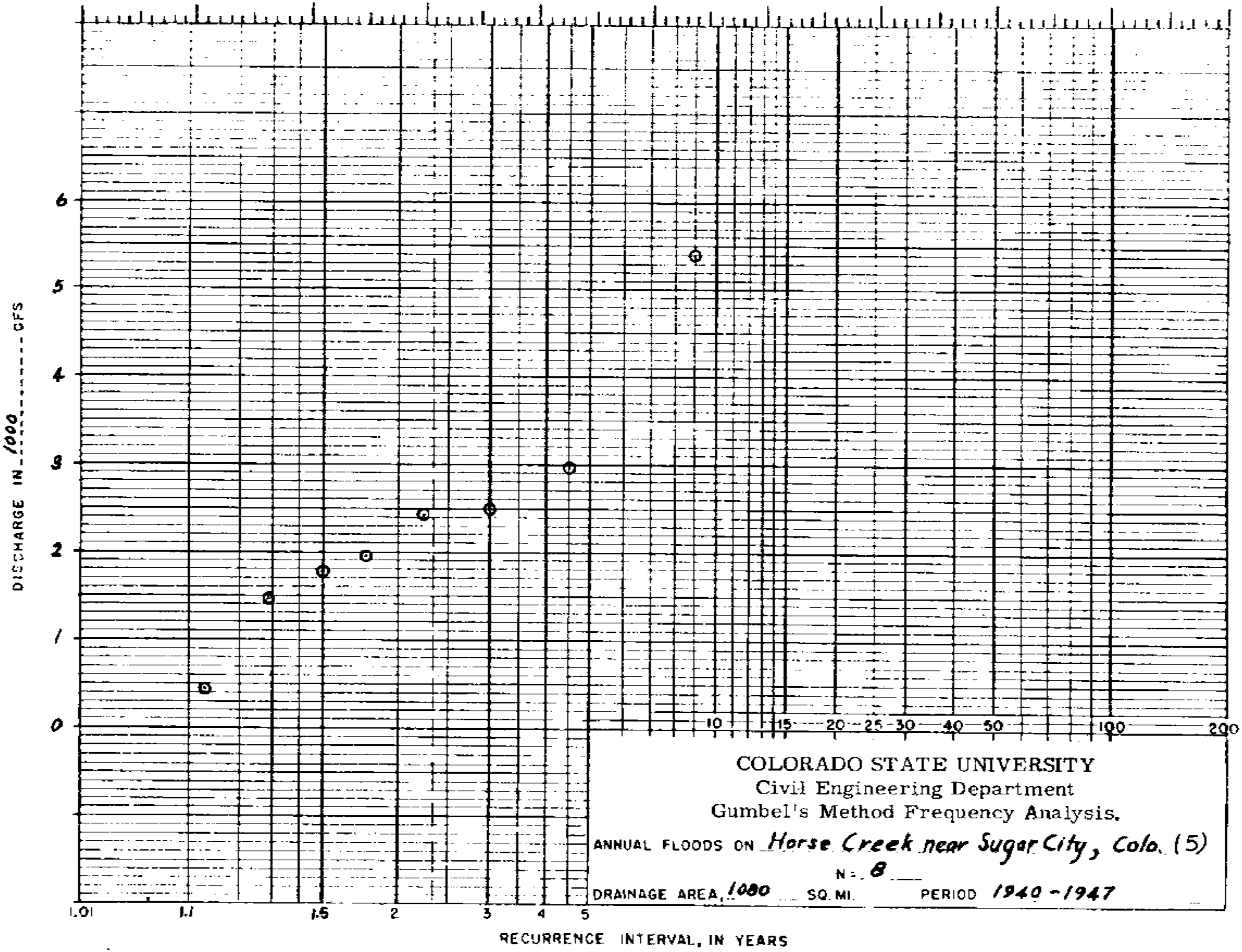
ANNUAL FLOODS ON *Timpas Creek near Rocky Ford, Colo.* (4)

N = 9

DRAINAGE AREA, 451 SQ MI PERIOD 1942 - 1950



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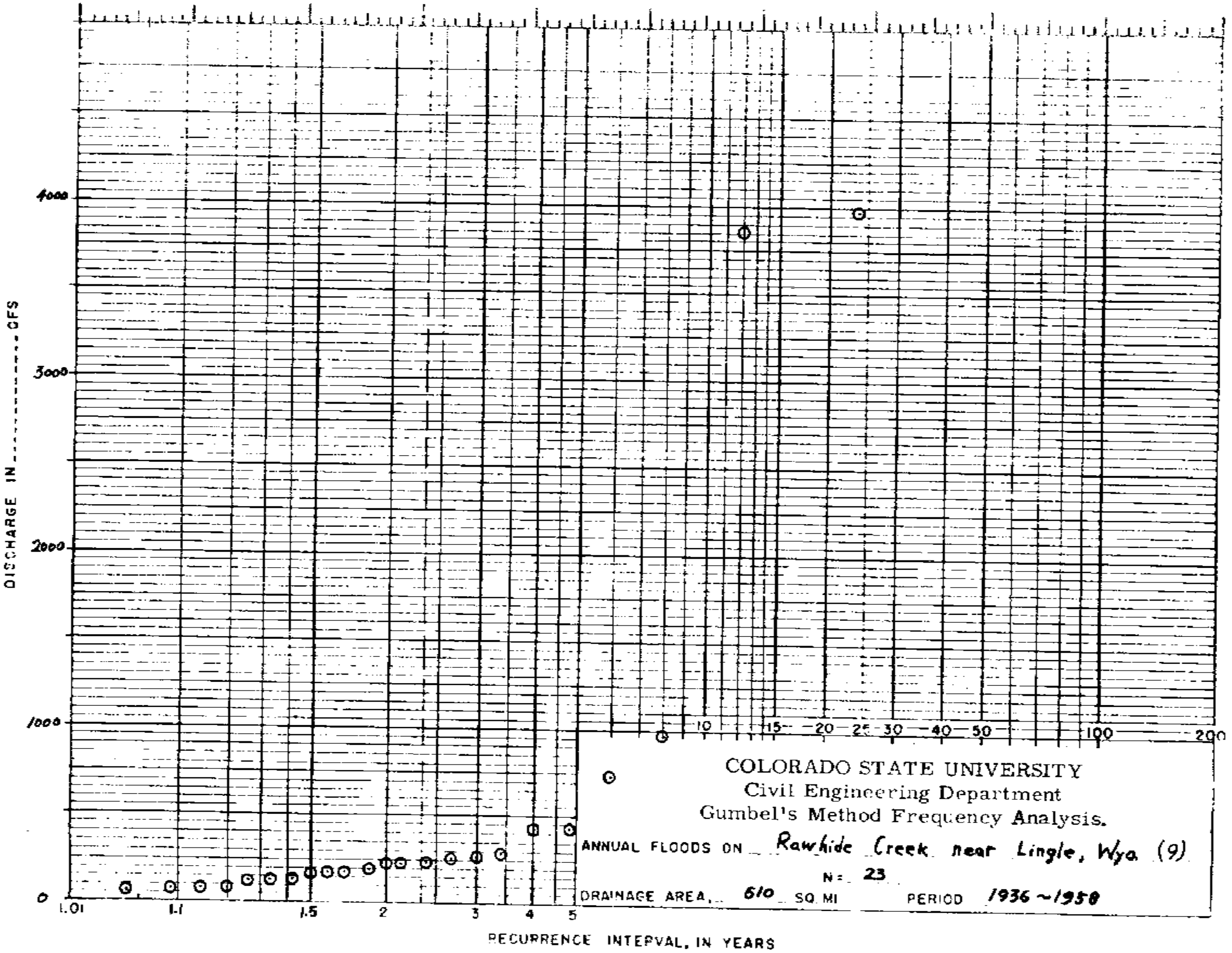
ANNUAL FLOODS ON Horse Creek near Sugar City, Colo. (5)

N = 8

DRAINAGE AREA, 1080 SQ. MI. PERIOD 1940 - 1947



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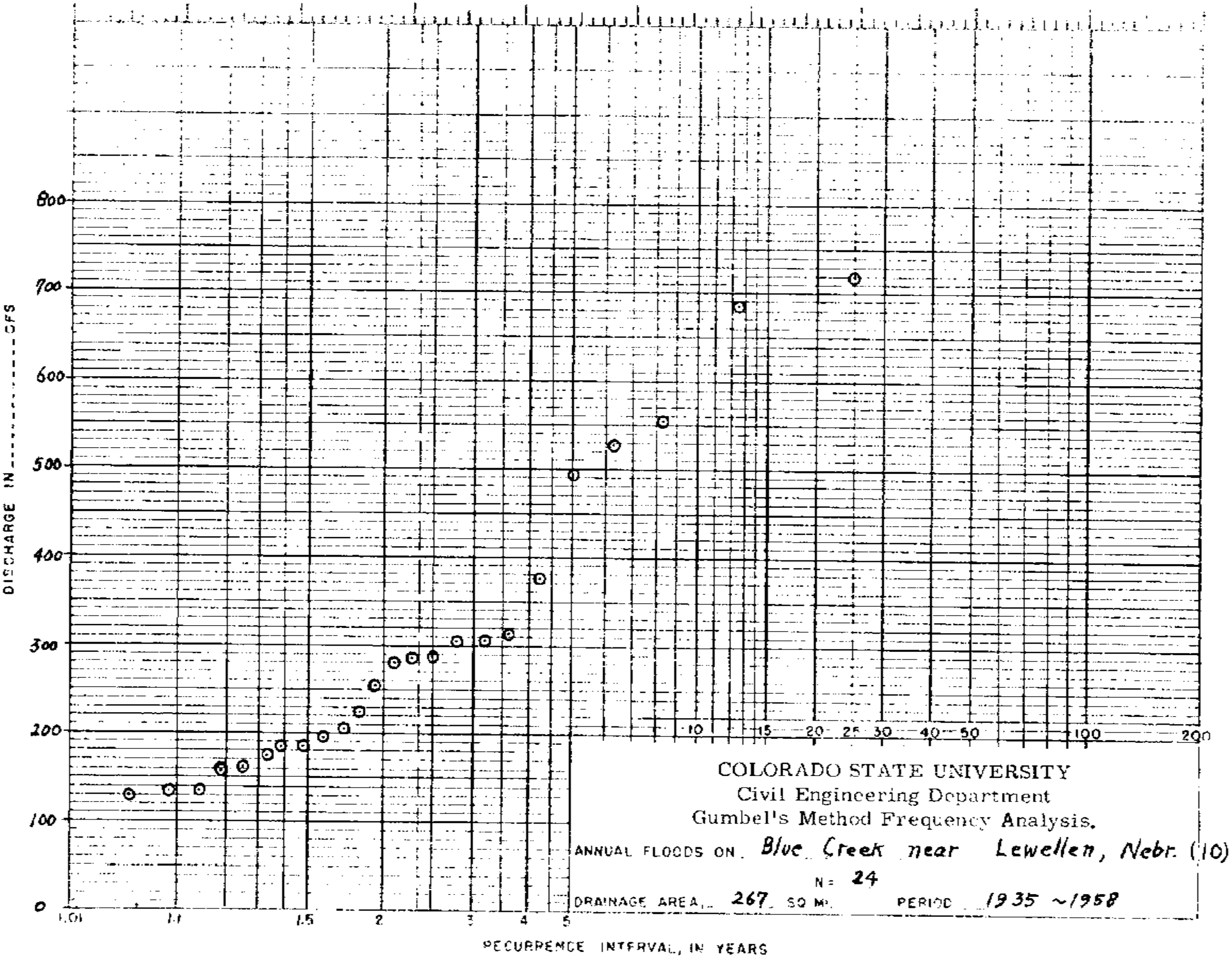
ANNUAL FLOODS ON Rawhide Creek near Lingle, Wyo. (9)

N = 23

DRAINAGE AREA 610 SQ. MI PERIOD 1936 ~ 1958



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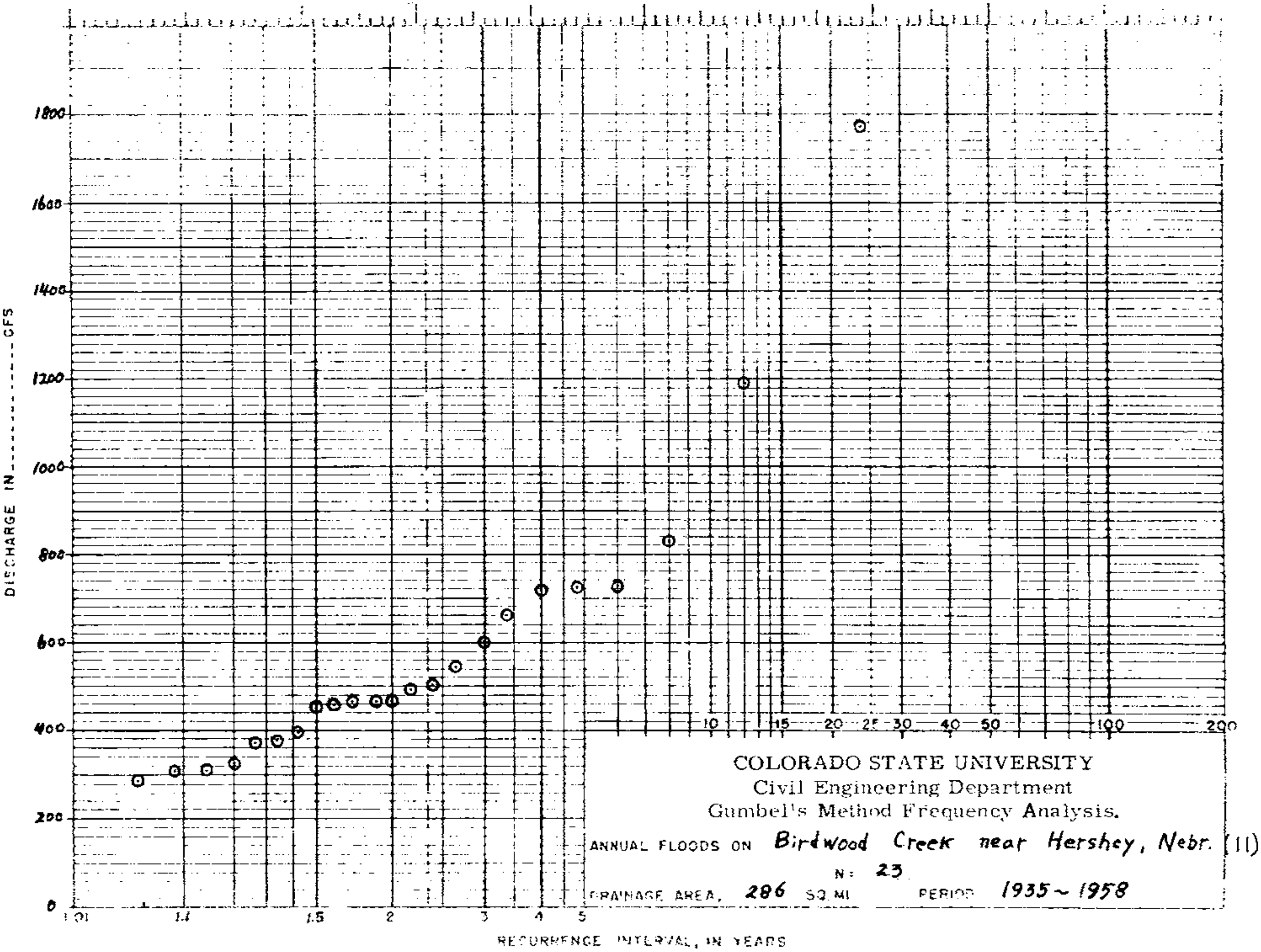
ANNUAL FLOODS ON Blue Creek near Lewellen, Nebr. (10)

N = 24

DRAINAGE AREA 267 SQ MI. PERIOD 1935 ~1958



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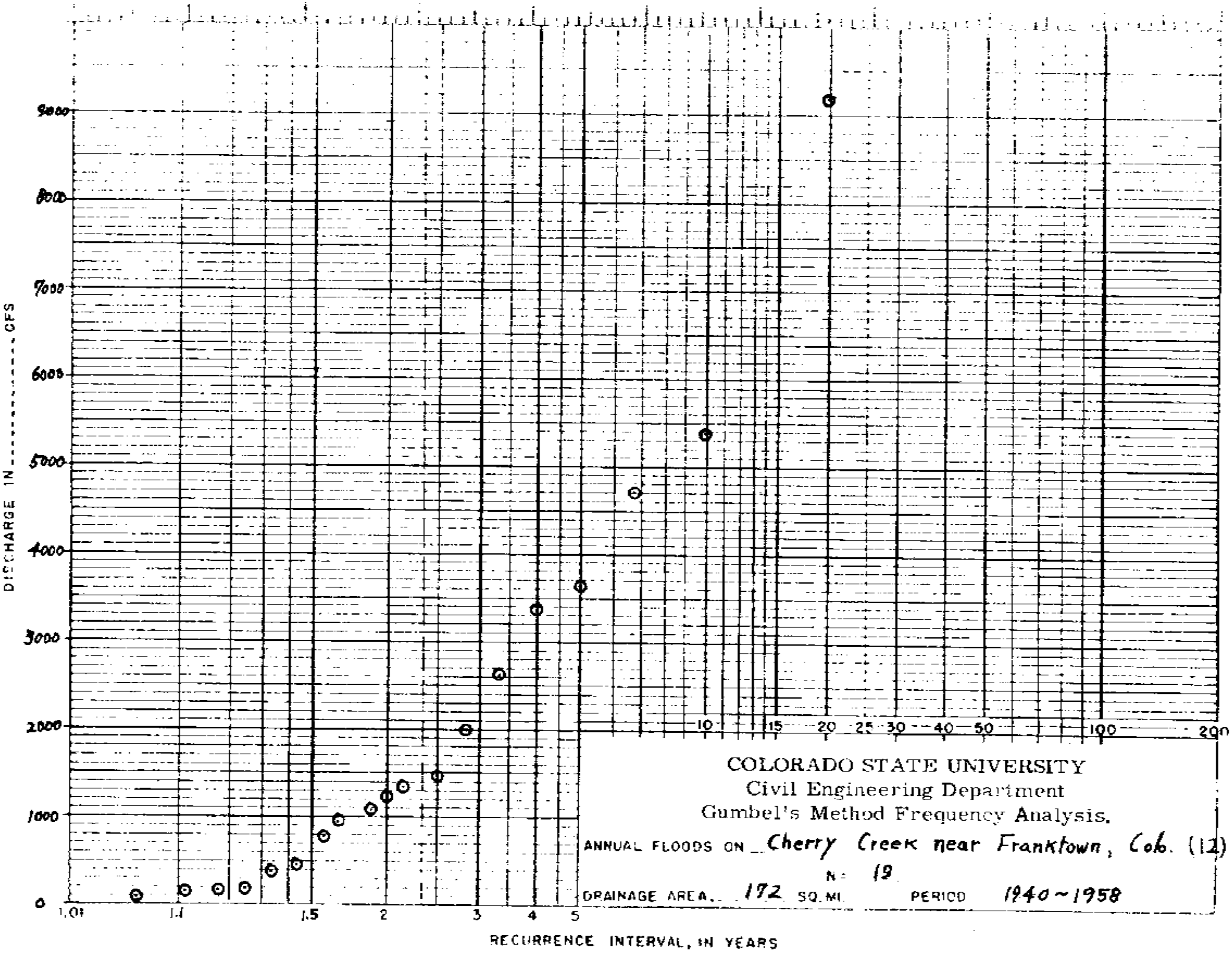
ANNUAL FLOODS ON Birdwood Creek near Hershey, Nebr. (11)
N: 23
DRAINAGE AREA, 286 SQ. MI PERIOD 1935 ~ 1958



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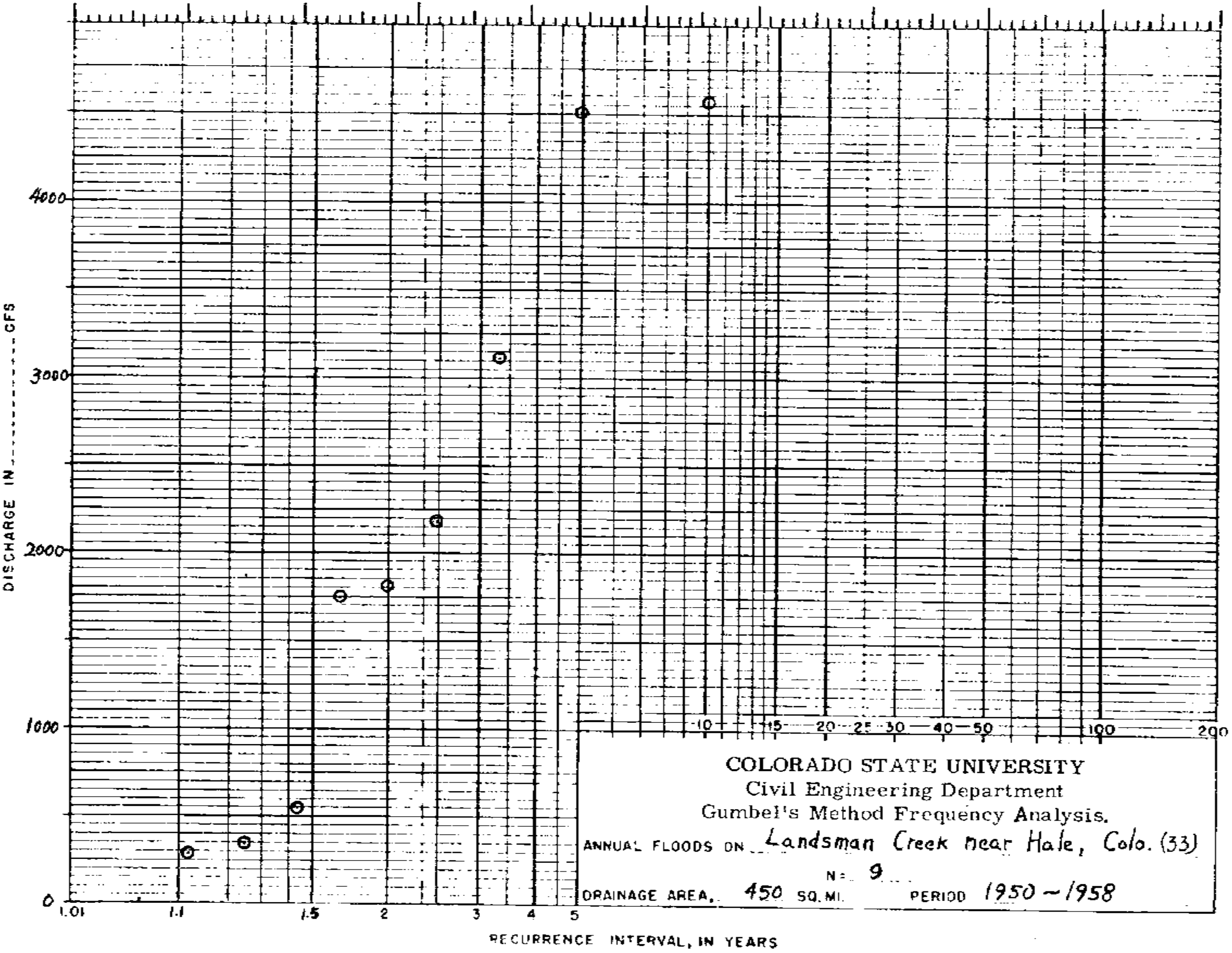
ANNUAL FLOODS ON Cherry Creek near Franktown, Colo. (12)

N = 19

DRAINAGE AREA 172 SQ. MI. PERIOD 1940 ~ 1958



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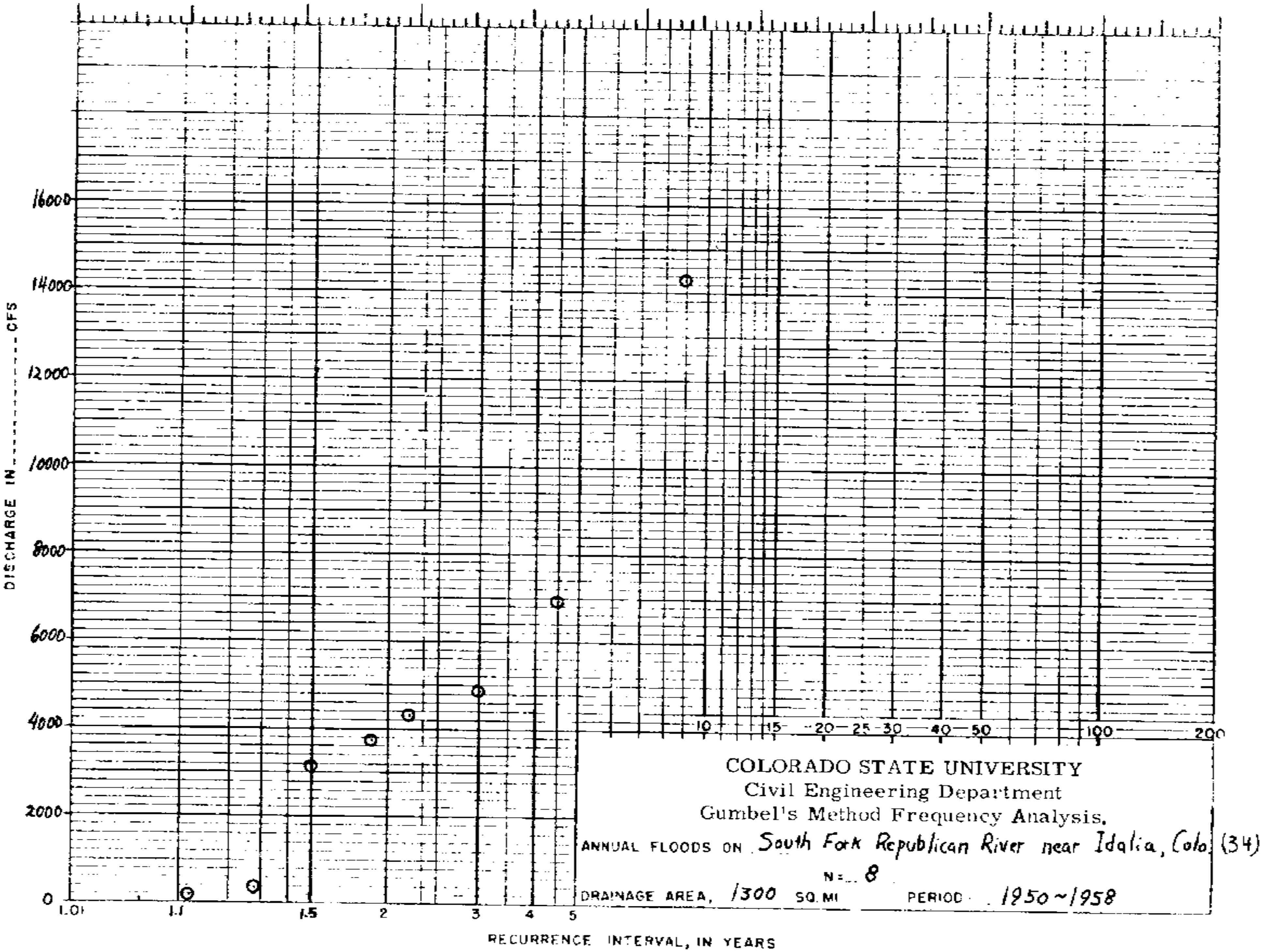
ANNUAL FLOODS ON Landsman Creek near Hale, Colo. (33)

N = 9

DRAINAGE AREA, 450 SQ. MI. PERIOD 1950 ~ 1958



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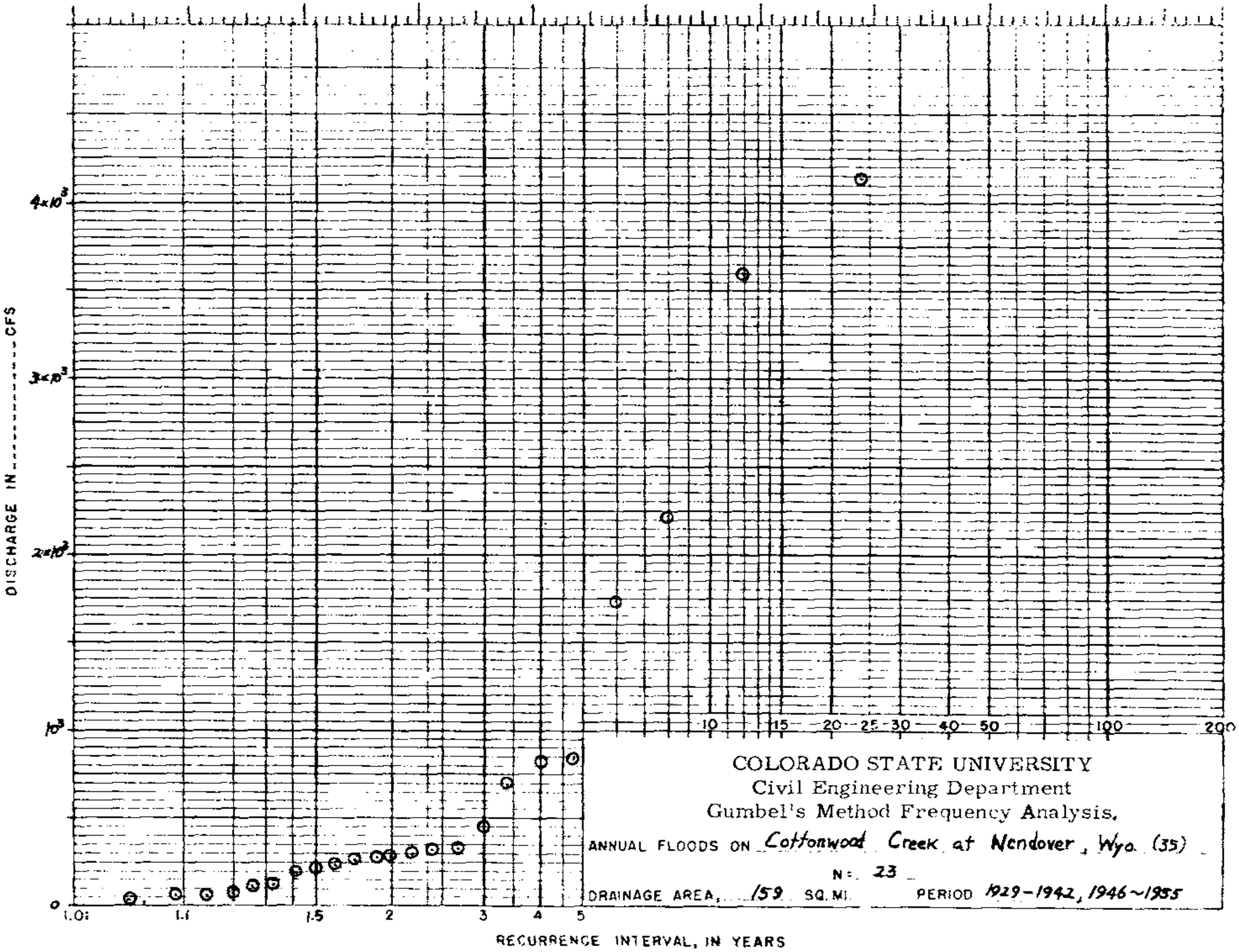
ANNUAL FLOODS ON South Fork Republican River near Idalia, Colo. (34)

N= 8

DRAINAGE AREA, 1300 SQ. MI PERIOD 1950~1958



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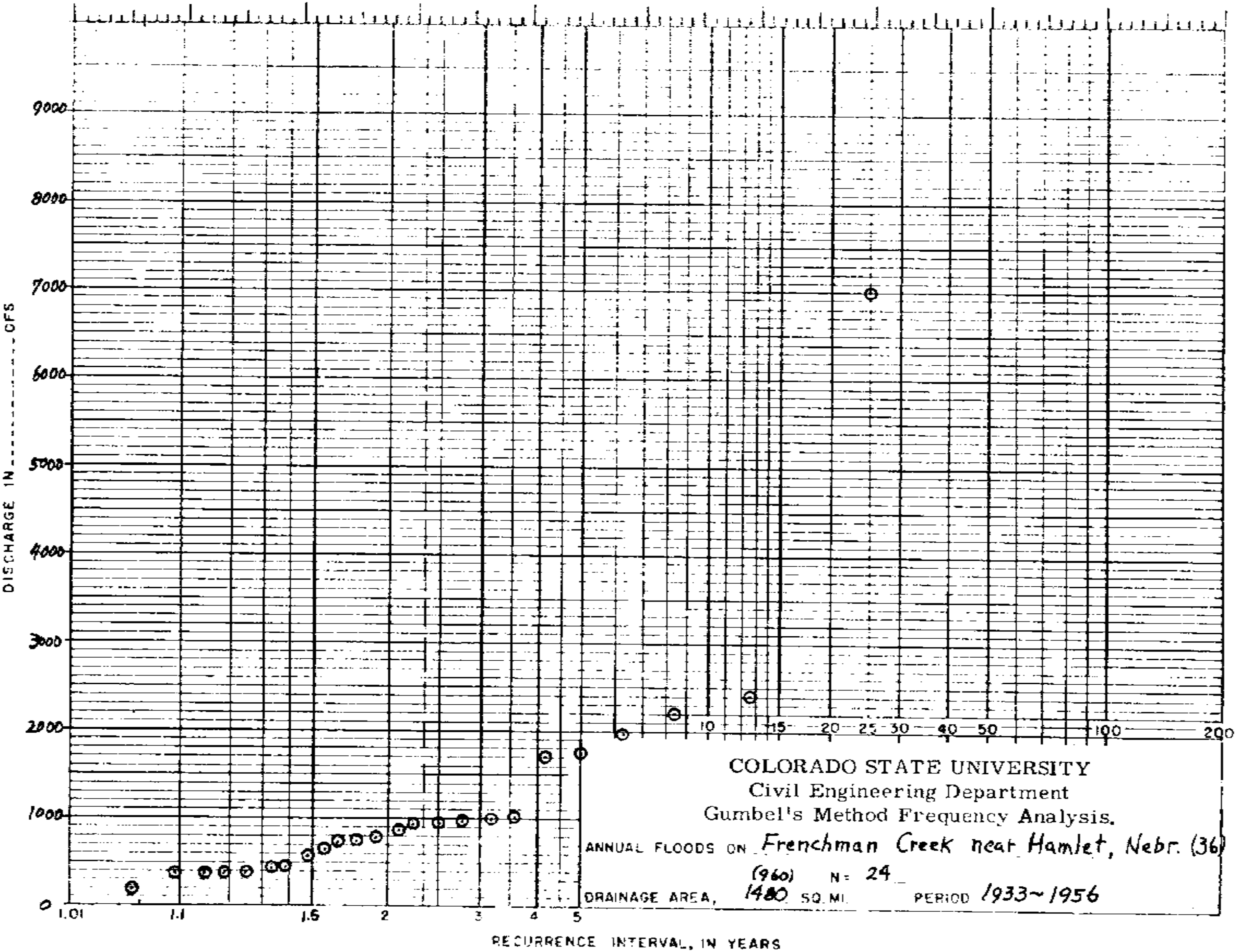
ANNUAL FLOODS ON Cottonwood Creek at Wendover, Wyo. (35)

N = 23

DRAINAGE AREA, 159 SQ. MI. PERIOD 1929-1942, 1946-1955



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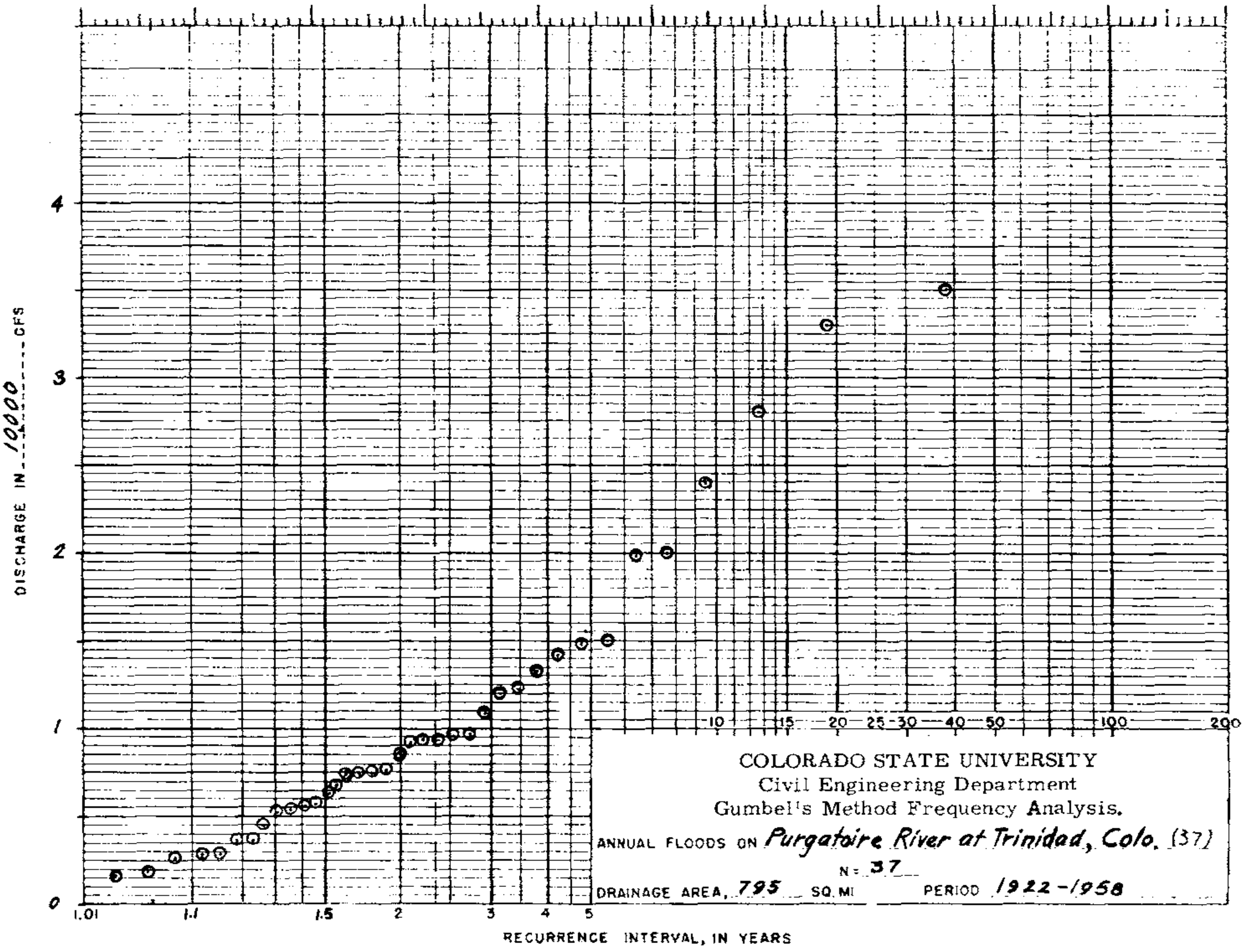
ANNUAL FLOODS ON Frenchman Creek near Hamlet, Nebr. (36)

(960) N= 24

DRAINAGE AREA, 1480 SQ. MI. PERIOD 1933~1956



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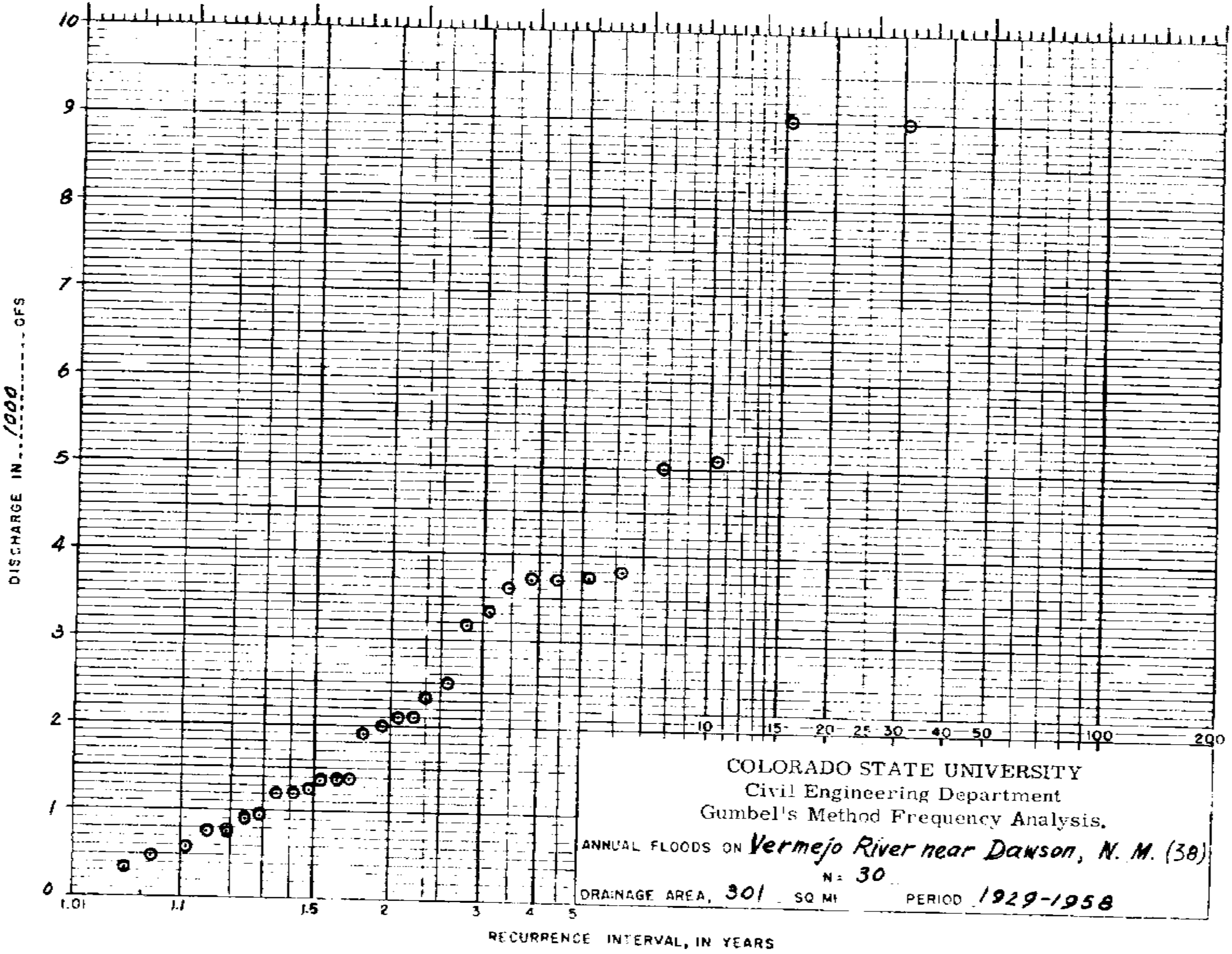
ANNUAL FLOODS ON *Purgatoire River at Trinidad, Colo.* (37)

N = 37

DRAINAGE AREA, 795 SQ. MI   PERIOD 1922-1958



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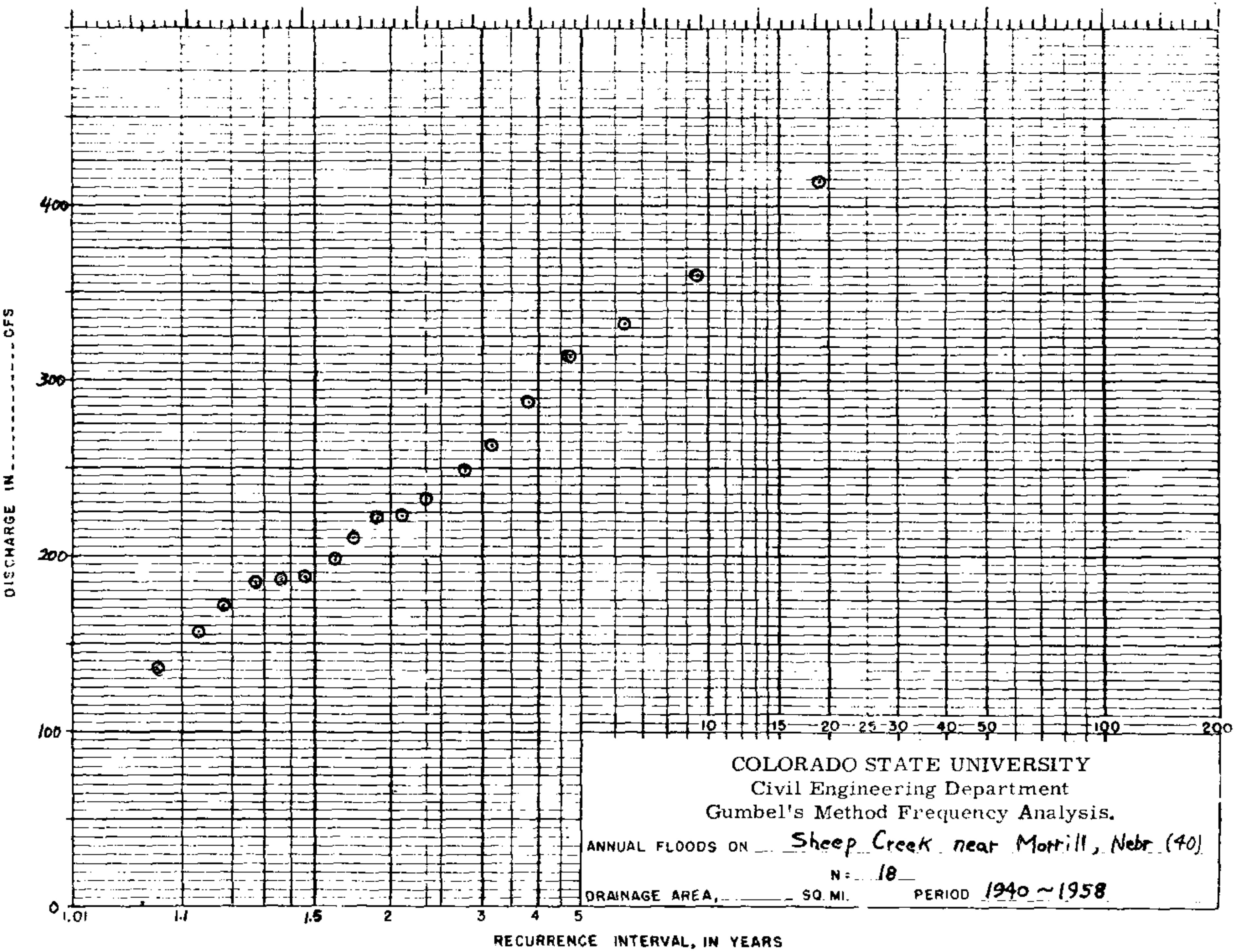
ANNUAL FLOODS ON *Vermejo River near Dawson, N. M. (38)*
N = *30*
DRAINAGE AREA, *301* SQ MI PERIOD *1929-1958*



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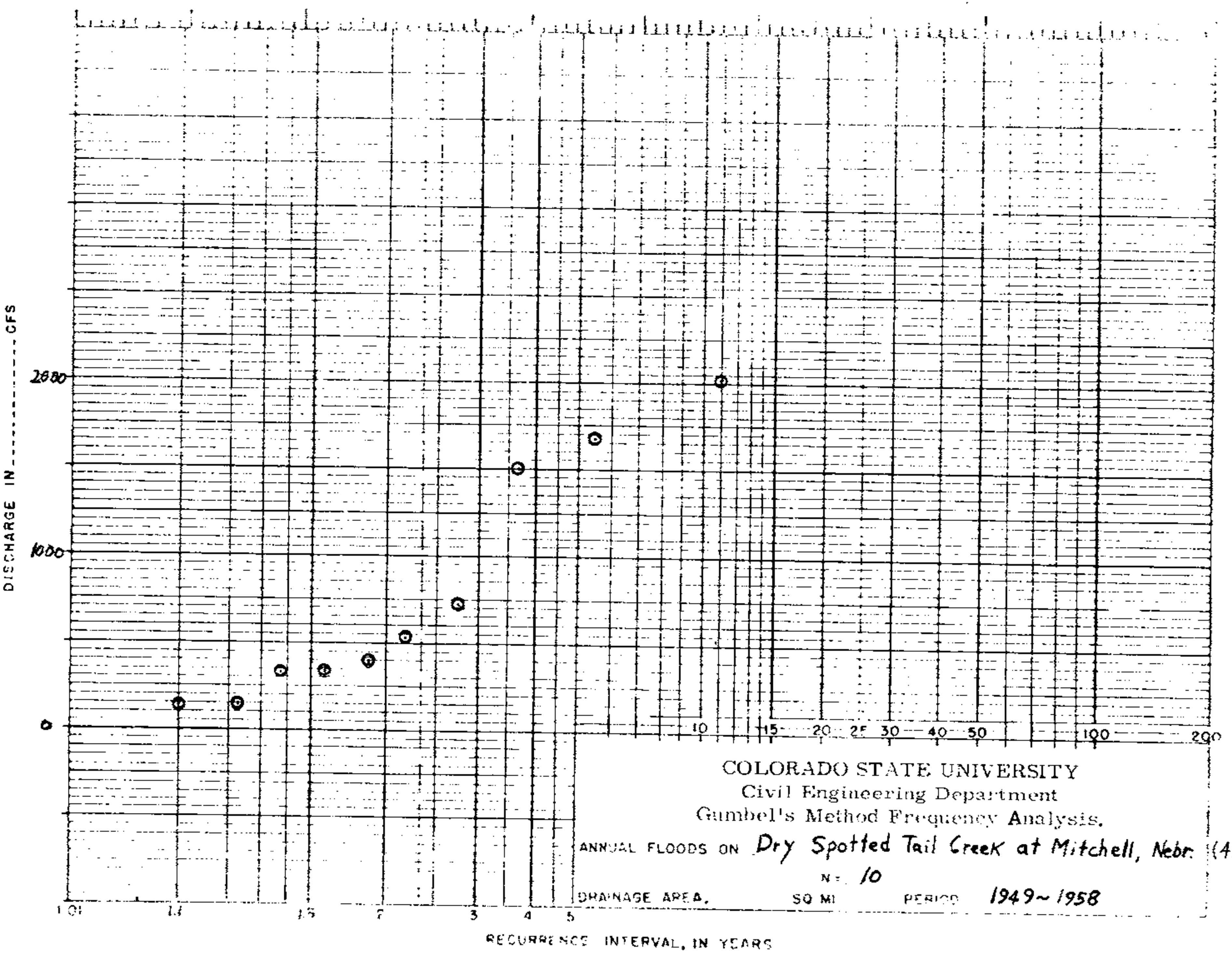
ANNUAL FLOODS ON Sheep Creek near Morrill, Nebr. (40)

N = 18

DRAINAGE AREA, ______ SQ. MI. PERIOD 1940 ~ 1958



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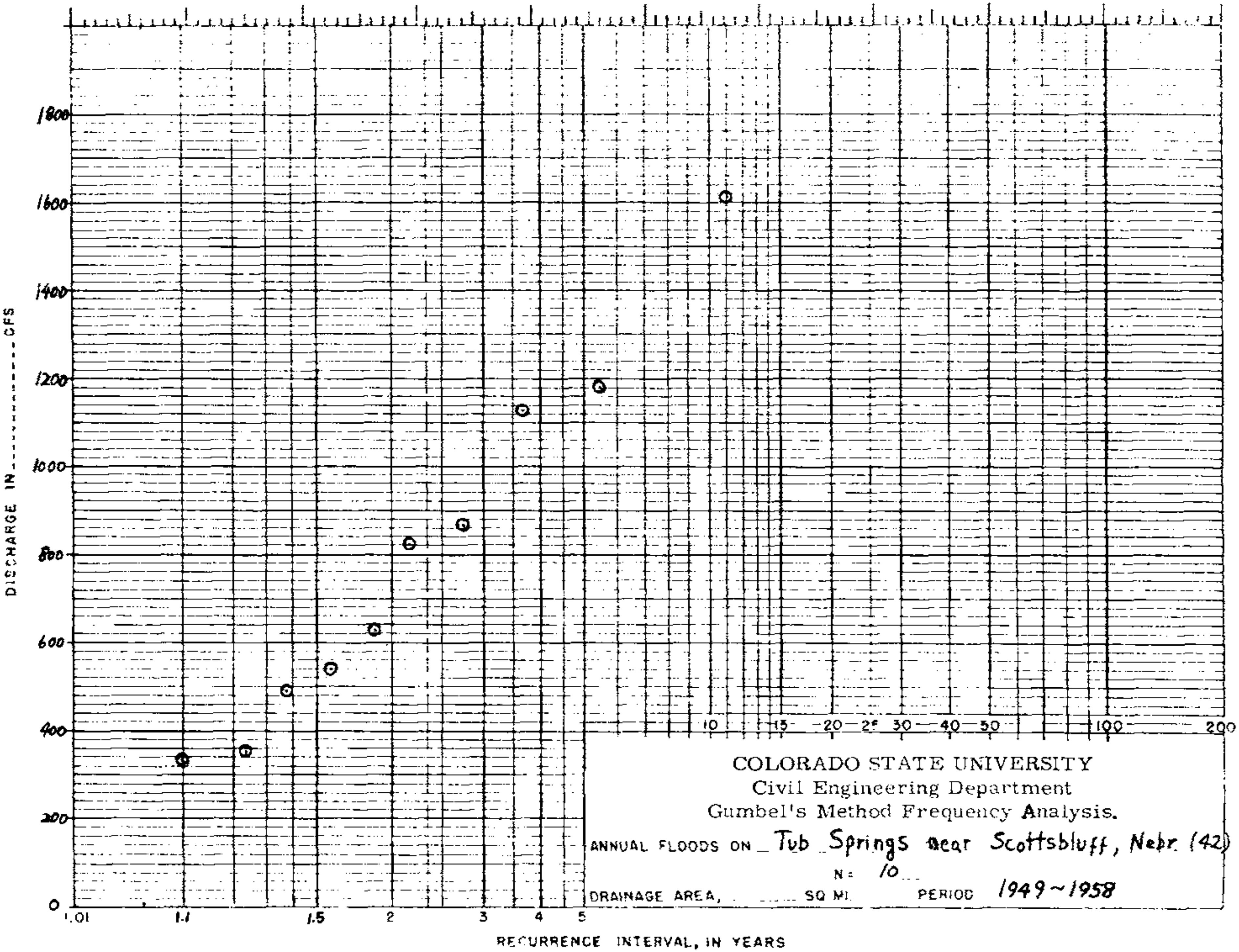
ANNUAL FLOODS ON Dry Spotted Tail Creek at Mitchell, Nebr. (41)
N = 10
DRAINAGE AREA, SQ MI PERIOD 1949~1958



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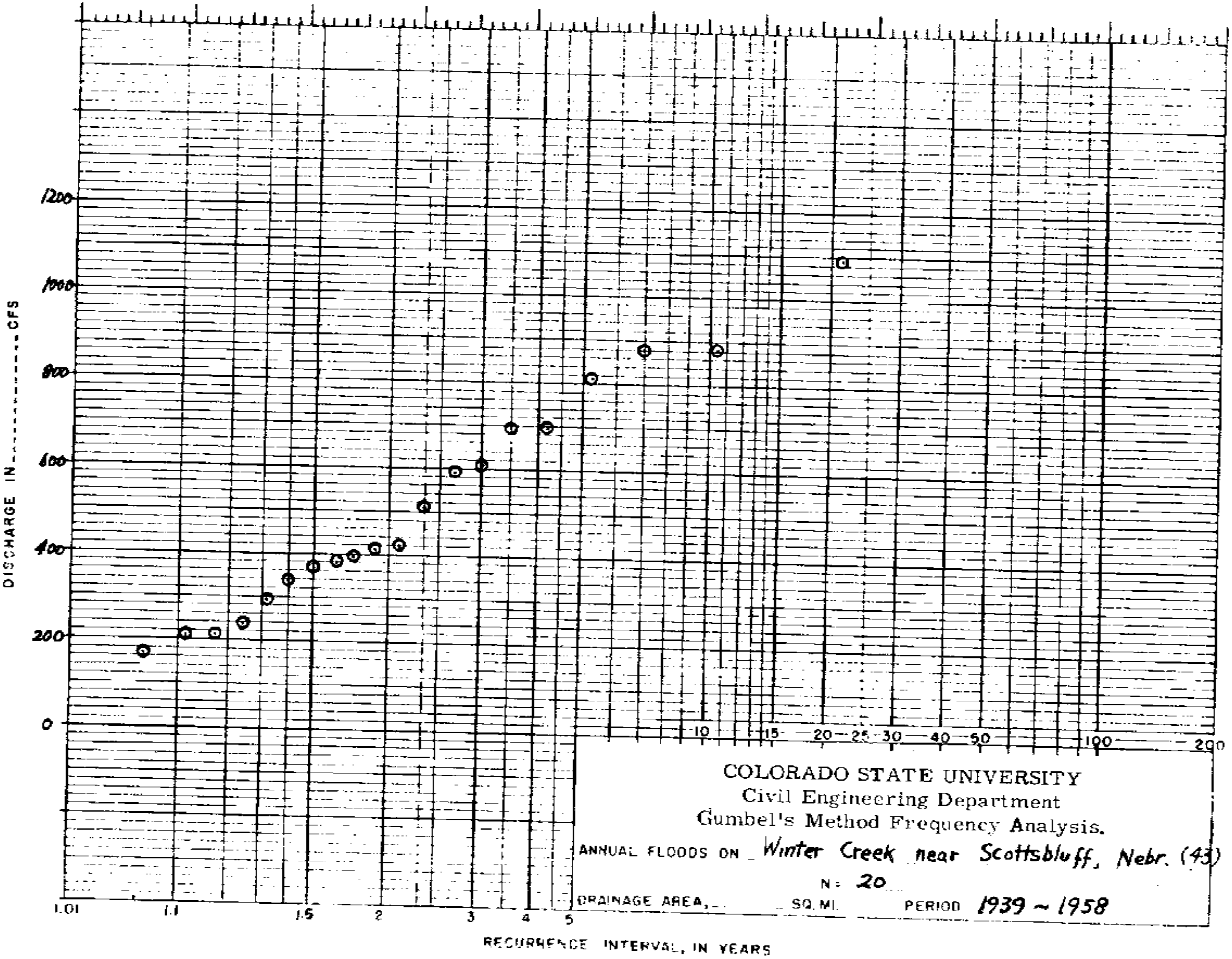
ANNUAL FLOODS ON Tub Springs near Scottsbluff, Nebr. (42)

N = 10

DRAINAGE AREA, ______ SQ MI PERIOD 1949~1958



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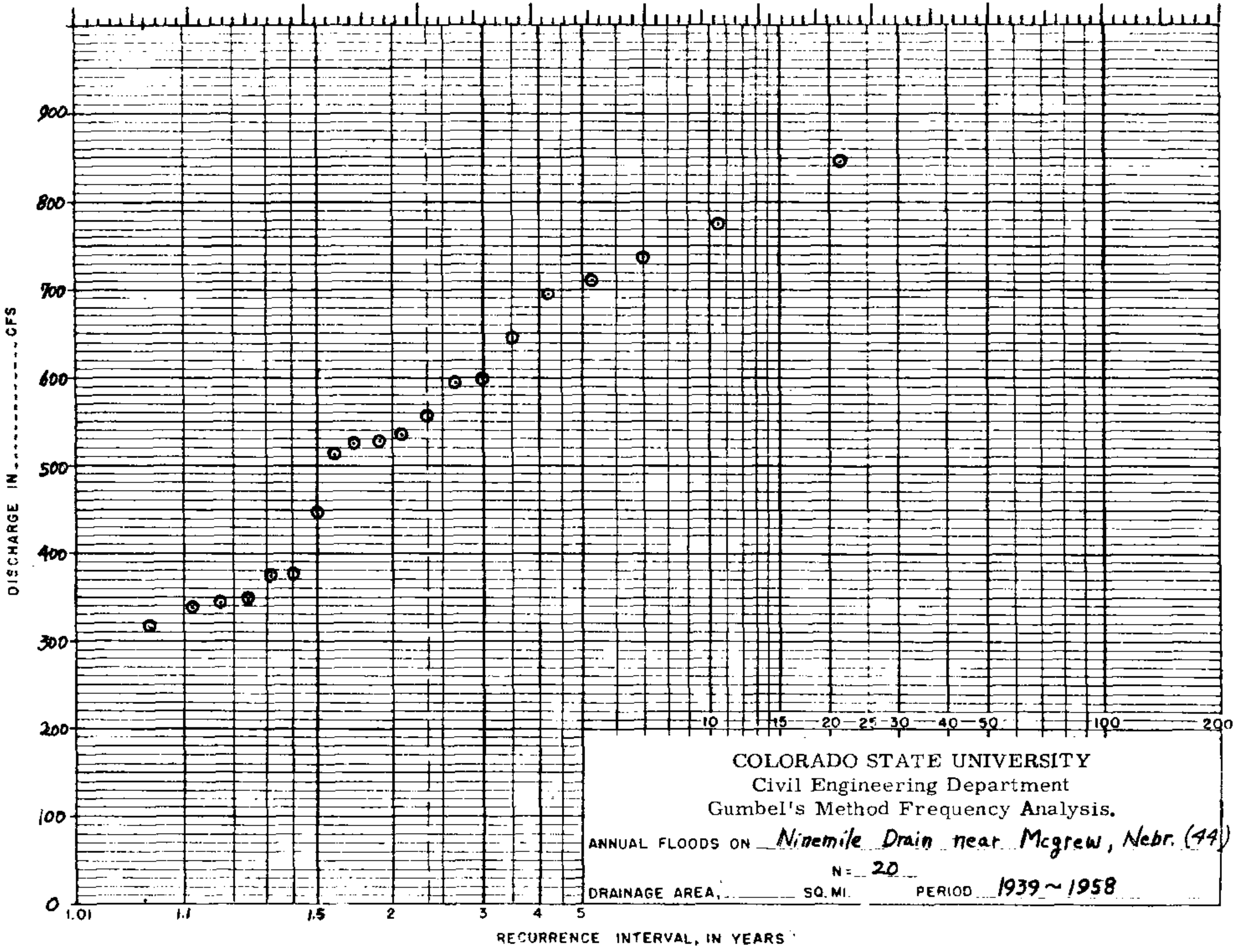
ANNUAL FLOODS ON Winter Creek near Scottsbluff, Nebr. (43)

N: 20

DRAINAGE AREA, ____ SQ. MI. PERIOD 1939 ~ 1958



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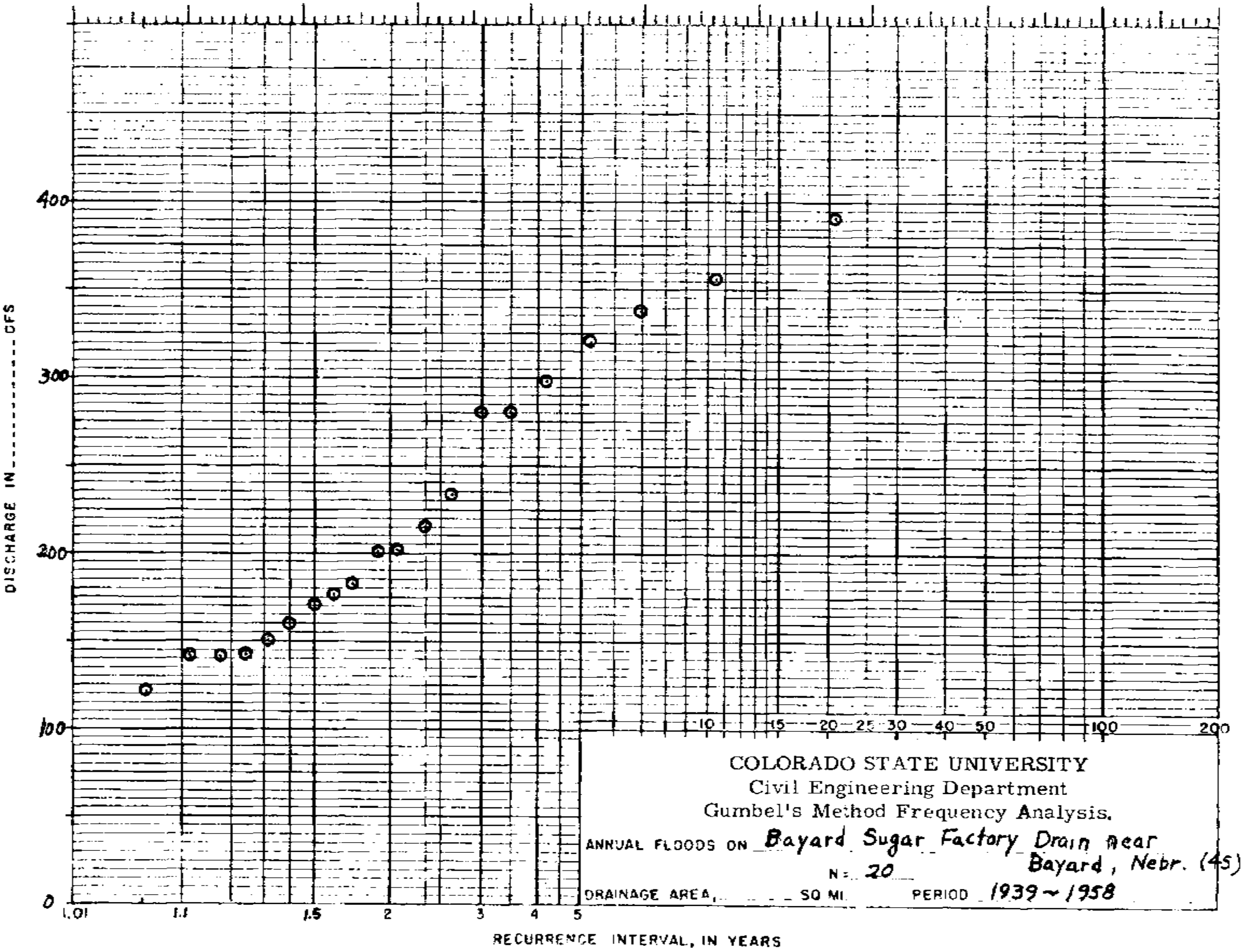
ANNUAL FLOODS ON Ninemile Drain near Mcgrew, Nebr. (44)

N = 20

DRAINAGE AREA, ______ SQ. MI. PERIOD 1939 ~ 1958



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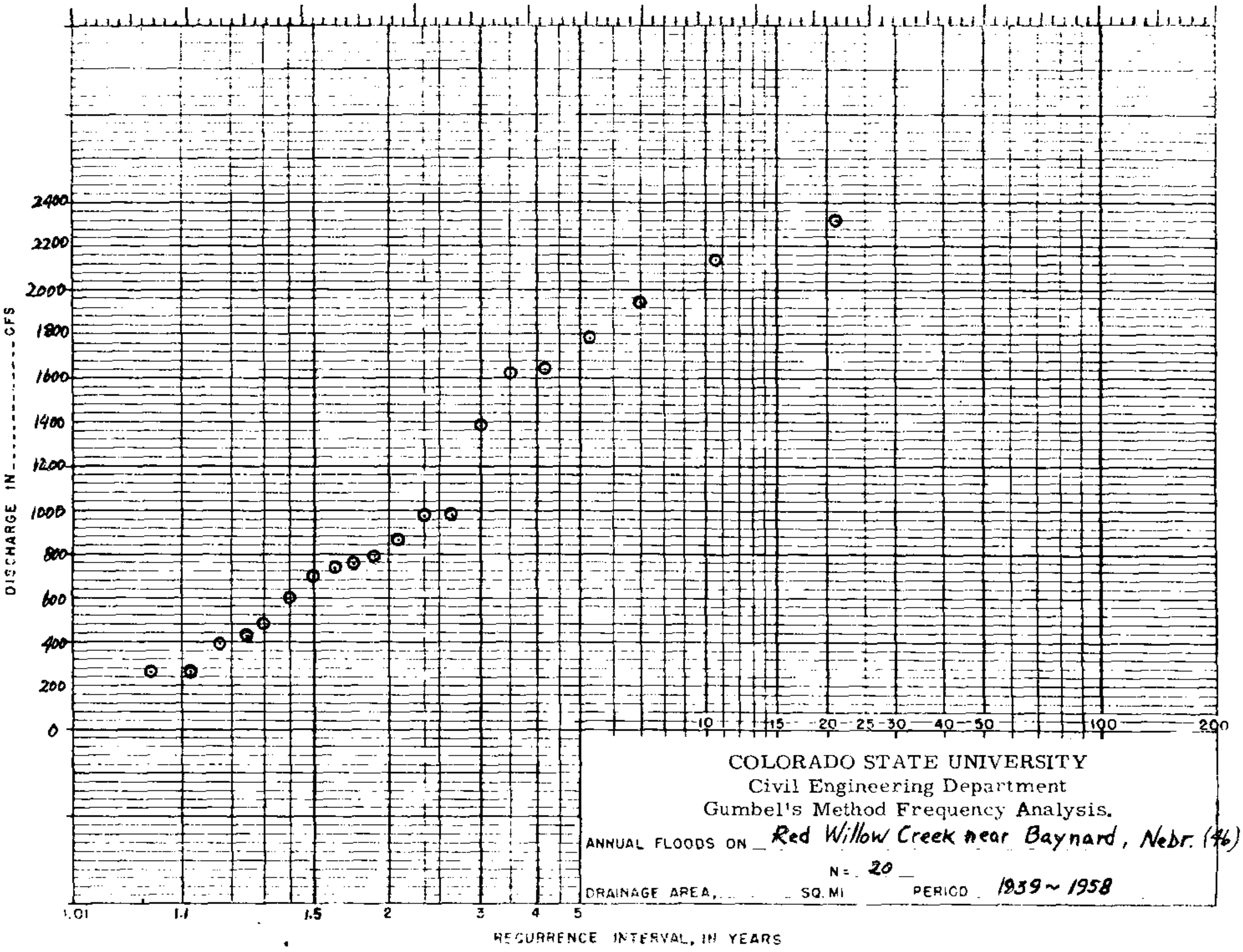
ANNUAL FLOODS ON Bayard Sugar Factory Drain near Bayard, Nebr. (45)

N = 20

DRAINAGE AREA, ____ SQ MI. PERIOD 1939 ~ 1958



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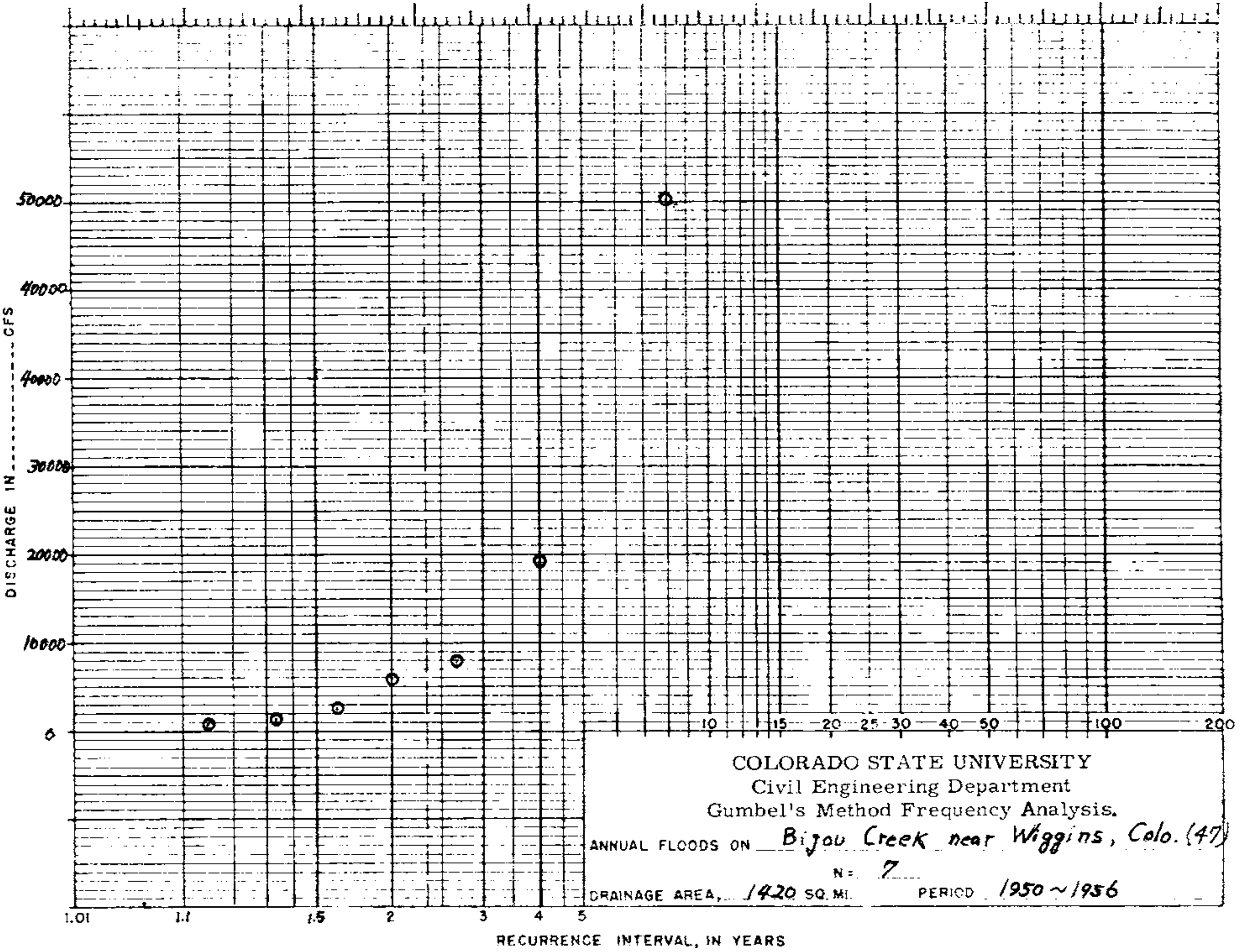
ANNUAL FLOODS ON Red Willow Creek near Baynard, Nebr. (46)

N = 20

DRAINAGE AREA, ______ SQ. MI PERIOD 1939 ~ 1958



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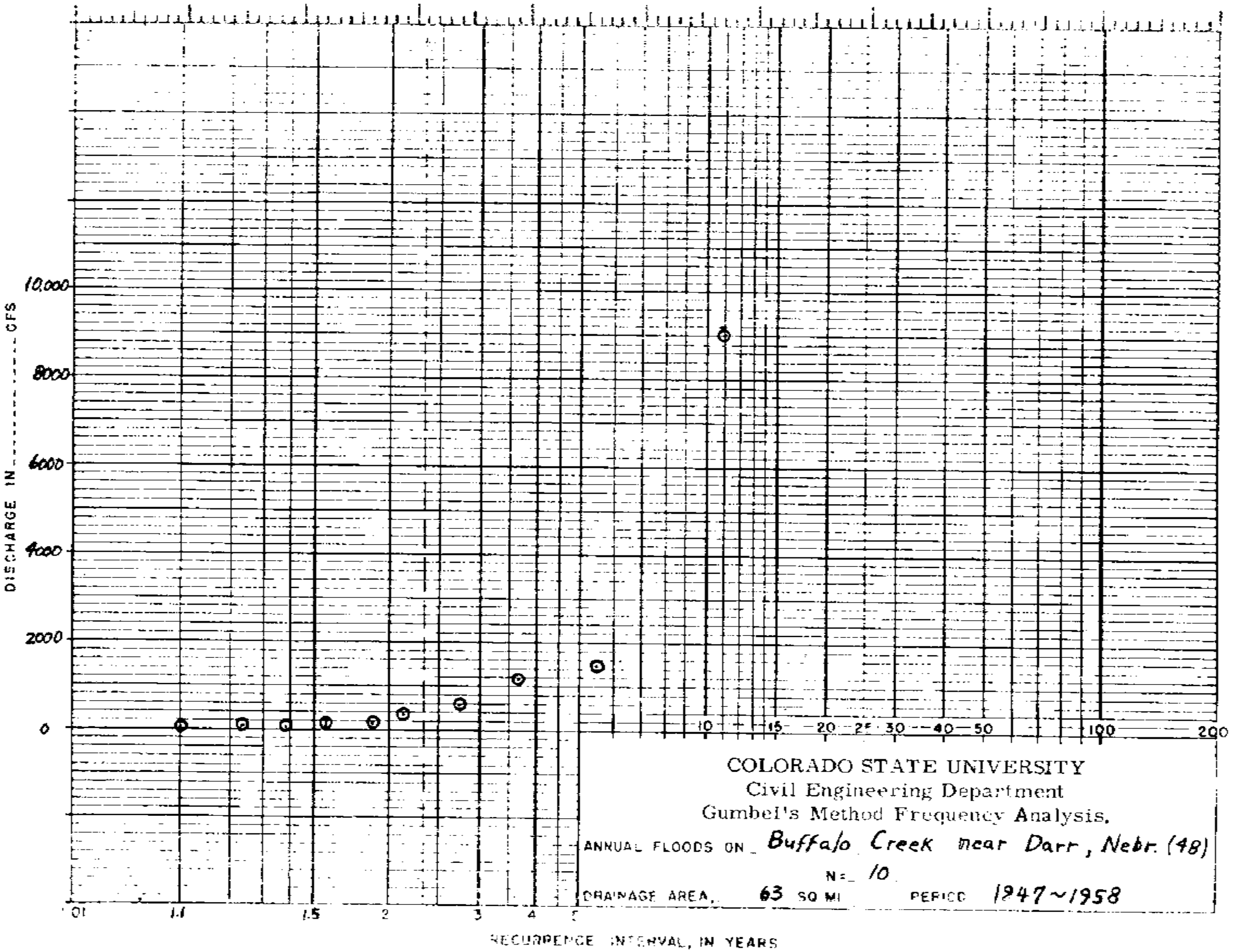
ANNUAL FLOODS ON Bijou Creek near Wiggins, Colo. (47)

N = 7

DRAINAGE AREA, 1420 SQ. MI. PERIOD 1950 ~ 1956



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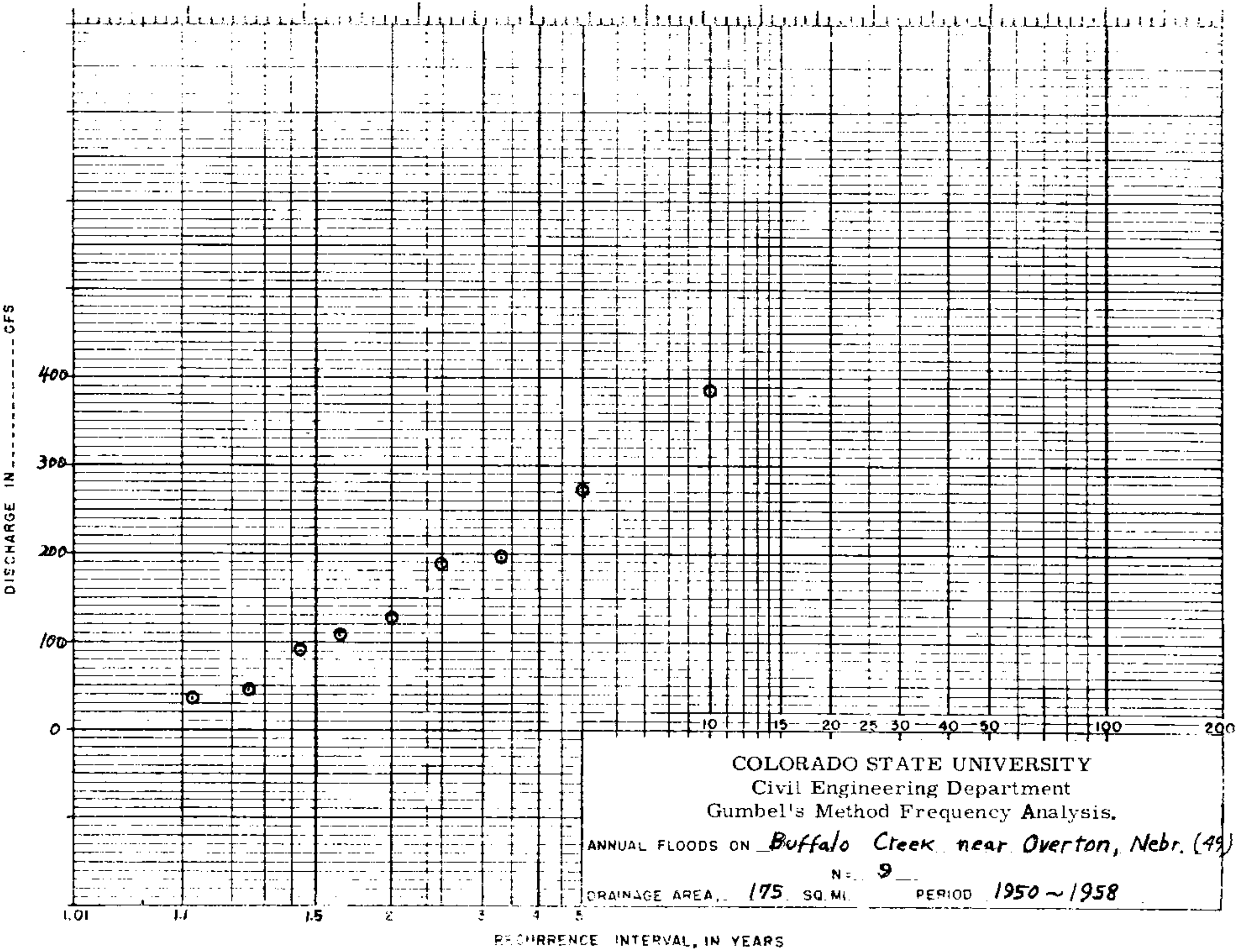
ANNUAL FLOODS ON *Buffalo Creek near Darr, Nebr. (48)*

N= *10*

DRAINAGE AREA, *63* SQ MI PERIOD *1947~1958*



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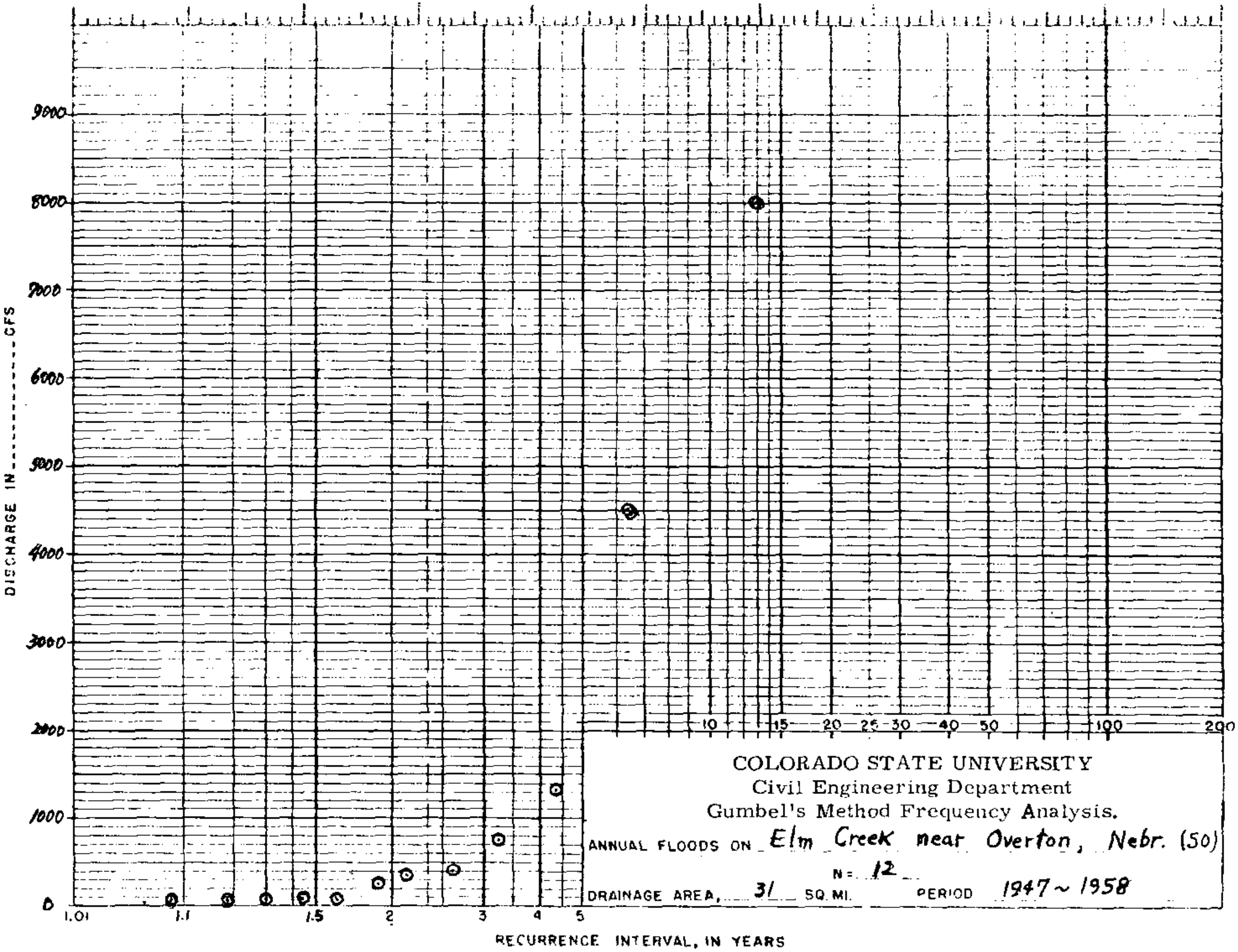
ANNUAL FLOODS ON Buffalo Creek near Overton, Nebr. (49)

N = 9

DRAINAGE AREA, 175 SQ. MI. PERIOD 1950 ~ 1958



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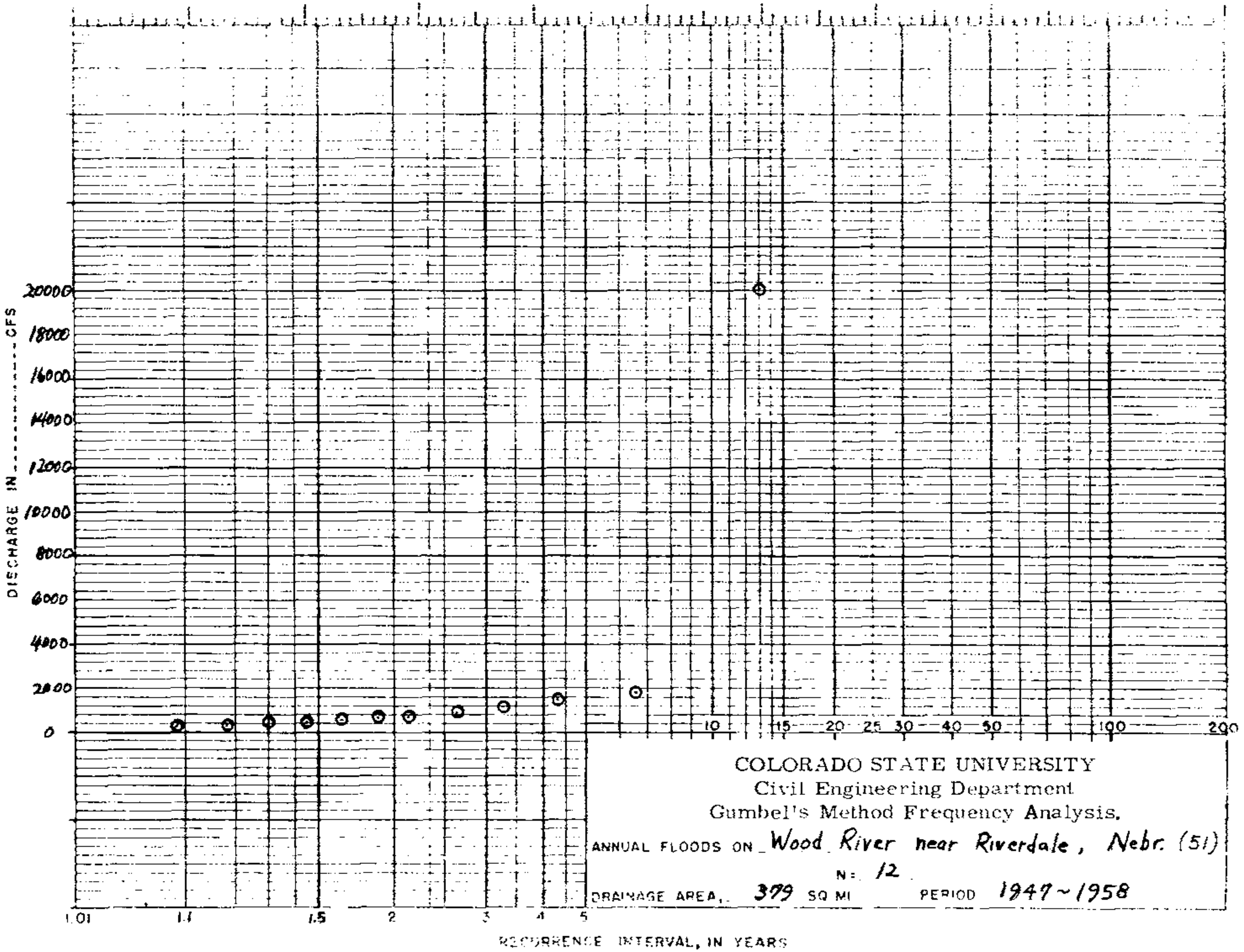
ANNUAL FLOODS ON Elm Creek near Overton, Nebr. (50)

N = 12

DRAINAGE AREA, 31 SQ. MI. PERIOD 1947 ~ 1958



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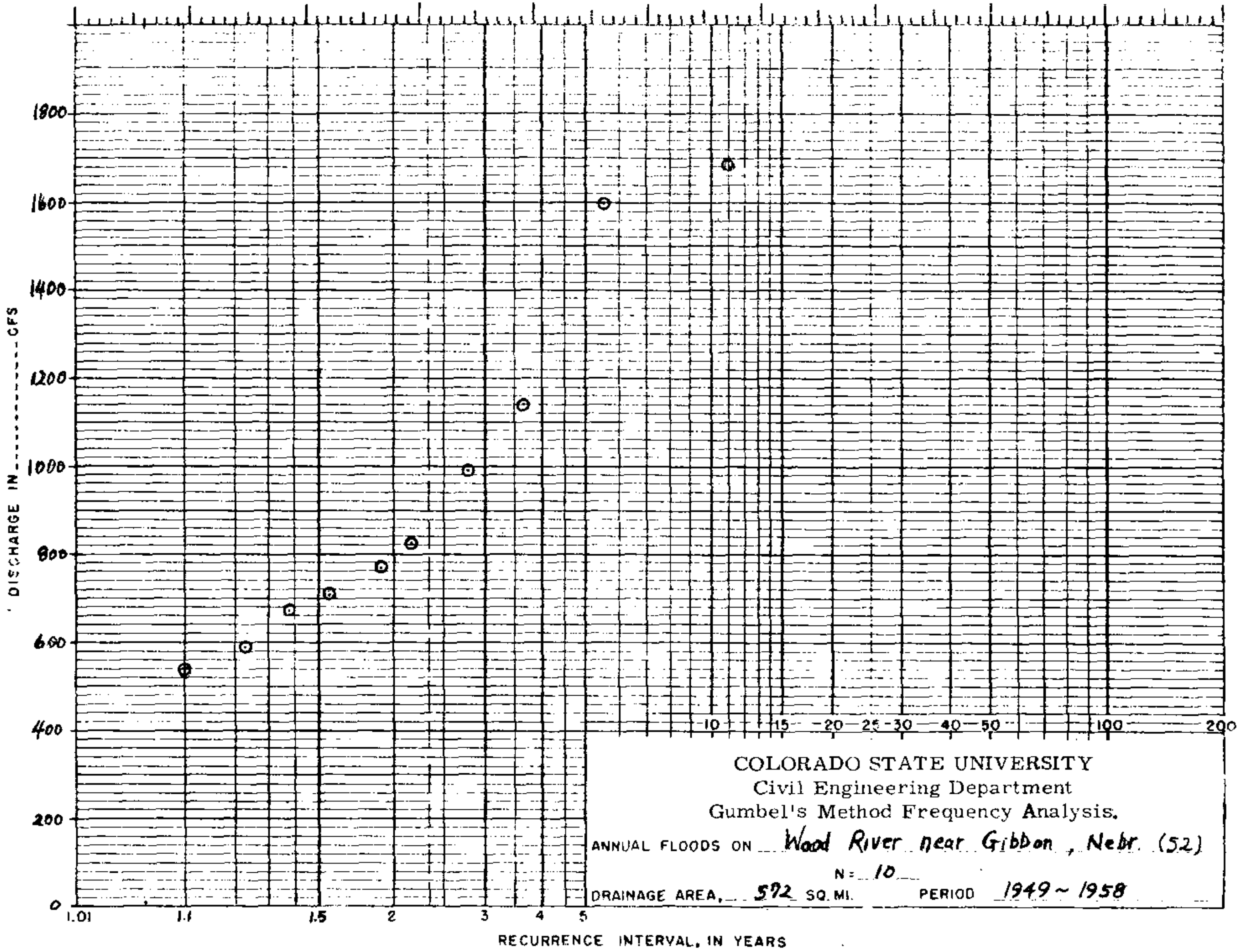
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Wood River near Riverdale, Nebr. (51)

N: 12

DRAINAGE AREA, 379 SQ MI PERIOD 1947~1958



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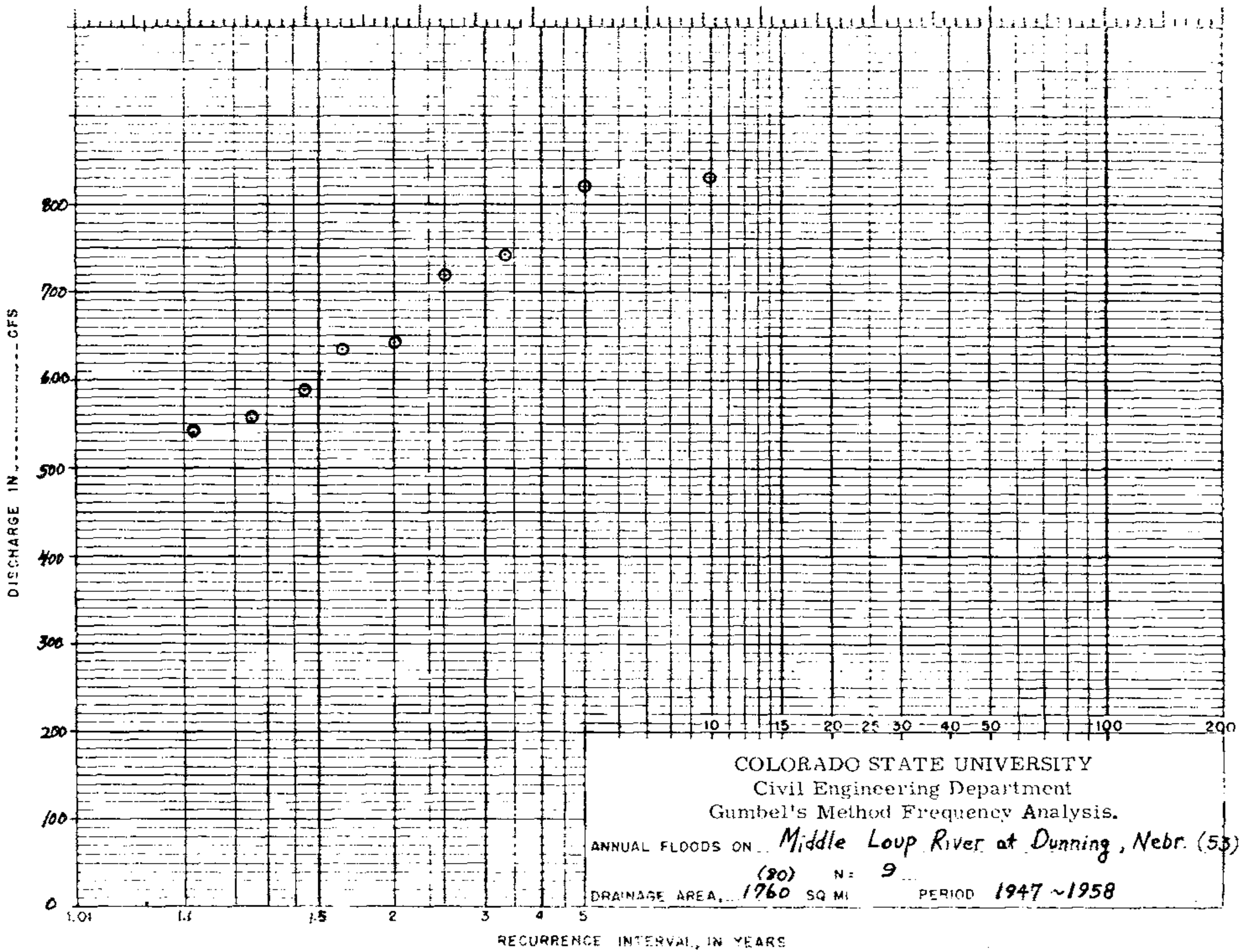
ANNUAL FLOODS ON Wood River near Gibbon, Nebr. (52)
N = 10
DRAINAGE AREA, 572 SQ. MI.
PERIOD 1949 ~ 1958



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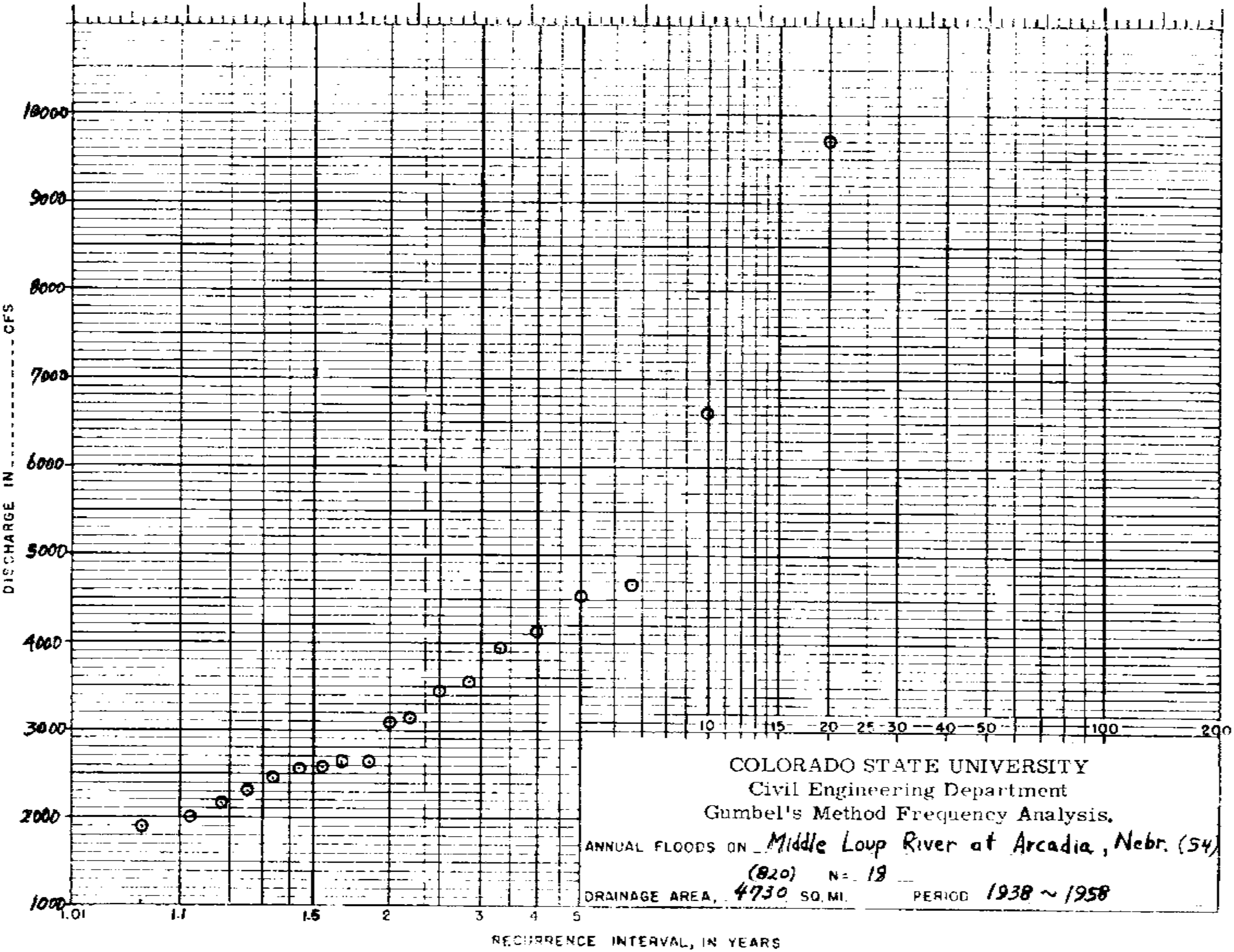
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Middle Loup River at Dunning, Nebr. (53)
(80) N: 9
DRAINAGE AREA, 1760 SQ MI PERIOD 1947 ~1958



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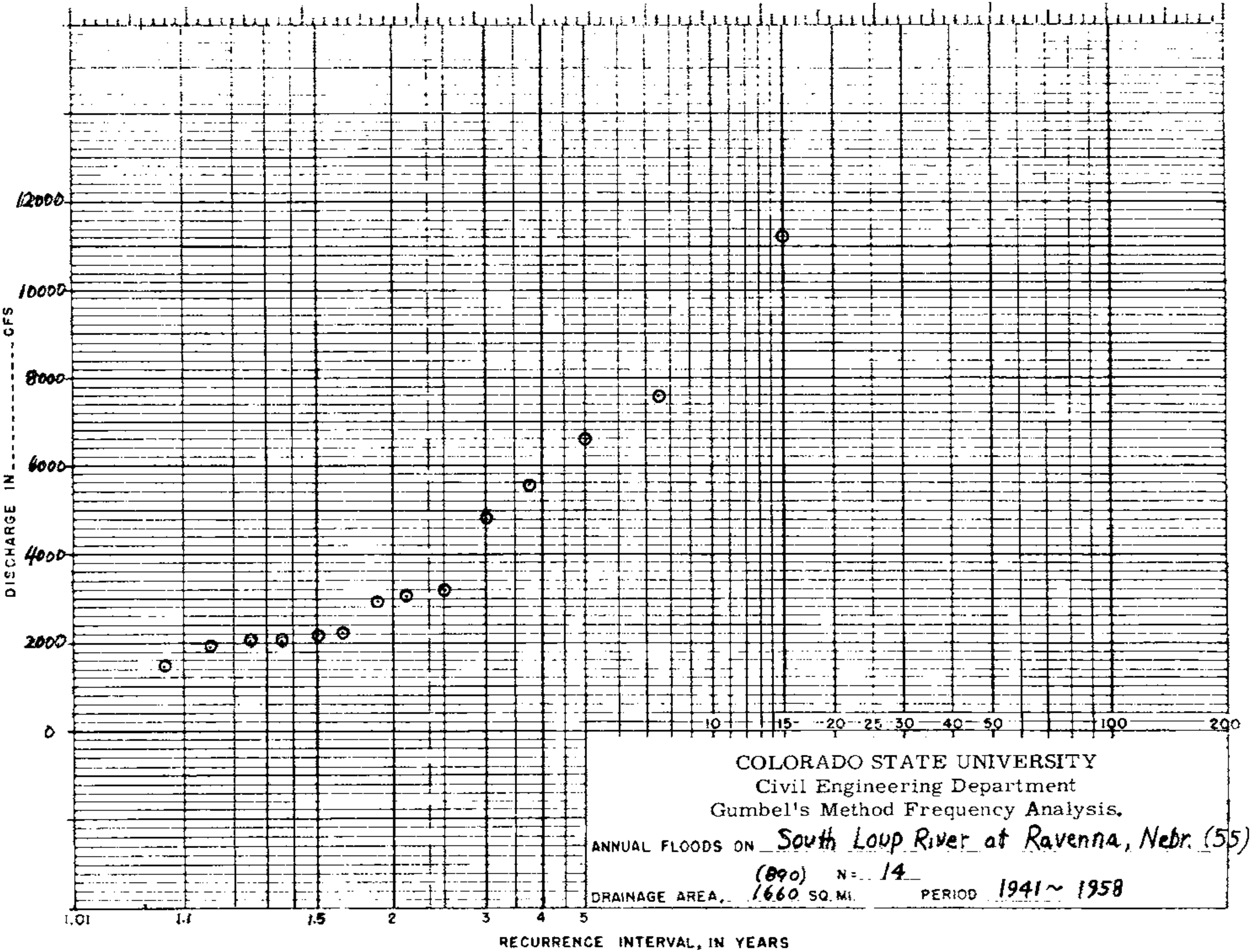
ANNUAL FLOODS ON Middle Loup River at Arcadia, Nebr. (54)
(820) N= 19
DRAINAGE AREA, 4730 SQ. MI. PERIOD 1938 ~ 1958



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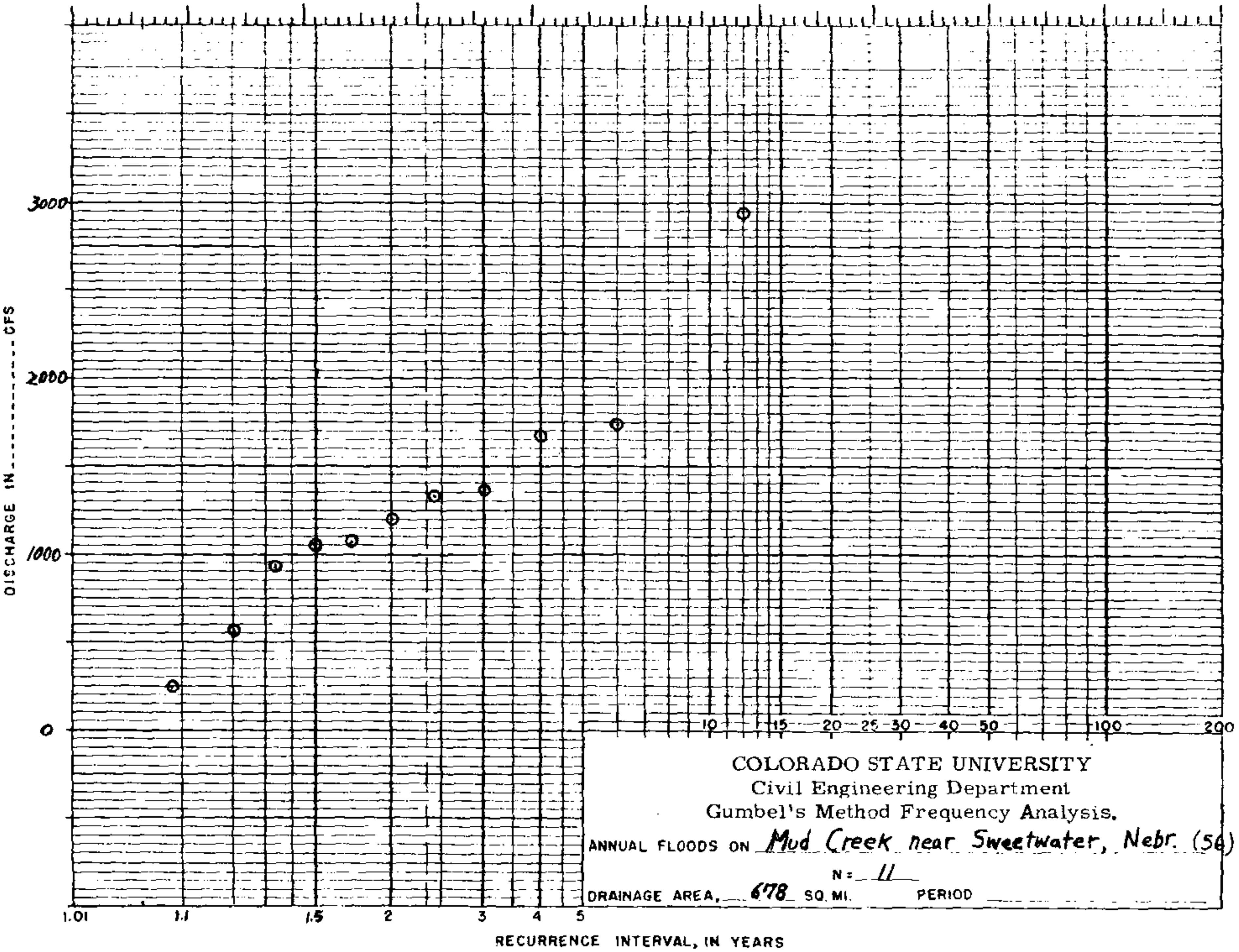
ANNUAL FLOODS ON South Loup River at Ravenna, Nebr. (55)
(890) N= 14
DRAINAGE AREA, 1660 SQ. MI. PERIOD 1941~ 1958



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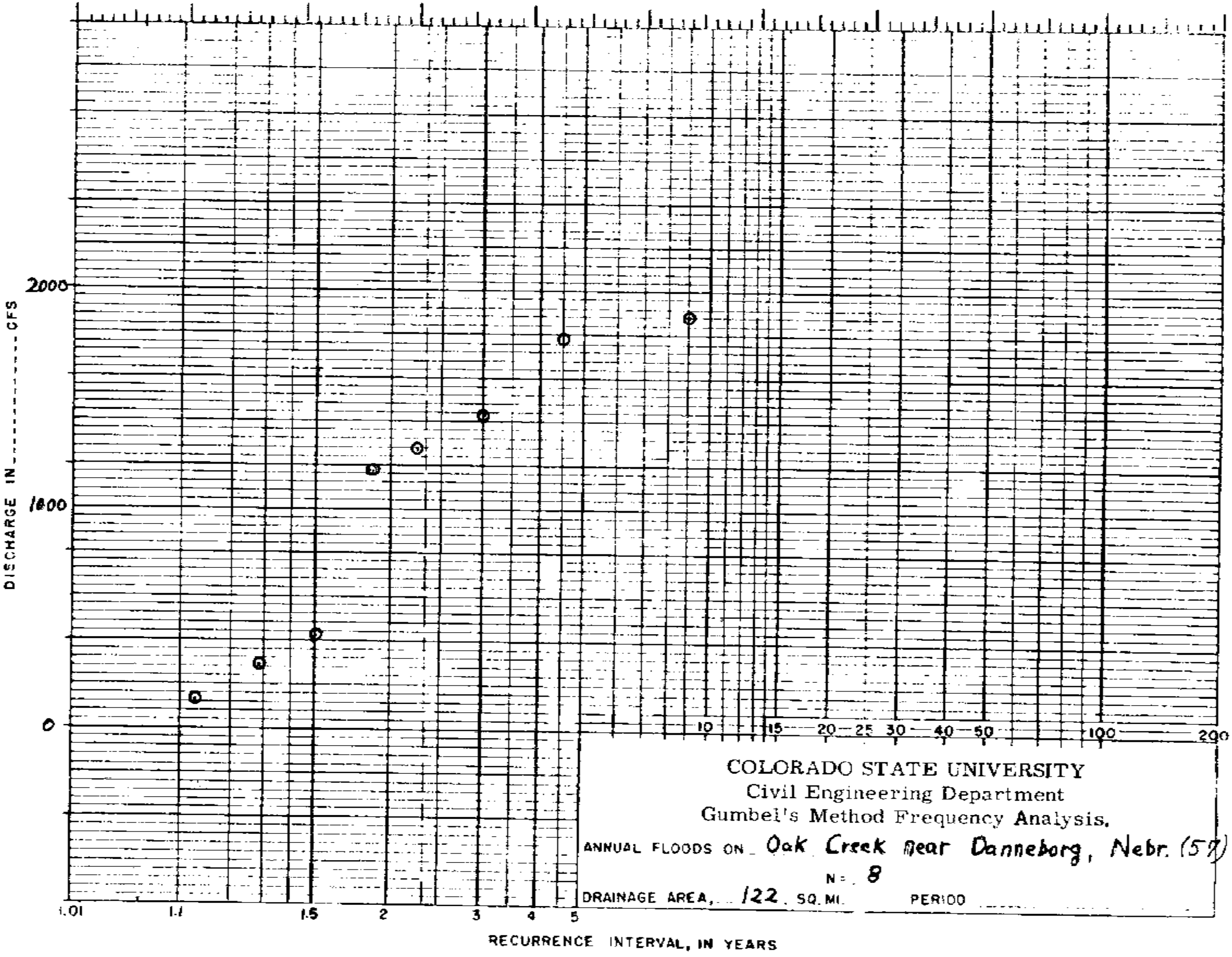
ANNUAL FLOODS ON Mud Creek near Sweetwater, Nebr. (56)

N = 11

DRAINAGE AREA, 678 SQ. MI. PERIOD



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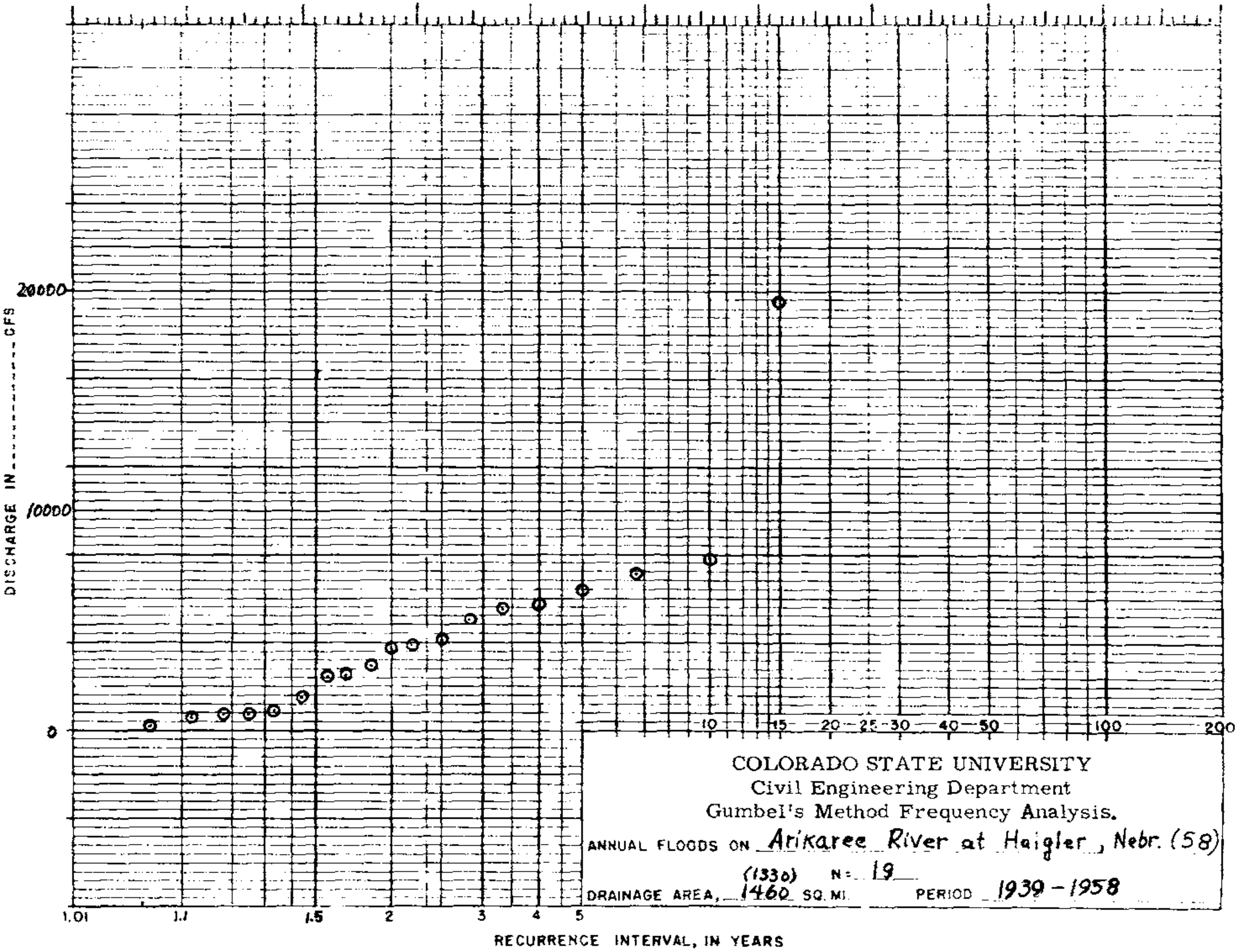
ANNUAL FLOODS ON Oak Creek near Danneborg, Nebr. (57)

N = 8

DRAINAGE AREA, 122 SQ. MI. PERIOD

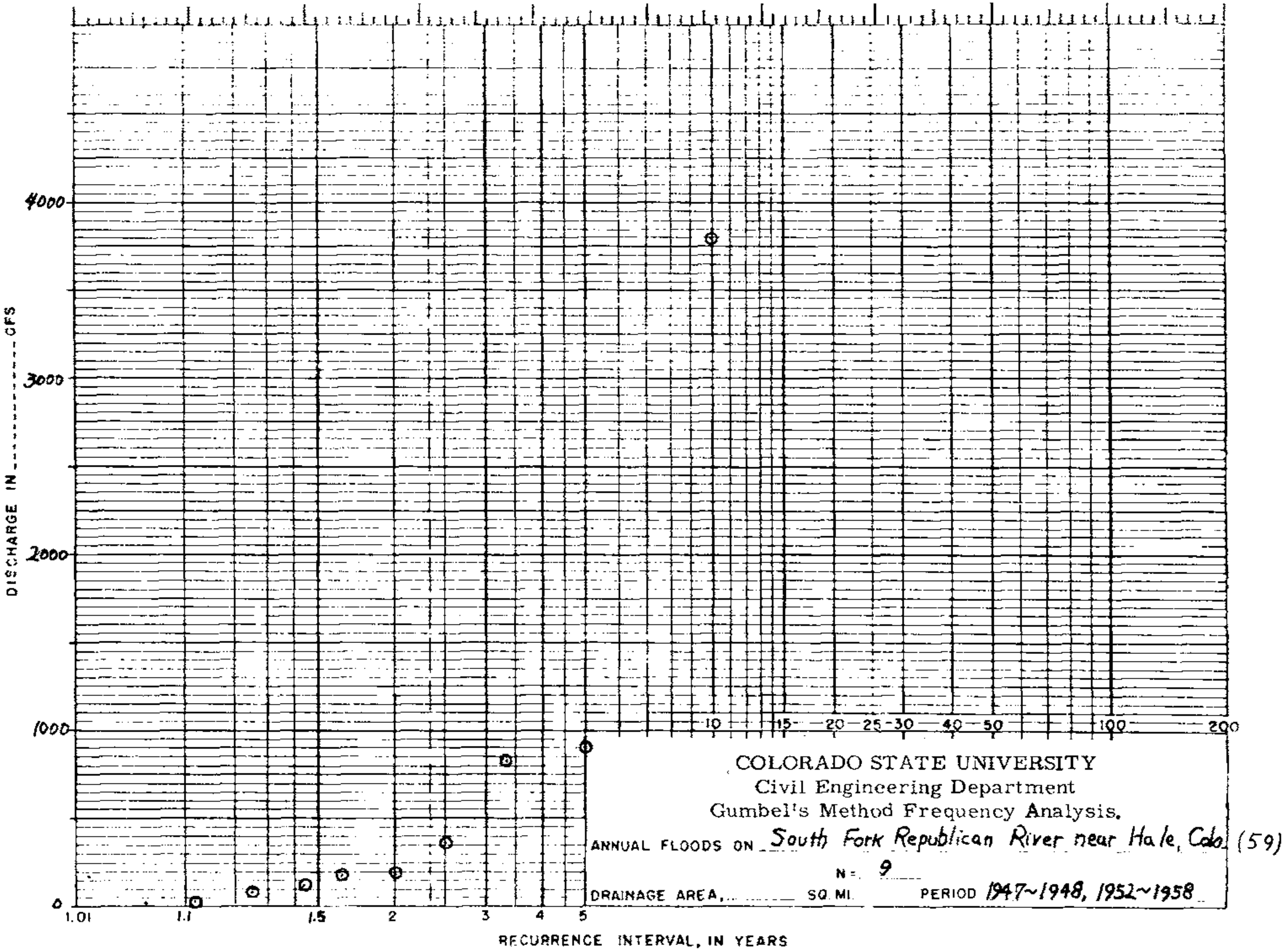


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Arikaree River at Haigler, Nebr. (58)

(1330) N= 19

DRAINAGE AREA, 1460 SQ. MI. PERIOD 1939 - 1958

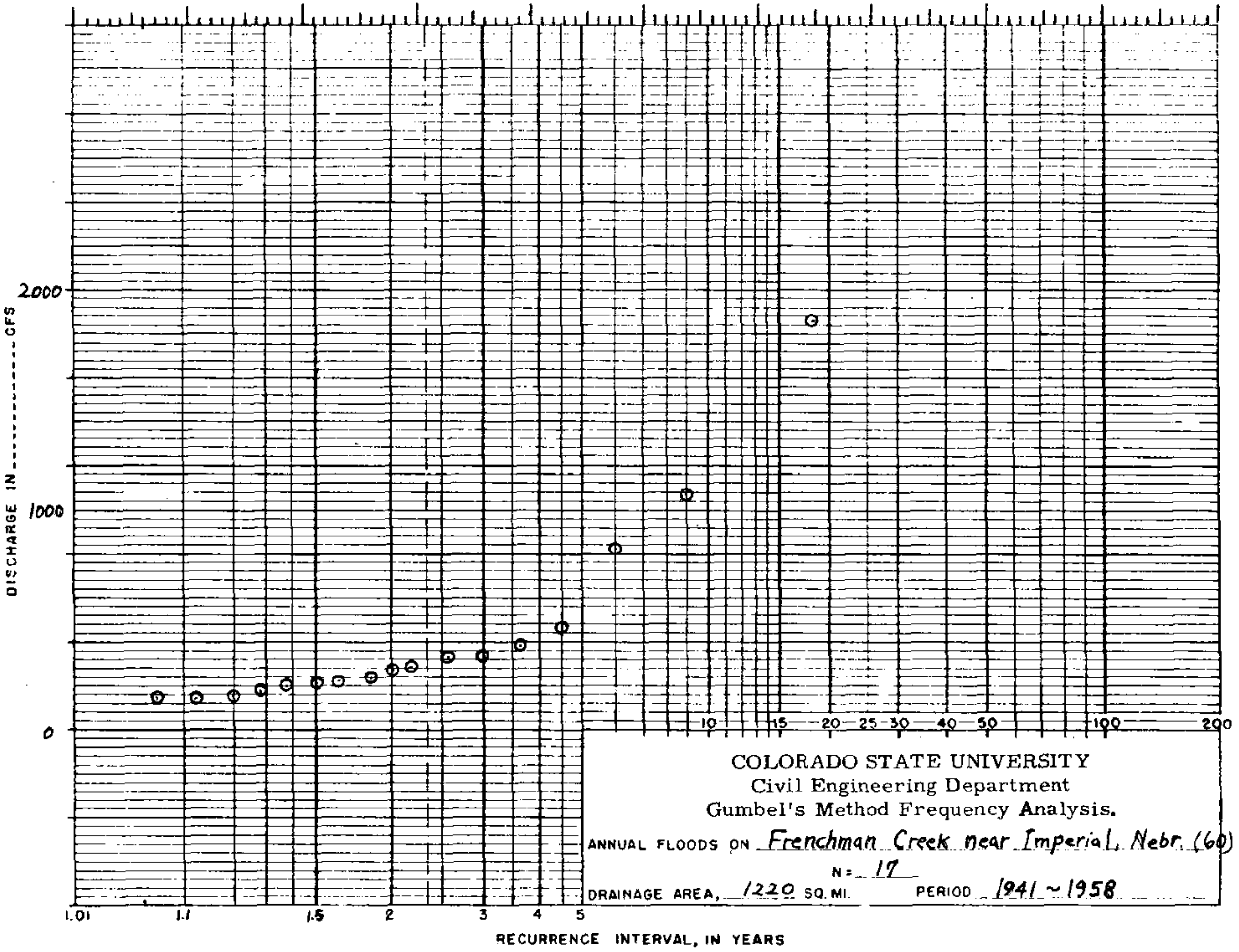


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON South Fork Republican River near Hale, Colo. (59)

N = 9

DRAINAGE AREA, ______ SQ. MI. PERIOD 1947~1948, 1952~1958



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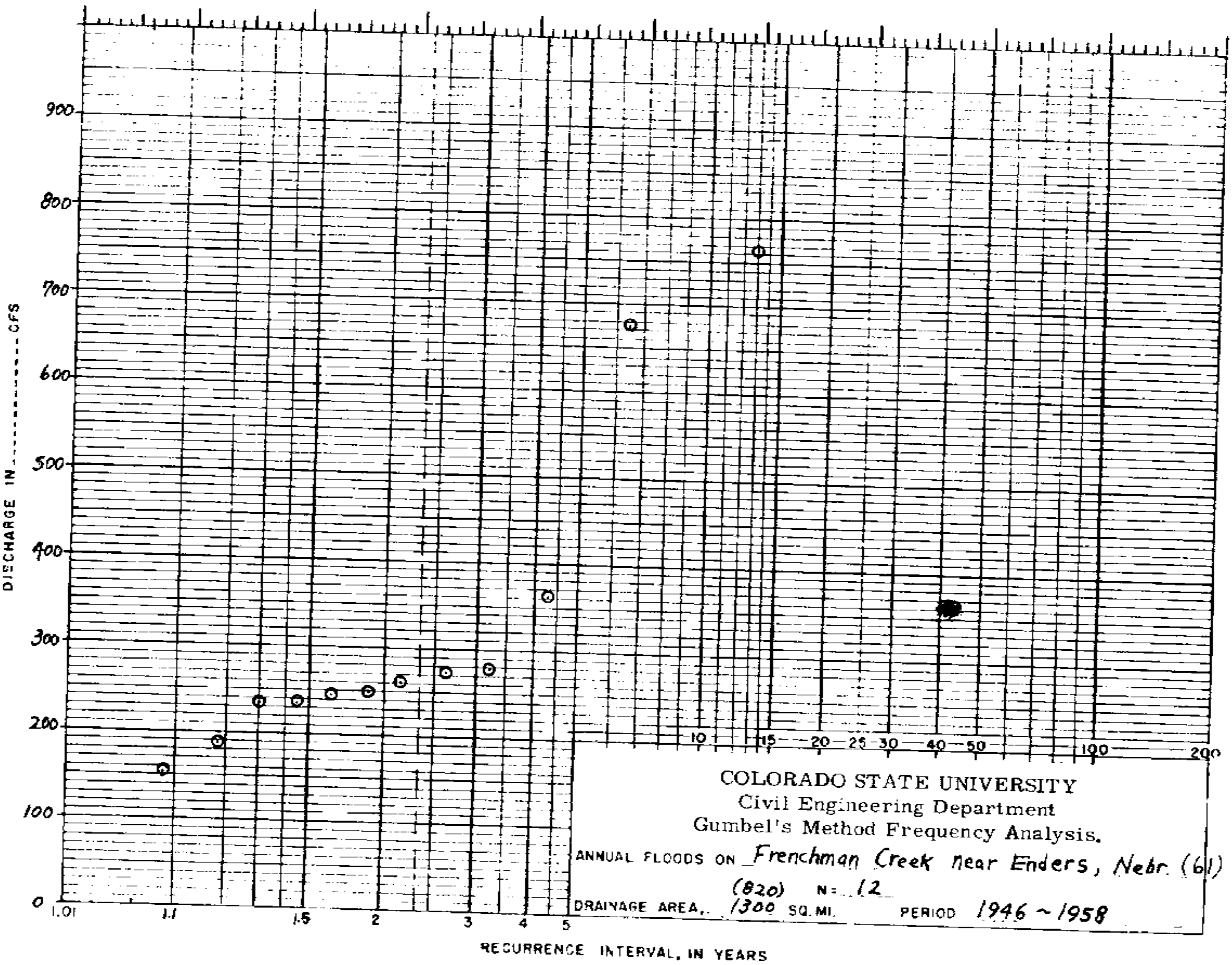
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Frenchman Creek near Imperial, Nebr. (60)

N: 17

DRAINAGE AREA, 1220 SQ. MI. PERIOD 1941 ~ 1958



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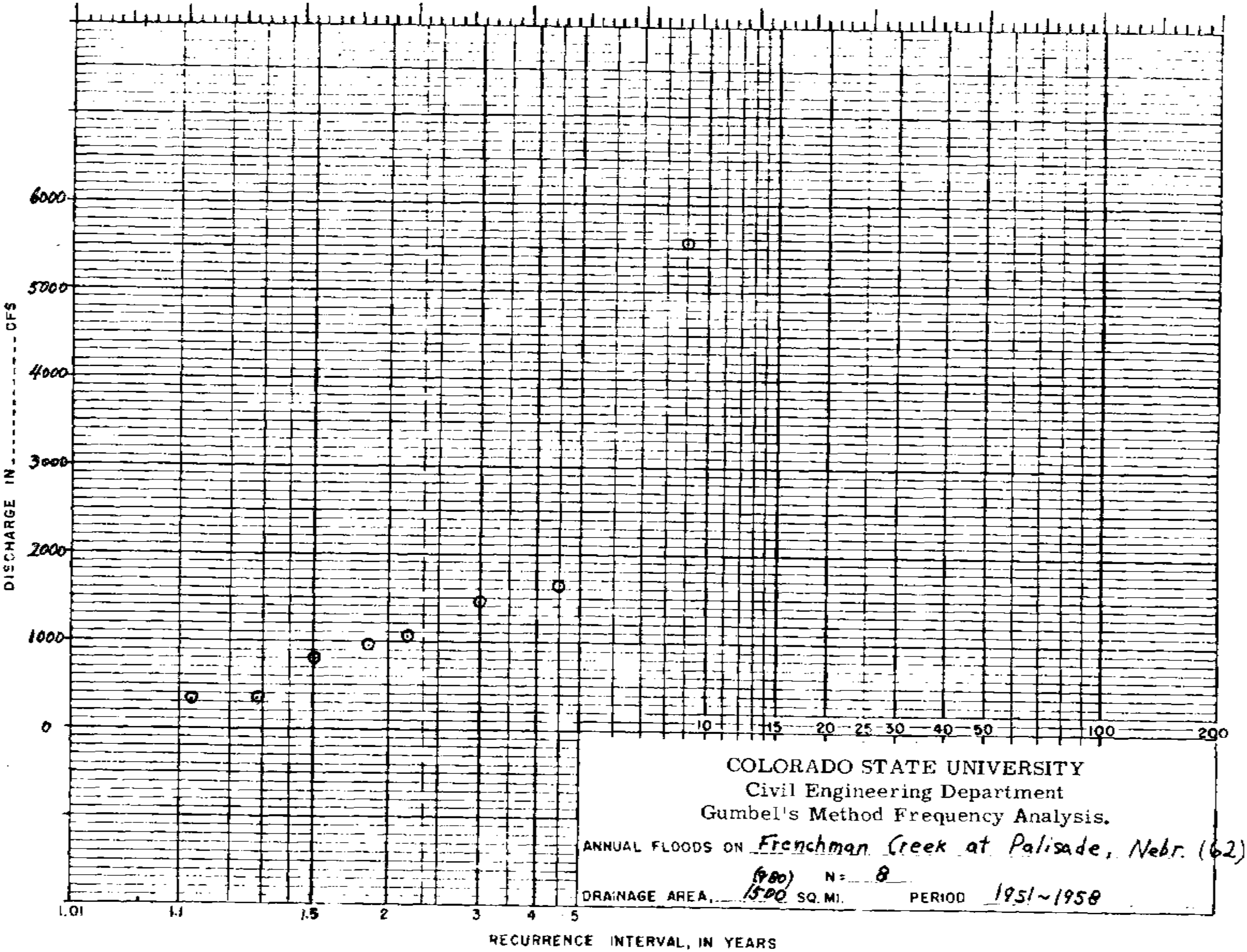
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Frenchman Creek near Enders, Nebr. (61)

(820) N: 12

DRAINAGE AREA 1300 SQ. MI. PERIOD 1946 ~ 1958



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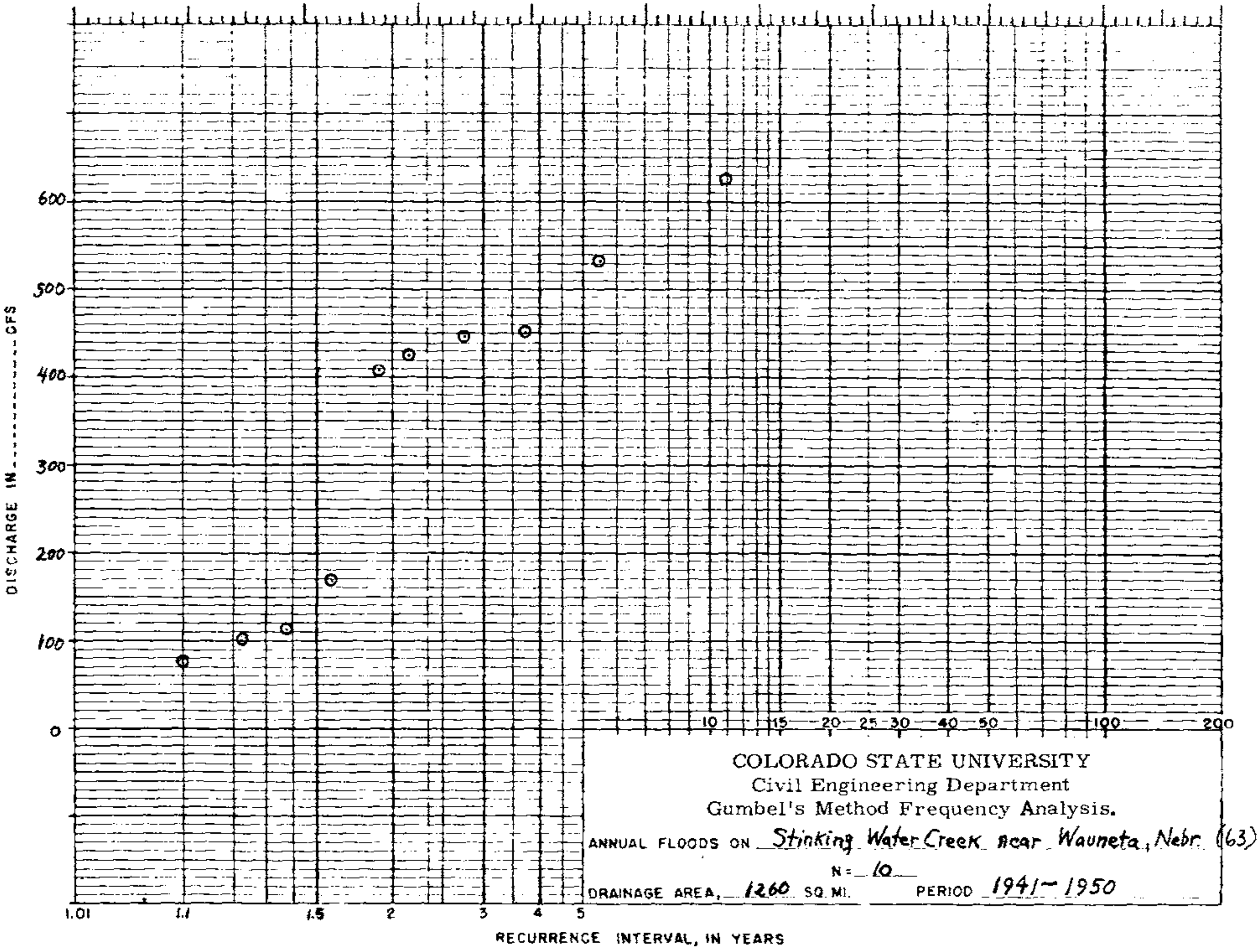
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Frenchman Creek at Palisade, Nebr. (62)

N = 8

DRAINAGE AREA, (980) 1500 SQ. MI. PERIOD 1951~1958



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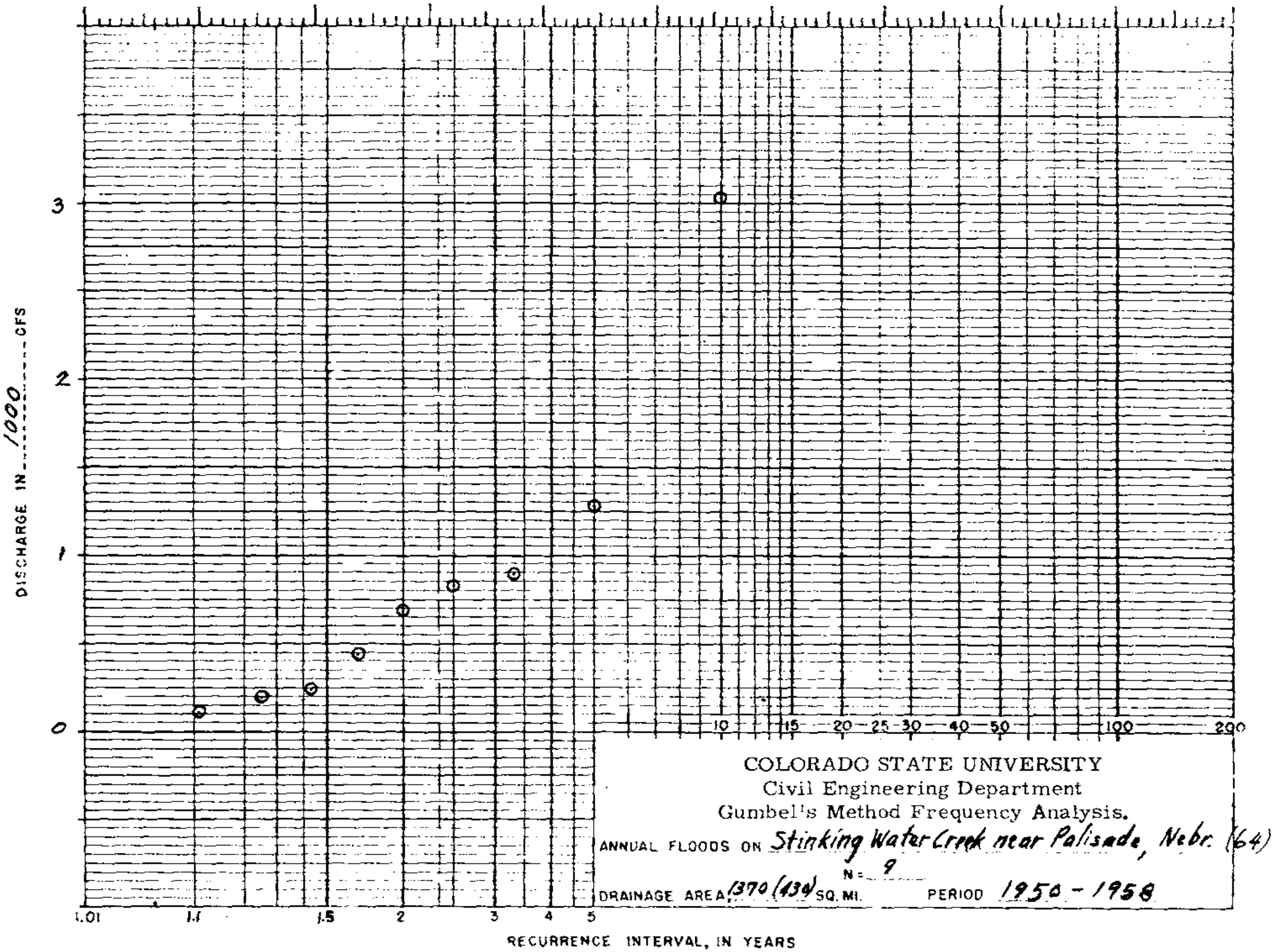
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Stinking Water Creek near Wauneta, Nebr. (63)

N = 10

DRAINAGE AREA, 1260 SQ. MI. PERIOD 1941– 1950



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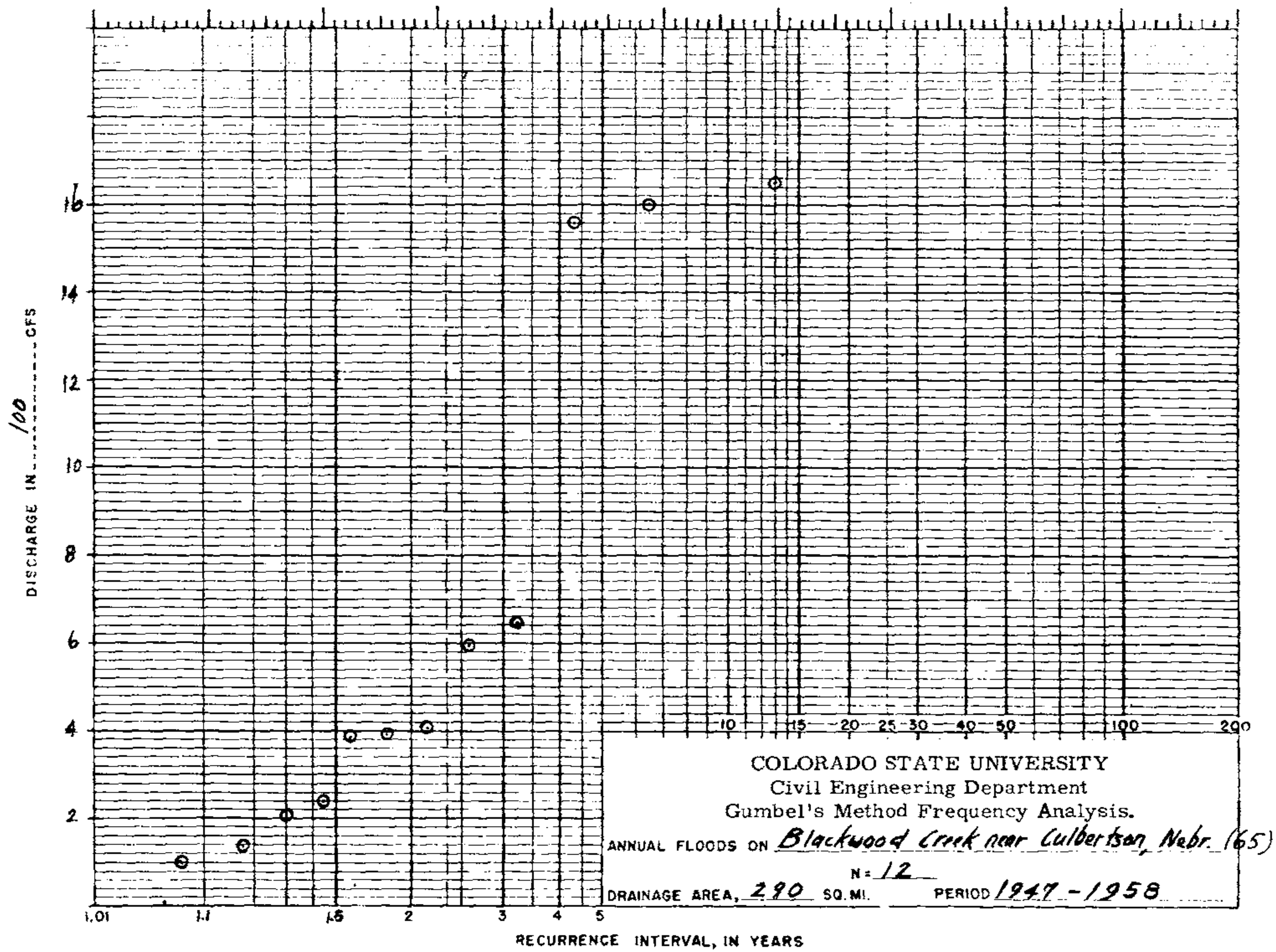
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Stinking Water Creek near Palisade, Nebr. (64)

N = 9

DRAINAGE AREA 1370 (430) SQ. MI. PERIOD 1950 - 1958



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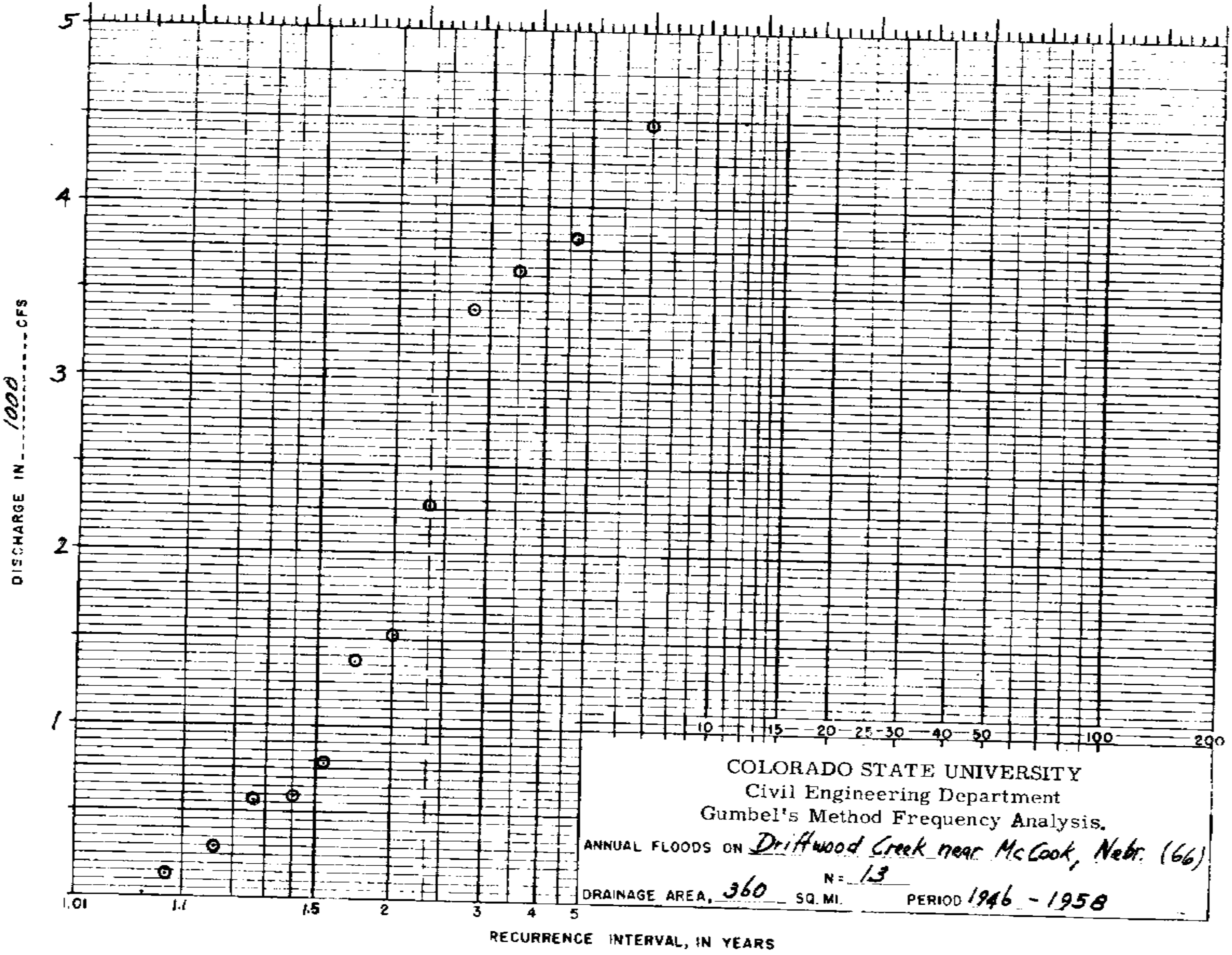
ANNUAL FLOODS ON Blackwood Creek near Culbertson, Nebr. (65)

N = 12

DRAINAGE AREA, 290 SQ.MI.   PERIOD 1947 - 1958



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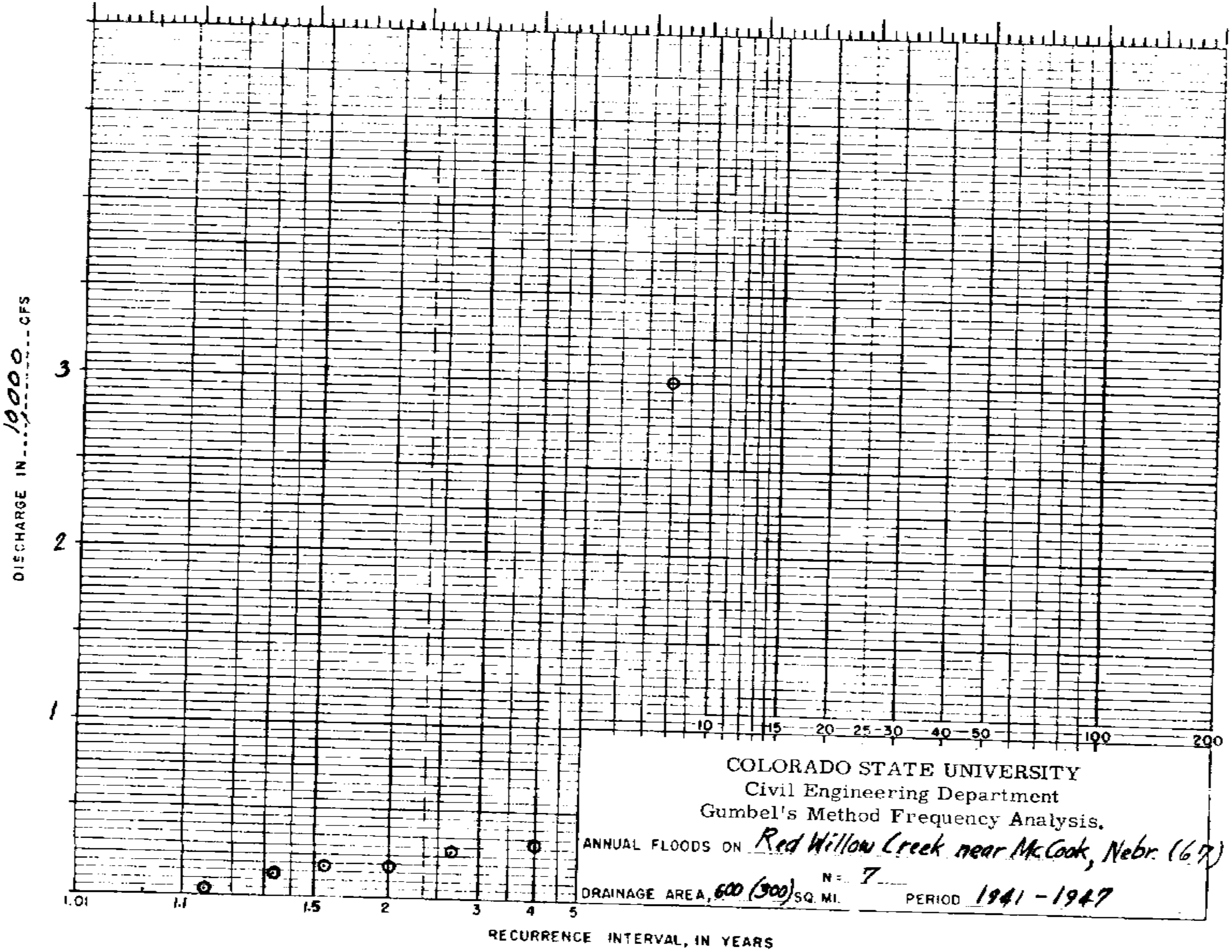
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Driftwood Creek near McCook, Nebr. (66)

N = 13

DRAINAGE AREA, 360 SQ. MI. PERIOD 1946 - 1958



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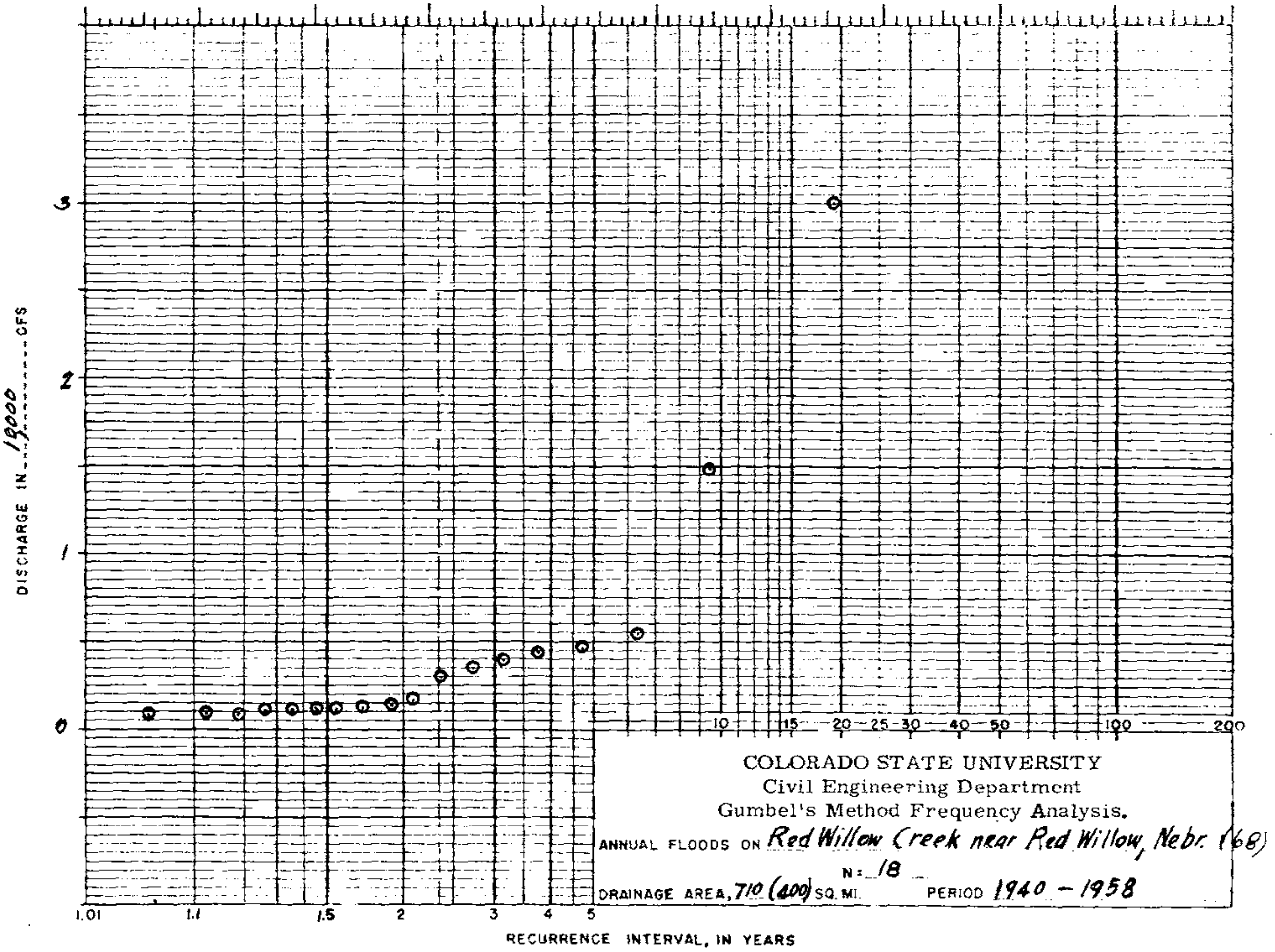
ANNUAL FLOODS ON Red Willow Creek near McCook, Nebr. (67)

DRAINAGE AREA, 600 (300) SQ. MI. N= 7 PERIOD 1941 - 1947



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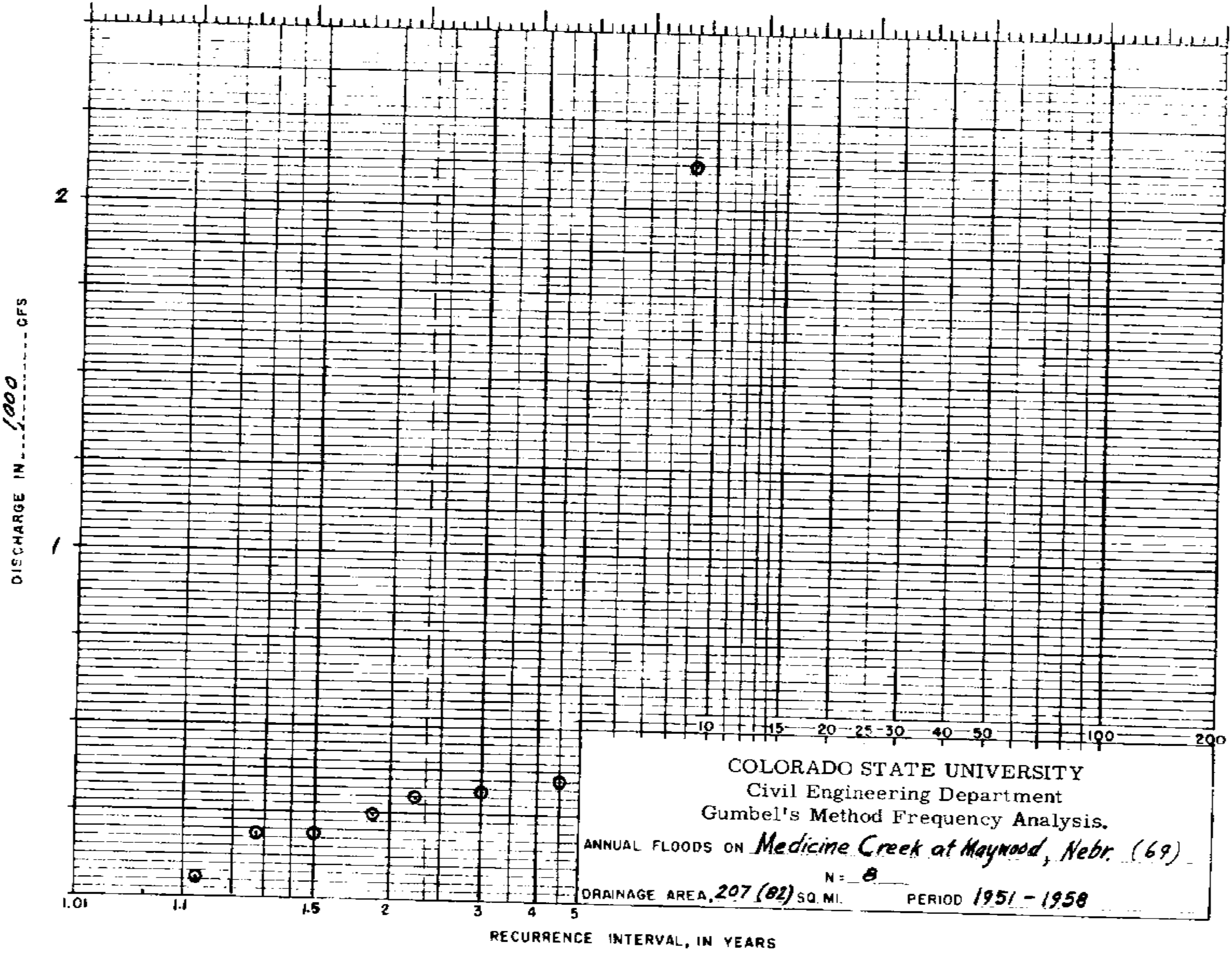
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Red Willow Creek near Red Willow, Nebr. (68)*

N: *18*

DRAINAGE AREA, *710 (400)* SQ. MI.   PERIOD *1940 - 1958*

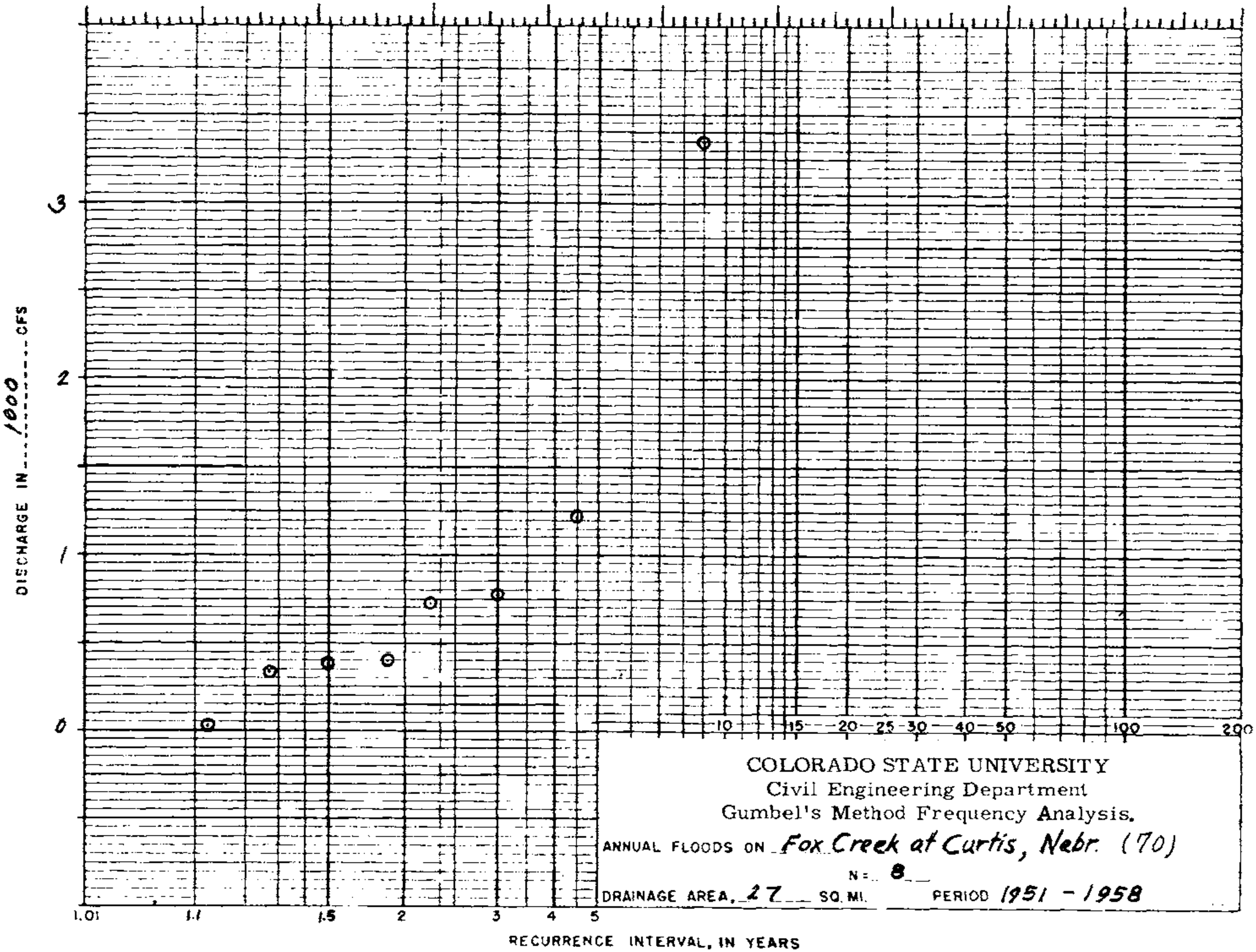


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Medicine Creek at Maywood, Nebr. (69)*

N = *8*

DRAINAGE AREA *207 (82)* SQ. MI. PERIOD *1951 - 1958*



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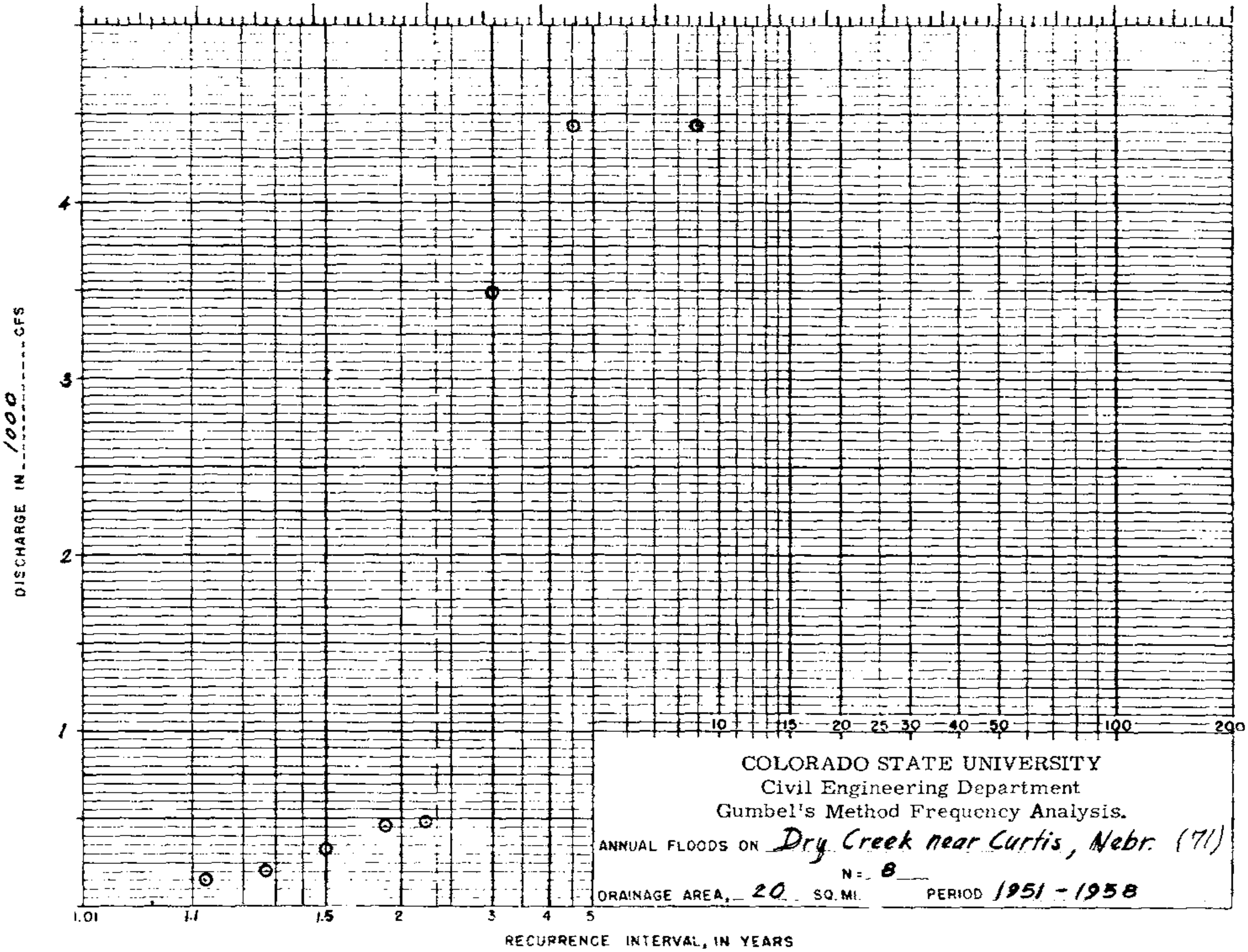
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Fox Creek at Curtis, Nebr. (70)

N = 8

DRAINAGE AREA, 27 SQ. MI. PERIOD 1951 - 1958

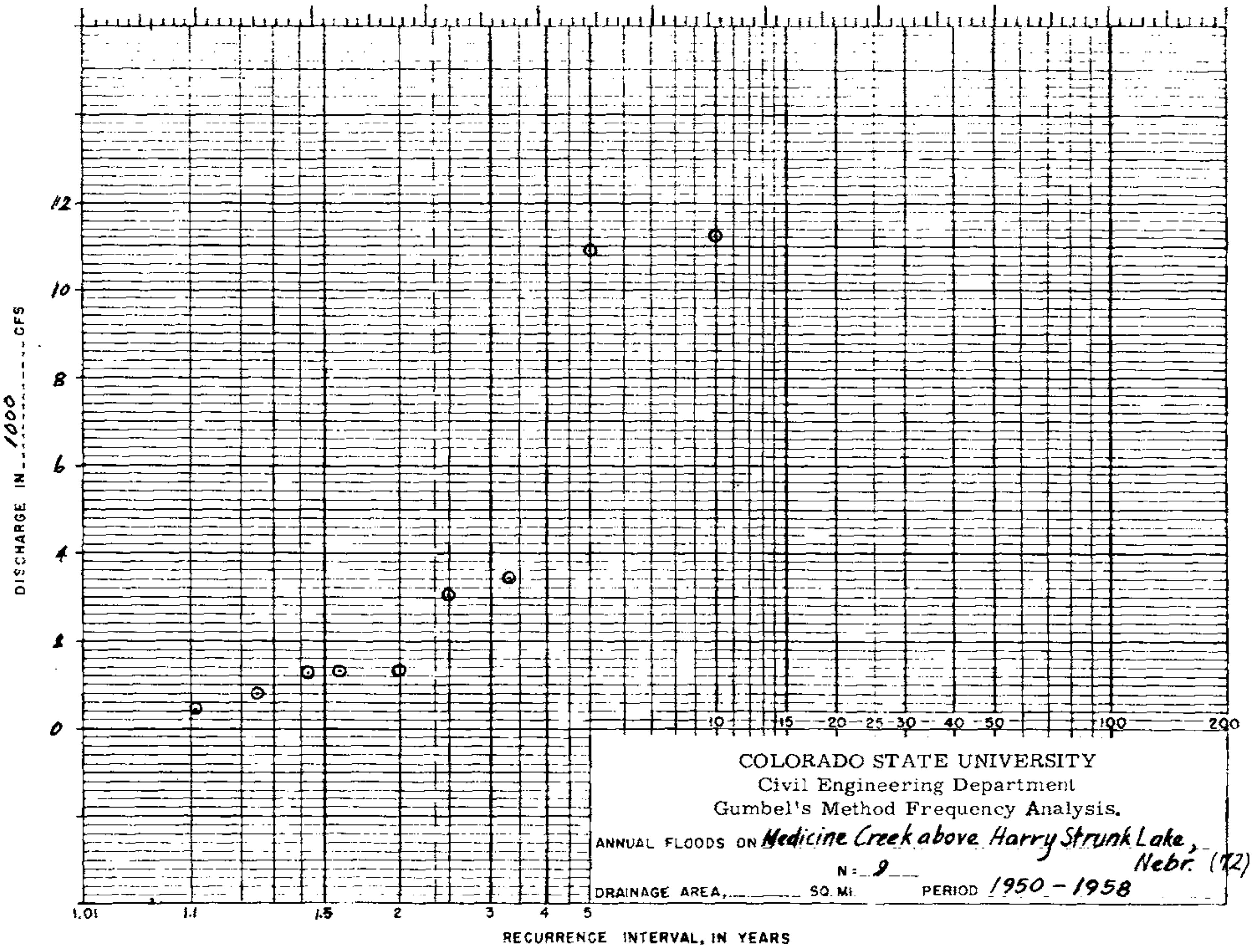


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Dry Creek near Curtis, Nebr. (71)*

N= *8*

DRAINAGE AREA, *20* SQ. MI. PERIOD *1951 - 1958*

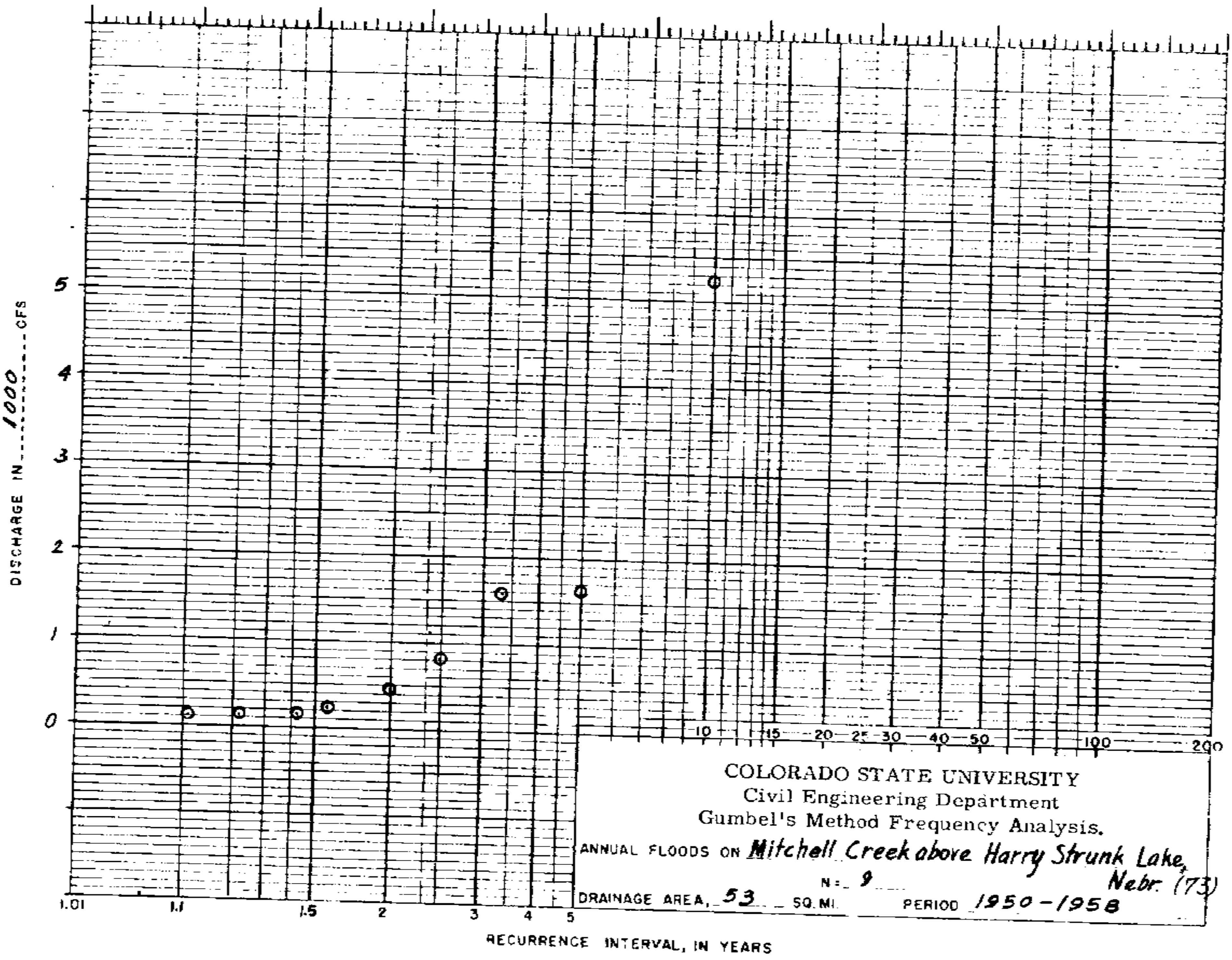


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Medicine Creek above Harry Strunk Lake, Nebr.* (72)

N = 9

DRAINAGE AREA, ______ SQ. MI. PERIOD 1950 - 1958

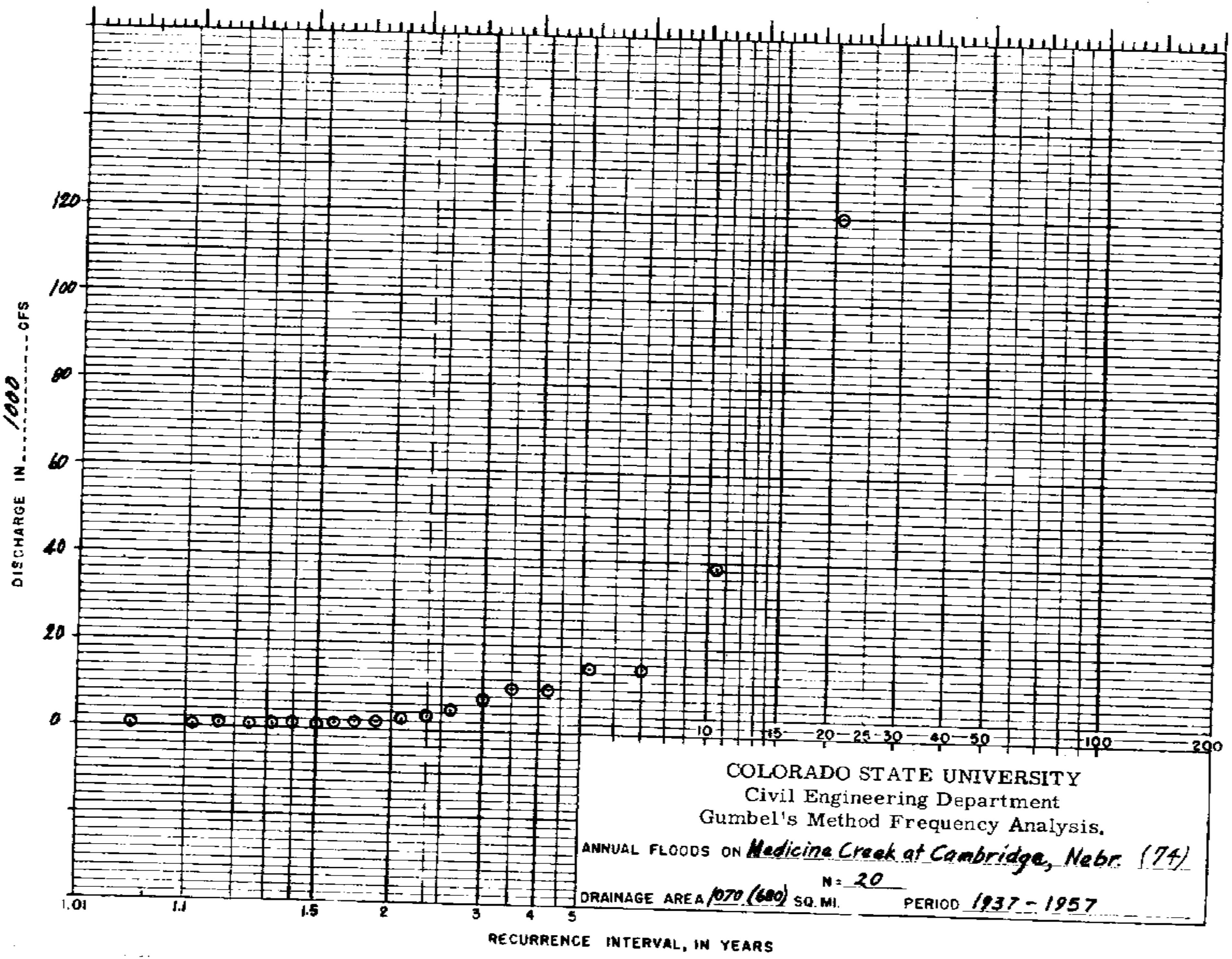


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Mitchell Creek above Harry Strunk Lake, Nebr. (73)

N = 9

DRAINAGE AREA, 53 SQ. MI. PERIOD 1950-1958



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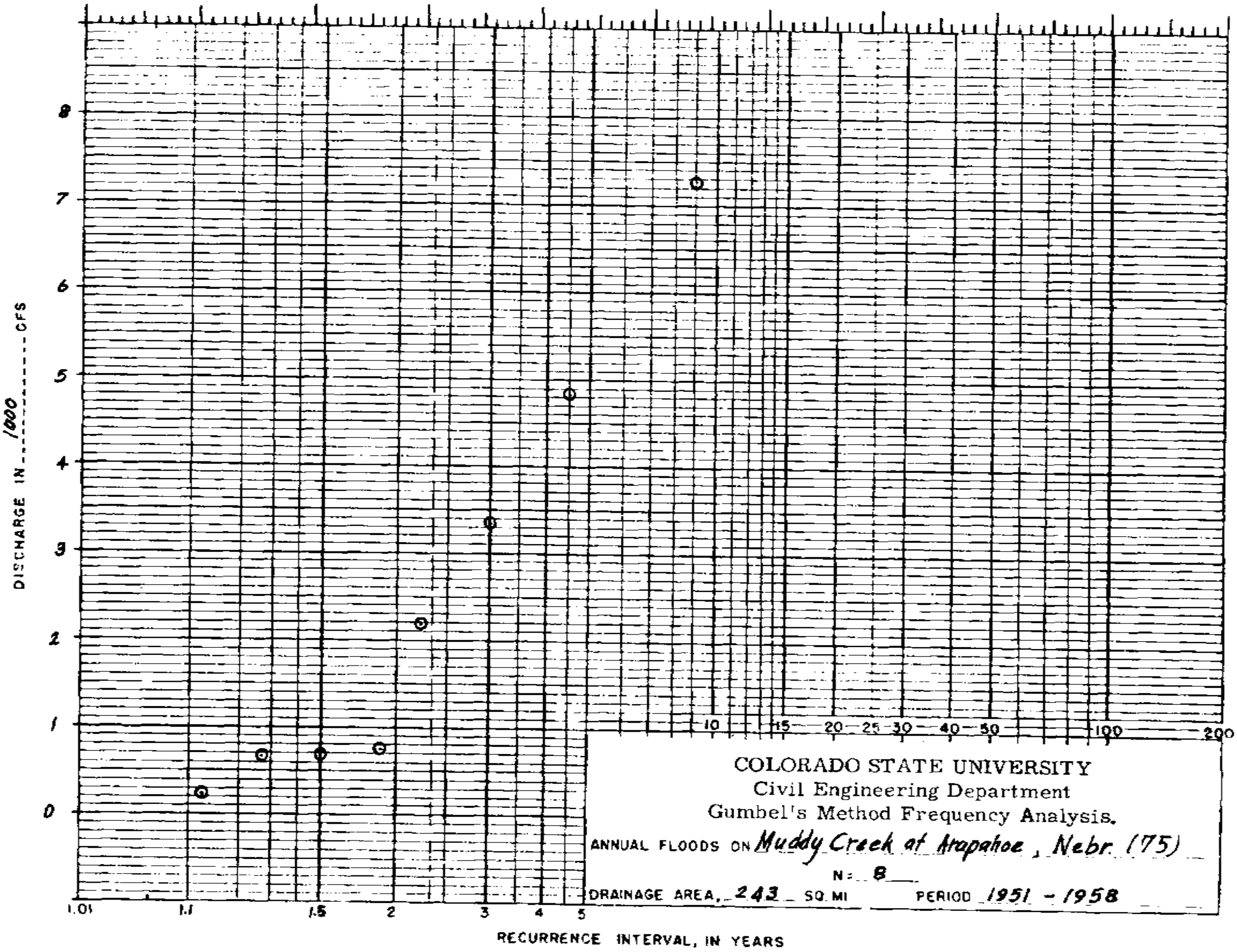
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Medicine Creek at Cambridge, Nebr. (74)*

N: *20*

DRAINAGE AREA *1070 (680)* SQ. MI. PERIOD *1937 - 1957*



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Civil Engineering Department
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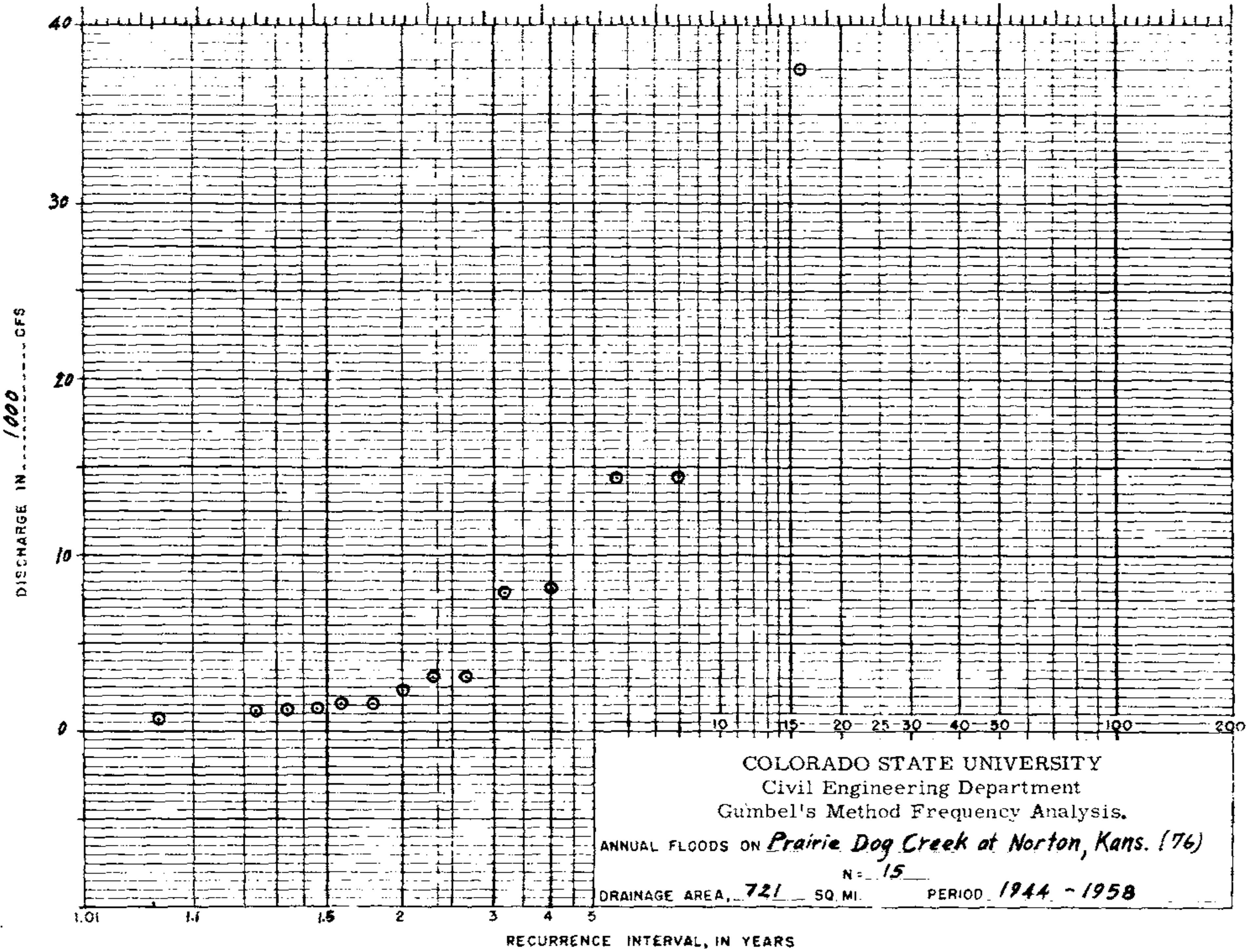
ANNUAL FLOODS ON *Muddy Creek at Arapahoe, Nebr. (75)*

N= *8*

DRAINAGE AREA, *243* SQ. MI PERIOD *1951 - 1958*



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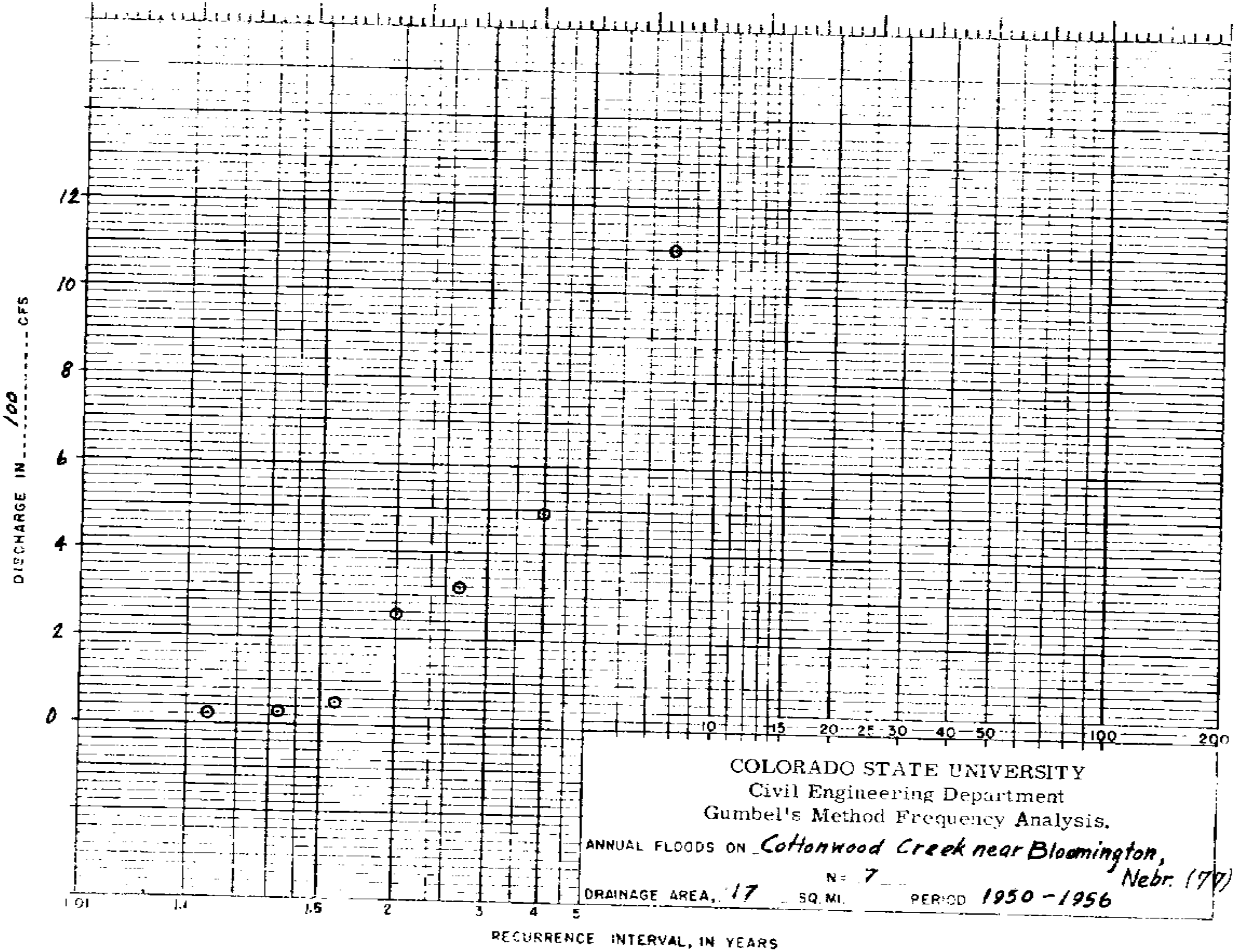
ANNUAL FLOODS ON *Prairie Dog Creek at Norton, Kans. (76)*

N = *15*

DRAINAGE AREA, *721* SQ. MI. PERIOD *1944 - 1958*



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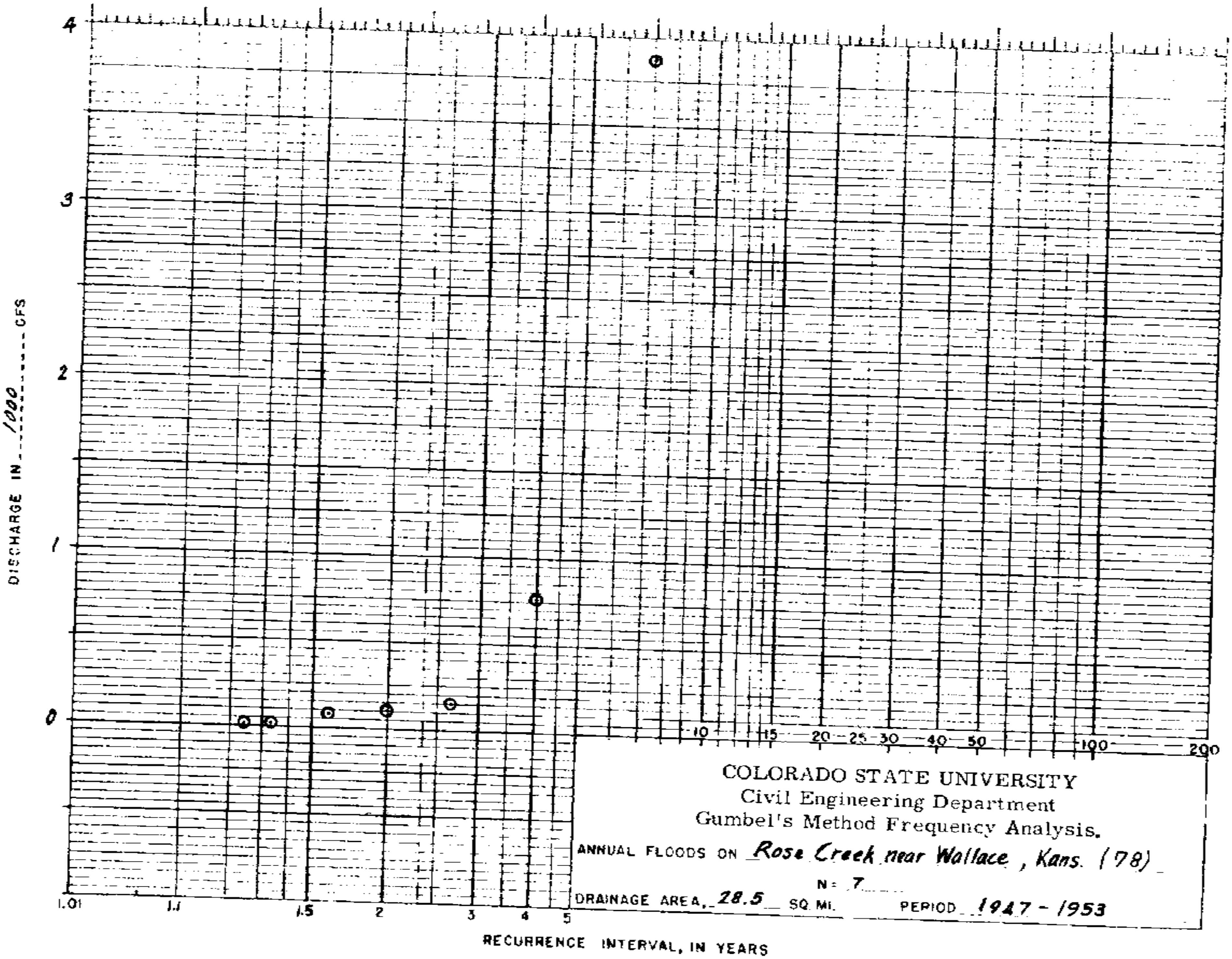
ANNUAL FLOODS ON *Cottonwood Creek near Bloomington, Nebr. (77)*

N = *7*

DRAINAGE AREA, *17* SQ. MI. PERIOD *1950 - 1956*



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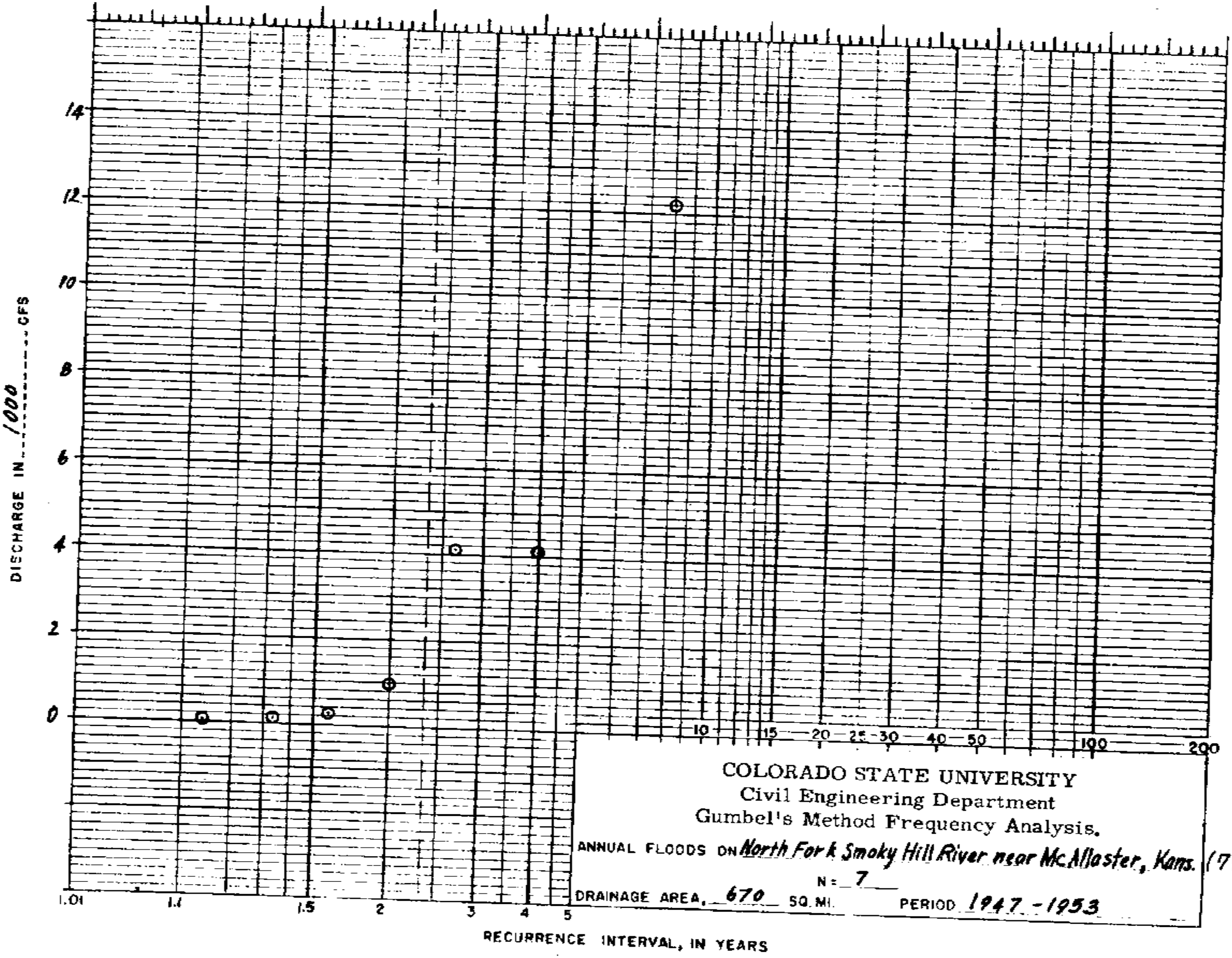
ANNUAL FLOODS ON *Rose Creek near Wallace, Kans. (78)*

N: *7*

DRAINAGE AREA, *28.5* SQ. MI. PERIOD *1947 - 1953*



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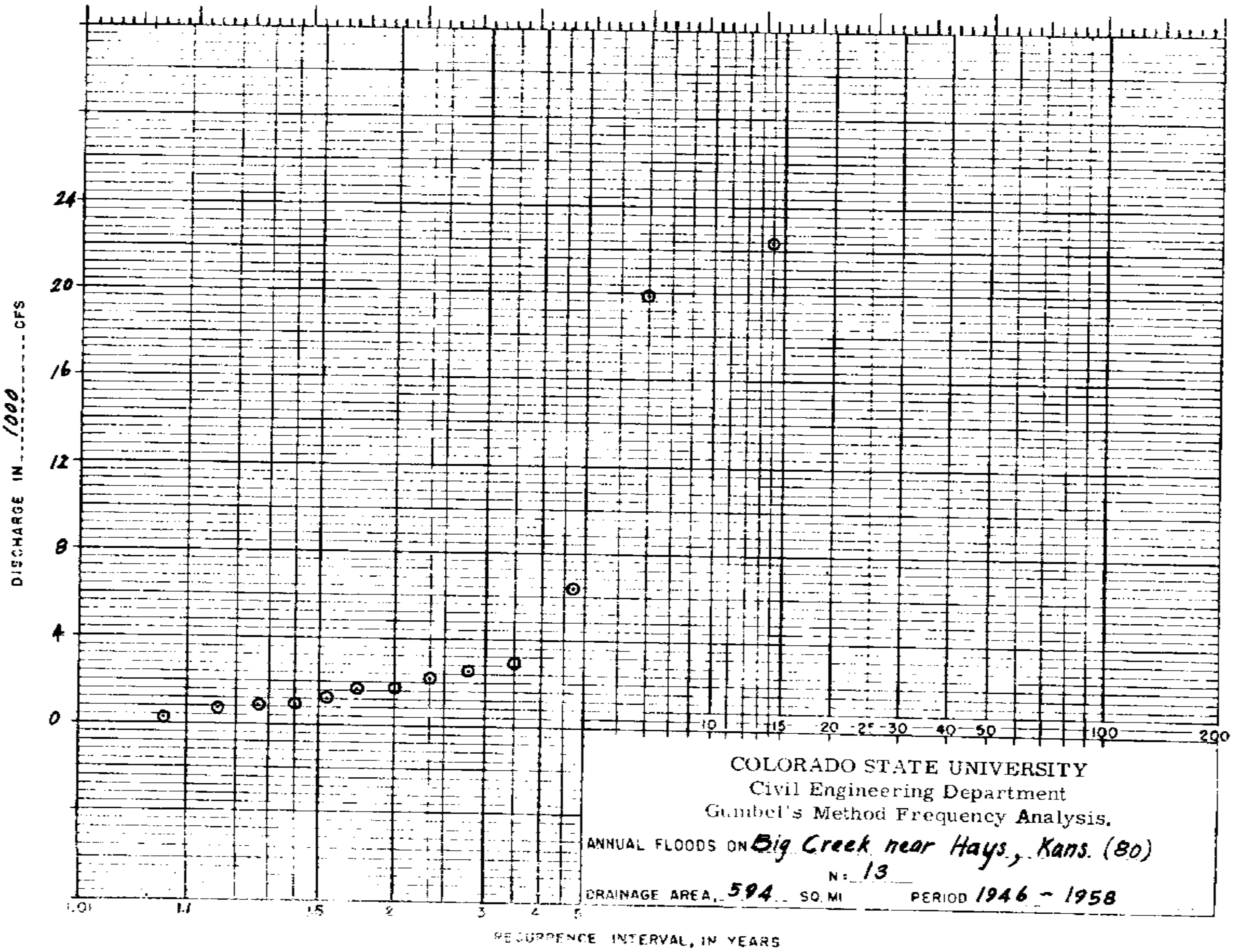
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON North Fork Smoky Hill River near McAllaster, Kans. (79)
N = 7
DRAINAGE AREA, 670 SQ. MI. PERIOD 1947 - 1953



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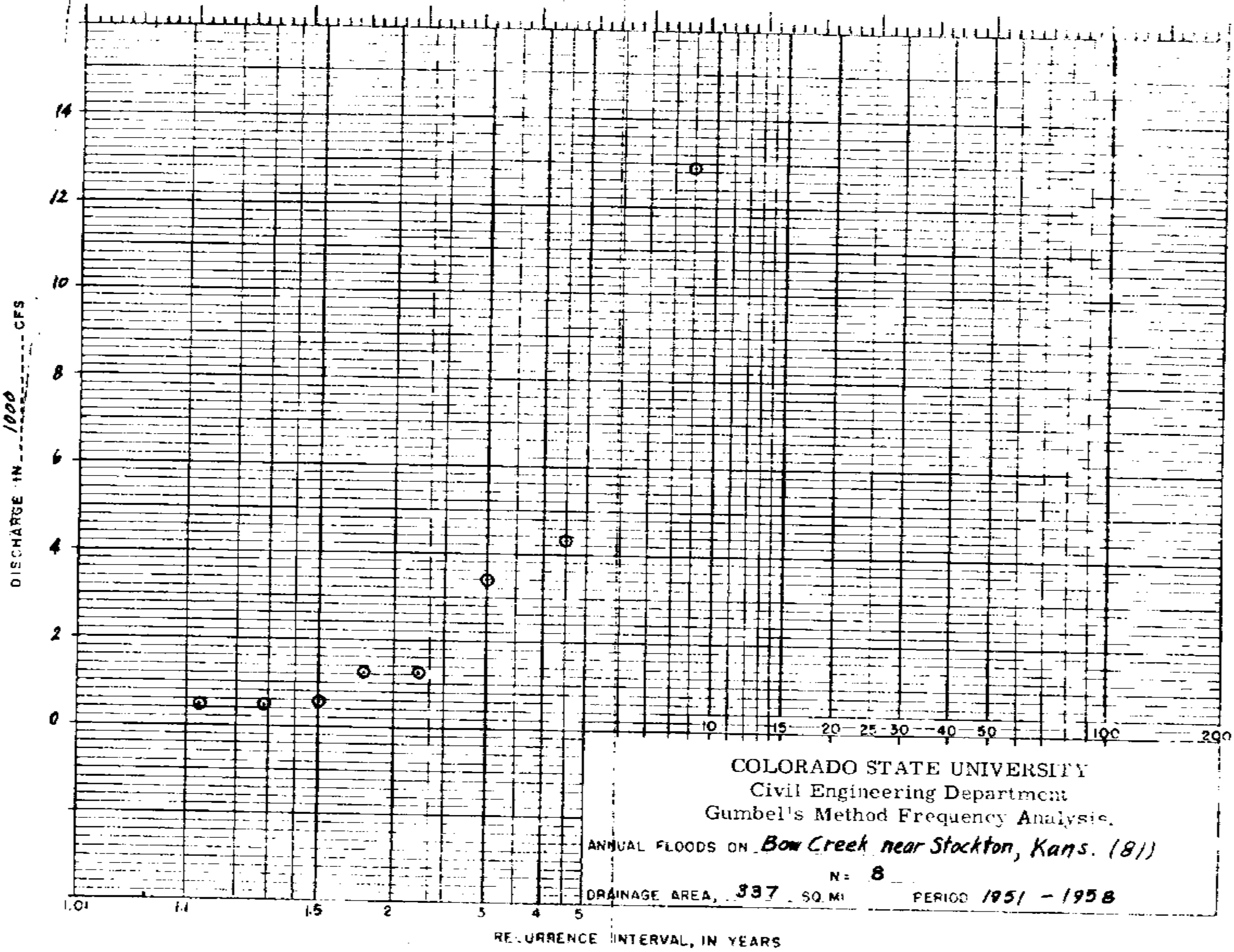
ANNUAL FLOODS ON *Big Creek near Hays, Kans. (80)*
N: *13*
DRAINAGE AREA, *594* SQ. MI   PERIOD *1946 - 1958*



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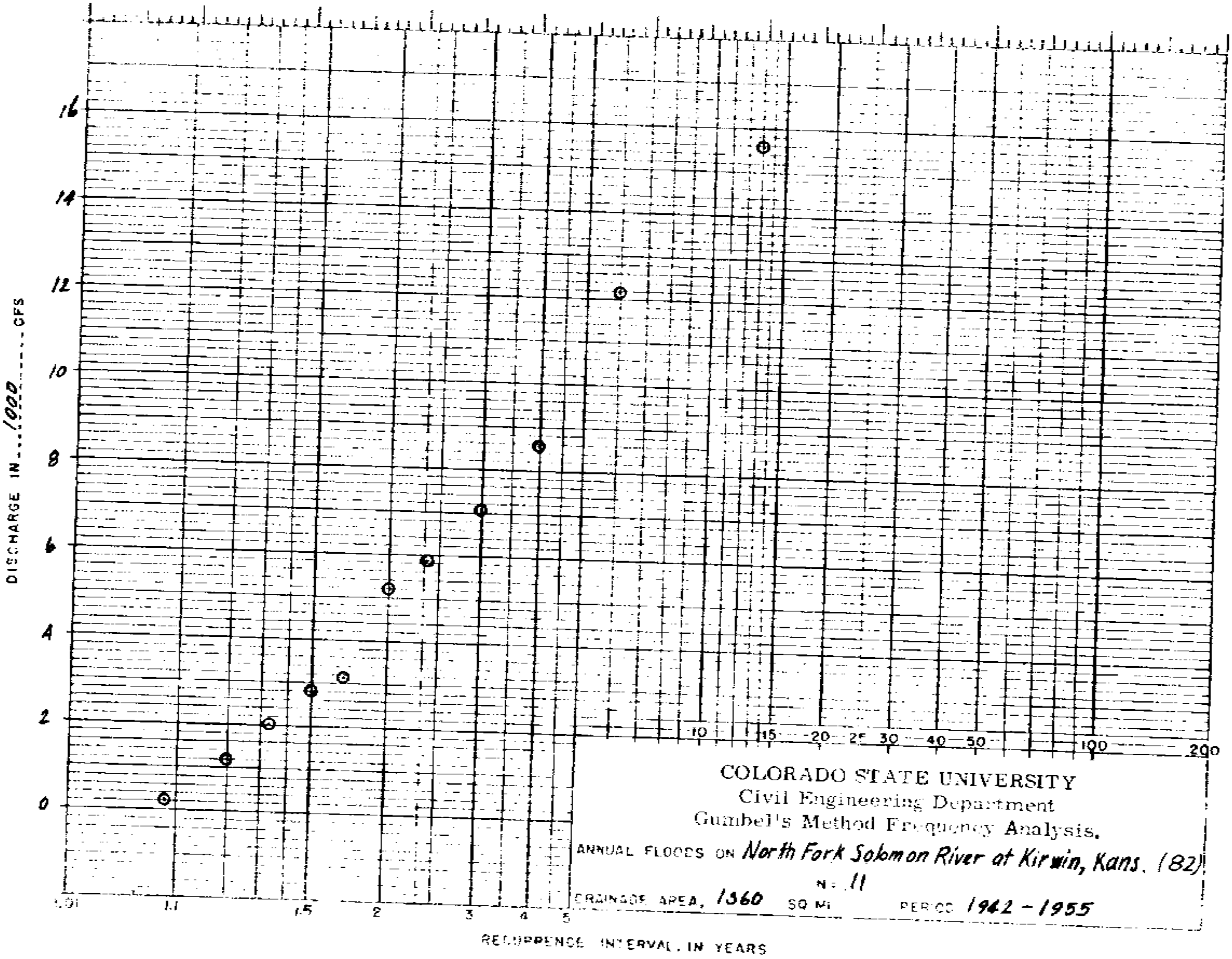
ANNUAL FLOODS ON *Bow Creek near Stockton, Kans. (81)*

N: *8*

DRAINAGE AREA, *337* SQ. MI PERIOD *1951 - 1958*



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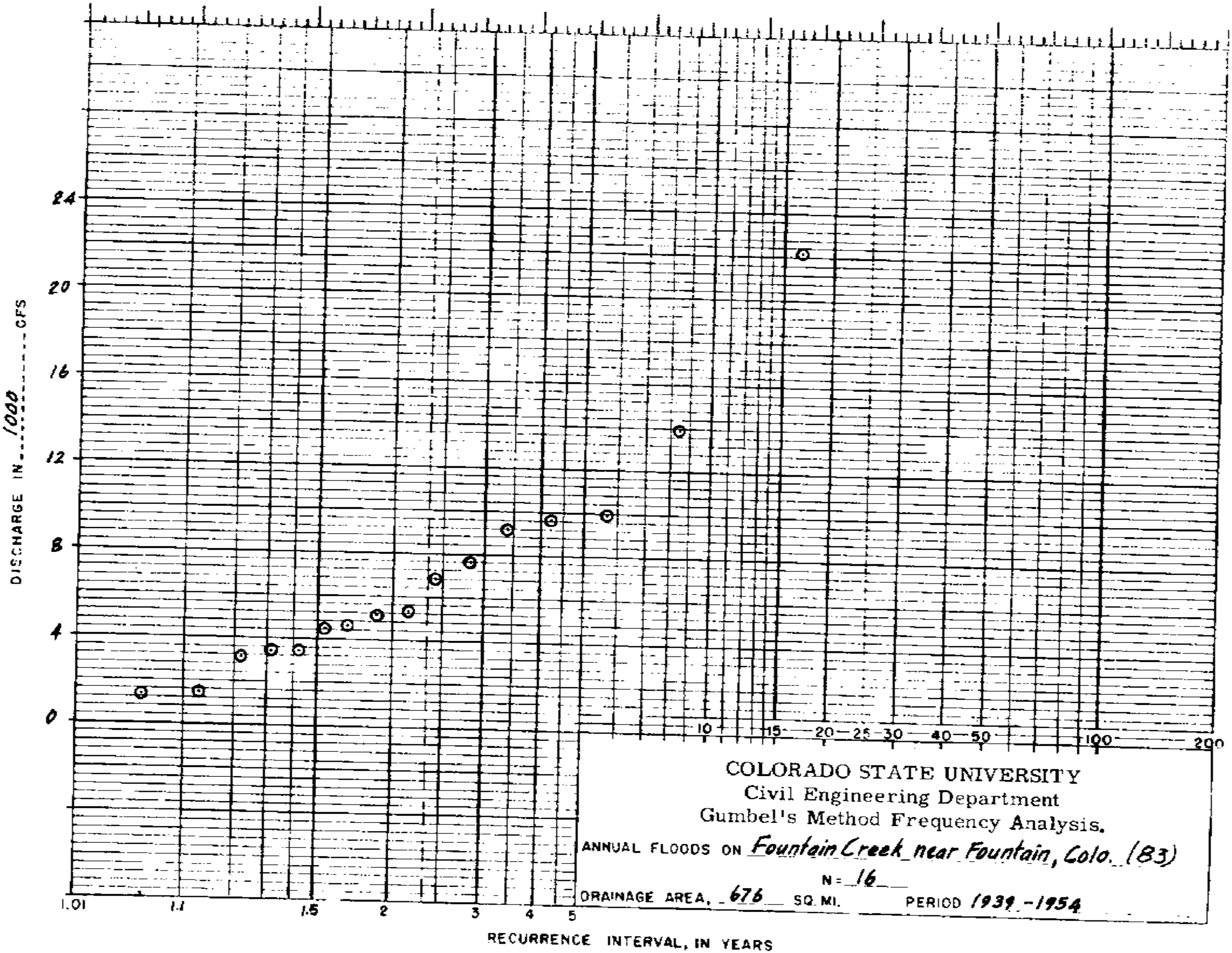
Civil Engineering Department
Gumbel's Method Frequency Analysis.
ANNUAL FLOODS ON *North Fork Solomon River at Kirwin, Kans. (82)*
N = *11*
DRAINAGE AREA, *1360* SQ MI PERIOD *1942 - 1955*



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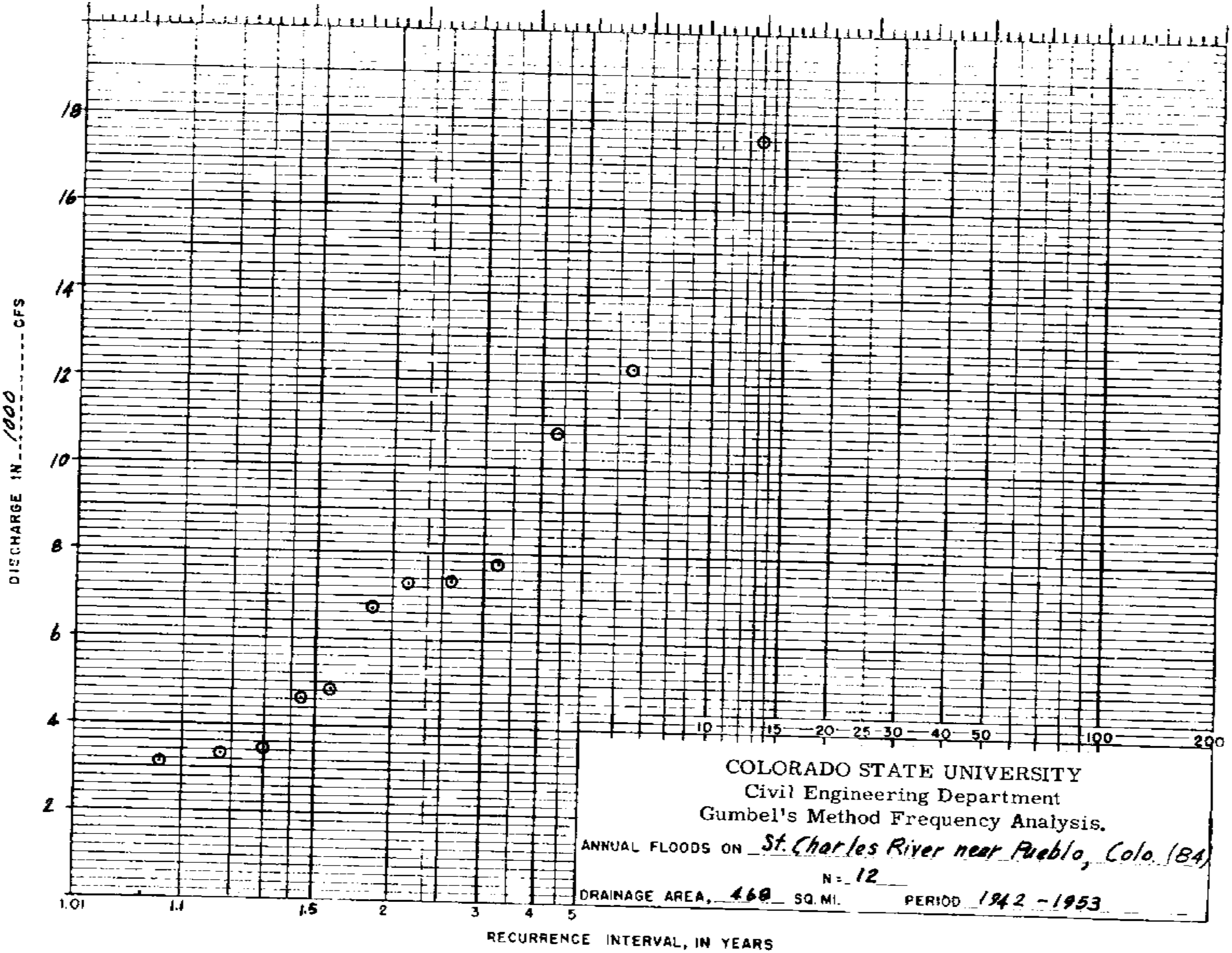
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Fountain Creek near Fountain, Colo. (83)*

N = *16*

DRAINAGE AREA, *676* SQ. MI. PERIOD *1939 -1954*



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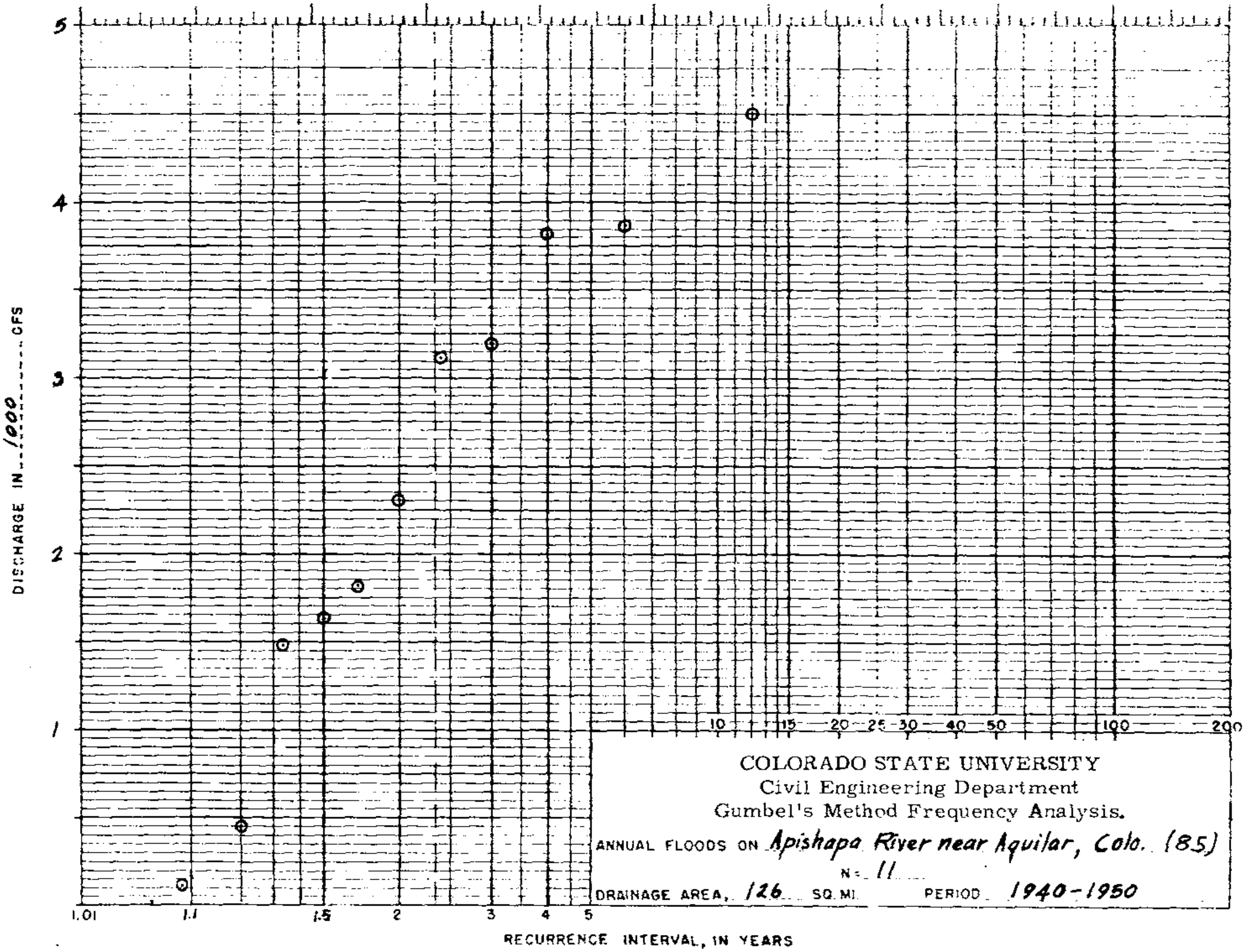
ANNUAL FLOODS ON St. Charles River near Pueblo, Colo. (84)

N = 12

DRAINAGE AREA, 460 SQ. MI. PERIOD 1942 - 1953



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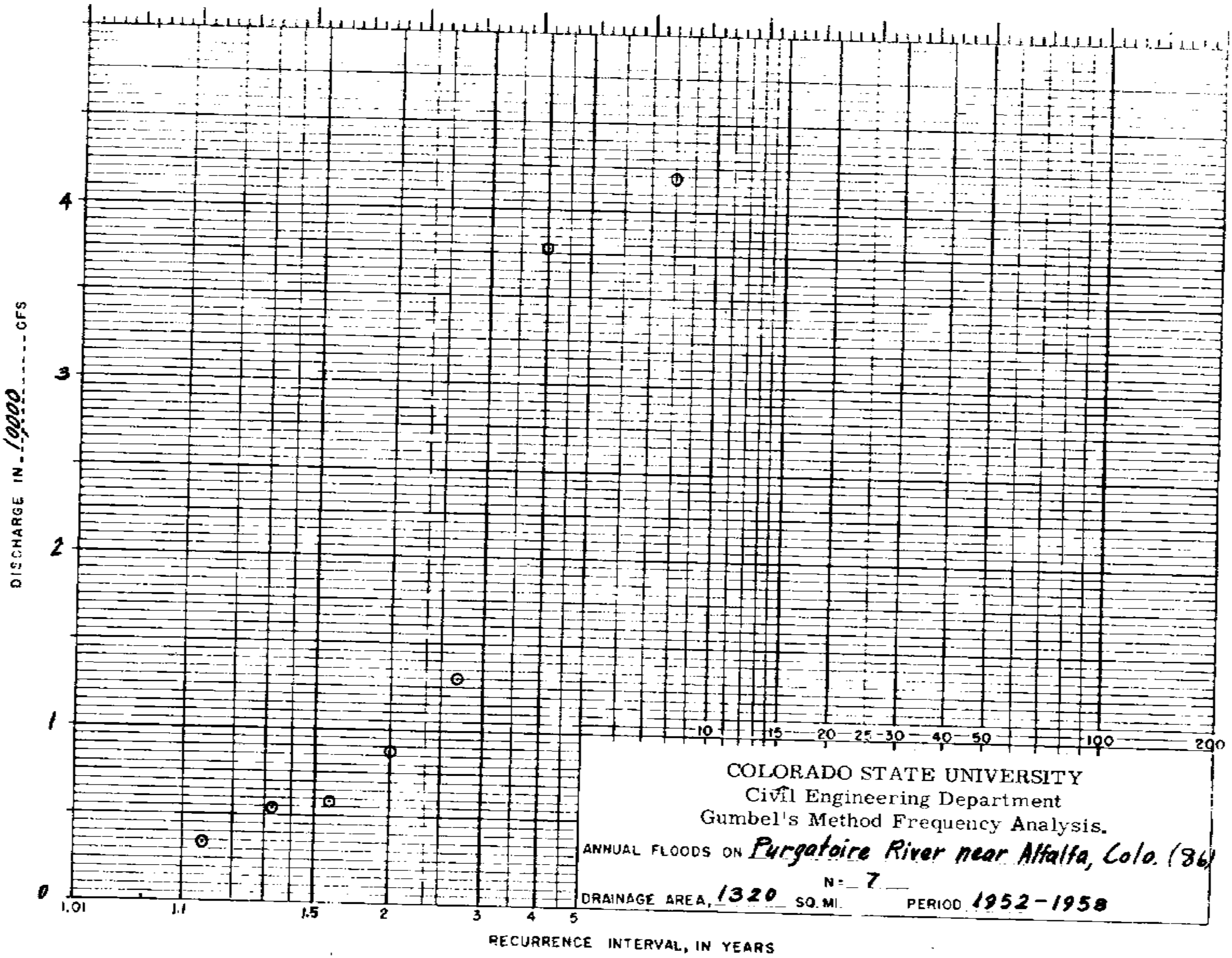
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Apishapa River near Aquilar, Colo. (85)*

N = *11*

DRAINAGE AREA, *126* SQ. MI. PERIOD *1940-1950*



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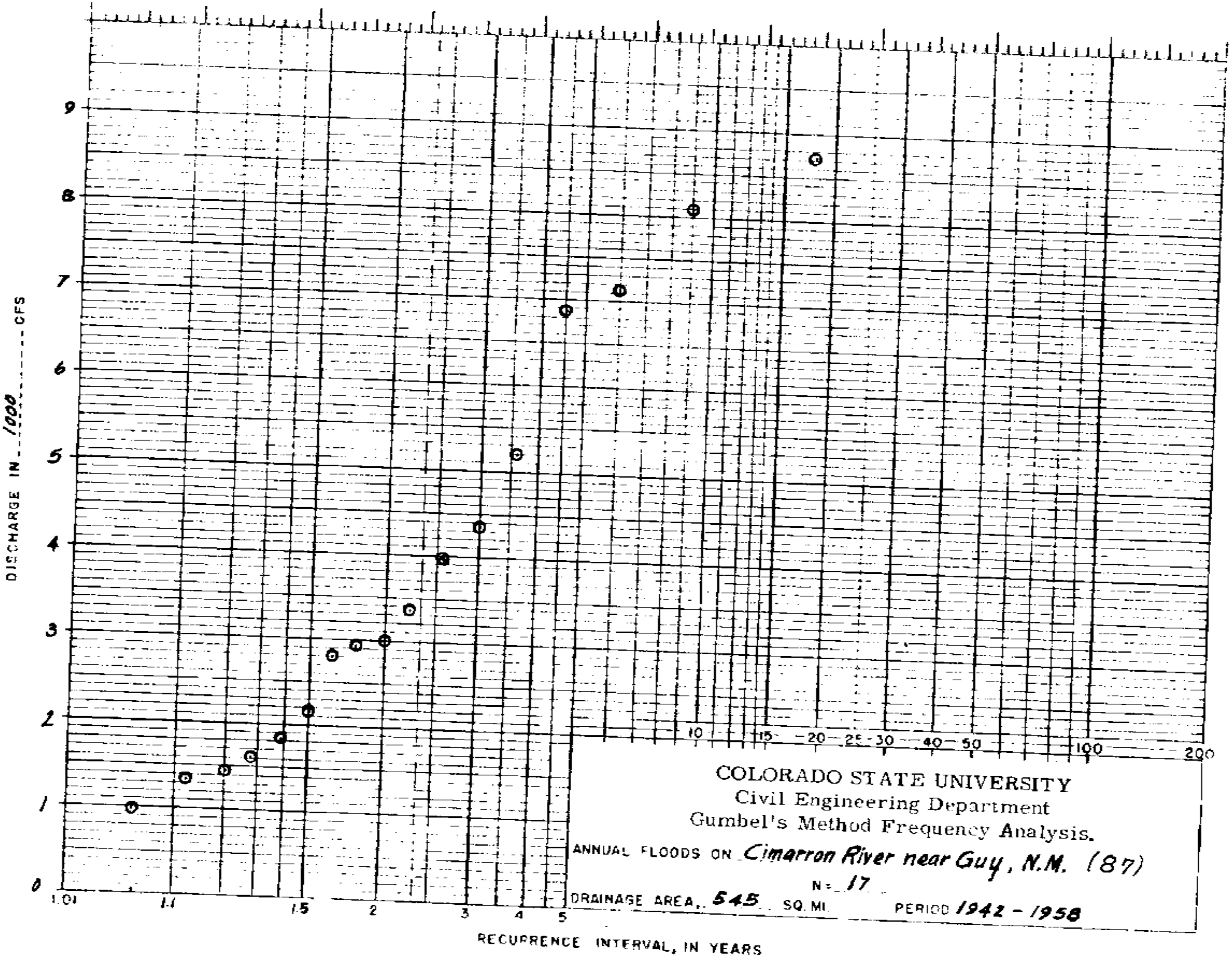
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Purgatoire River near Alfalfa, Colo. (86)

N = 7

DRAINAGE AREA, 1320 SQ. MI. PERIOD 1952-1958



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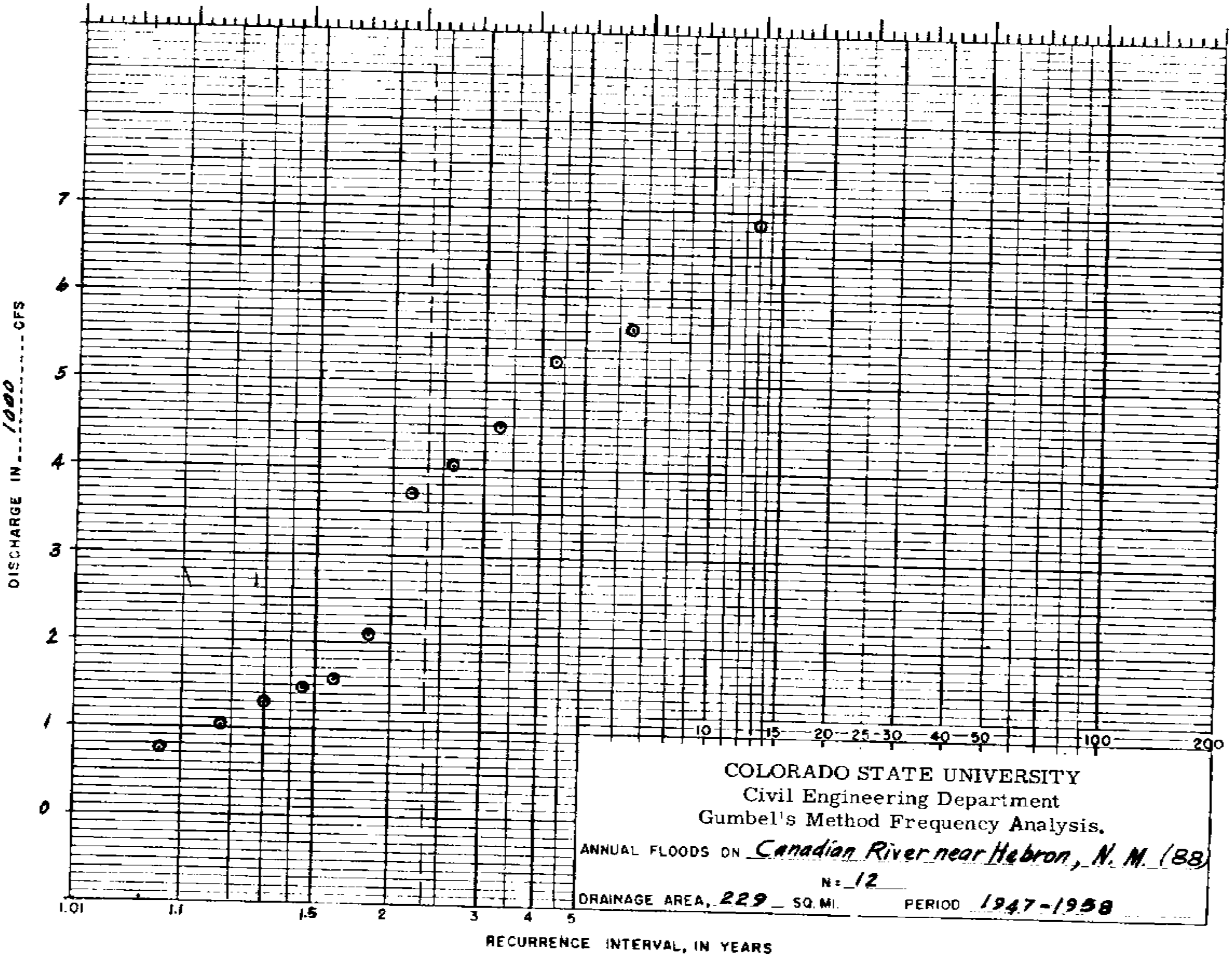
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Cimarron River near Guy, N.M. (87)

N = 17

DRAINAGE AREA, 545 SQ. MI.

PERIOD 1942 - 1958



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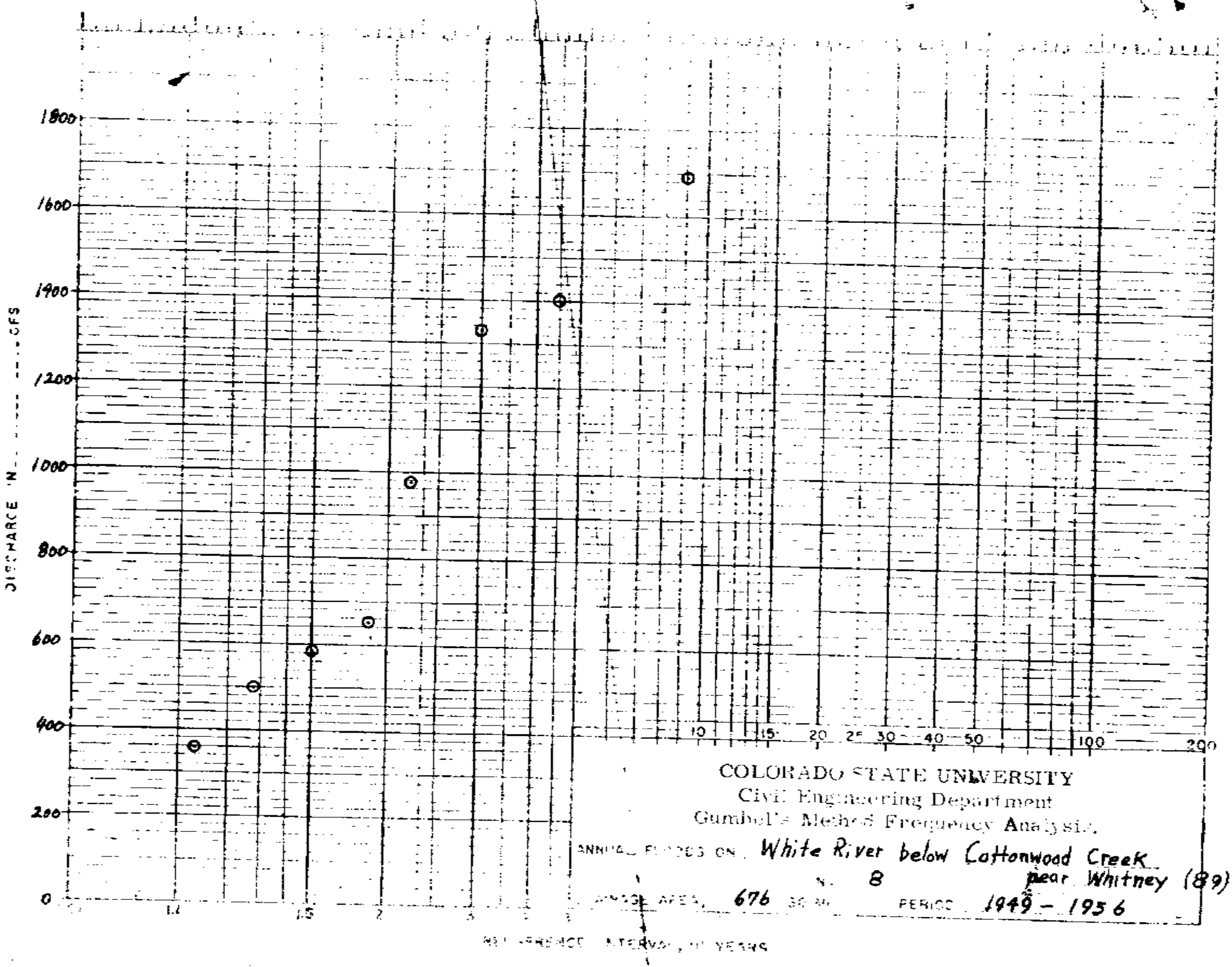
ANNUAL FLOODS ON *Canadian River near Hebron, N. M. (88)*

N = *12*

DRAINAGE AREA, *229* SQ. MI. PERIOD *1947-1958*



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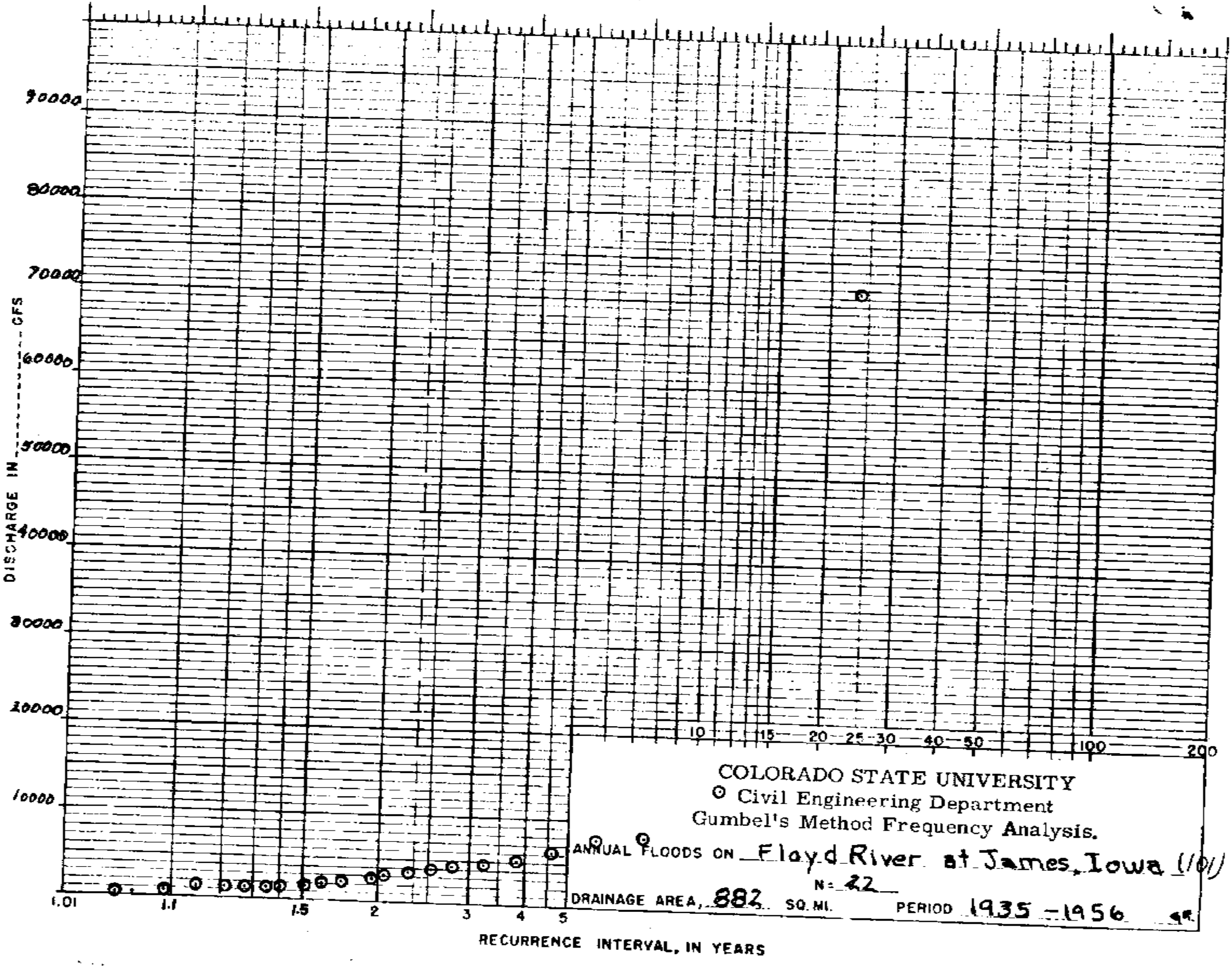
ANNUAL FLOODS ON *White River below Cottonwood Creek near Whitney (89)*
No. *8*
DRAINAGE AREA *676* SQ MI PERIOD *1949 - 1956*



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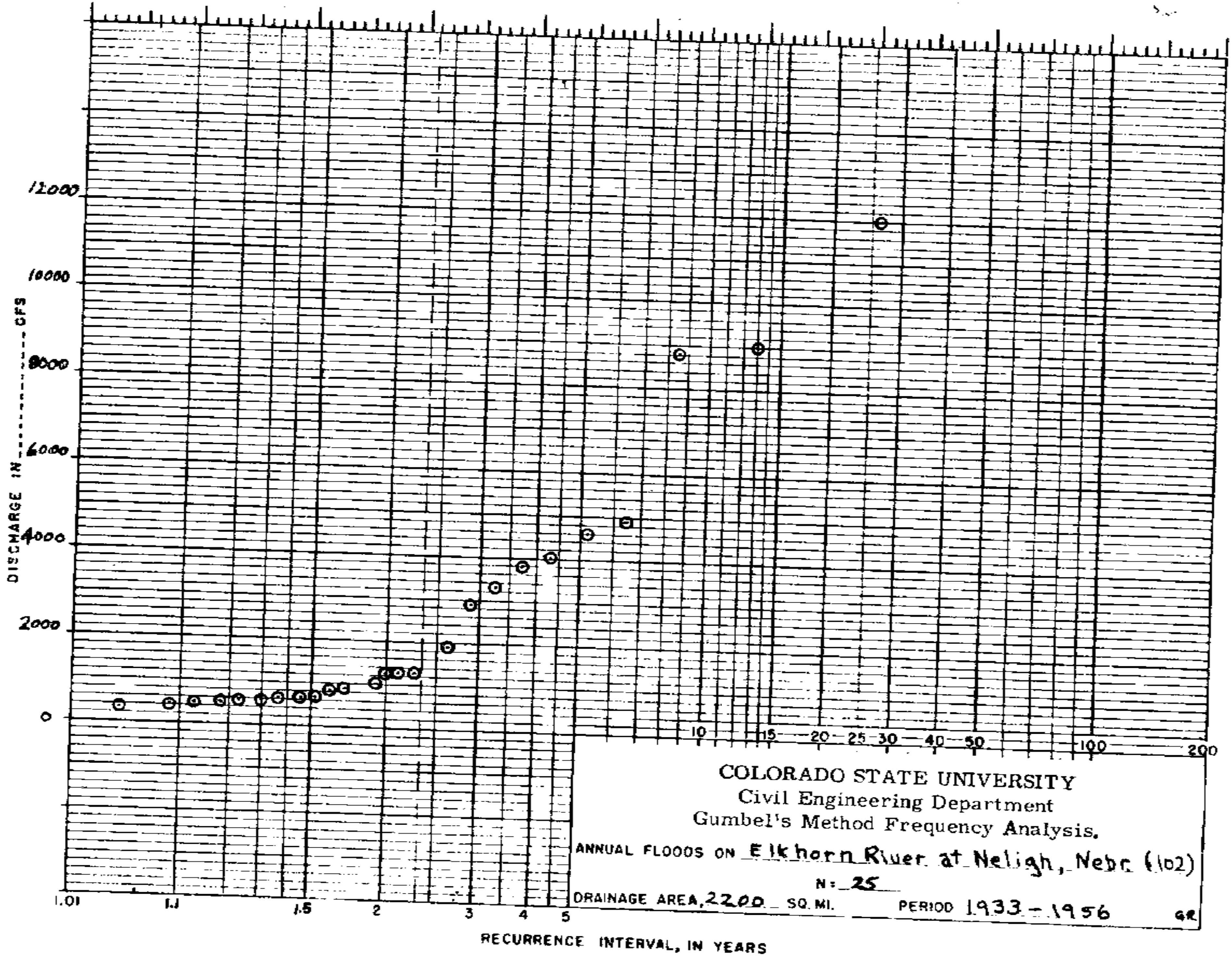
ANNUAL FLOODS ON Floyd River at James, Iowa (101)

N= 22

DRAINAGE AREA, 882 SQ. MI. PERIOD 1935 - 1956 YR.



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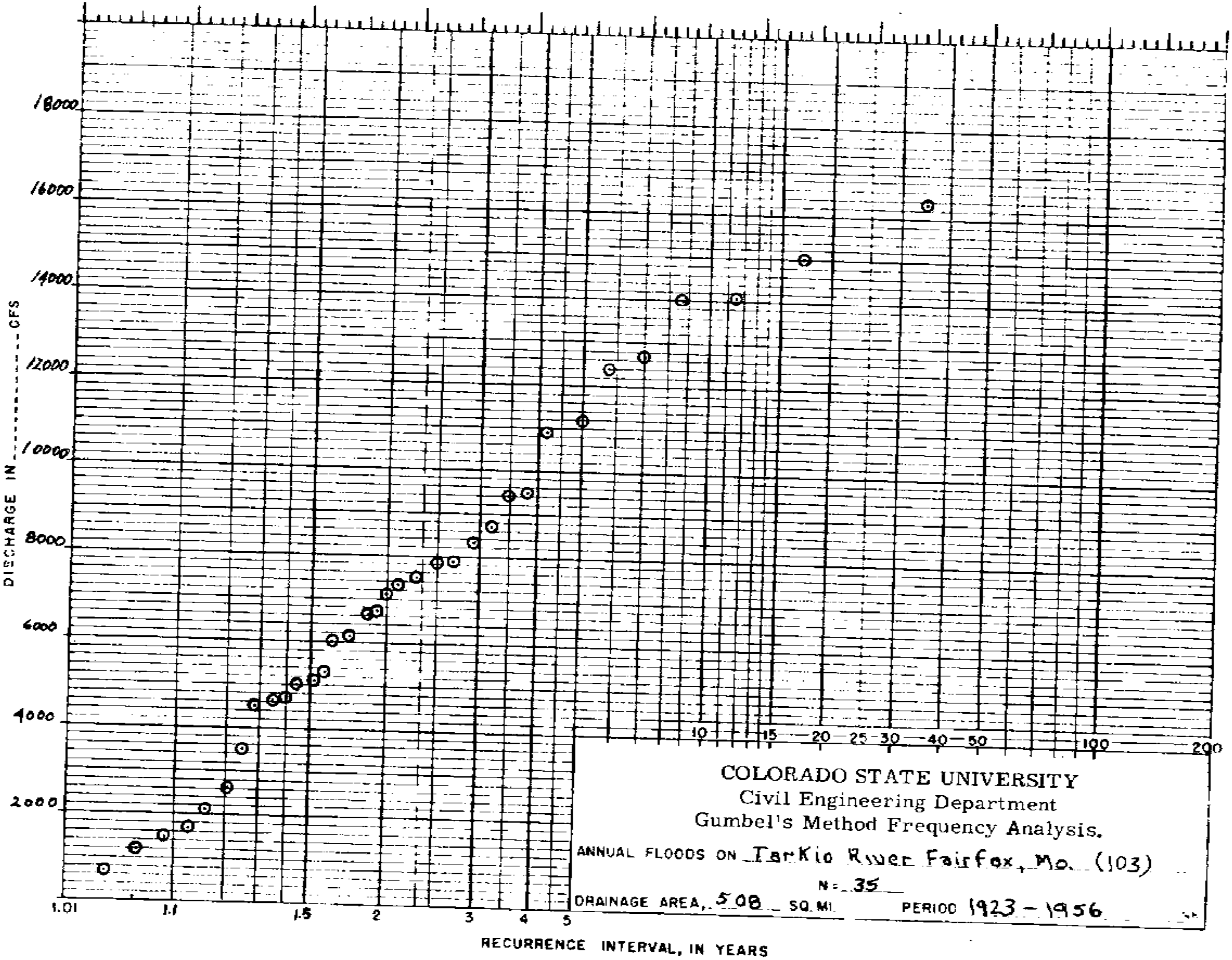
ANNUAL FLOODS ON Elkhorn River at Neligh, Nebr. (102)

N: 25

DRAINAGE AREA, 2200 SQ. MI. PERIOD 1933 - 1956 GR



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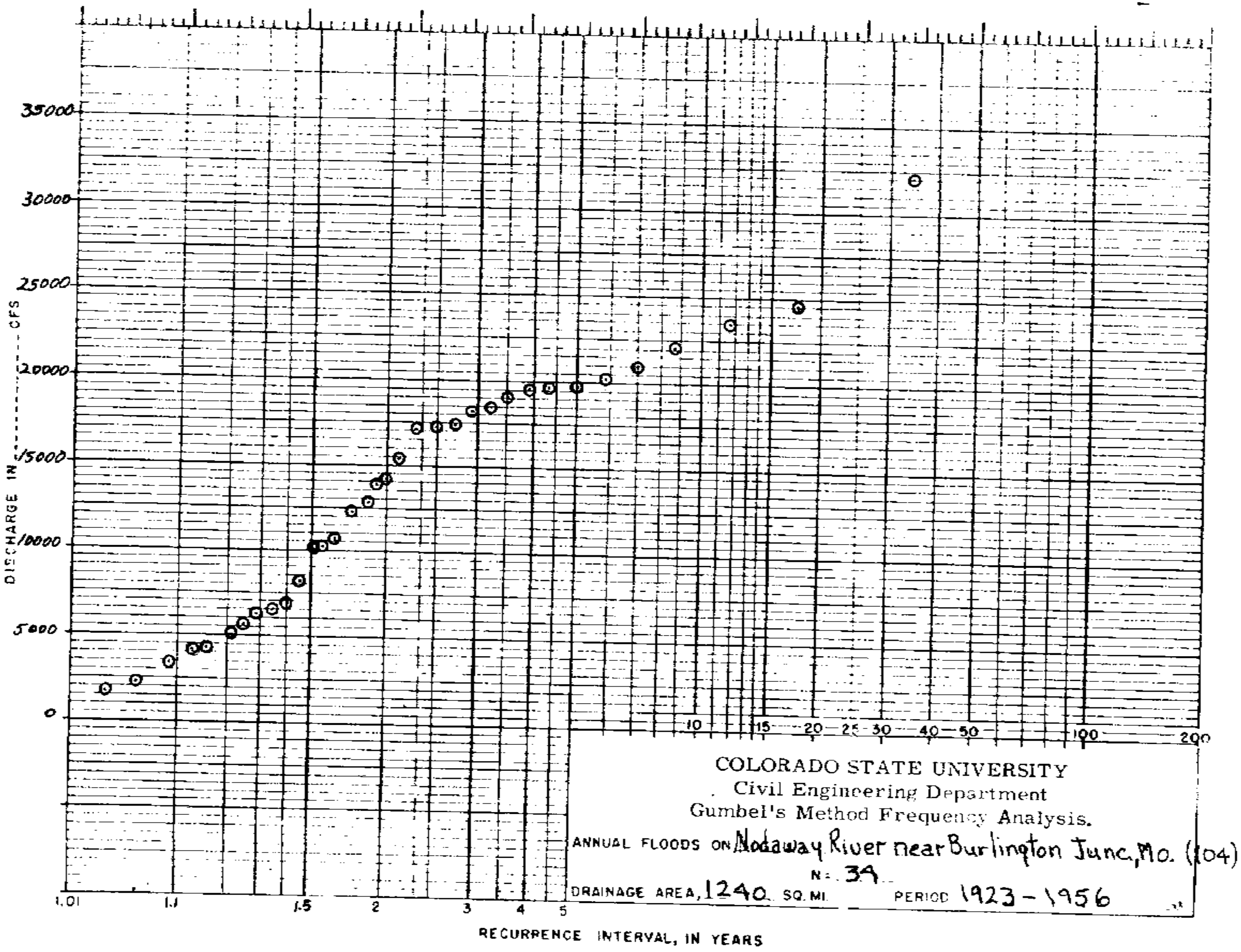
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Tarkio River Fairfax, Mo. (103)

N= 35

DRAINAGE AREA, 508 SQ. MI. PERIOD 1923 - 1956



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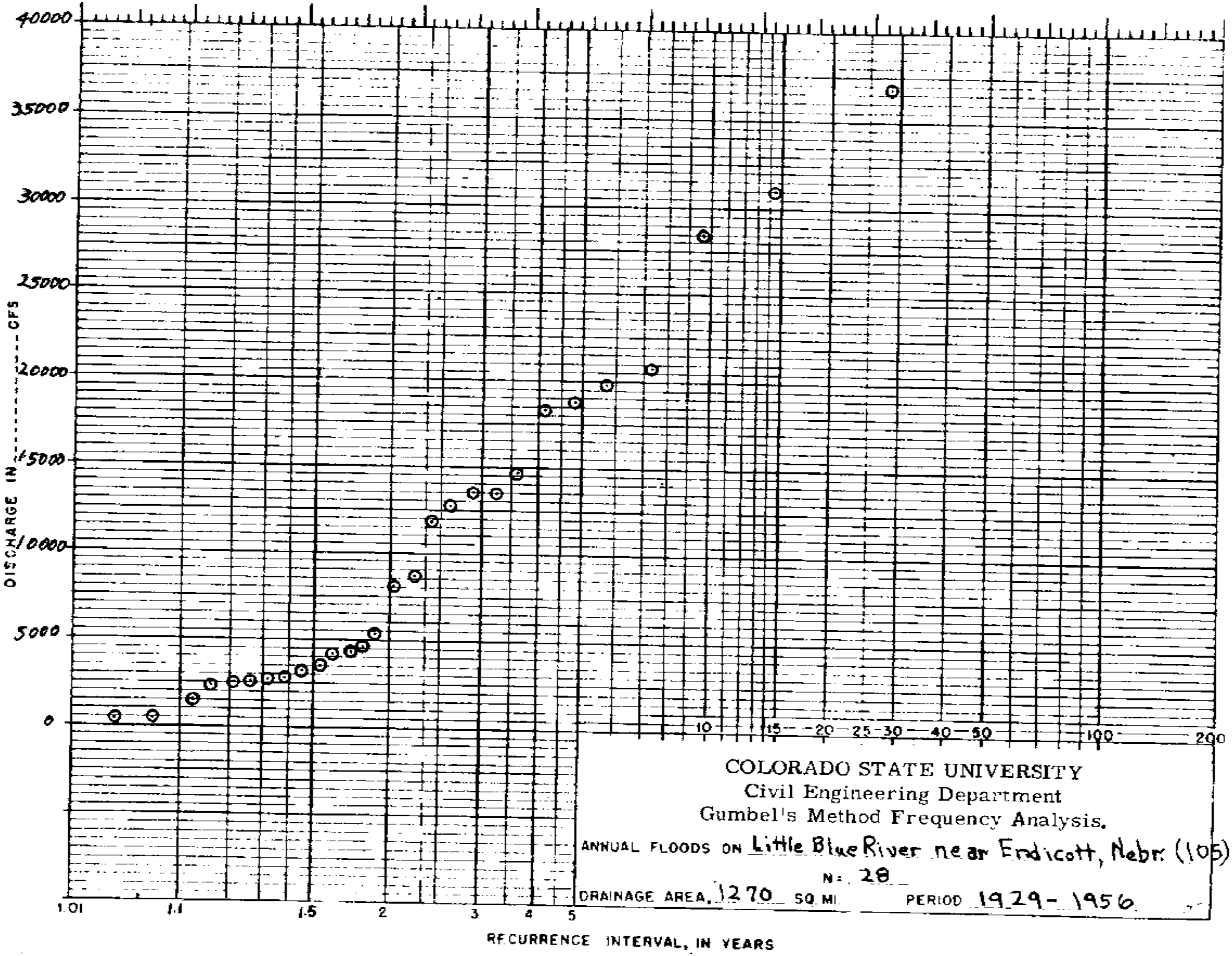
ANNUAL FLOODS ON Nodaway River near Burlington Junc, Mo. (104)

N = 34

DRAINAGE AREA, 1240 SQ. MI. PERIOD 1923 - 1956



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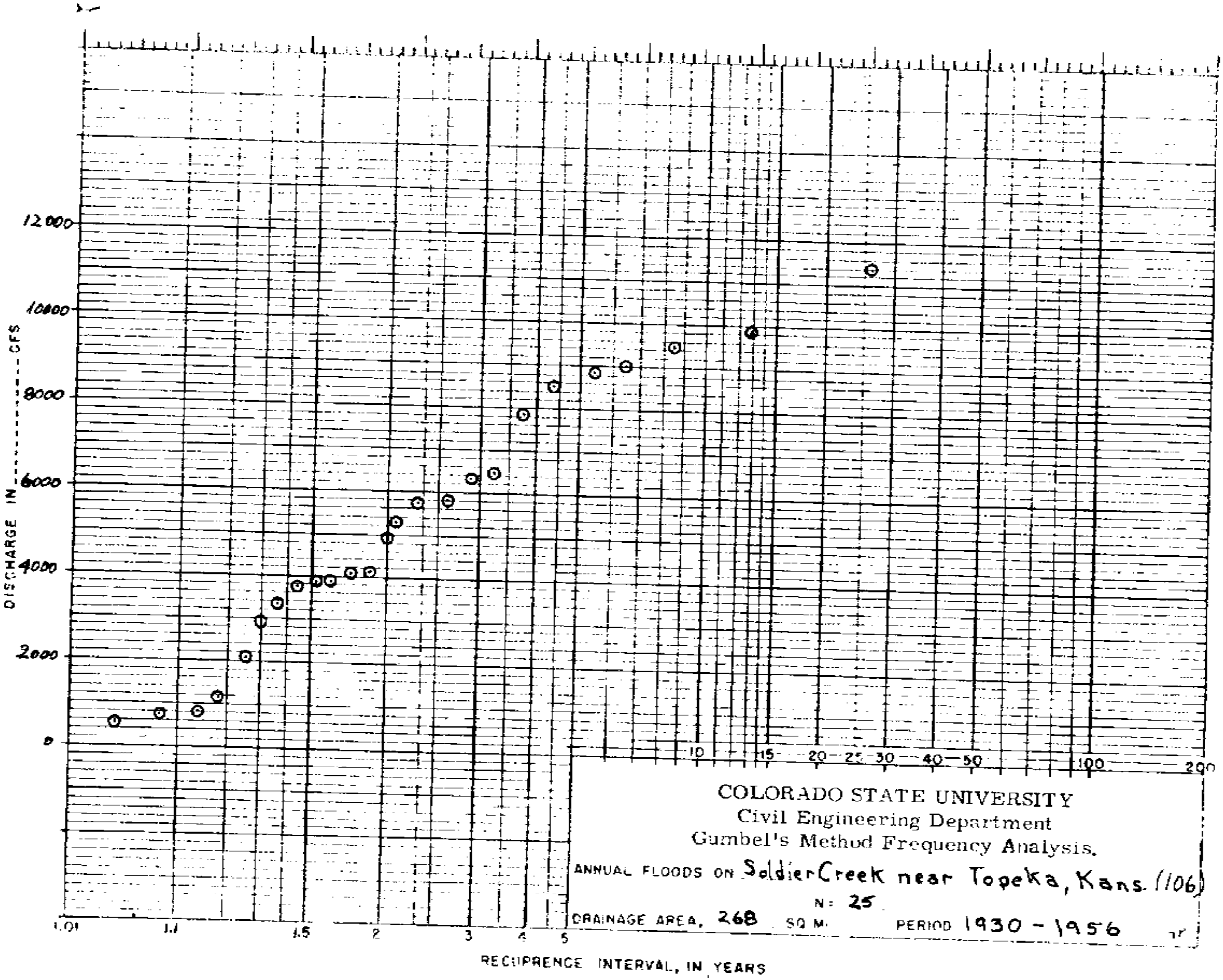
ANNUAL FLOODS ON Little Blue River near Endicott, Nebr. (105)
N = 28
DRAINAGE AREA, 1270 SQ. MI. PERIOD 1929 - 1956



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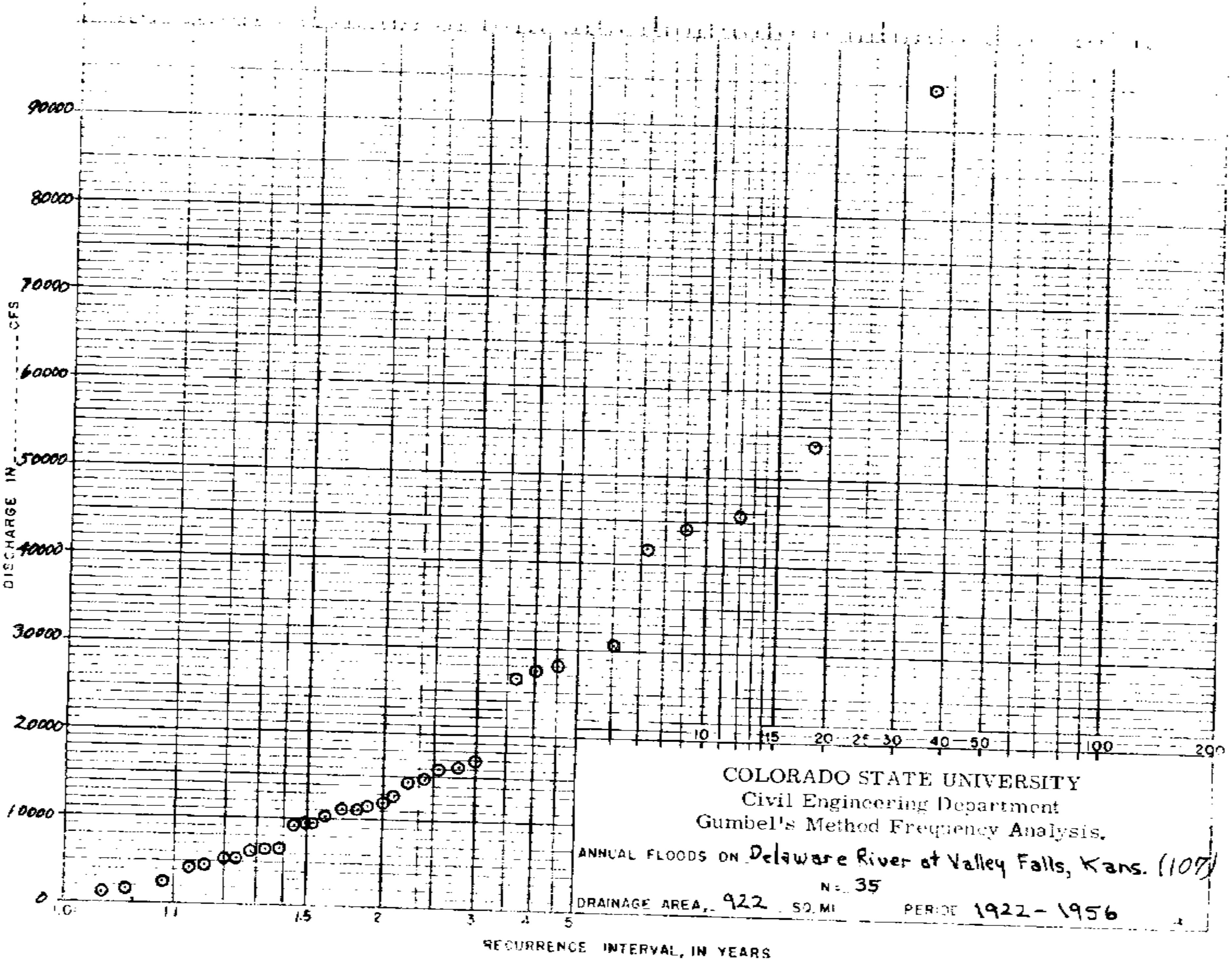
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Soldier Creek near Topeka, Kans. (106)
N: 25
DRAINAGE AREA, 268 SQ. MI. PERIOD 1930 - 1956



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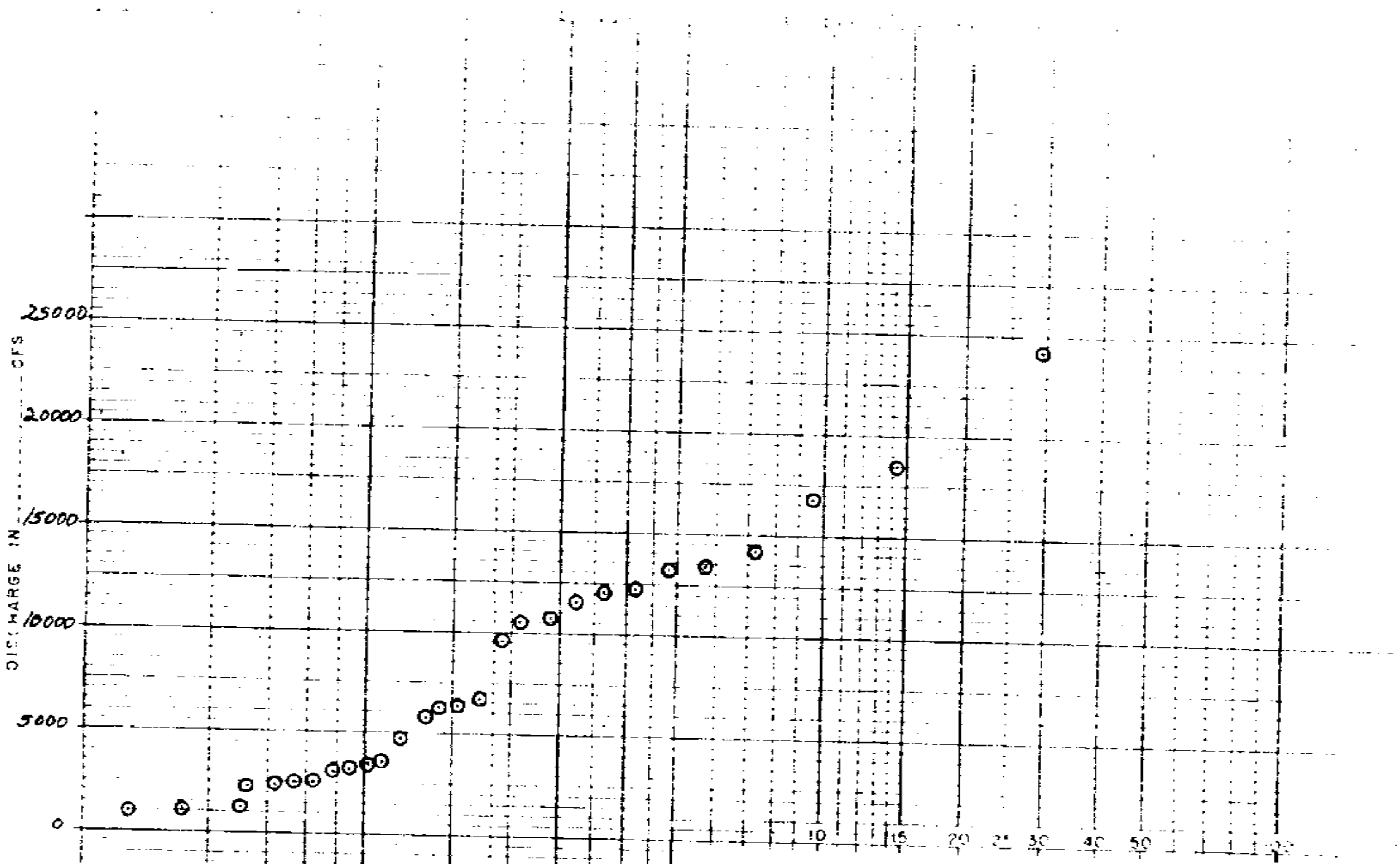
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Delaware River at Valley Falls, Kans. (107)

N = 35

DRAINAGE AREA, 922 SQ. MI PERIOD 1922 - 1956



COLORADO STATE UNIVERSITY

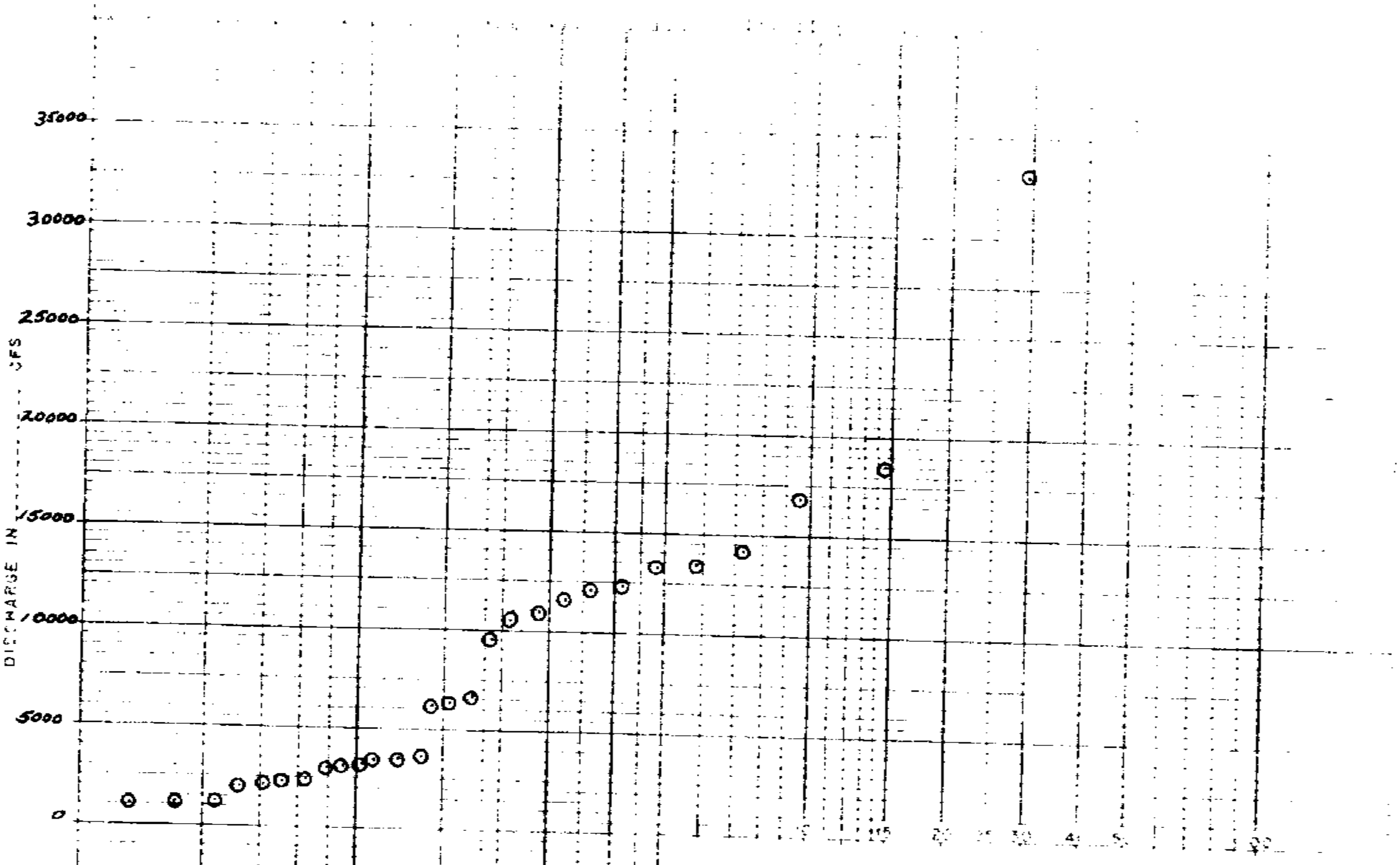
Civil Engineering [illegible]

Gumbel's Method [illegible]

ANNUAL FLOODS ON Wakarusa River near Lawrence, Kans [illegible]

n 28

DRAINAGE AREA 458 [illegible] 1929-1956 GR



COLOR[illegible] UNIVERSITY

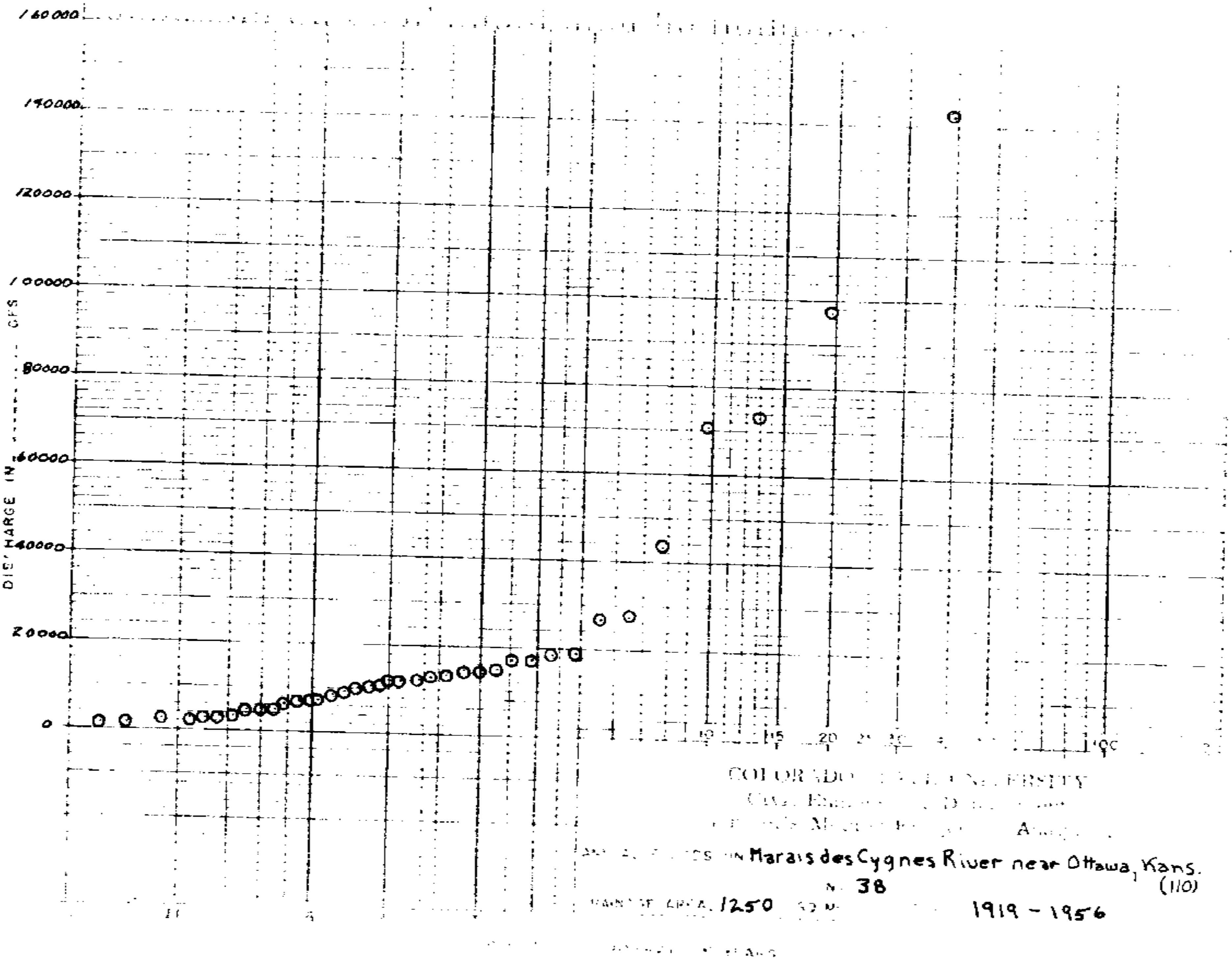
C[illegible]

[illegible] A

[illegible] Stranger Creek near Tonganoxia, Kans

28 (709)

[illegible] 406 [illegible] 1929-1956



COLORADO [illegible] UNIVERSITY

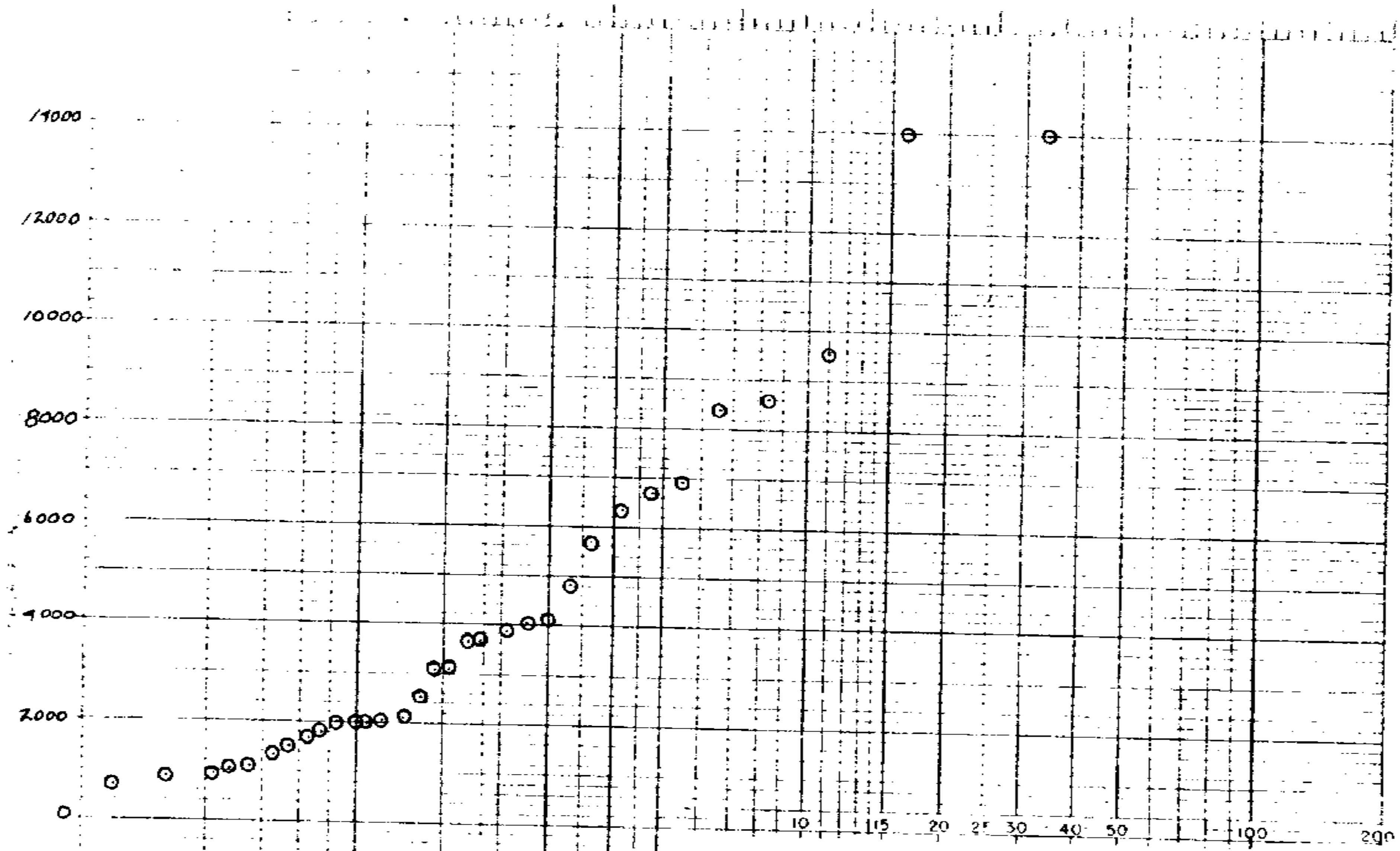
CIVIL ENGINEERING [illegible]

[illegible] A[illegible]

ANNUAL FLOODS ON Marais des Cygnes River near Ottawa, Kans.

No. 38 (110)

DRAINAGE AREA 1250 SQ MI. 1919 - 1956



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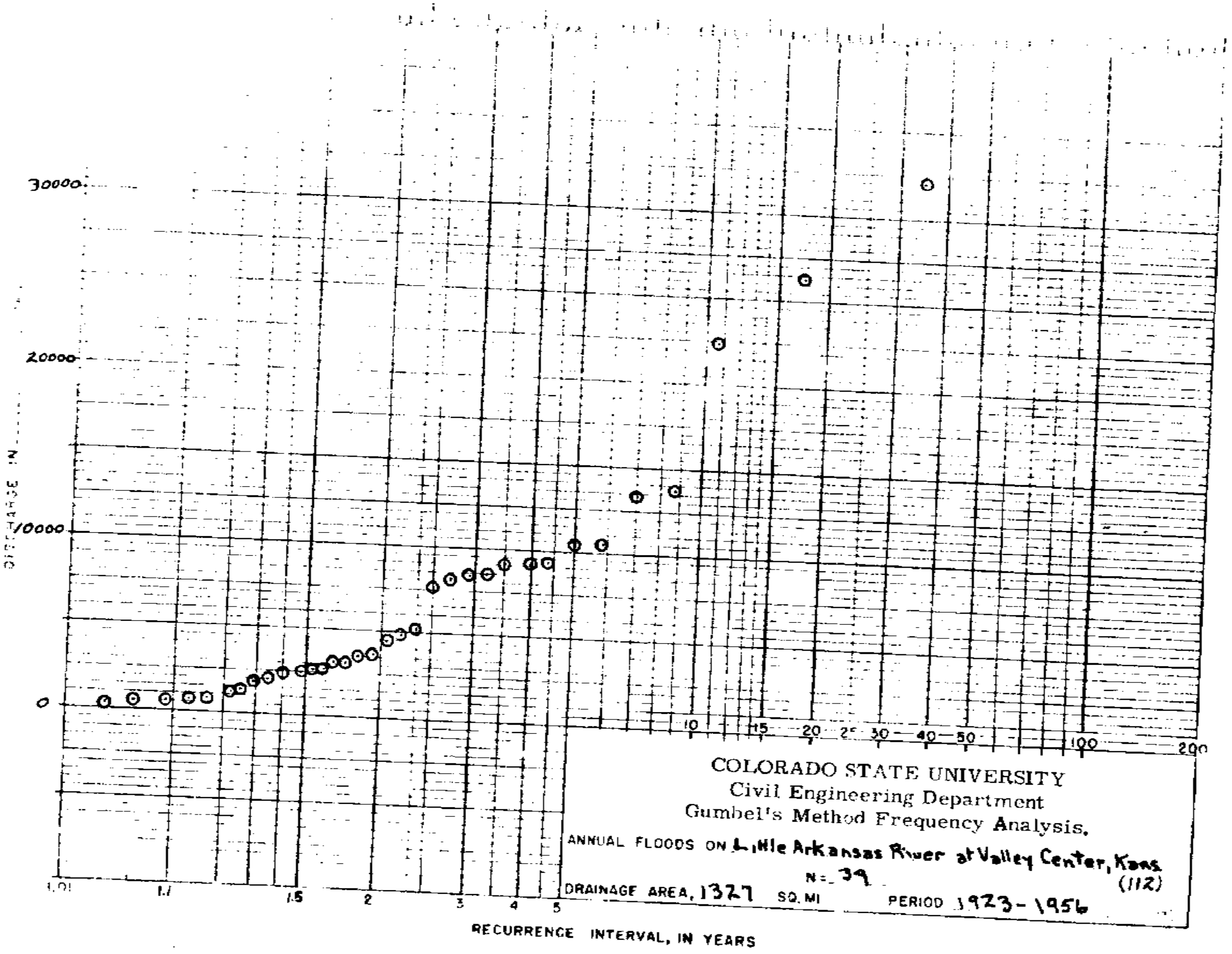
Gumbel's Method Frequency Analysis,

ANNUAL FLOODS ON Pawnee River near Larned, Kans.

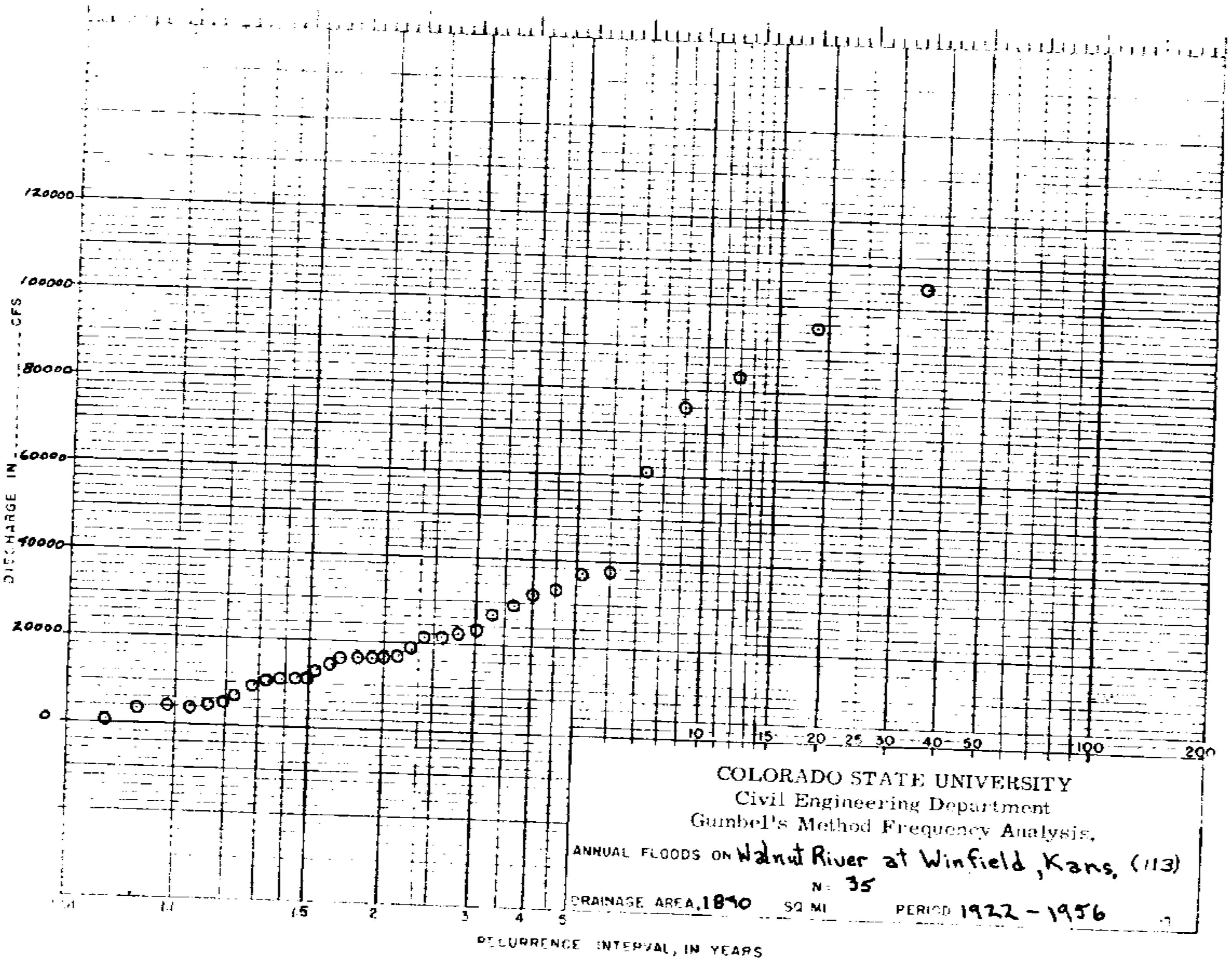
No. 32 (III)

DRAINAGE AREA 2148 SQ. MI. PERIOD 1925 - 1956



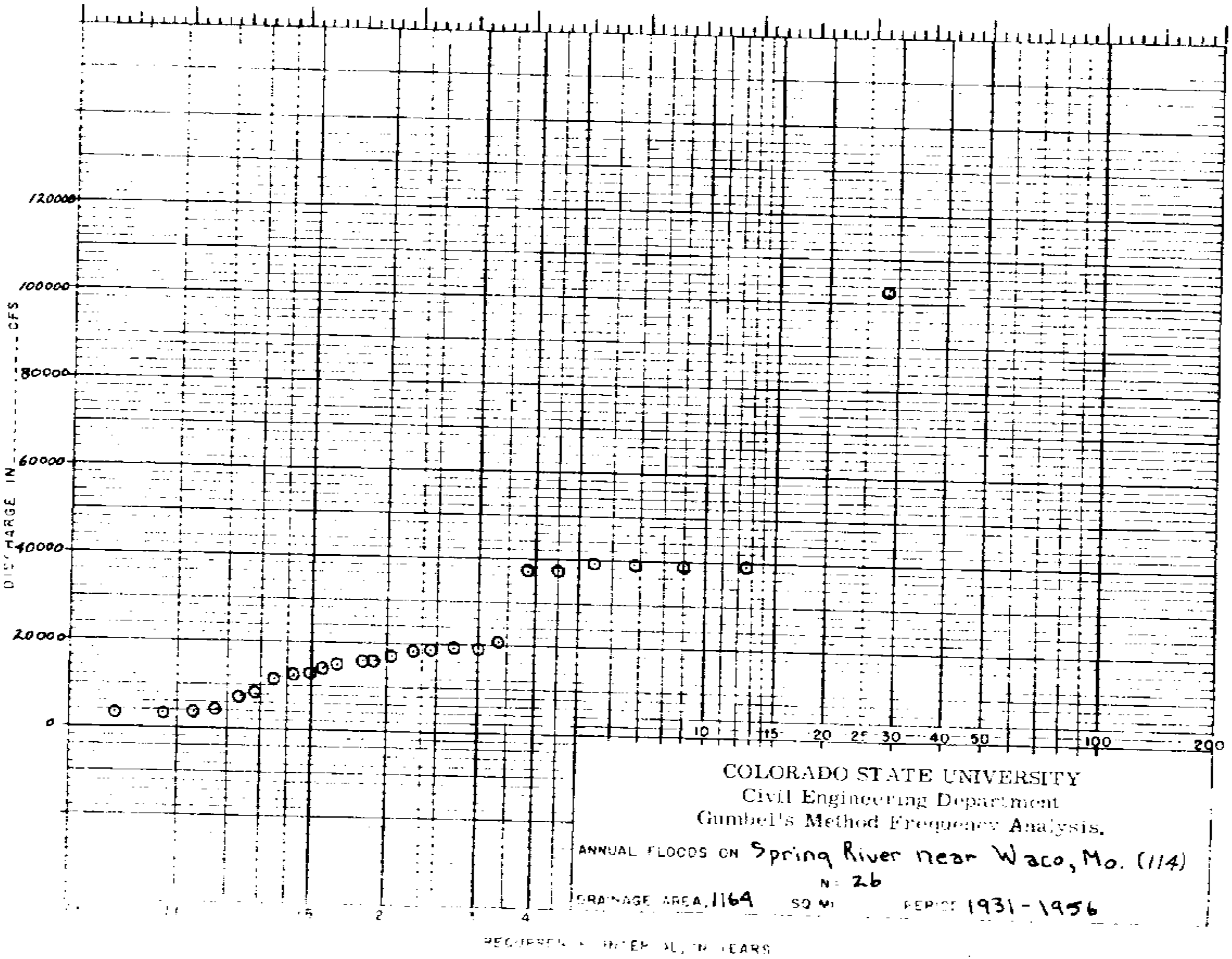
COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Little Arkansas River at Valley Center, Kans.
N = 39
(112)
DRAINAGE AREA, 1327 SQ. MI PERIOD 1923-1956



COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis,

ANNUAL FLOODS ON Walnut River at Winfield, Kans, (113)
N: 35
DRAINAGE AREA 1890 SQ MI PERIOD 1922 - 1956

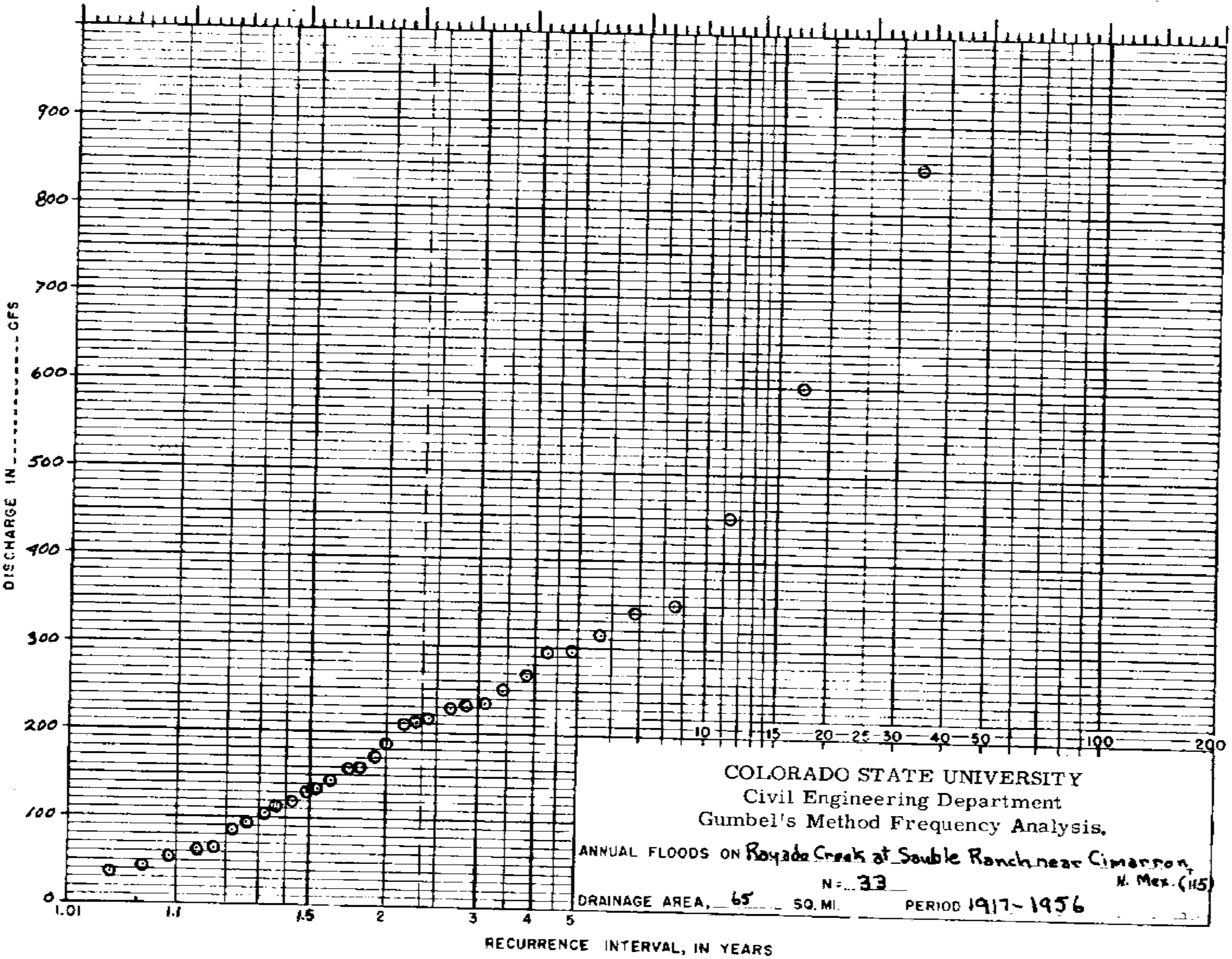


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Spring River near Waco, Mo. (114)

N = 26

DRAINAGE AREA 1164 SQ MI PERIOD 1931-1956

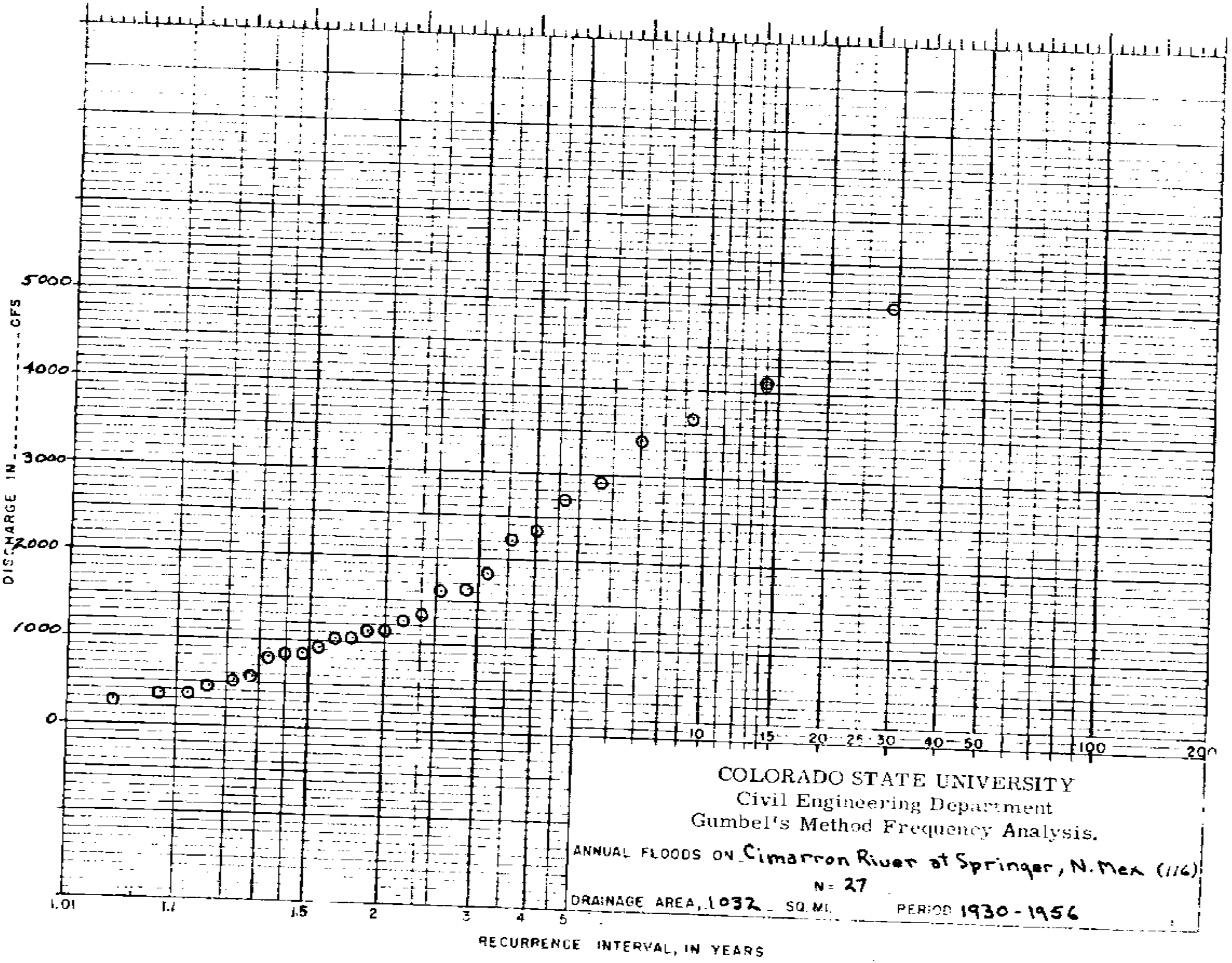


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Royado Creek at Souble Ranch near Cimarron, N. Mex. (115)

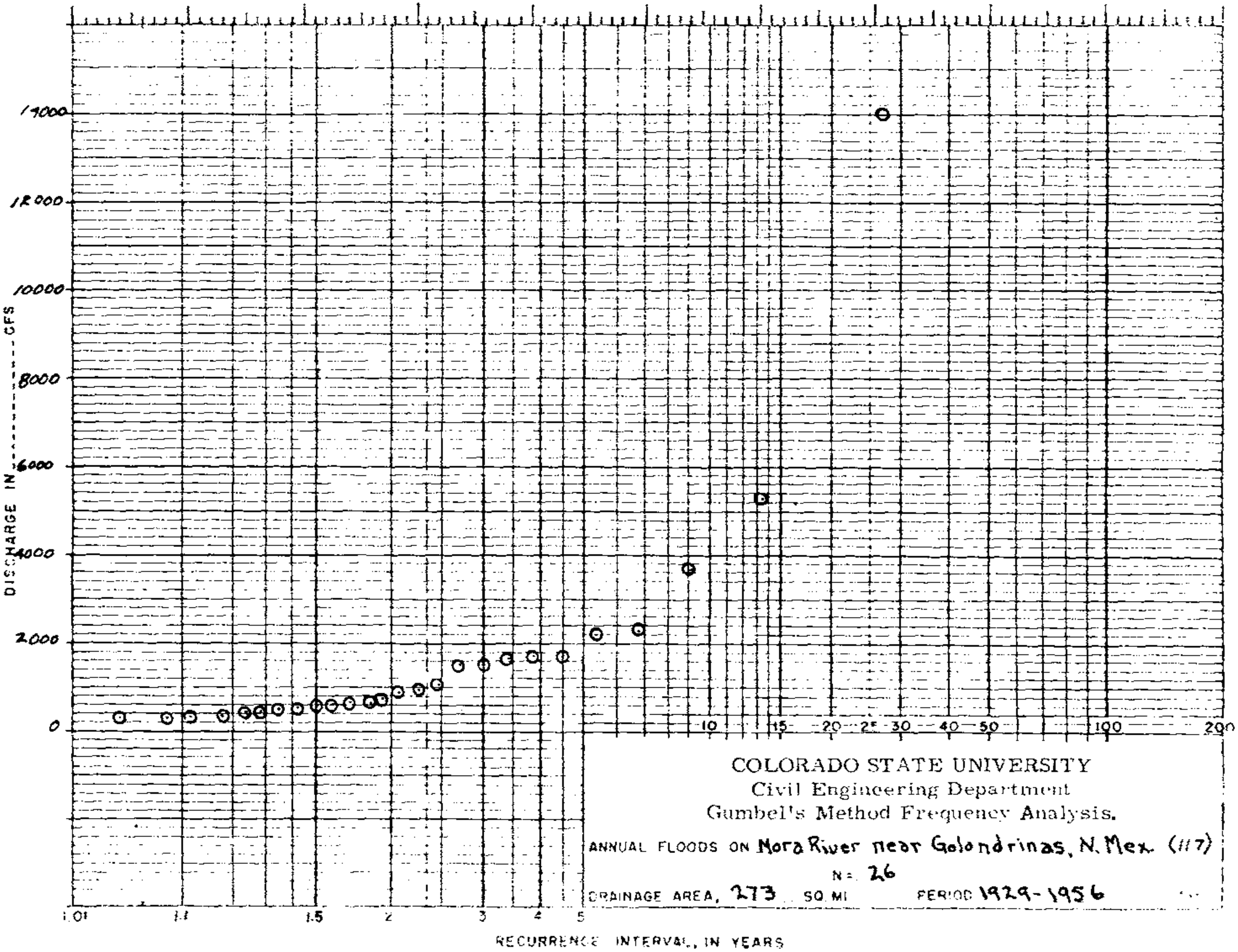
N = 33

DRAINAGE AREA, 65 SQ. MI. PERIOD 1917-1956



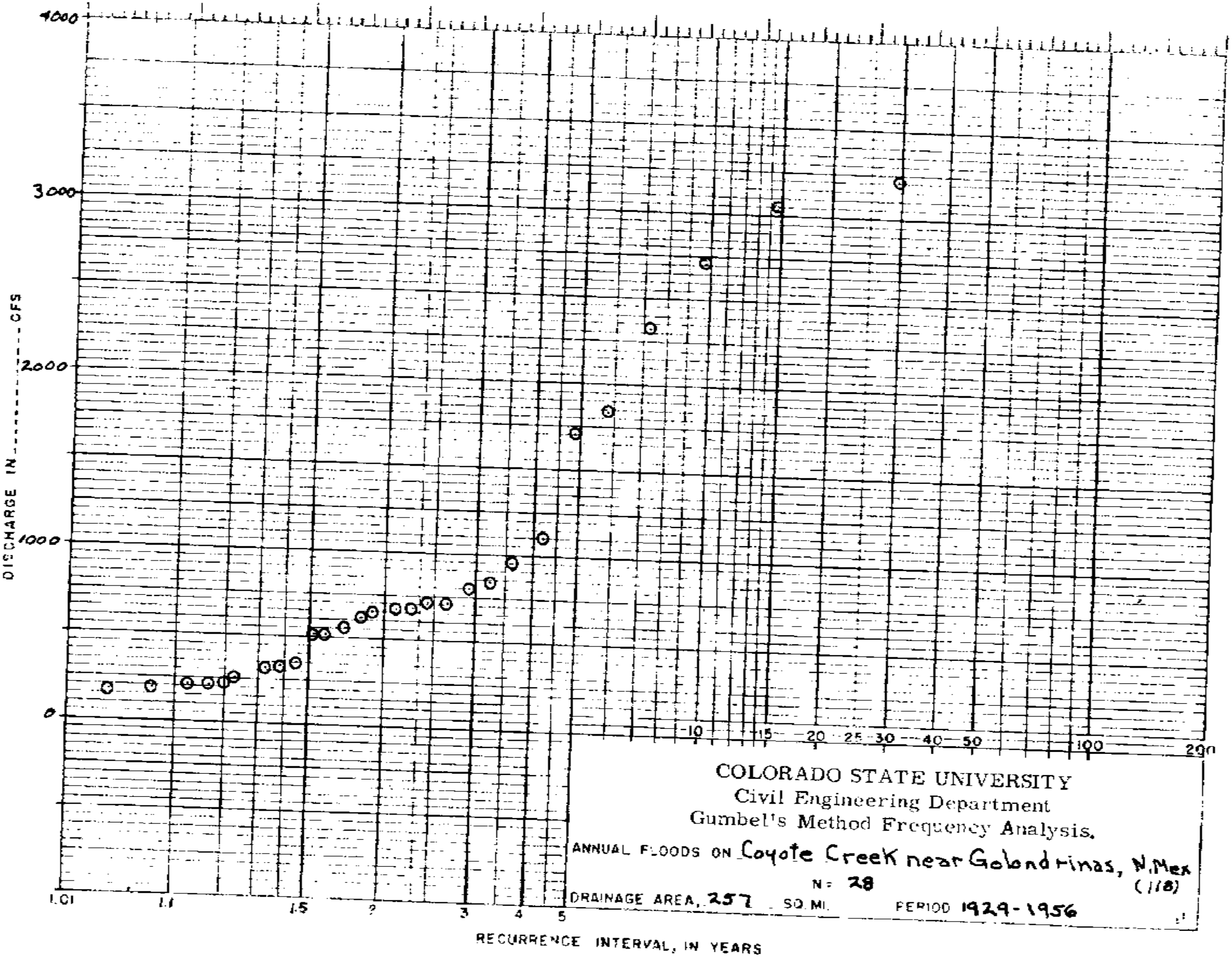
COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Cimarron River at Springer, N. Mex (116)
N = 27
DRAINAGE AREA, 1032 SQ. MI. PERIOD 1930 - 1956



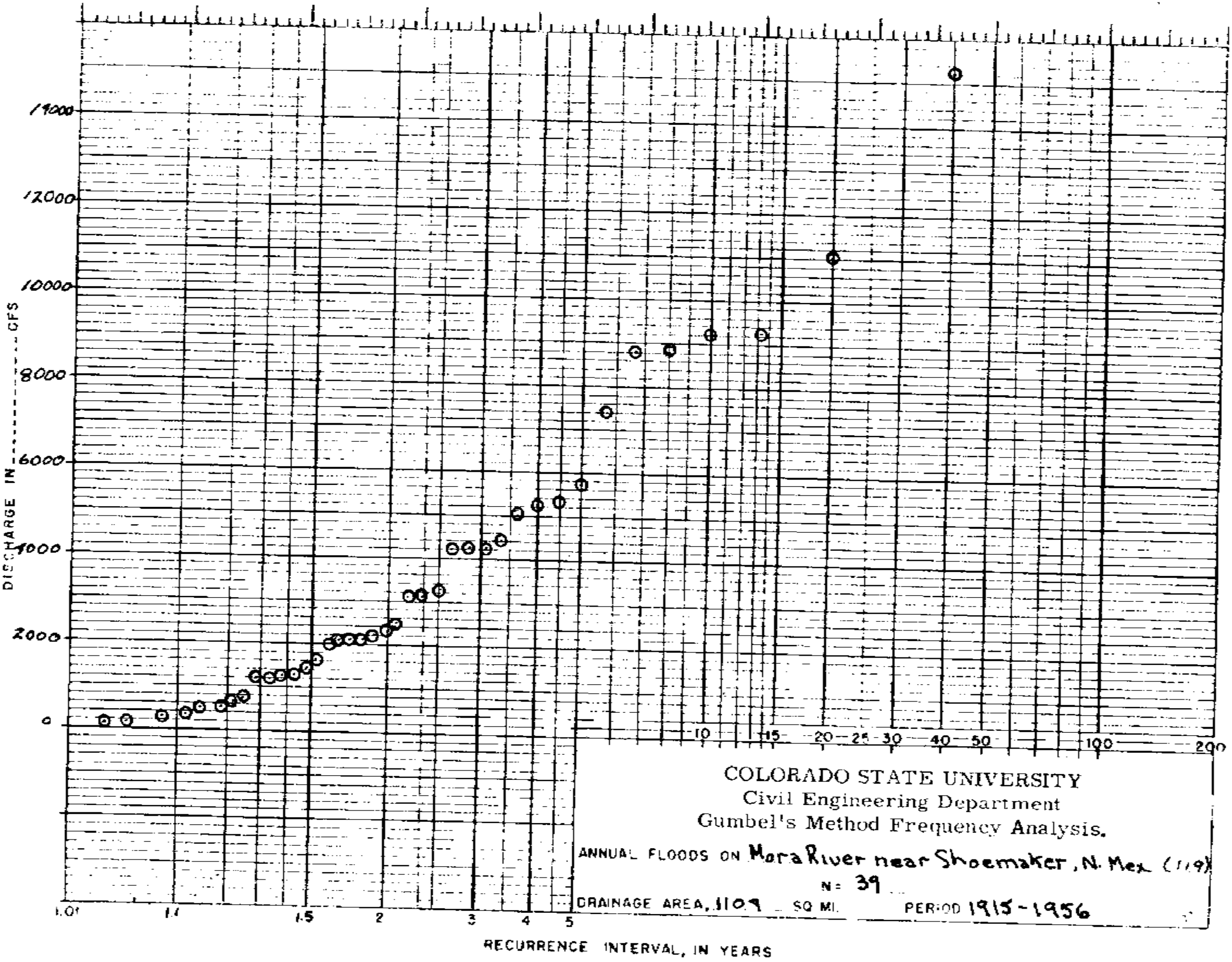
COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Mora River near Golondrinas, N. Mex. (117)
N = 26
DRAINAGE AREA, 273 SQ. MI. PERIOD 1929-1956



COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Coyote Creek near Golondrinas, N.Mex
(118)
N= 28
DRAINAGE AREA, 257 SQ.MI. PERIOD 1929-1956

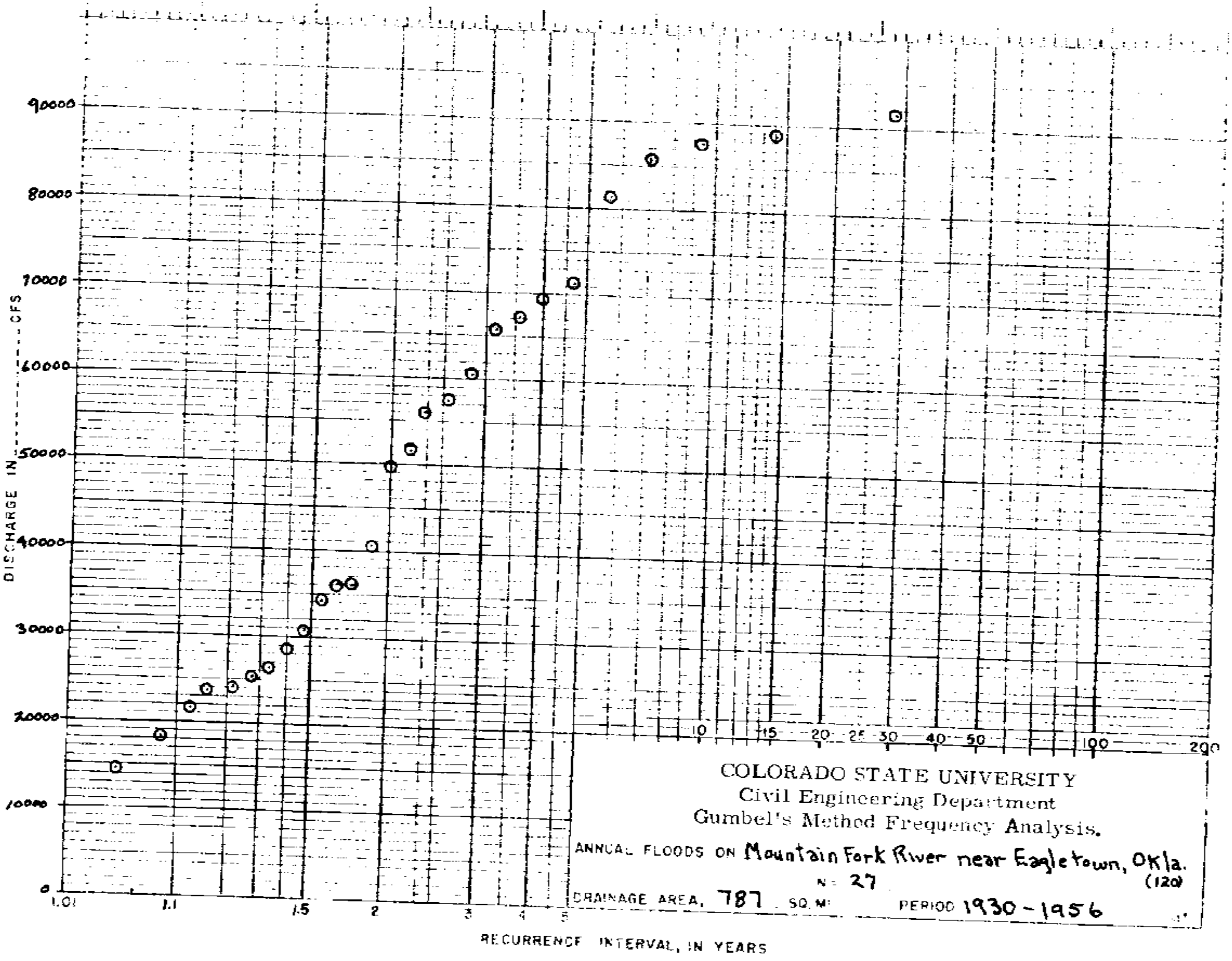


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Mora River near Shoemaker, N. Mex (119)

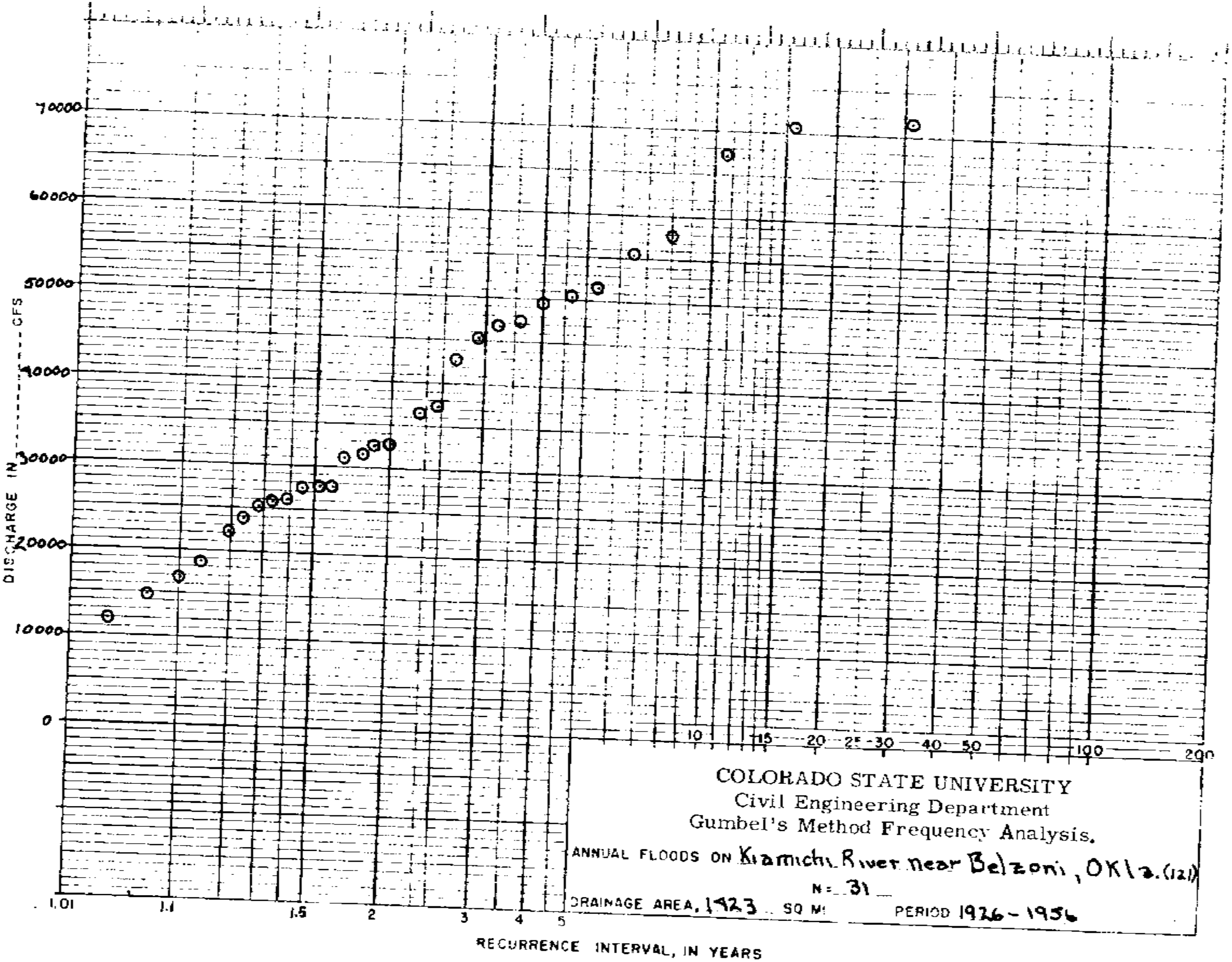
N= 39

DRAINAGE AREA, 1109 SQ MI. PERIOD 1915-1956



COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Mountain Fork River near Eagletown, Okla.
N = 27
(120)
DRAINAGE AREA, 787 SQ. MI.
PERIOD 1930 - 1956

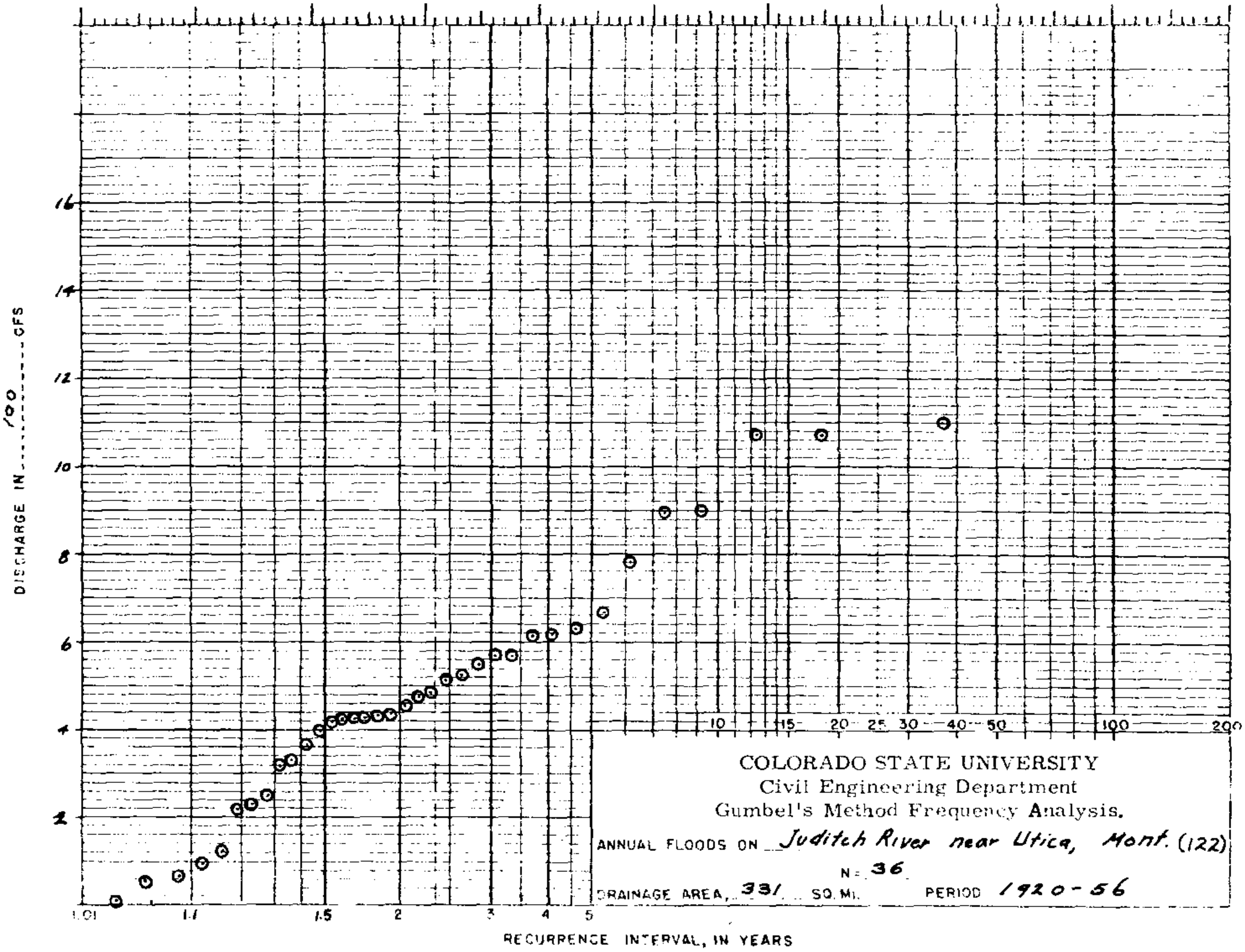


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Kiamichi River near Belzoni, Okla. (121)

N = 31

DRAINAGE AREA, 1423 SQ MI PERIOD 1926 - 1956

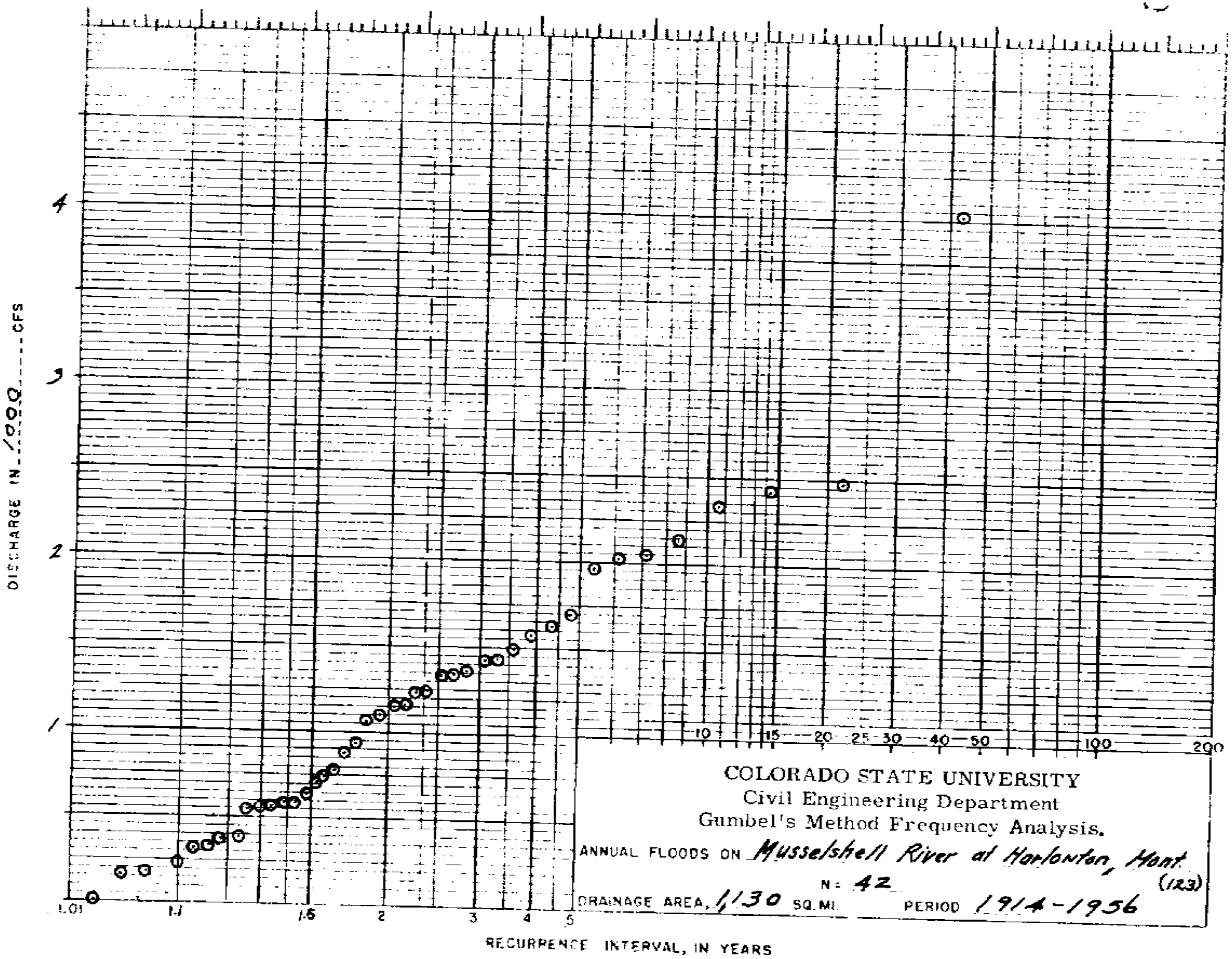


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Juditch River near Utica, Mont.* (122)

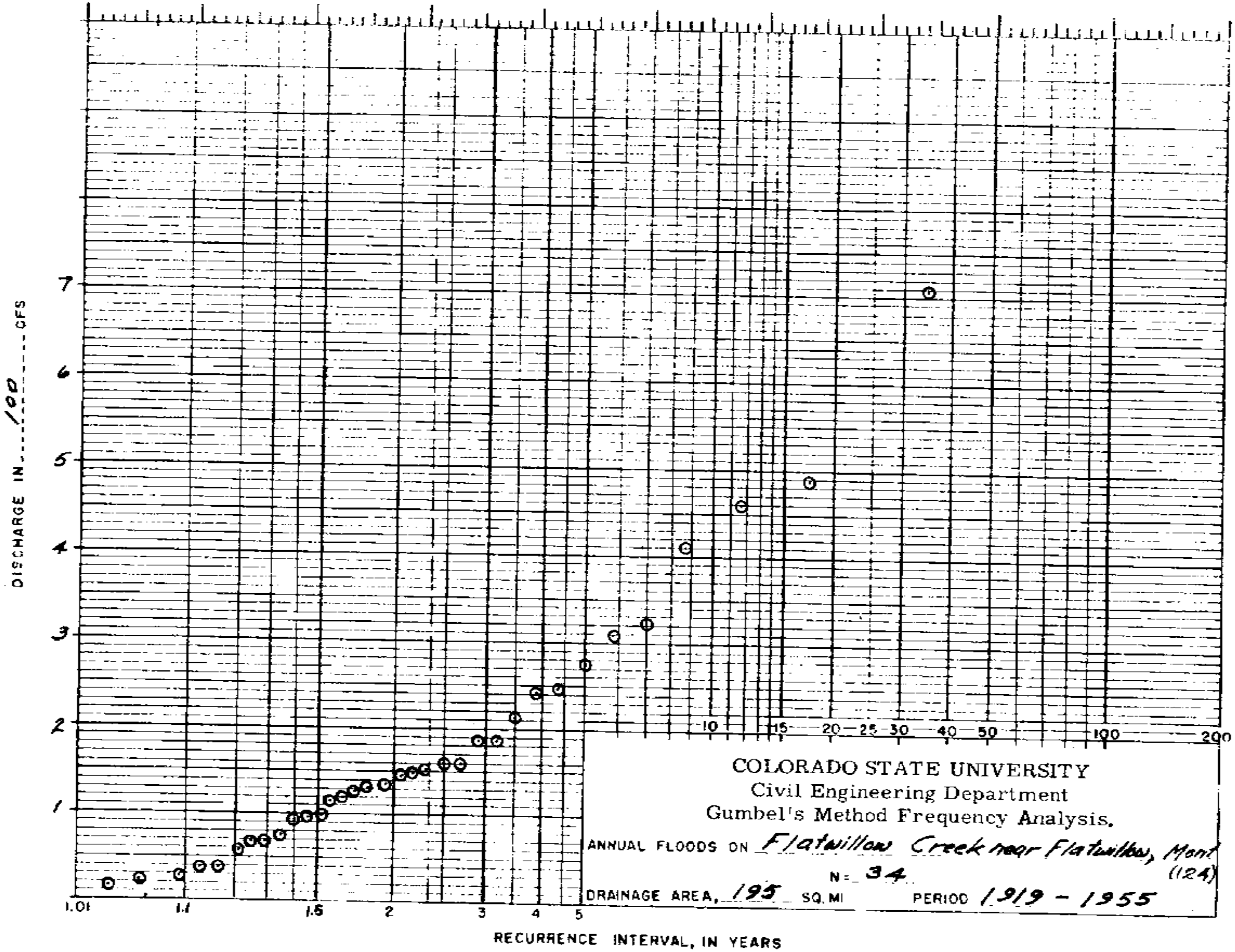
N = *36*

DRAINAGE AREA, *331* SQ. MI. PERIOD *1920-56*



COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Musselshell River at Harlowton, Mont.*
N: *42*
(123)
DRAINAGE AREA, *1,130* SQ.MI. PERIOD *1914-1956*

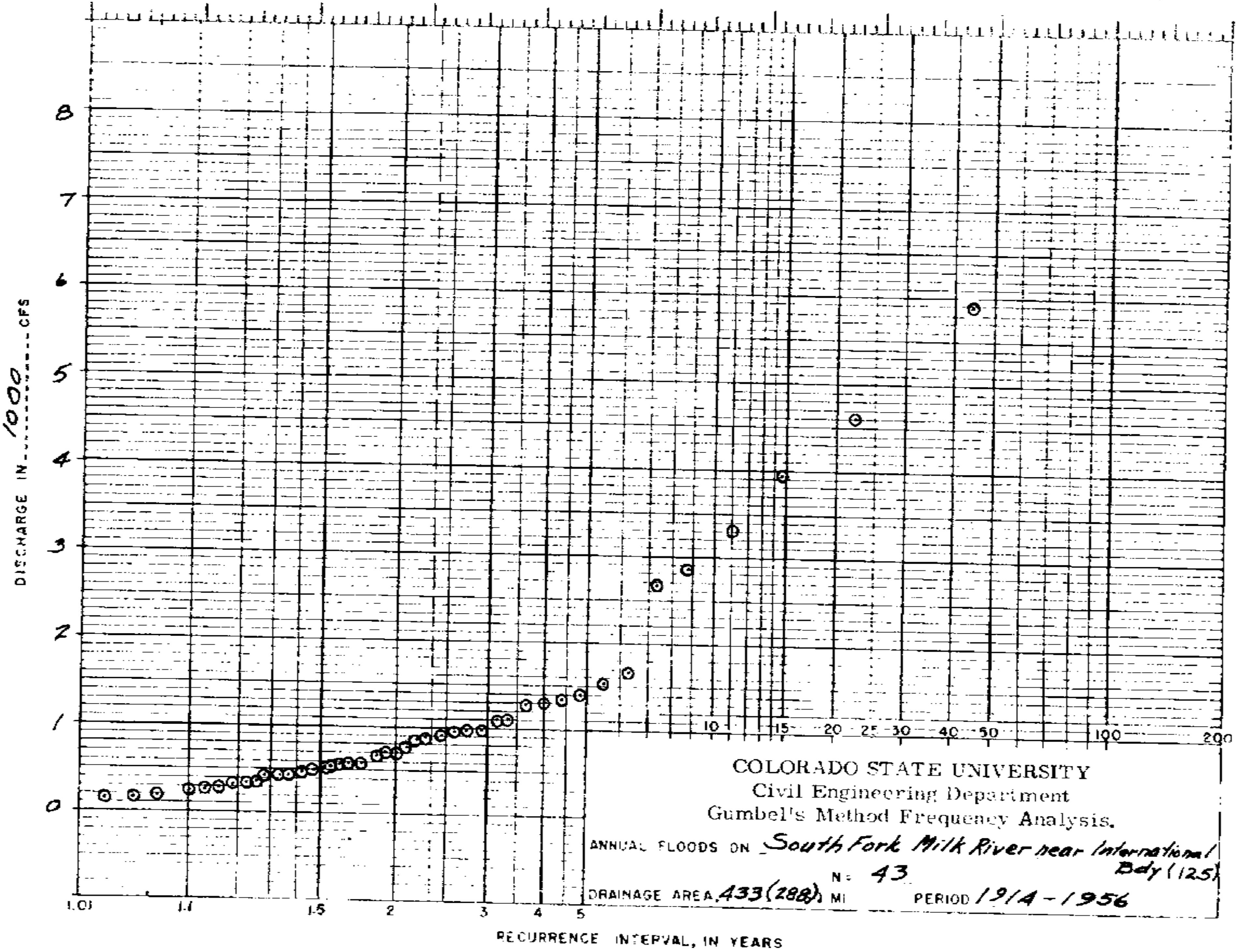


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Flatwillow Creek near Flatwillow, Mont
(124)

N = 34

DRAINAGE AREA, 195 SQ. MI PERIOD 1919 - 1955



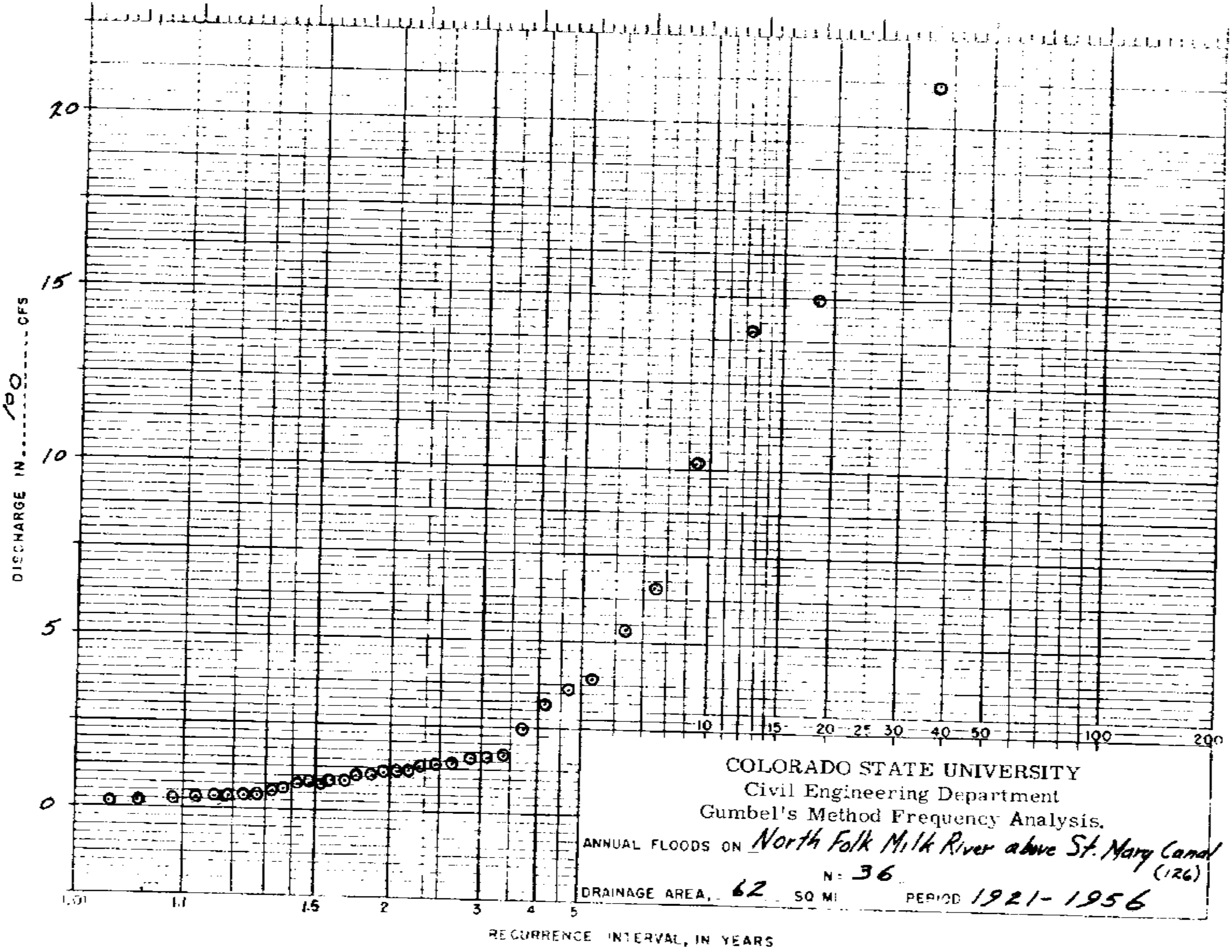
COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON South Fork Milk River near International Bdy (125)

N: 43

DRAINAGE AREA 433(288) MI

PERIOD 1914 - 1956

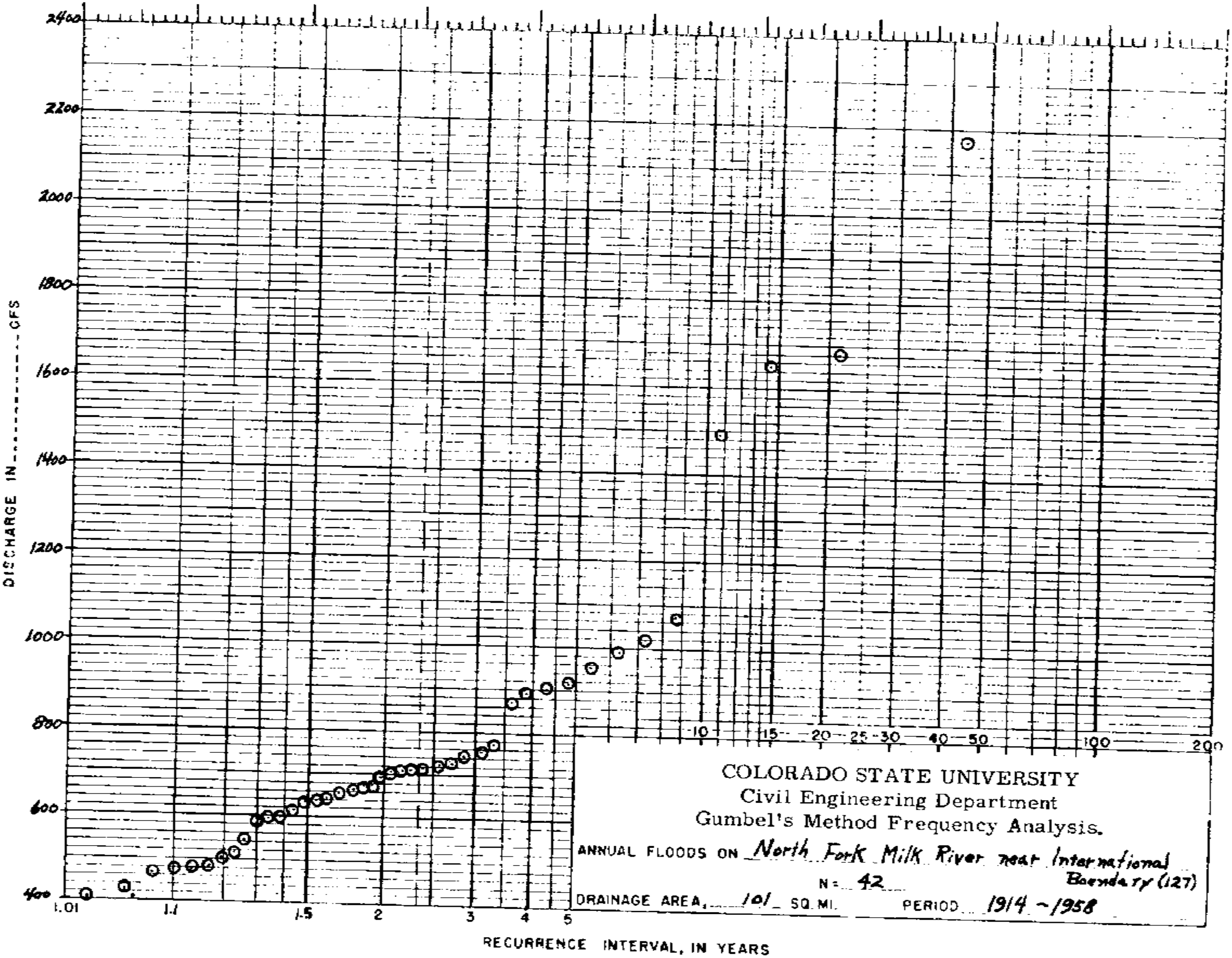


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON North Folk Milk River above St. Mary Canal (126)

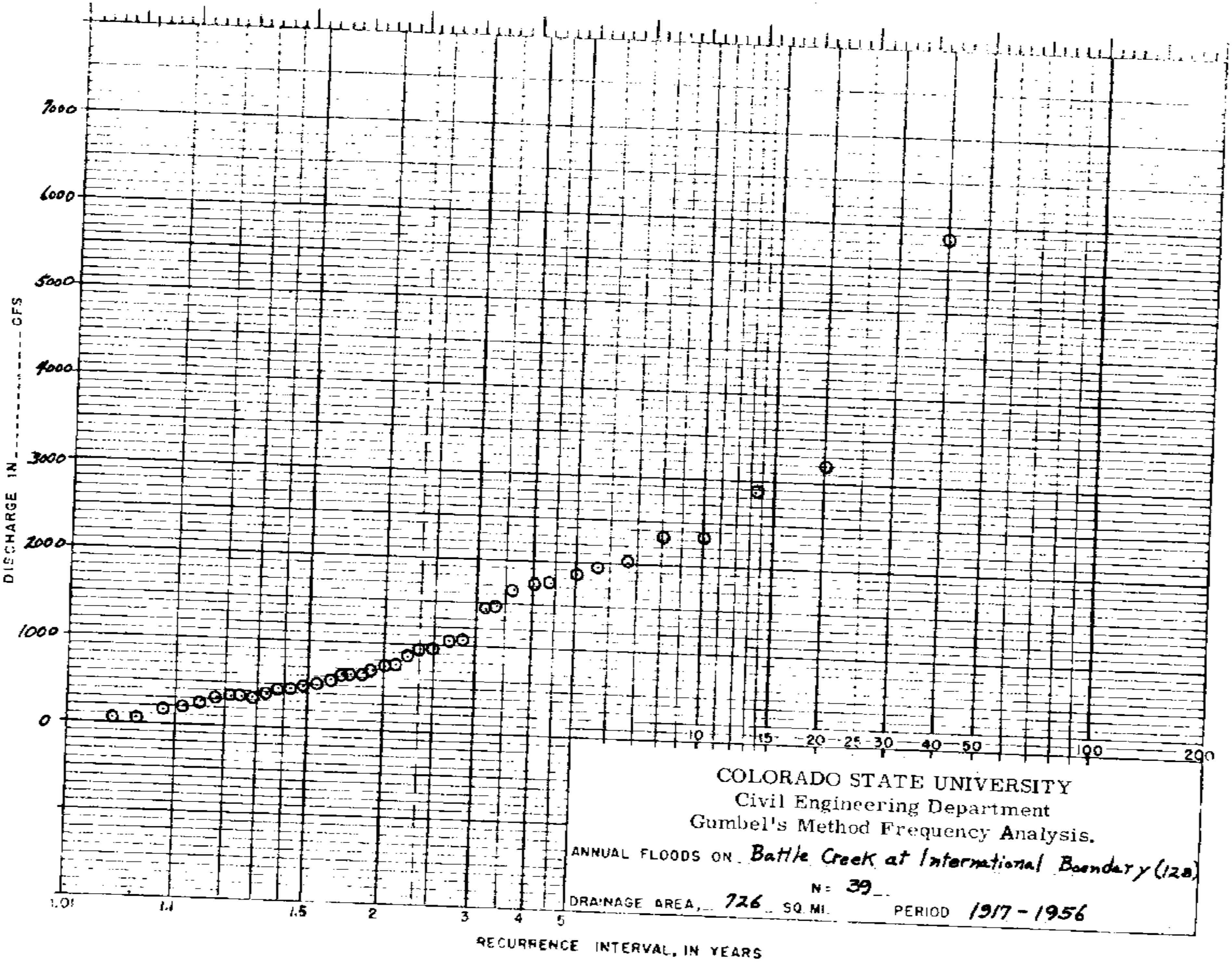
N: 36

DRAINAGE AREA, 62 SQ MI PERIOD 1921-1956



COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON North Fork Milk River near International Boundary (127)
N= 42
DRAINAGE AREA, 101 SQ. MI. PERIOD 1914 ~1958

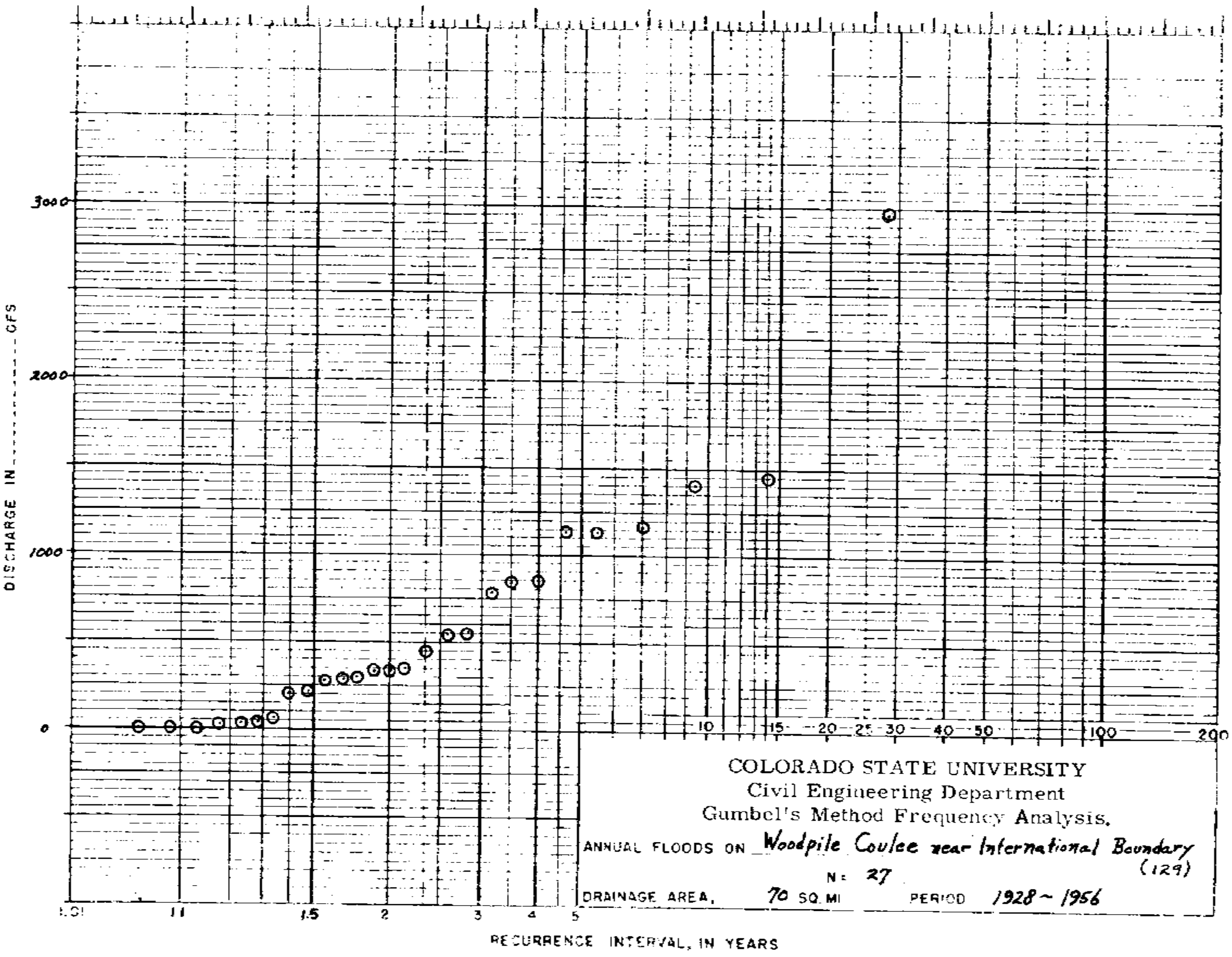


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Battle Creek at International Boundary (12B)*

N: *39*

DRAINAGE AREA, *726* SQ. MI. PERIOD *1917 - 1956*

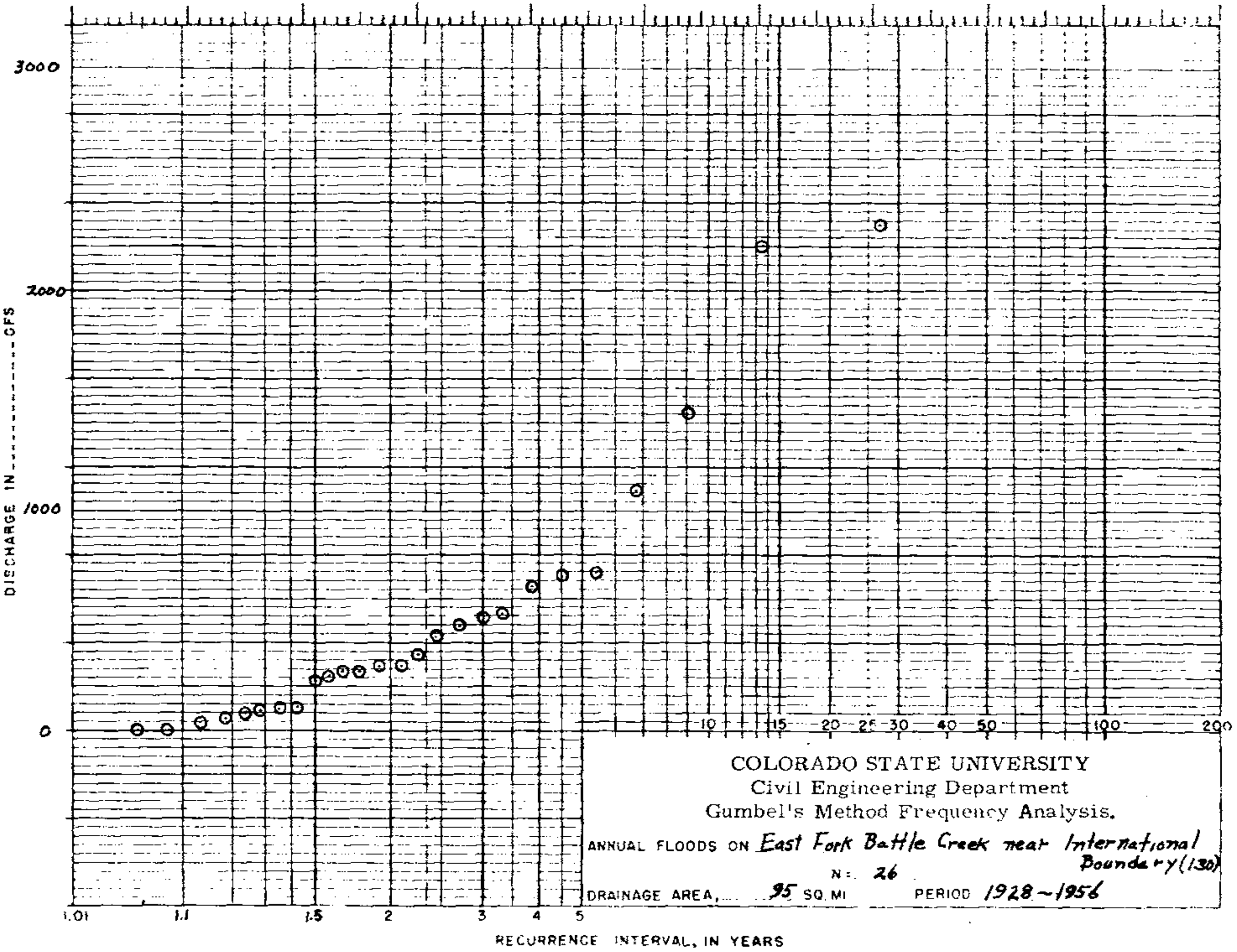


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Woodpile Coulee near International Boundary* *(129)*

N = *27*

DRAINAGE AREA, *70* SQ. MI PERIOD *1928 ~ 1956*

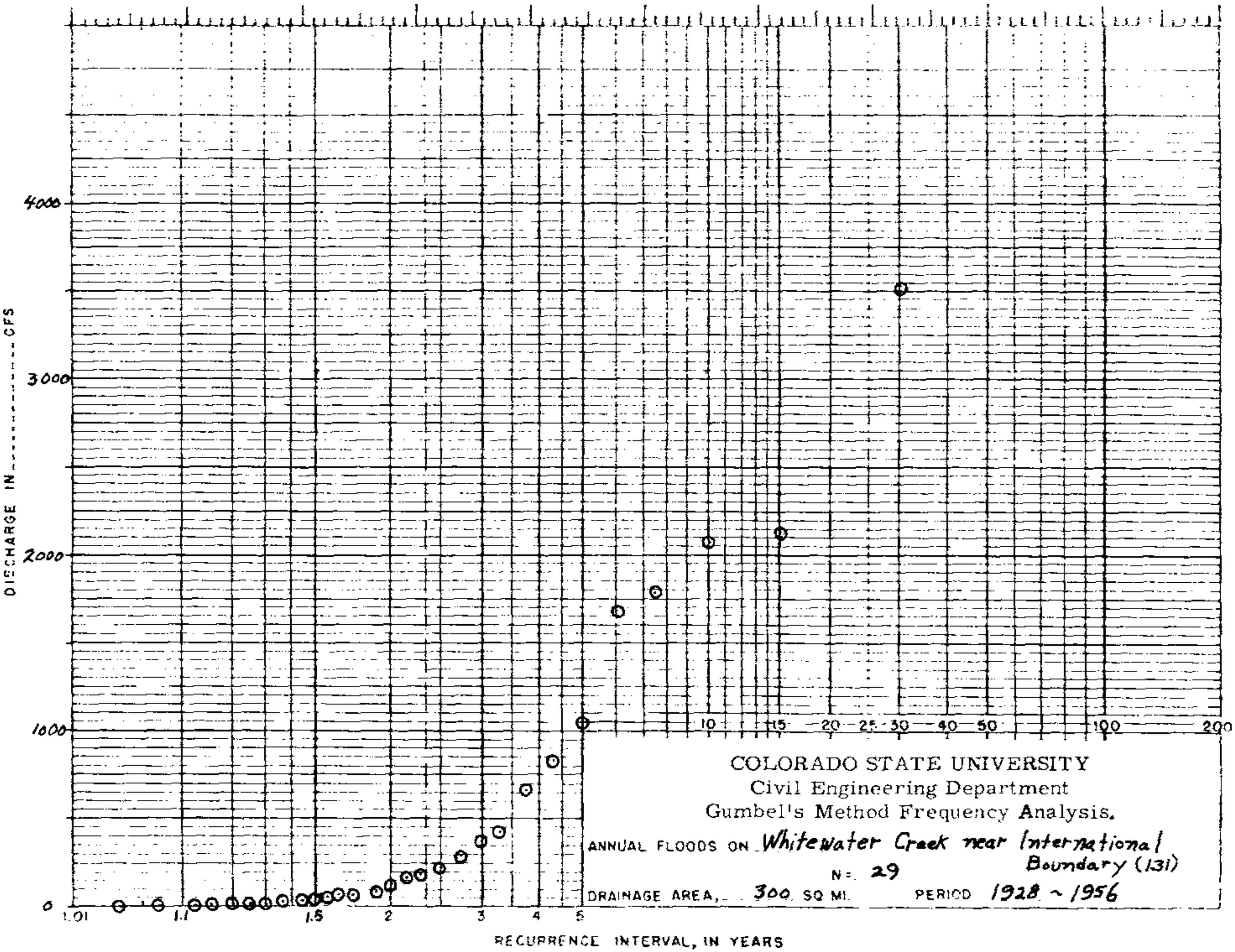


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *East Fork Battle Creek near International Boundary (130)*

N: *26*

DRAINAGE AREA, *95* SQ. MI PERIOD *1928 – 1956*

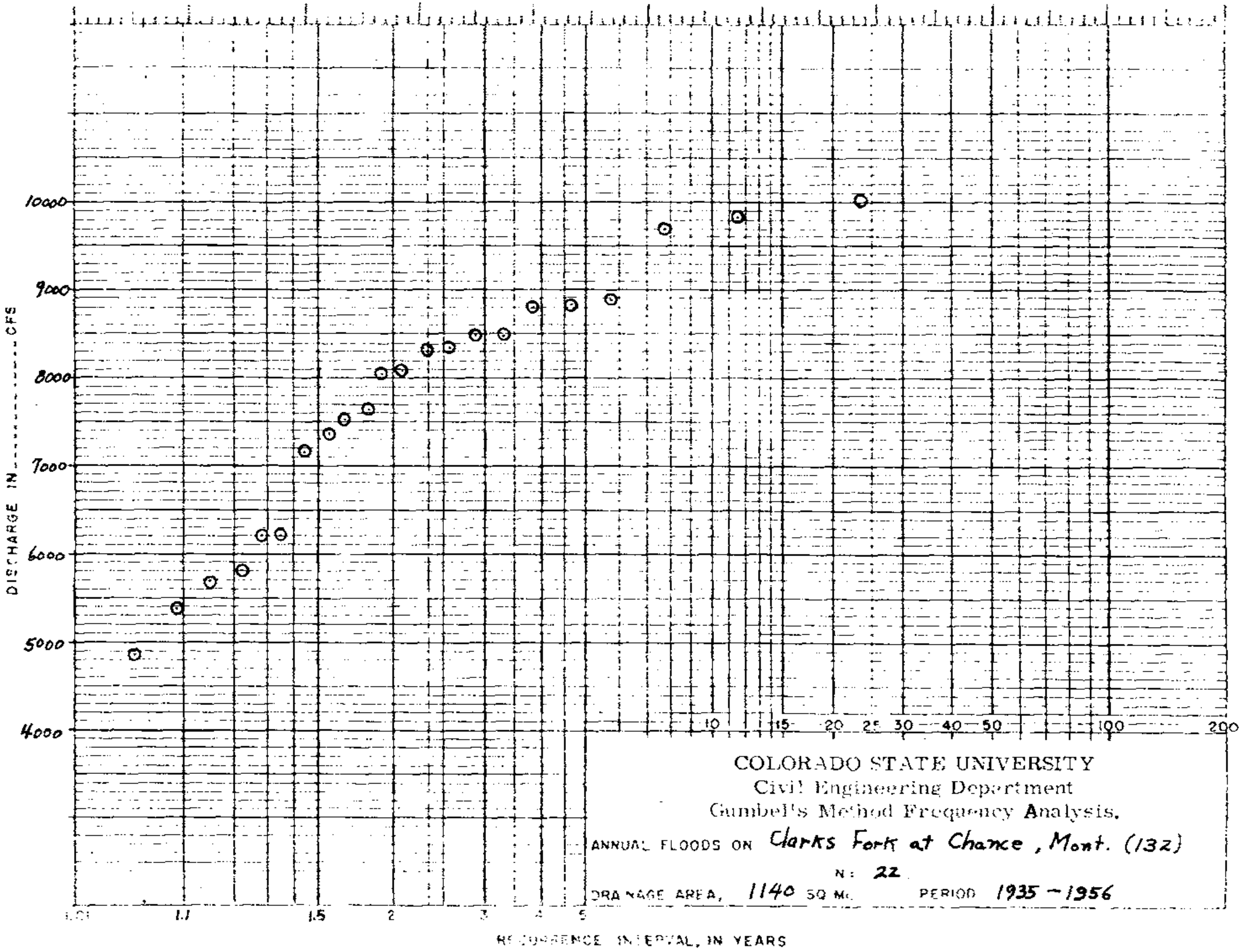


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Whitewater Creek near International Boundary (131)

N = 29

DRAINAGE AREA, 300 SQ MI. PERIOD 1928 ~ 1956

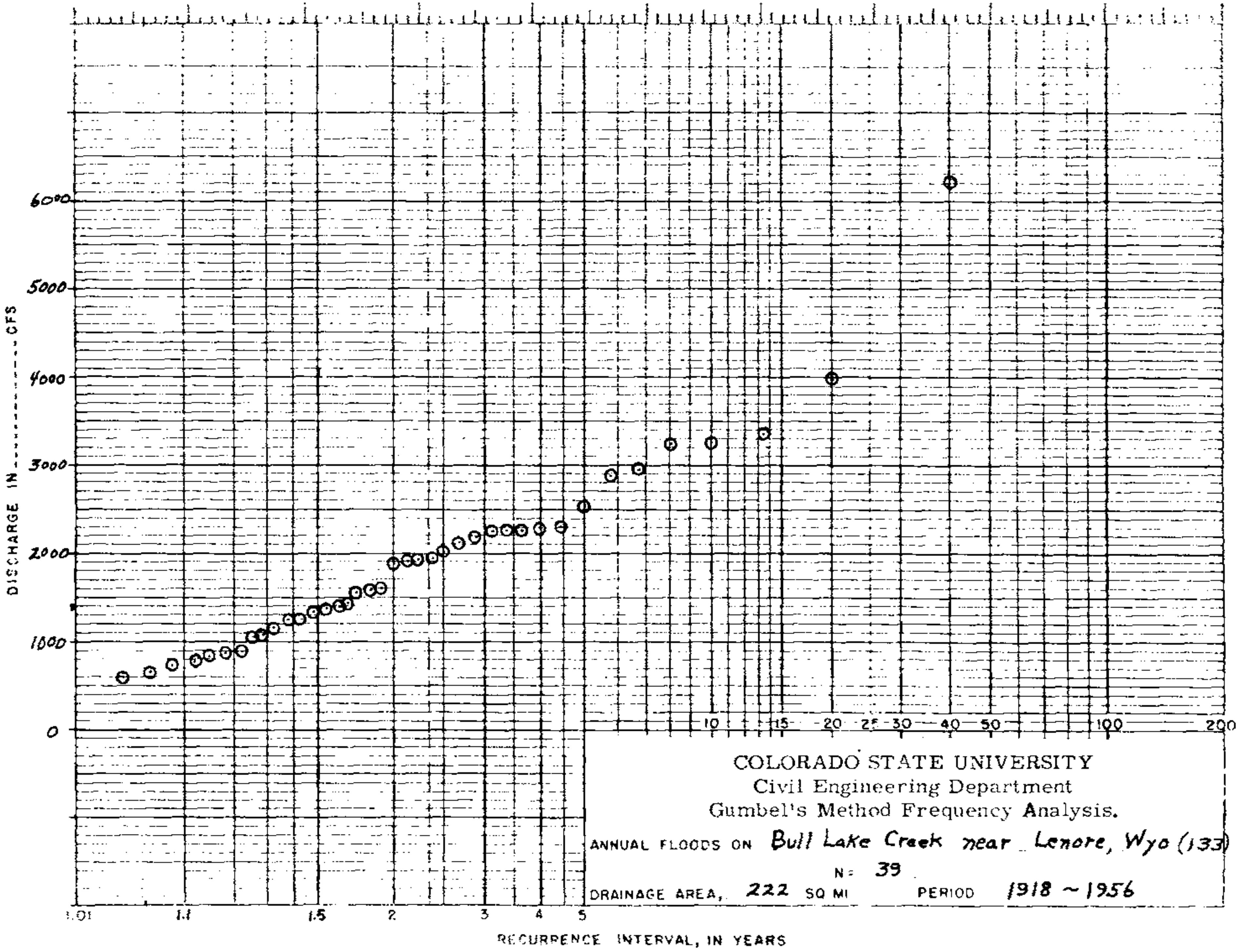


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Clarks Fork at Chance, Mont. (132)*

N: *22*

DRAINAGE AREA, *1140* SQ MI. PERIOD *1935 – 1956*

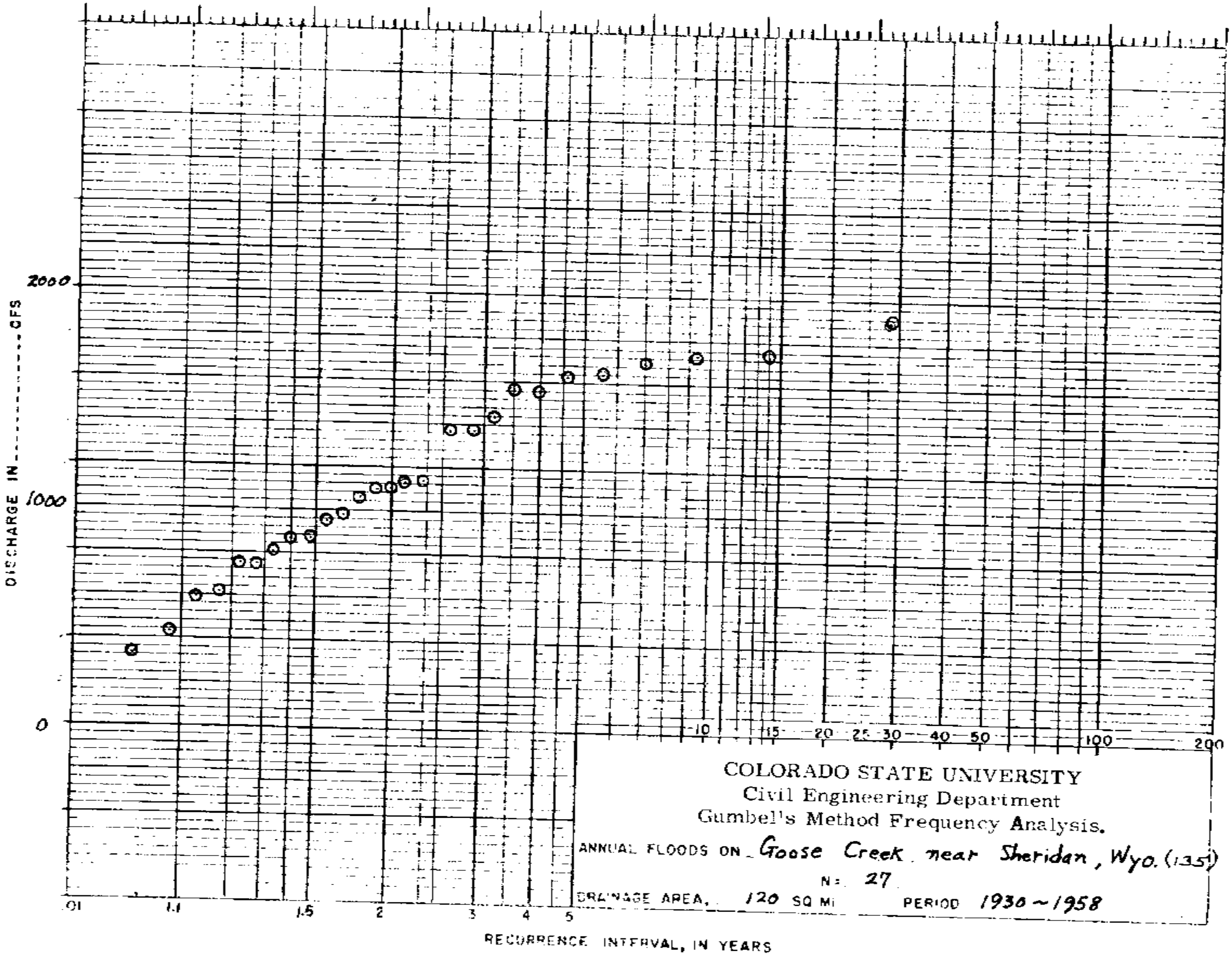


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Bull Lake Creek near Lenore, Wyo (133)*

N= *39*

DRAINAGE AREA, *222* SQ MI PERIOD *1918 ~ 1956*

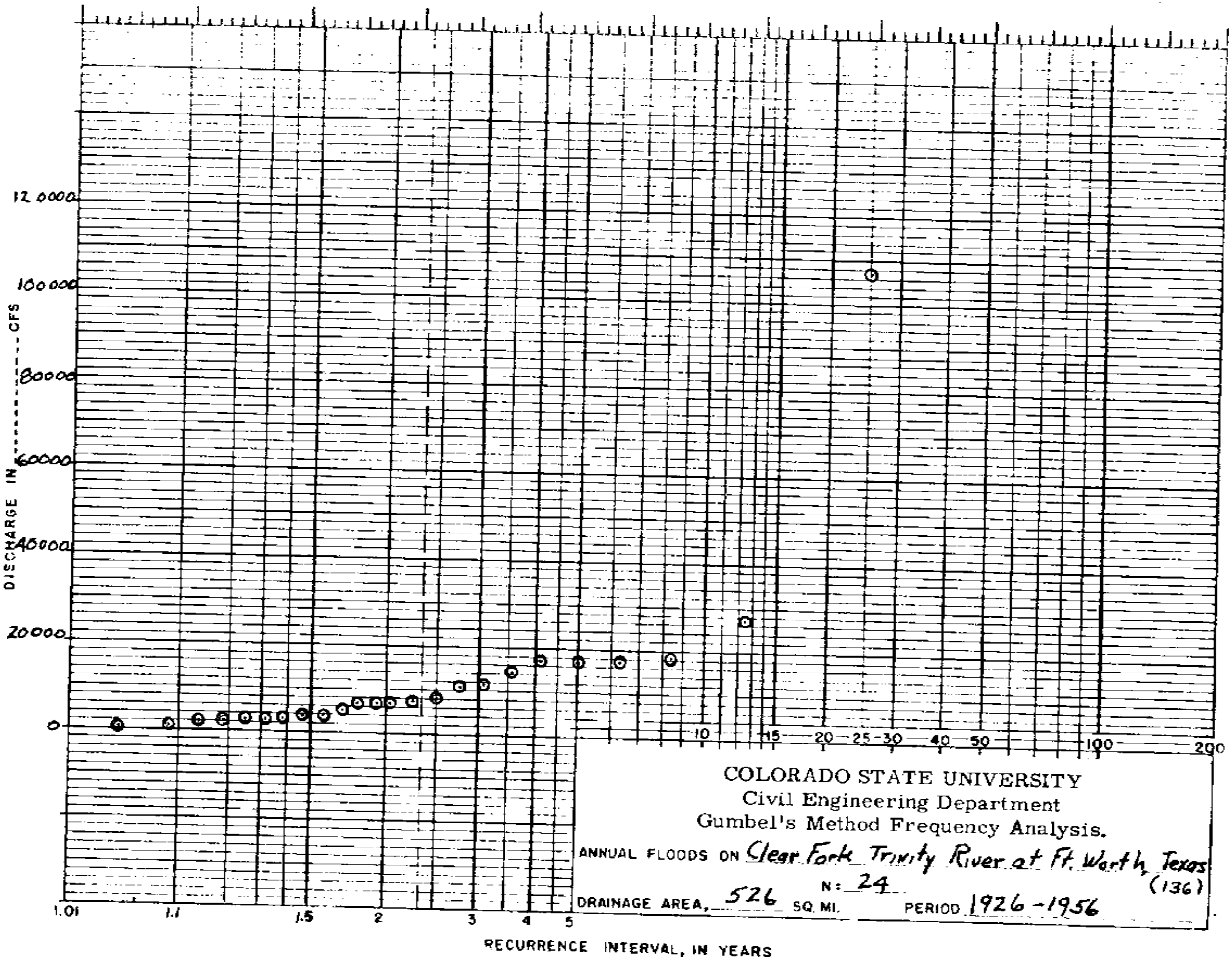


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Goose Creek near Sheridan, Wyo. (135)

N = 27

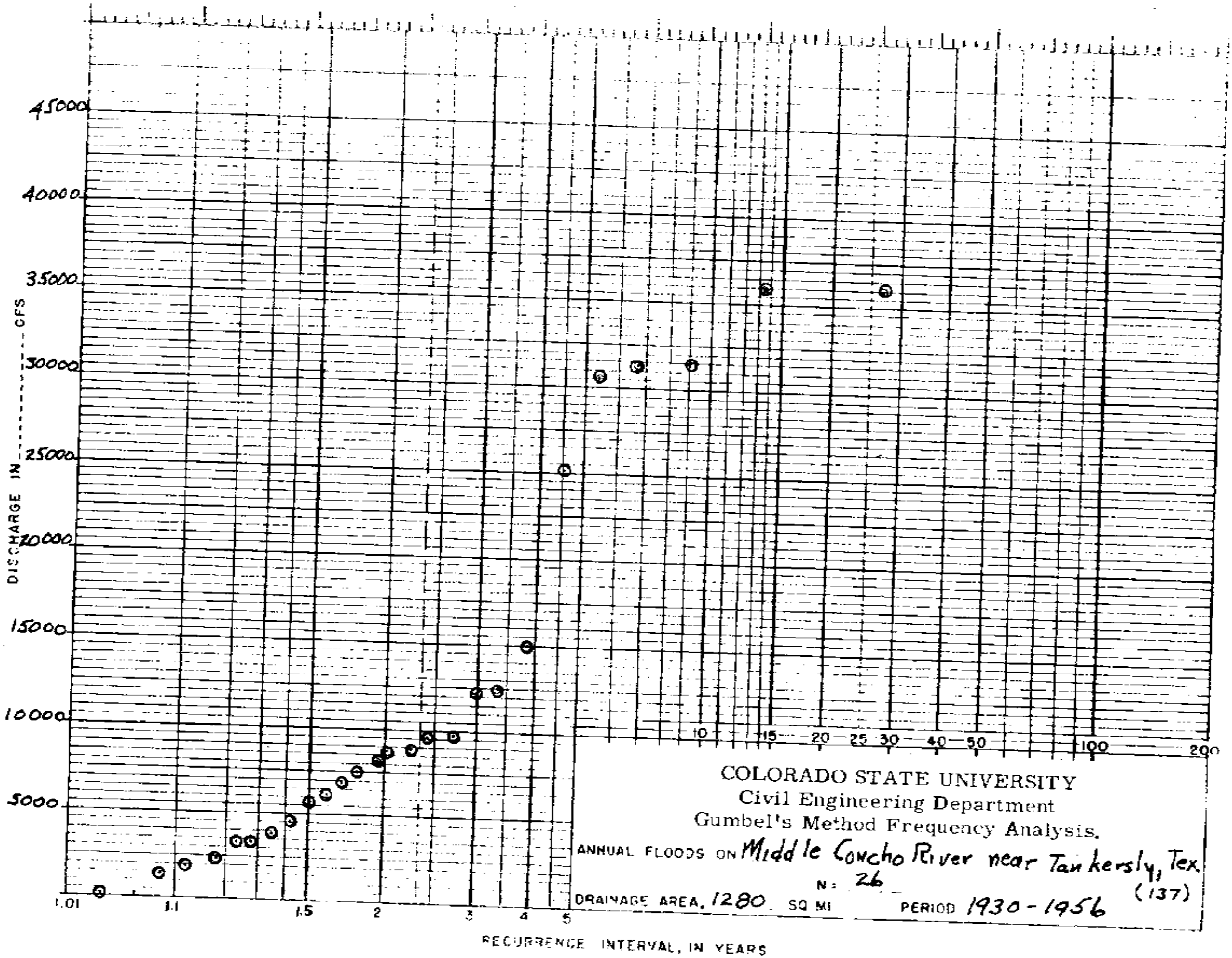
DRAINAGE AREA, 120 SQ MI PERIOD 1930 ~ 1958



COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

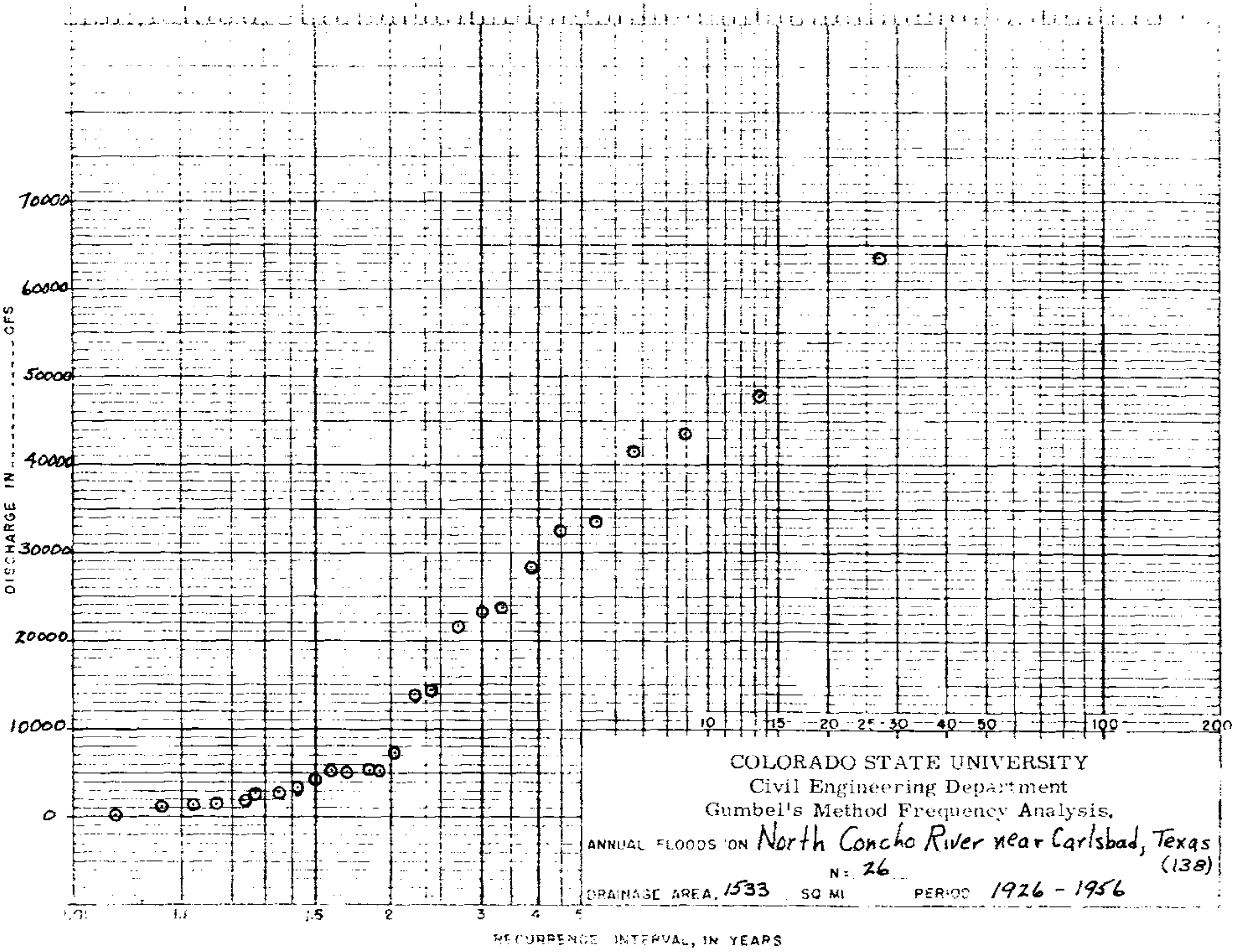
ANNUAL FLOODS ON Clear Fork Trinity River at Ft. Worth, Texas
(136)

DRAINAGE AREA, 526 SQ. MI. N: 24 PERIOD 1926-1956



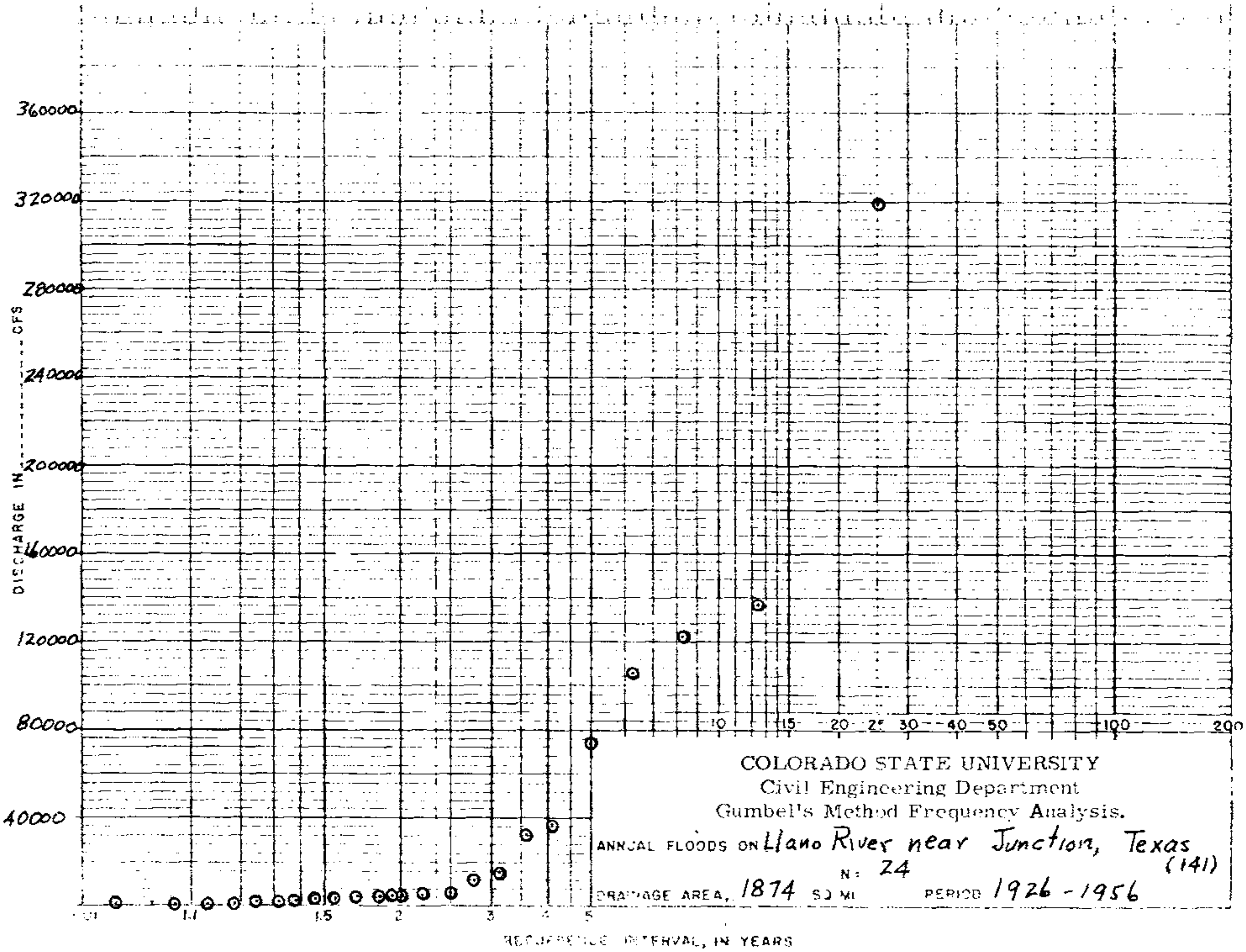
COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Middle Concho River near Tankersly, Tex.
N = 26
(137)
DRAINAGE AREA, 1280 SQ MI PERIOD 1930 - 1956



COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis,

ANNUAL FLOODS ON North Concho River near Carlsbad, Texas
(138)
N = 26
DRAINAGE AREA 1533 SQ MI PERIOD 1926 - 1956



COLORADO STATE UNIVERSITY

Civil Engineering Department

Gumbel's Method Frequency Analysis.

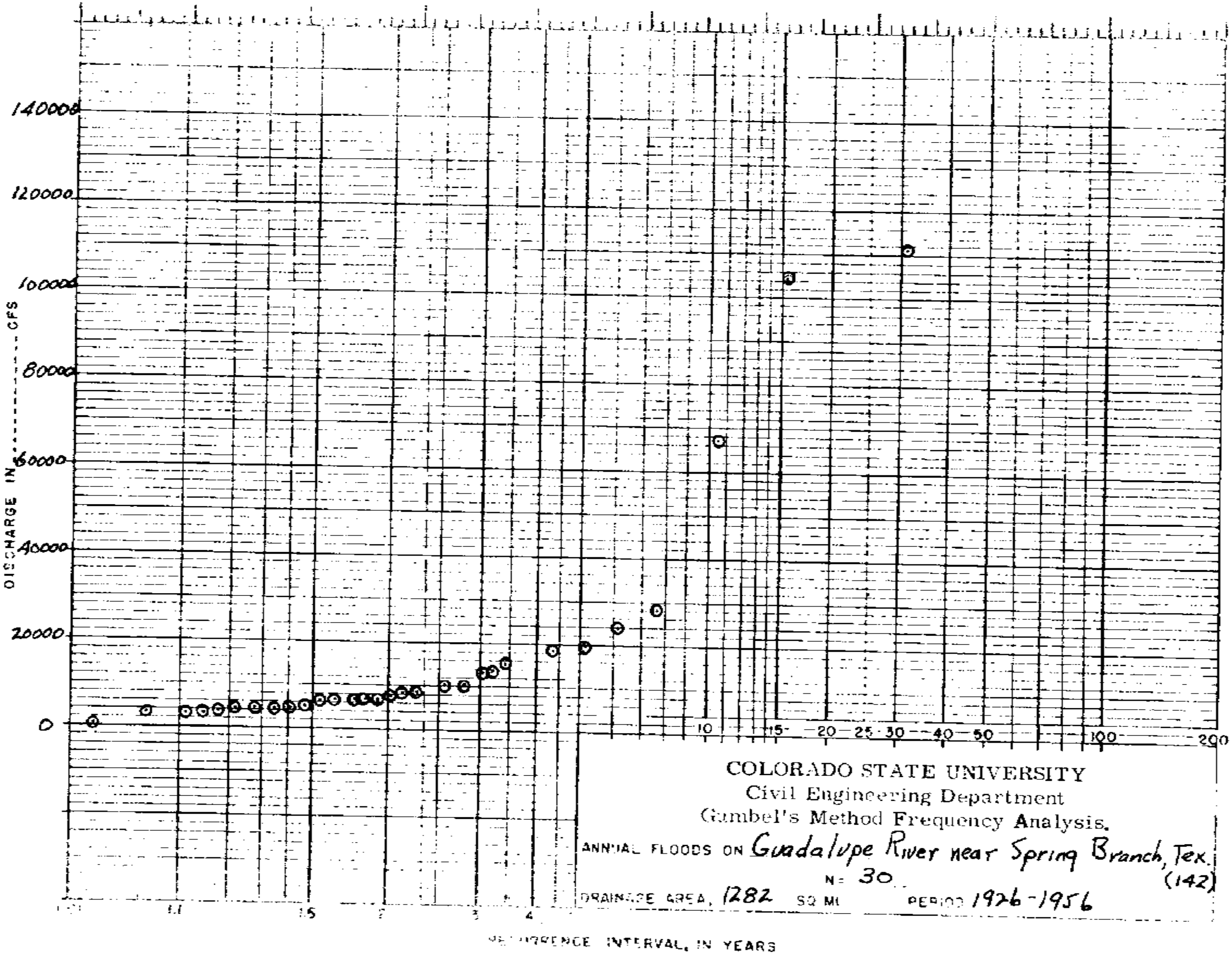
ANNUAL FLOODS ON Llano River near Junction, Texas

(141)

N: 24

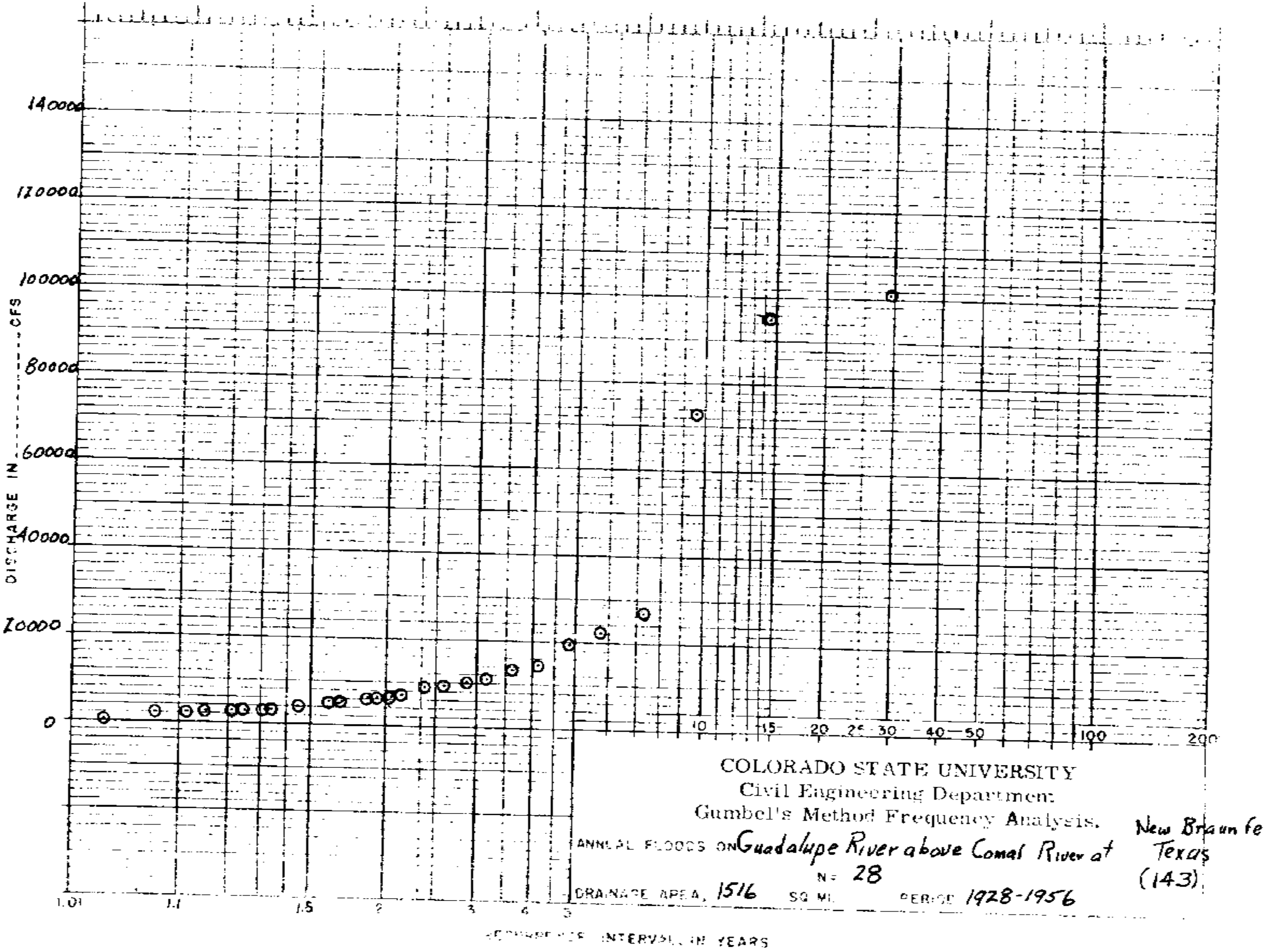
DRAINAGE AREA, 1874 SQ MI

PERIOD 1926 - 1956



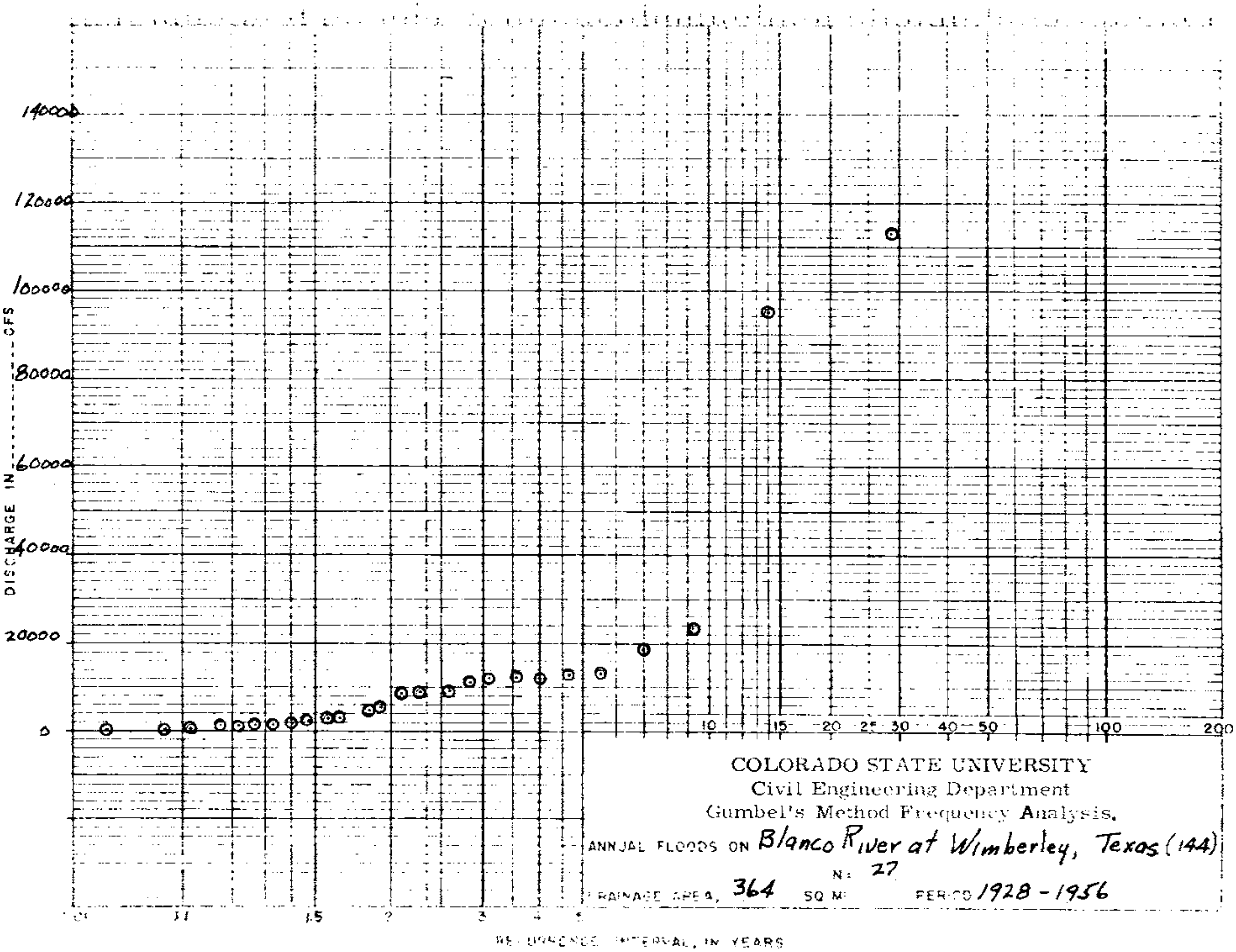
COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Guadalupe River near Spring Branch, Tex.
(142)
N = 30
DRAINAGE AREA, 1282 SQ MI PERIOD 1926-1956



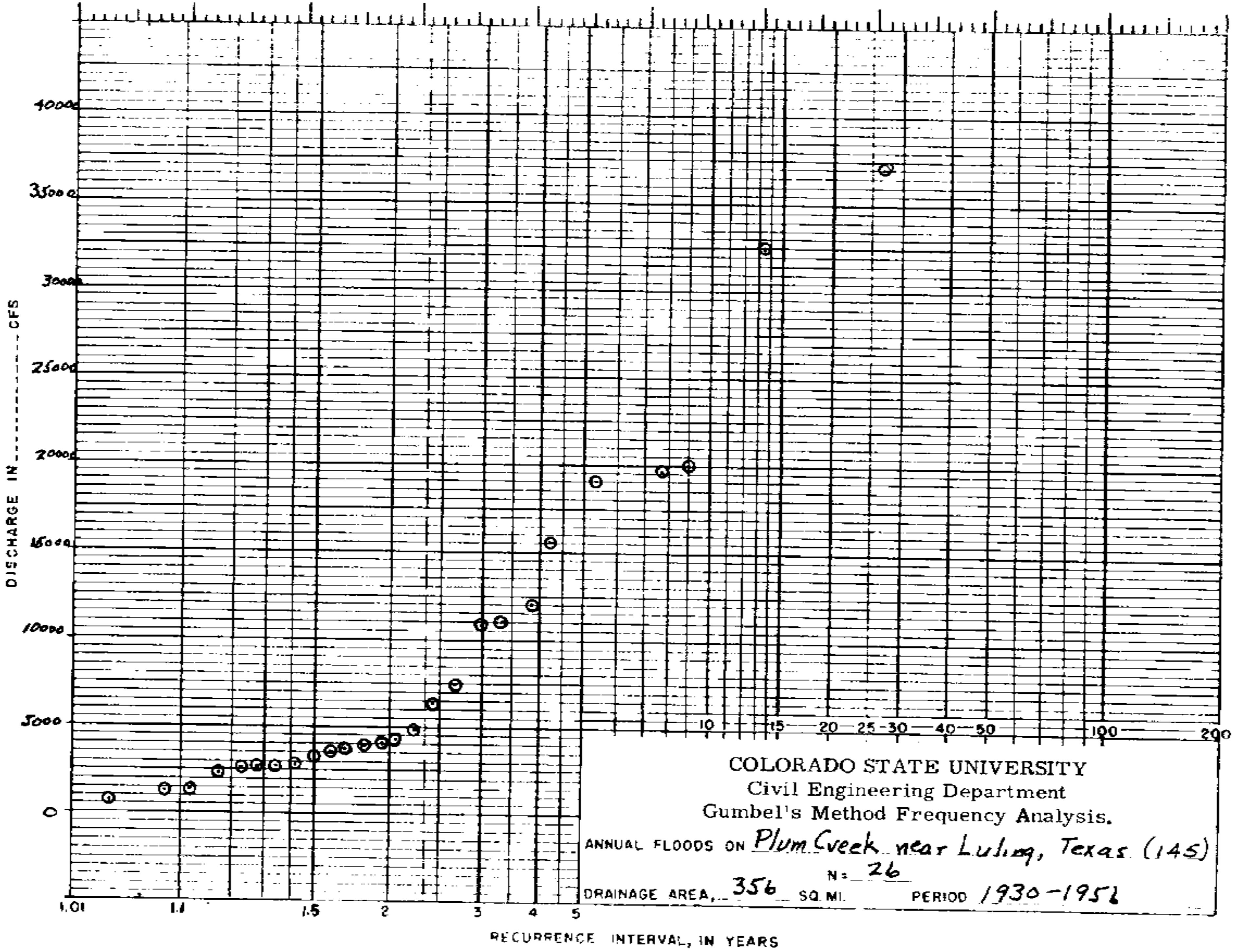
COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Guadalupe River above Comal River at New Braunfe Texas
N = 28
(143)
DRAINAGE AREA, 1516 SQ MI. PERIOD 1928-1956



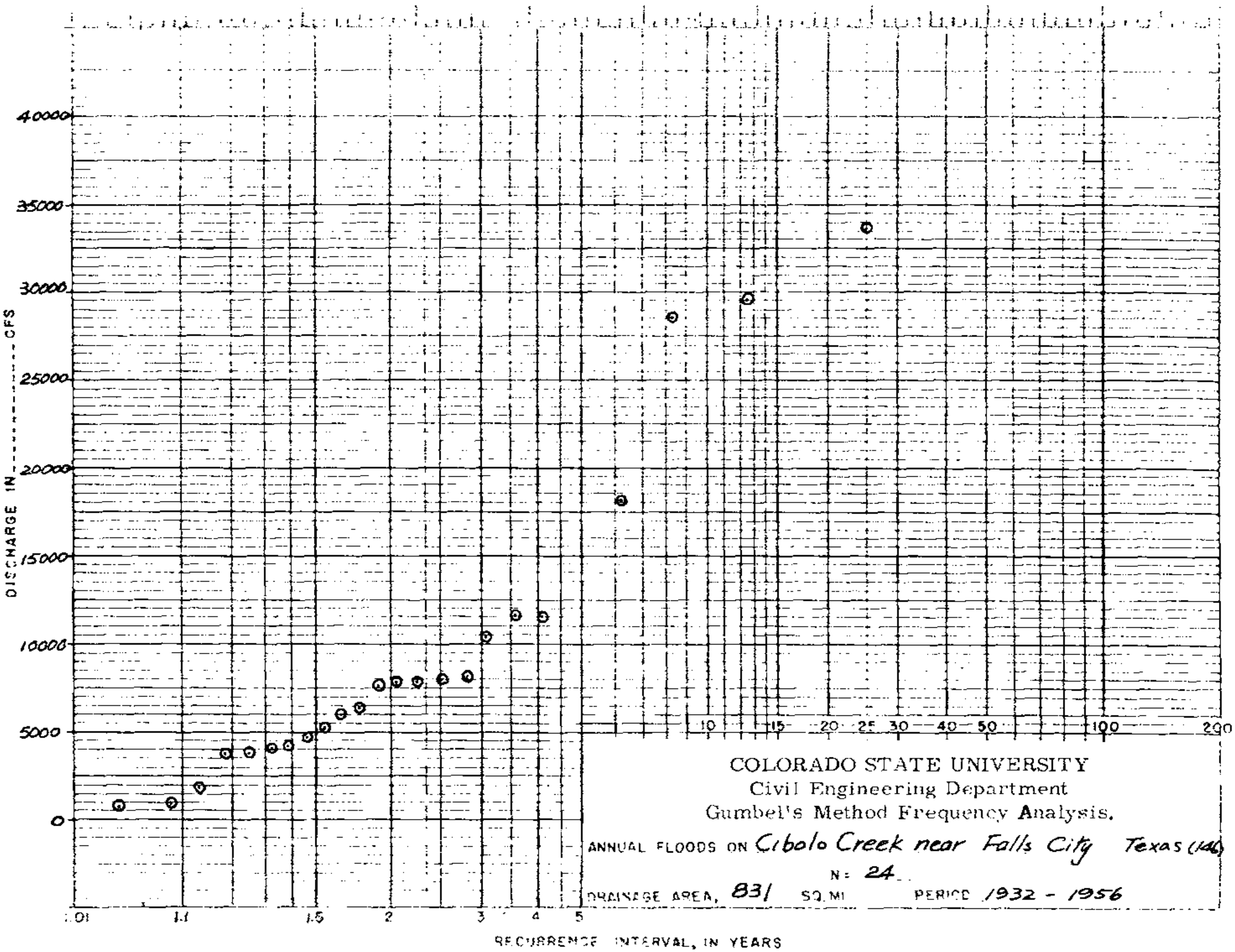
COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Blanco River at Wimberley, Texas (144)
N: 27
DRAINAGE AREA, 364 SQ MI PERIOD 1928 - 1956



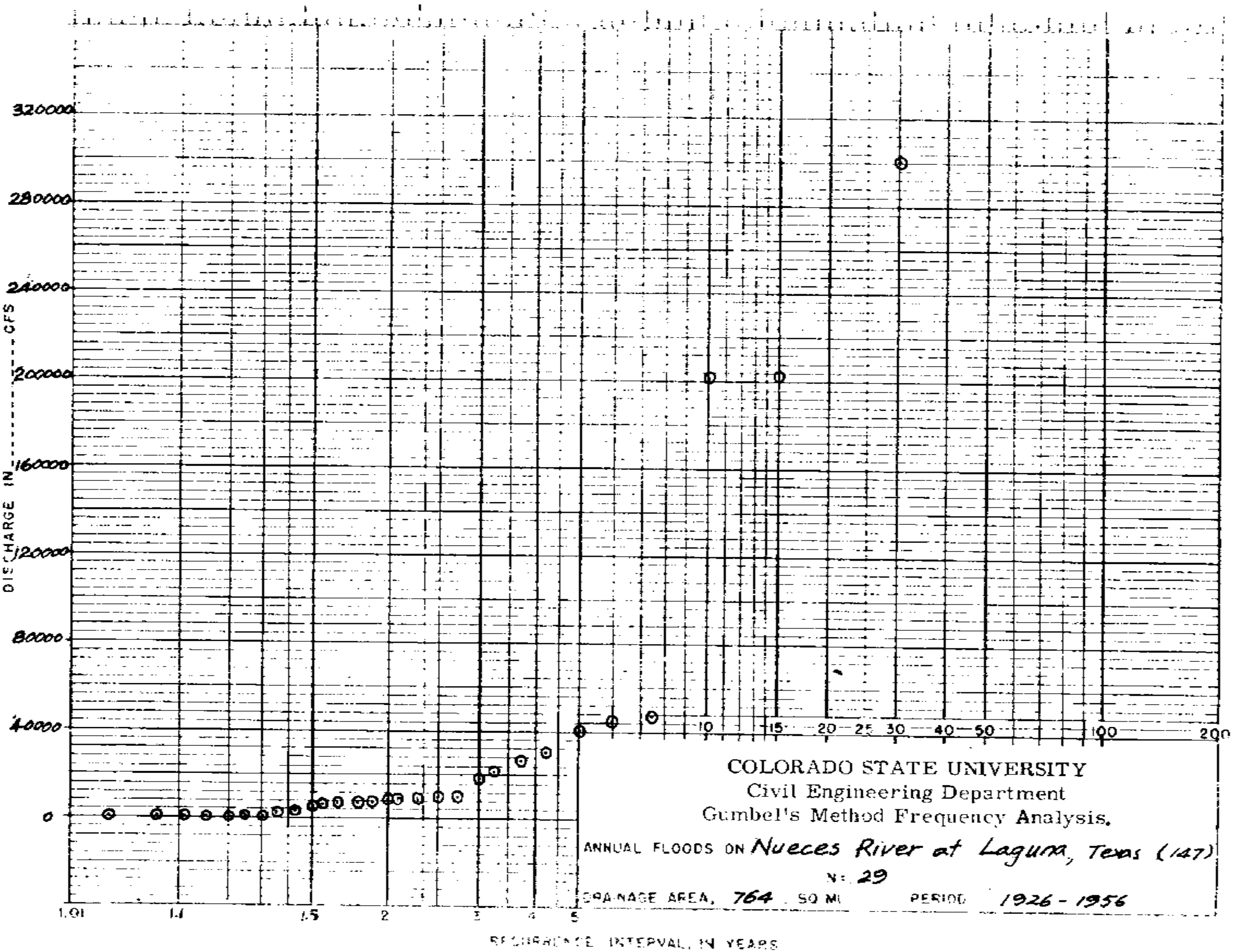
COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Plum Creek near Luling, Texas (145)
N = 26
DRAINAGE AREA, 356 SQ. MI. PERIOD 1930-1956



COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Cibolo Creek near Falls City Texas (146)
N: 24
DRAINAGE AREA, 831 SQ.MI PERIOD 1932 - 1956

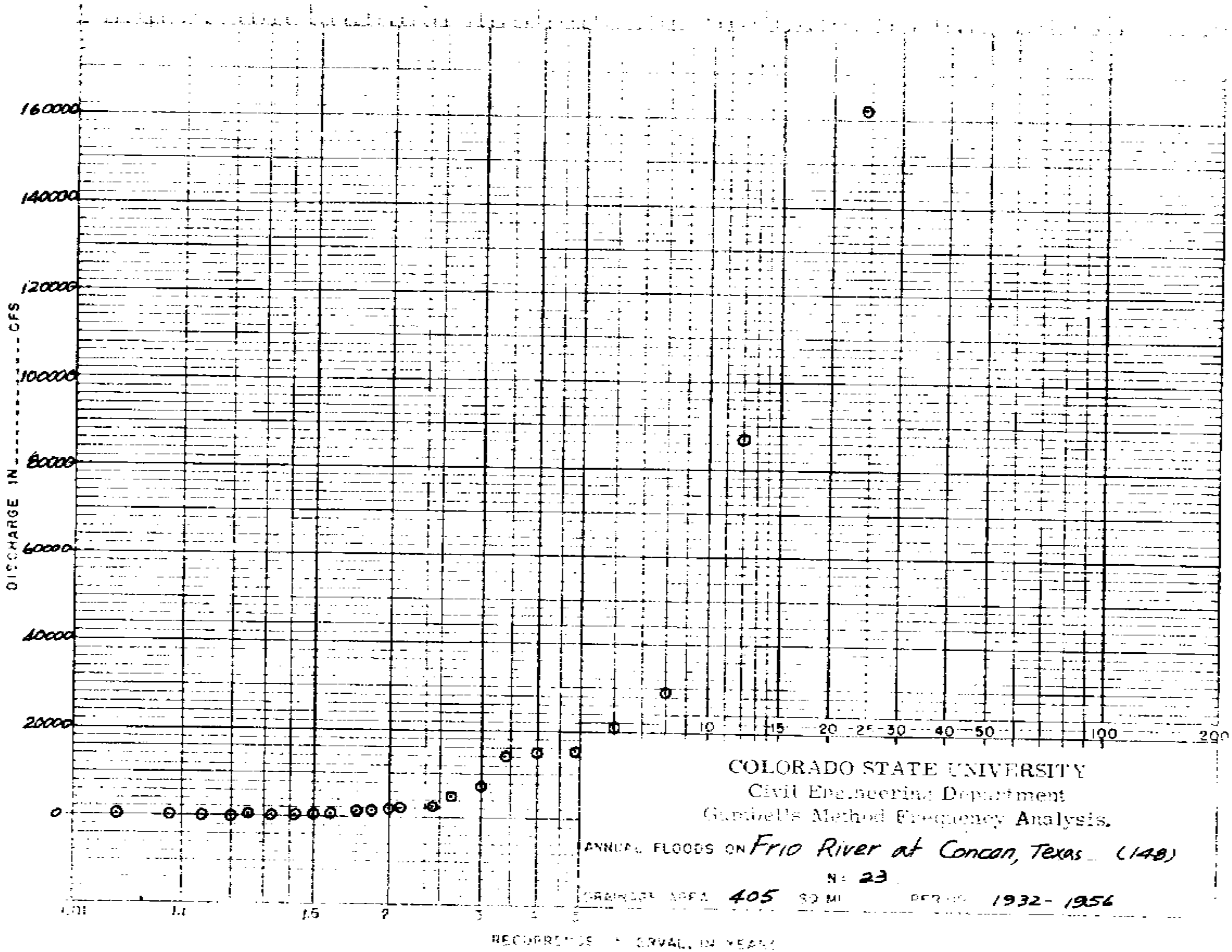


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON *Nueces River at Laguna, Texas (147)*

N: *29*

DRAINAGE AREA, *764* SQ MI PERIOD *1926 - 1956*

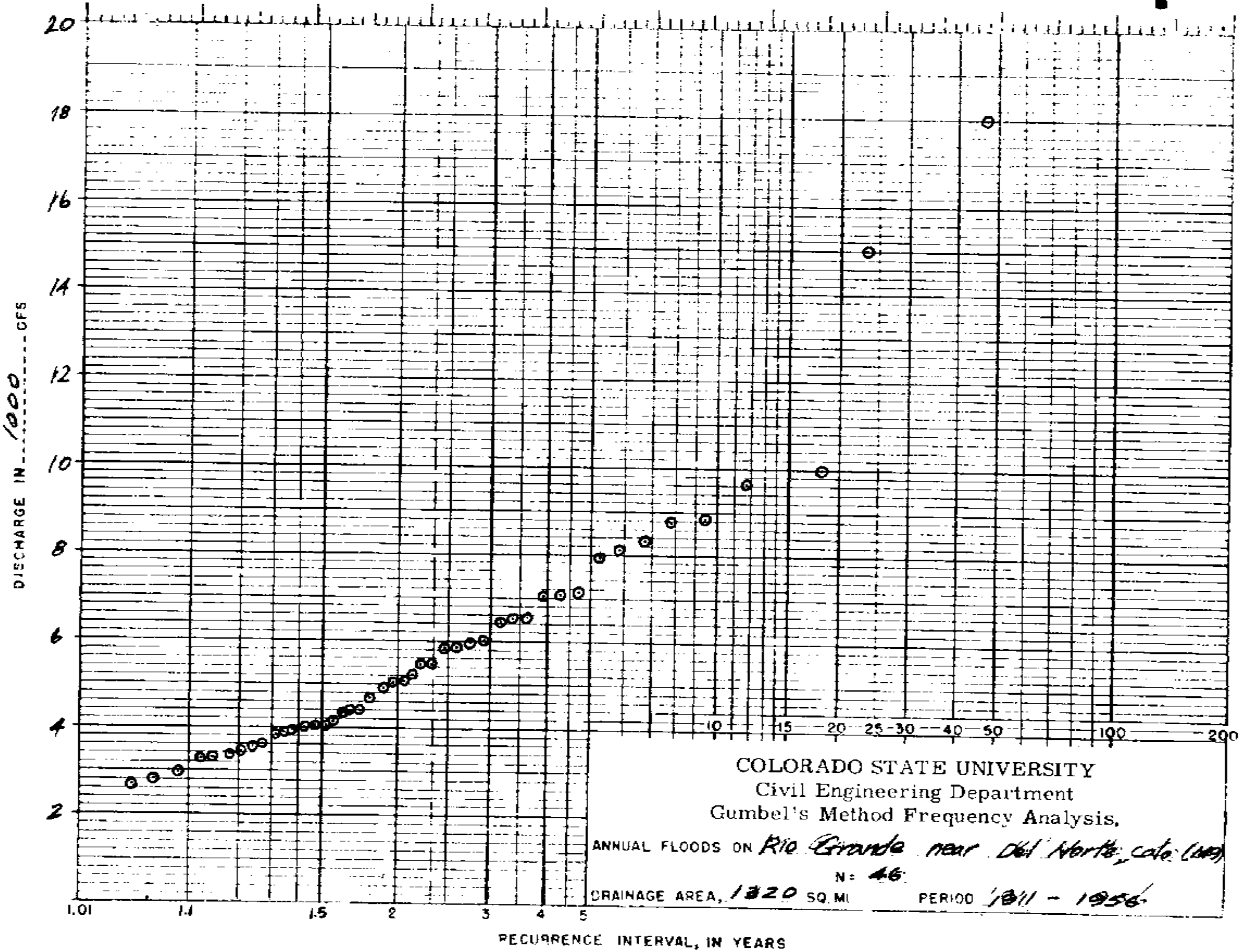


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Frio River at Concan, Texas (148)

N: 23

DRAINAGE AREA 405 SQ MI PERIOD 1932- 1956

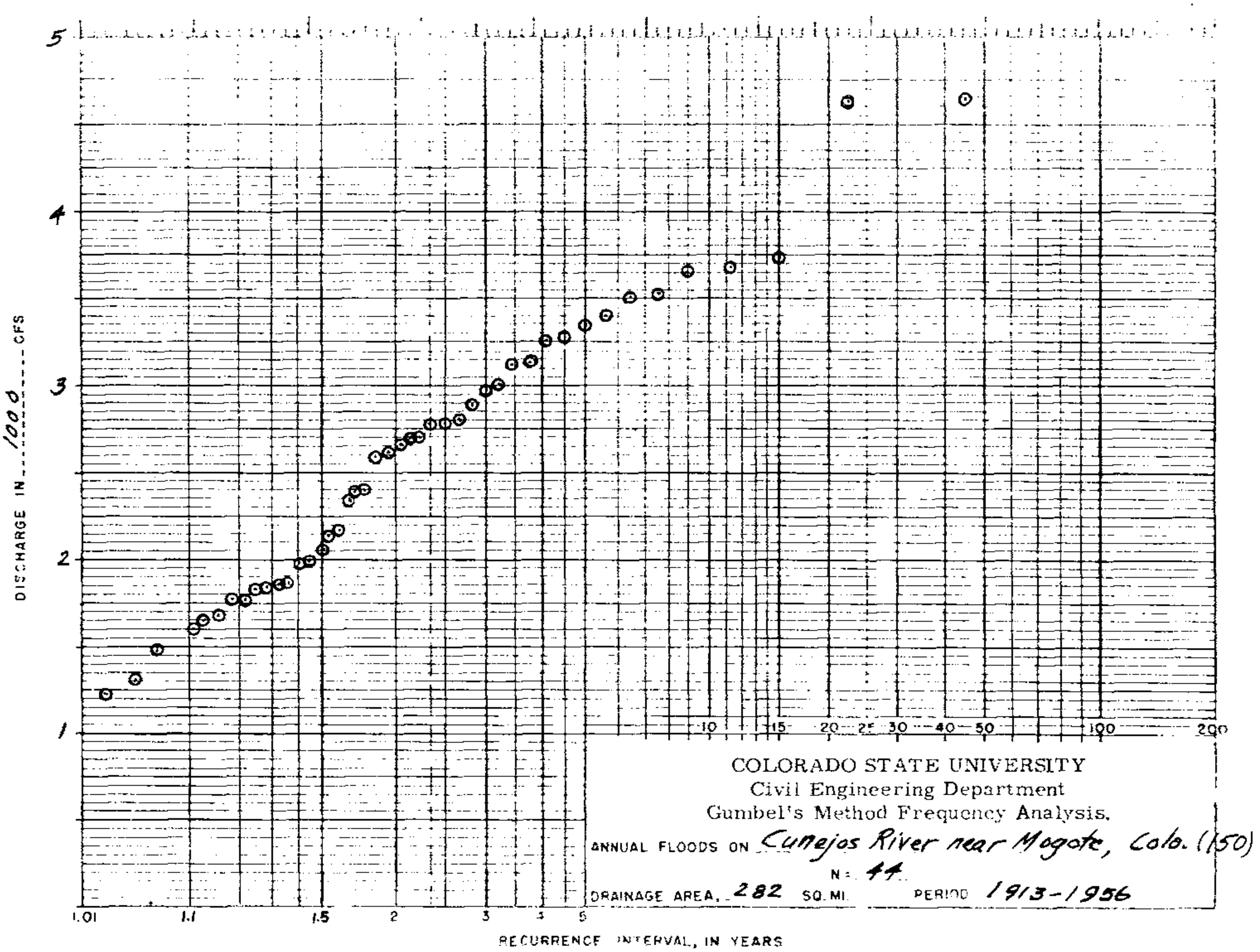


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Rio Grande near Del Norte, Colo. (49)

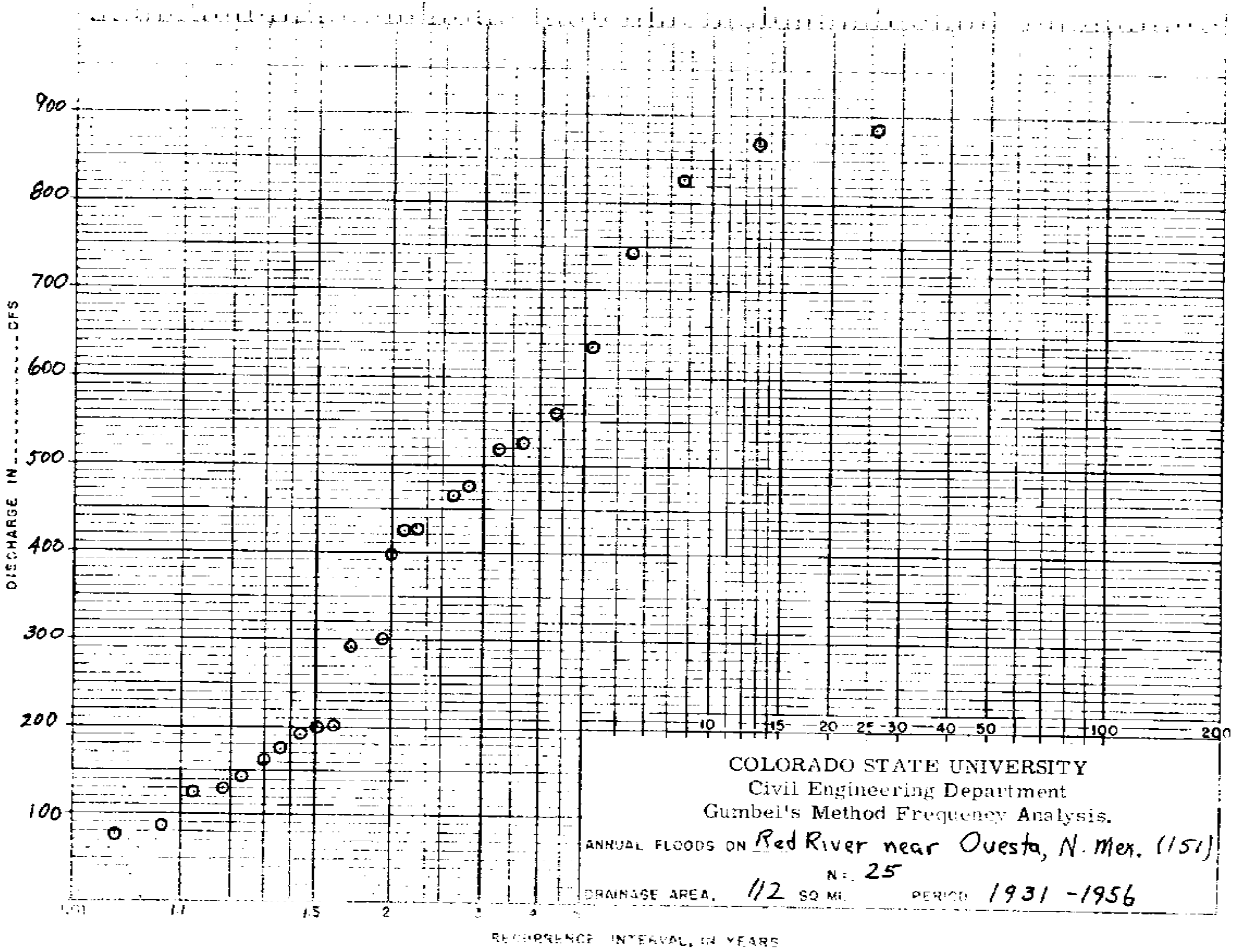
N = 46

DRAINAGE AREA, 1320 SQ. MI PERIOD 1911 - 1956



COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Cunejos River near Mogote, Colo. (150)
N = 44
DRAINAGE AREA, 282 SQ. MI. PERIOD 1913-1956

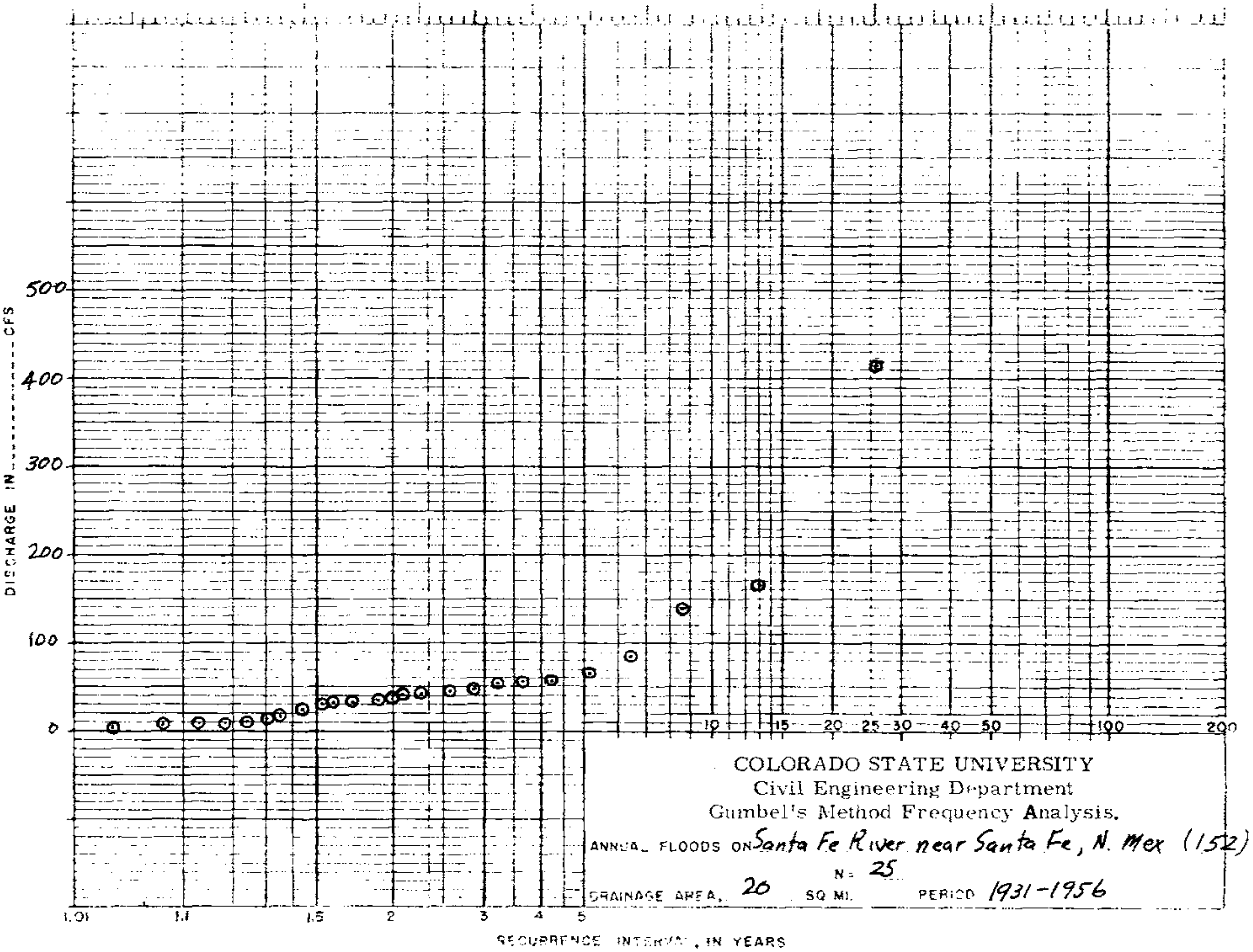


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Red River near Ouesta, N. Mex. (151)

N = 25

DRAINAGE AREA, 112 SQ MI. PERIOD 1931 - 1956

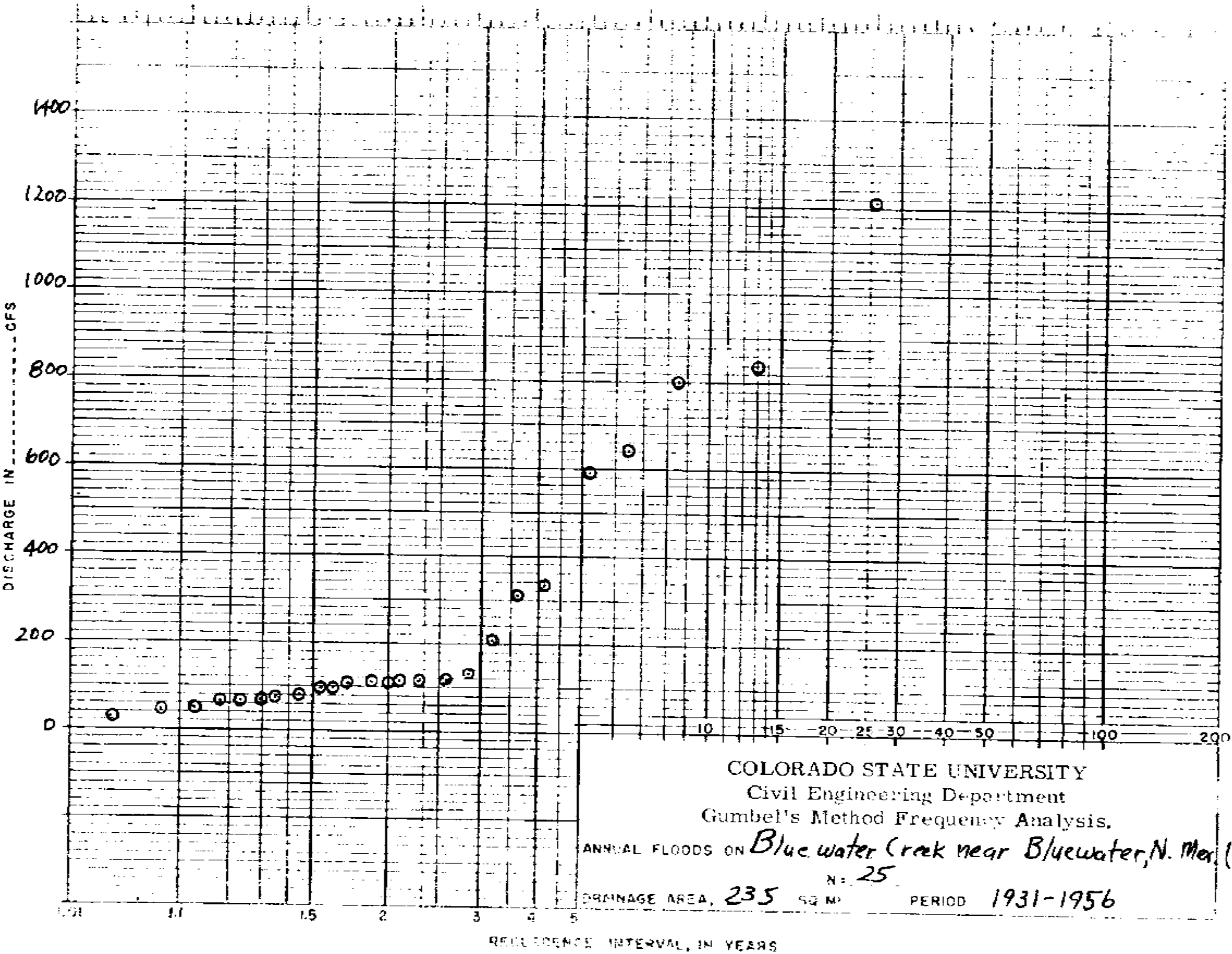


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Santa Fe River near Santa Fe, N. Mex (152)

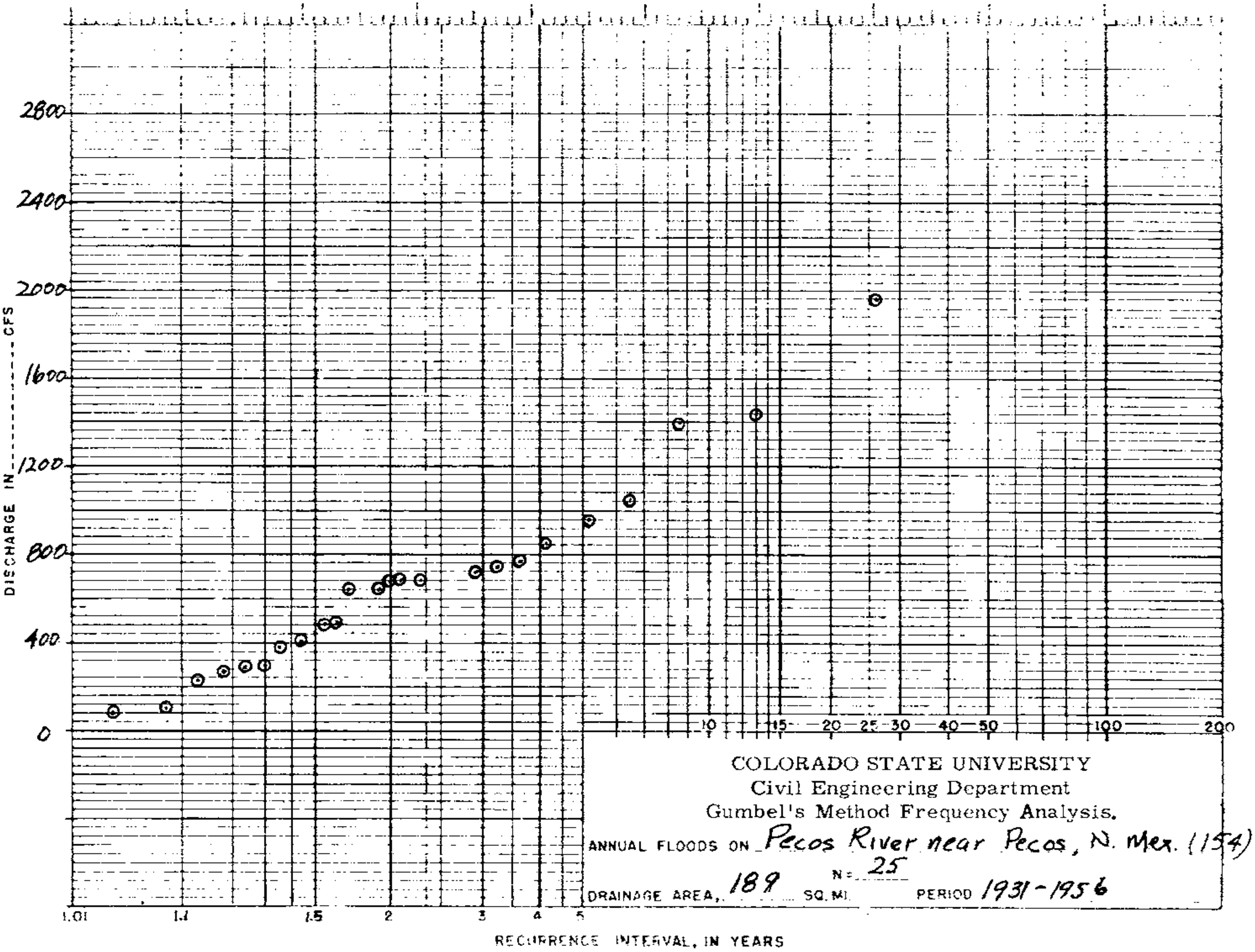
N = 25

DRAINAGE AREA, 20 SQ MI. PERIOD 1931-1956



COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Blue water Creek near Bluewater, N. Mex. (153)
N: 25
DRAINAGE AREA, 235 SQ MI PERIOD 1931-1956

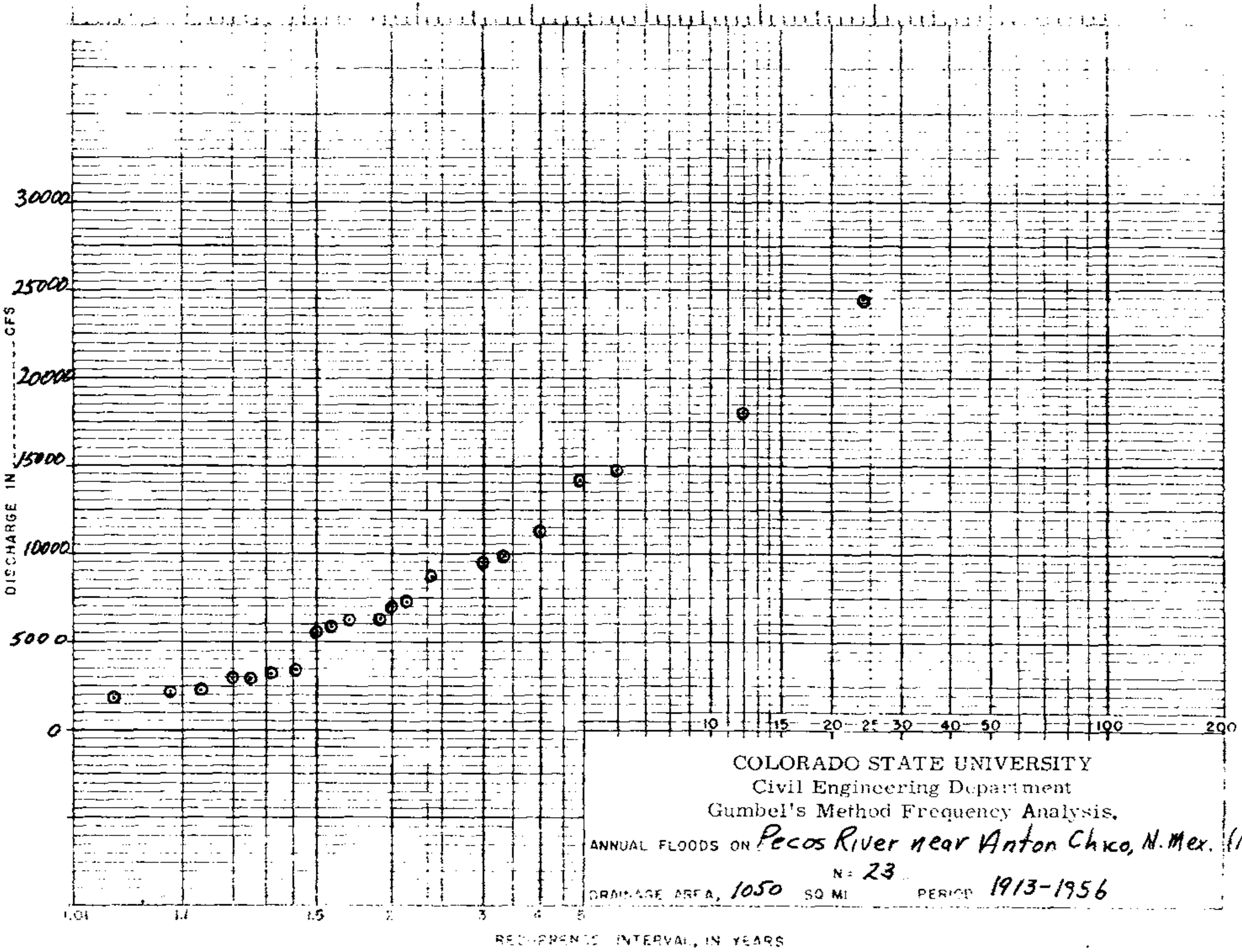


COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Pecos River near Pecos, N. Mex. (154)

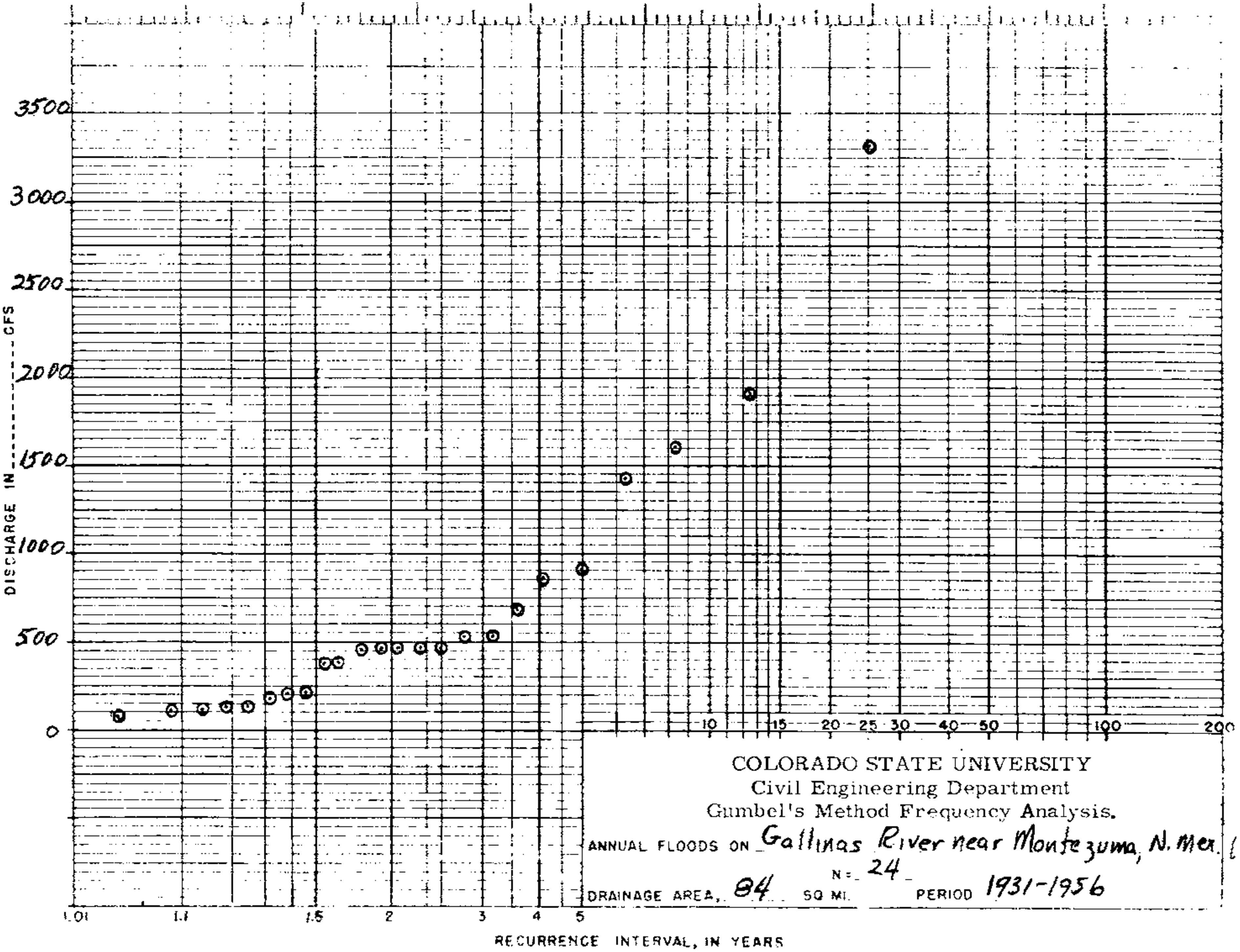
N= 25

DRAINAGE AREA, 189 SQ. MI. PERIOD 1931-1956



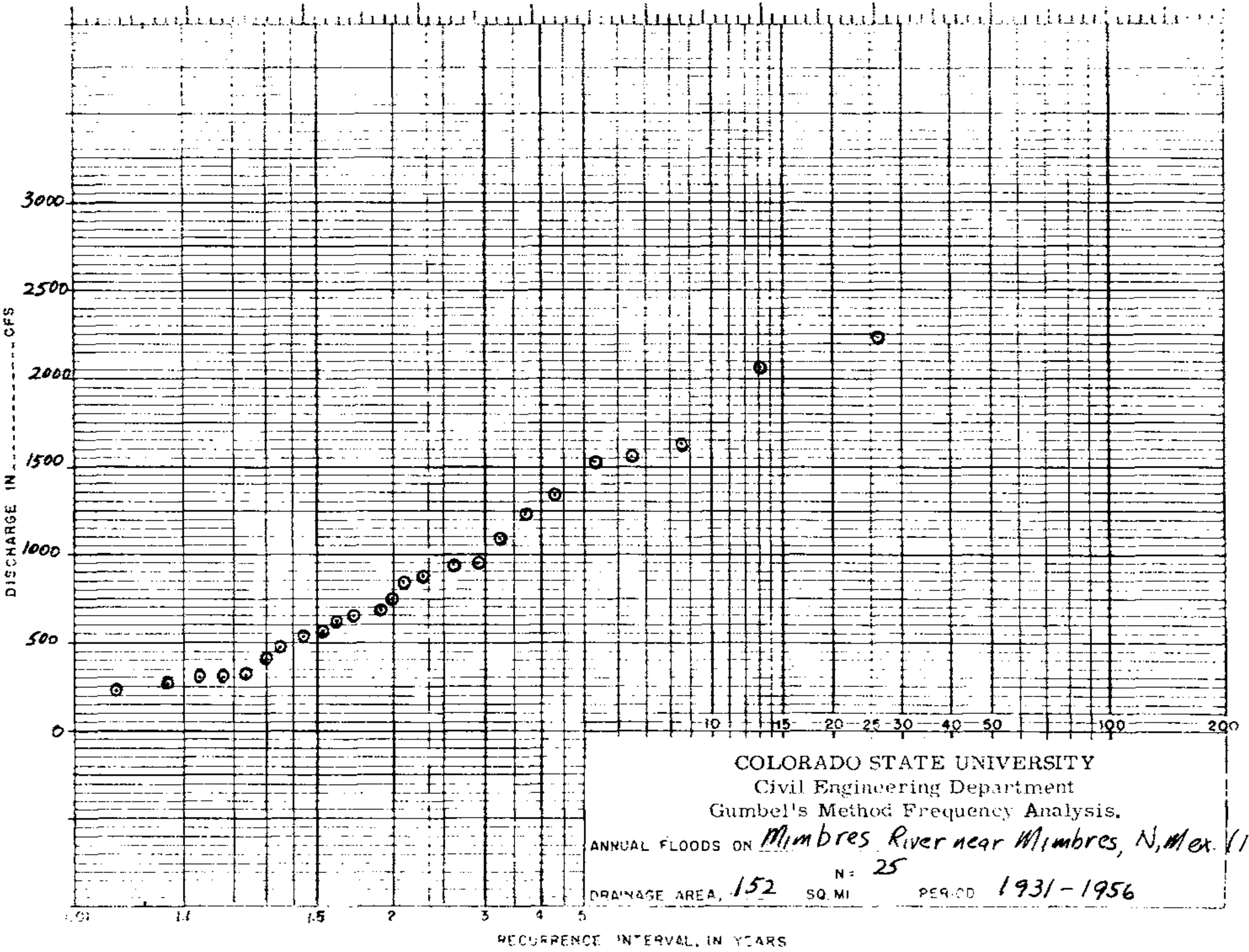
COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Pecos River near Anton Chico, N. Mex. (155)
N = 23
DRAINAGE AREA, 1050 SQ MI PERIOD 1913-1956



COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Gallinas River near Montezuma, N. Mex. (156)
N = 24
DRAINAGE AREA, 84 SQ MI. PERIOD 1931-1956



COLORADO STATE UNIVERSITY
Civil Engineering Department
Gumbel's Method Frequency Analysis.

ANNUAL FLOODS ON Mimbres River near Mimbres, N.Mex. (15-8)

N = 25

DRAINAGE AREA, 152 SQ.MI PERIOD 1931 - 1956

APPENDIX NO. 3.

LIST OF PERSONS CONTACTED

DURING THE STUDY.

APPENDIX NO. 4.

USE OF "RELATIVE WETNESS" PARAMETERS FOR ESTIMATES OF CLOCK-HOURLY PRECIPITATION IN EASTERN COLORADO

ABSTRACT

This is a report of an investigation made to determine the interrelations among precipitation amounts for various durations for a given recurrence interval for precipitation records from stations located in parts of eastern Colorado. The concept of "Relative Wetness" is introduced to provide estimates of clock-hourly precipitation amounts for the two-year recurrence interval from precipitation amounts of longer durations for the same recurrence interval. Comparisons are made of the accuracy of these estimates. Preliminary studies show that estimates of clock-hourly precipitation can be made with acceptable accuracy from the records of precipitation amounts of longer duration.

I. INTRODUCTION

The intensity and frequency of precipitation is one of the factors that affect runoff from small watersheds. For small watersheds, particularly in areas where thunderstorm precipitation predominates, short-duration precipitation is of paramount importance.

Records of short-duration rainfall are available in the published records of clock-hourly rainfall, derived from records of recording rain gages. These recording gages are fewer in number than the non-recording gages. In order to provide additional information on short duration rainfall, it would be desirable to utilize the more plentiful data from non-recording gages. In addition to being more plentiful, the non-recording gages offer the advantage that on the average, the records are of longer duration than the recording rain gages.

II. OBJECTIVE

The objective of the study was to evaluate methods for making estimates of clock-hourly precipitation for a given recurrence interval from parameters derived from non-recording rain gages for an area in eastern Colorado.

III. METHOD OF INVESTIGATION

STUDY AREA

The area covered in this study included part of Colorado east of the Continental Divide in the vicinity of Denver. The study area was divided into five subareas, each subarea containing five or more recording gage stations. A map of subareas is given in Fig. 17. In the course of the study, one additional subarea was selected. (Area VI, shown on Fig. 17.)

SOURCE OF PRECIPITATION INFORMATION

Precipitation records were obtained from climatological data published by the U.S. Weather Bureau.

DEFINITION AND COMPUTATION OF "RELATIVE WETNESS"

Following are definitions of terms used in this study.

"Relative Wetness" refers to the ratio R_{ij}, d_{ij}, M_{ij}, A_{ij}, defined as follows:

$$R_{ij} = \frac{\text{2 year freq. max. hourly precipitation in inches at station } i}{\text{2 year freq. max. hourly precipitation in inches at station } j}$$

$$d_{ij} = \frac{\text{2 year freq. max. daily precipitation in inches at station } i}{\text{2 year freq. max. daily precipitation in inches at station } j}$$

$$M_{ij} = \frac{\text{2 year freq. max. monthly precipitation in inches at station } i}{\text{2 year freq. max. monthly precipitation in inches at station } j}$$

$$A_{ij} = \frac{\text{2 year freq. max. yearly precipitation in inches at station } i}{\text{2 year freq. max. yearly precipitation in inches at station } j}$$

The subscript is an index notation with $i = 1, 2, 3, \ldots\ldots n-1$, and $j = i+1, i+2, \ldots n$, where n is the total number of stations in the subarea. Ranking of stations was made in such a way that d_{ij}, M_{ij}, and A_{ij} were all less than unity.

From records from selected stations for the period 1948-57, annual maximum and summer seasonal (May - August) maximum precipitation values for each of the above durations were compiled for each station. Using Gumbel plotting positions, the precipitation amounts having a two-year recurrence interval was determined for hourly, daily, monthly and annual values. An example of the Gumbel plots is shown in Fig. 18.

Stations within each subarea were then ranked suitably to yield values of d_{ij}, M_{ij}, $A_{ij} \leq 1.0$, and values of R_{ij}, d_{ij}, M_{ij}, and A_{ij}, were then computed. Note that the subscript "s" refers to seasonal values (May - August) and the subscript "a" refers to annual values.

IV. RESULTS

RELATIONS AMONG R_{ij}, d_{ij}, M_{ij}, and A_{ij}.

R_{ij} vs d_{ij}, R_{ij} vs M_{ij}, and R_{ij} vs A_{ij} were plotted both for annual and seasonal values for each subarea. Assuming an equation of the form $y = mx$, the best fit line was computed by the method of least squares. A distribution of error chart was prepared for each plot. These error charts were prepared to give a measure of the dispersion of the data from the best-fit curves. Results were presumed to be of acceptable accuracy if 67 per cent of the data fell within ±25 per cent of the fitted regression line. Figures 19 and 20 illustrate these procedures.

Examination of 25 plots comparable to Fig. 20 revealed that only 3 had error greater than ±25 per cent for 67 per cent of the plotted points. This indicates generally acceptable accuracy for the technique. To further delimit the dispersion of the data from the best-fit lines, the areas between the ordinate and the distribution-of-error curve for 0-67 per cent of the sample were determined. Using these areas as a measure of dispersion, the various combinations of relative wentess ratios were arranged in order of increasing error as shown in Table 1. Numbers shown in Table 1 indicate planimeter readings.

TABLE 1. RANKING OF RELATIVE WETNESS RATIO IN ORDER OF INCREASING ERROR OF ESTIMATE **OF R_{ij}

Area	1 (least error)	2	3	4	5 (Most error)
I	Rs/ds 39.5	Ra/Ma 41.0	Rs/Ms 43.0	Ra/da* 43.0	Ra/A 57.0
II	Rs/Ms 18.0	Rs/ds 26.0	Ra/da 29.0	Ra/Ma 39.5	Ra/A 45.0
III	Ra/A 5.0	Ra/Ma 10.0	Rs/Ms 23.0	Ra/da 28.0	Rs/ds 30.0
IV	Rs/Ms 10.0	Rs/ds 13.5	Ra/da 19.0	Ra/A 23.0	Ra/Ma 32.0
V	Rs/ds 30.0	Ra/A* 37.5	Rs/Ms 50.0	Ra/Ma*56.0	Ra/da 63.0

** Based on areas between ordinate and distribution of error curve for 0-67 per cent of the sample.

*Indicates greater error than 67 per cent of the sample within ±25 per cent.

It will also be noted from Table 1 that for four out of five cases, the best estimates resulted from use of seasonal data. Conversely, for four out of five cases, the worst estimates were associated with use of annual data.

Since R_{ij} vs d_{ij} (seasonal basis) showed least error for subareas I and V, and gave accuracy better than 67 per cent of the sample within ±25 per cent for each of the other three areas, R_{ij} vs d_{ij} was chosen as the relation for use throughout all five subareas, plus an additional subarea - No. VI. The relation between d_{ij} and R_{ij} for each of the subareas I through VI, is shown in Fig. 21.

V. CONCLUSIONS

1. Summer season (May through August) and annual precipitation values can serve as suitable parameters for making estimates of clock-hourly precipitation amounts having a two-year recurrence interval.

2. Seasonal precipitation parameters give slightly more accurate estimates of clock-hourly precipitation than annual parameters in the areas studied.

3. Procedures for making estimates of clock-hourly precipitation described herein apply to two-year recurrence interval values only.

4. Techniques for obtaining a clock-hourly precipitation estimate from relative wetness data should be applicable for any point within the subareas.

VI. ILLUSTRATION OF THE USE OF RELATIVE WETNESS PARAMETERS FOR ESTIMATING CLOCK-HOURLY PRECIPITATION.

In this section a description is given of the procedure to be followed in estimating the clock-hourly precipitation amount (two-year recurrence interval) from the 24 hour precipitation amount having a two-year recurrence interval. The procedure illustrated is applicable to any of the areas shown in Fig. 17, using data for the appropriate areas as given in Fig. 21.

For this illustration the stations of Nunn and Greeley will be used. Both of these stations have clock-hourly precipitation records so a check can be made of the accuracy of estimating the two-year clock-hourly rainfall at Nunn from the 24-hour precipitation amounts at Nunn and the clock-hourly and 24-hour precipitation amounts at Greeley.

The procedure is described in the following steps:

1. Select station "j"; (in this case Nunn) a station for which daily rainfall records are available, and for which an estimate of the two-year

clock-hourly precipitation amount is desired.

2. From examination of the rainfall records in published climatological data, determine the maximum 24-hour precipitation amount that fell during each summer season (May through August) for each of the last ten years at Nunn.

3. Plot these data on Gumbel frequency paper.

4. From such a plot (not illustrated here) the 24-hour amount having a two-year recurrence interval was determined to be 1.21 inches. The value is $d_{24j} = 1.21$ inches.

5. Select station "i"; (in this case Greeley) the nearest station having clock-hourly data available.

6. Repeat steps 2, 3, and 4 above for station "i" , using both clock-hourly and 24-hour rainfall data. These data are plotted in Fig. 18, from which the values having a 2-year recurrence interval were determined to be

   a. Clock-hourly amount, $P_{60i} = .42$ inch.

   b. Daily (24-hour) amount, $d_{24i} = .95$ inch.

7. Form the ratio d_{ij} , such that $d_{ij} \leq 1.0$

$$d_{ij} = \frac{d_{24i}}{d_{24j}} = \frac{.95}{1.21} = .785$$

8. Enter Fig. 21 with $d_{ij} = 0.785$ and estimate $R_{ij} = \frac{P_{60i}}{P_{60j}} = 0.725$,

   using the curve for area D.

9. Compute $P_{60j} = P_{60i}/0.725$, using the value of $P_{60i} = 0.42$ as determined in step six; $P_{60j} = \frac{0.42}{0.725}$ $P_{60j} = 0.58$ inch.

This is the estimate of the clock-hourly precipitation amount having a two-year recurrence interval at station j , Nunn, Colorado.

10. The actual value of P_{60j} as taken from a Gumbel plot (not reproduced here) was 0.69 inch.

11. Error of estimate $= \frac{\text{deviation}}{\text{estimate}} \times 100 = \frac{.69-.58}{.69} \times 100 = 16$ per cent.

VII. COMMENTS REGARDING USE OF "RELATIVE WETNESS" RELATIONS FOR ESTIMATES OF RUNOFF

The precipitation parameters that were used in attempts to explain differences in runoff characteristics (Page 5 of main report) consisted of 24-hour rainfall amounts having a 2-year and a 5-year recurrence interval. Sparcity of data from recording rain gages prevented use of comparable data for the 60-minute duration.

The "Relative Wetness" study described herein indicates that sufficient correlation exists between 60-minute and 24-hour rainfall amounts that the latter provides an acceptable estimate of the former. This principle is being used to develop a precipitation map of the study area for future use in runoff studies. Sufficient time was not available for completion of this study at the time of preparation of this report.

APPENDIX NO. 5.

CORRELATION OF CPS-9 RADAR ECHO INTENSITY WITH CLOCK-HOURLY PRECIPITATION

CORRELATION OF CPS-9 RADAR ECHO INTENSITY WITH CLOCK-HOURLY PRECIPITATION

OBJECTIVE:

The objective of the study was to correlate clock-hourly precipitation amounts with CPS-9 radar echo intensity data reconstructed from original records of CPS-9 data from Lowry Air Force Base, Denver, Colorado, from 3-15 June 1958.

PROCEDURE:

The positions of radar echoes in relation to 45 recording rain gage. sites were determined by superimposing a plastic map of rain gage location over the reconstructed sketches of CPS-9 data. The presence or absence of an echo over the locations of the rain gaging stations were recorded, along with the type of echo. These data were then compared with concurrent clock-hourly precipitation data. The clock-hourly precipitation data were divided into four classes, and the radar echo data were divided into six classes, as shown in Table 1.

Table 1. Clock-hourly precipitation and radar echo classes

Clock-hourly precipitation classes, inch per hour:

0, 0.01 - 0.05, 0.06 - .10, and .11

Radar echo class code (Convective echoes only)

Intensity:	Low	Medium	Strong		
	1	2	3	Scattered,	$\leq$ .5 coverage
	4	5	6	Broken	$\geq$ .6 coverage

The number of occurrences of each of the precipitation classes was determined for each echo class. The results are given in Table II.

A similar procedure was followed to determine the number of occurrences of each echo class concurrent with each category of clock-hourly precipitation. The results are given in Table III.

RESULTS:

The results of the study are given in Tables II and III. In addition to the total number of occurrences, the fractions of the totals within each class are given as percentages.

DISCUSSION OF RESULTS:

1. Table II shows that 1348 out of 1545 radar observations, or 87 per cent of the total, were associated with zero precipitation.

2. Nearly half (48 percent) of all echoes were in echo category 3, i.e., scattered, strong convective echoes. The next largest group, 39 per cent, were in category 6, i.e., broken, strong convective echoes.

3. This preponderance of echoes in categories 3 and 6 suggests an operator bias toward designation of echoes as strong, since the categories of low or medium intensity echoes were listed less than 15 per cent of all observations, despite the fact that low intensity precipitation (0.01 - 0.5 in/hr.) accounted for 71 per cent of all precipitation observations.

CONCLUSIONS:

1. The CPS-9 data do not provide a suitable means for determination of rainfall intensity.

2. An operator bias toward designation of echoes as strong is indicated.

3. The limited sample studied showed approximately 85 per cent of all clock-hourly precipitation having an intensity of 0.10 inch per hour or less.

TABLE II

Table II. Clock-hourly precipitation associated with various radar echo* categories. (Convective precipitation.)

RADAR ECHO CLASSES **

Precipitation Classes
Inch per hour

	1	2	3	4	5	6	No	Per Cent
No precip.	45	87	686	4	45	481	1348	87
***	0	0	1	0	0	1	2	<1
.01-.05	6	7	39	1	4	74	131	8
.06-.10	1	0	6	2	0	14	23	1
> .10	1	0	14	0	0	26	41	3
No:	53	94	746	7	49	596	1545	100
Per cent:	3	6	48	<1	3	39		

* Radar data from CPS-9 at Lowry Air Force Base Denver, Colorado 3-15 June 1959.

** Echo Glass Code:

Intensity	Low	Medium	Strong		
	1	2	3	Scattered,	≤ .5 coverage
	4	5	6	Broken,	≥ .6 coverage

*** No record of precipitation distribution.

TABLE III

Table III. Radar echo amounts and intensities associated with various measured clock-hourly precipitation amounts. (Convective precipitation.)

CLOCK-HOURLY PRECIPITATION CLASSES
Inches Per Hour

Echo Classes*	**	.01-.05	.06-.10	>.10	No.	Percent
No echo	2	138	22	17	179	46
1	0	6	1	1	8	2
2	0	7	0	0	7	2
3	2	48	10	16	76	20
4	0	0	0	0	0	
5	0	4	0	0	4	1
6	0	74	17	24	115	30
No:	4	277	50	58	389	100
Percent:	1	71	13	15		

*Echo Class Code:

Intensity	Low	Medium	Strong		
	1	2	3	Scattered,	<.5 coverage
	4	5	6	Broken,	≥.6 coverage

** No record of precipitation distribution.

0 No echo.

APPENDIX NO. 6.

CORRELATION OF RADAR ECHO INTENSITY WITH CLOCK-HOURLY PRECIPITATION

CORRELATION OF RADAR ECHO INTENSITY WITH CLOCK-HOURLY PRECIPITATION

OBJECTIVE:

The objective of the study was to correlate clock-hourly precipitation amounts with radar echo intensity as determined from hand-drawn sketches of the PPI scope of the United Air Lines 5.5 cm radar set at Stapleton Field, Denver, Colorado.

PROCEDURE:

The positions of the radar echoes in relation to recording rain gages were determined by superimposing a plastic map of rain gage location over the hand-drawn sketches of the PPI scope. The presence or absence of echoes and the intensities of echoes at the gage locations were then recorded. Two methods of analysis were used -- in the first method the position of the echo was interpolated between successive hourly (or half-hourly) observations. In the second method, the positions of the echoes were considered at hourly (or half-hourly) intervals only.

The frequency of occurrence of low, moderate, or high echo intensity was tabulated and compared with the concurrent clock-hourly precipitation amounts at each of 45 sites for each of the two methods of analysis described above. Precipitation class limits were established by dividing the maximum hourly precipitation rate by ten. This analysis was performed for ranges of 0-25, 25-50, 50-75, and 75-100 miles.

RESULTS:

1. No correlation was indicated between radar echo intensity and precipitation intensity for either of the two methods of analysis.

2. Most of the clock-hourly precipitation amounts fell into the lowest precipitation class interval.

3. The data indicate that the hand-drawn sketches of the PPI scope cannot be used successfully to indicate clock-hourly precipitation intensity.

DISCUSSION:

The lack of correlation between radar echo intensity and rainfall intensity could be caused by any combination of the following factors:

1. Error in drawing the sketches of the PPI scope.
2. Non-linearities in the scope presentation.
3. Problems in relating the time of the echo to the time of the clock-hourly precipitation.
4. The problem of evaporation of raindrops between the cloud base and the ground, typical of the high-based clouds of this area.

No attempt was made to assess the relative importance of each of these factors. Reports from other investigators* indicate that the lack of correlation between point rainfall rates and echo intensity may be a characteristic of present radar equipment.

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* Hiser, H. W., H. V. Senn, and L. F. Conover. Rainfall Measurement by Radar using Photographic Integration Techniques. American Geophysical Union Transactions, 39 (6) 1043 - 47, December, 1958.

APPENDIX NO. 7

EFFECT OF ELEVATION AND WATERSHED SIZE ON SEASONAL DISTRIBUTION OF ANNUAL MAXIMUM FLOOD EVENTS.

maximum flood occurrence are later on the plains than in the mountains or the foothills.

A tabulation of the relative time of occurrence for annual flood events as a function of elevation and watershed size is given in Table 1.

TABLE 1.

TABULATION OF DATE OF OCCURRENCE OF 67 PER CENT OF ALL ANNUAL FLOOD EVENTS AS A FUNCTION OF ELEVATION AND WATERSHED SIZE.

Elevation Class ft. msl	Area Class sq. mi.	Approximate date of occurrence	Average date
H	Small	21 June	
M	"	30 May	11 June
L	"	12 June	
H	Medium	7 June	
M	"	12 June	14 June
L	"	24 July	
H	Large	1 July	
M	"	9 June	23 June
L	"	29 June	

H = High elevation range: 7800-11,000 ft. msl

M = Medium elevation, range: 6091-7683 ft. msl

L = Low elevation, range: 2798-6080 ft. msl

Small:	1-127	sq. mi.
Medium:	139-448	sq. mi.
Large:	460-1766	sq. mi.

CONCLUSIONS:

1. Examination of Table 1 shows that the average date of 67 per cent of annual maximum floods advances with increase in watershed size.

2. For watersheds of 139-448 square miles, the date of 67 per cent of annual maximum flood advances with decrease in elevation.

3. For watersheds less than 139 square miles and between 460 and 1766 square miles, the date of occurrence of 67 per cent of annual maximum floods advances with decreasing elevation below 7683 feet msl.

4. The dates of flood occurrence are later on the plains than in the mountain areas and foothills. This 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.

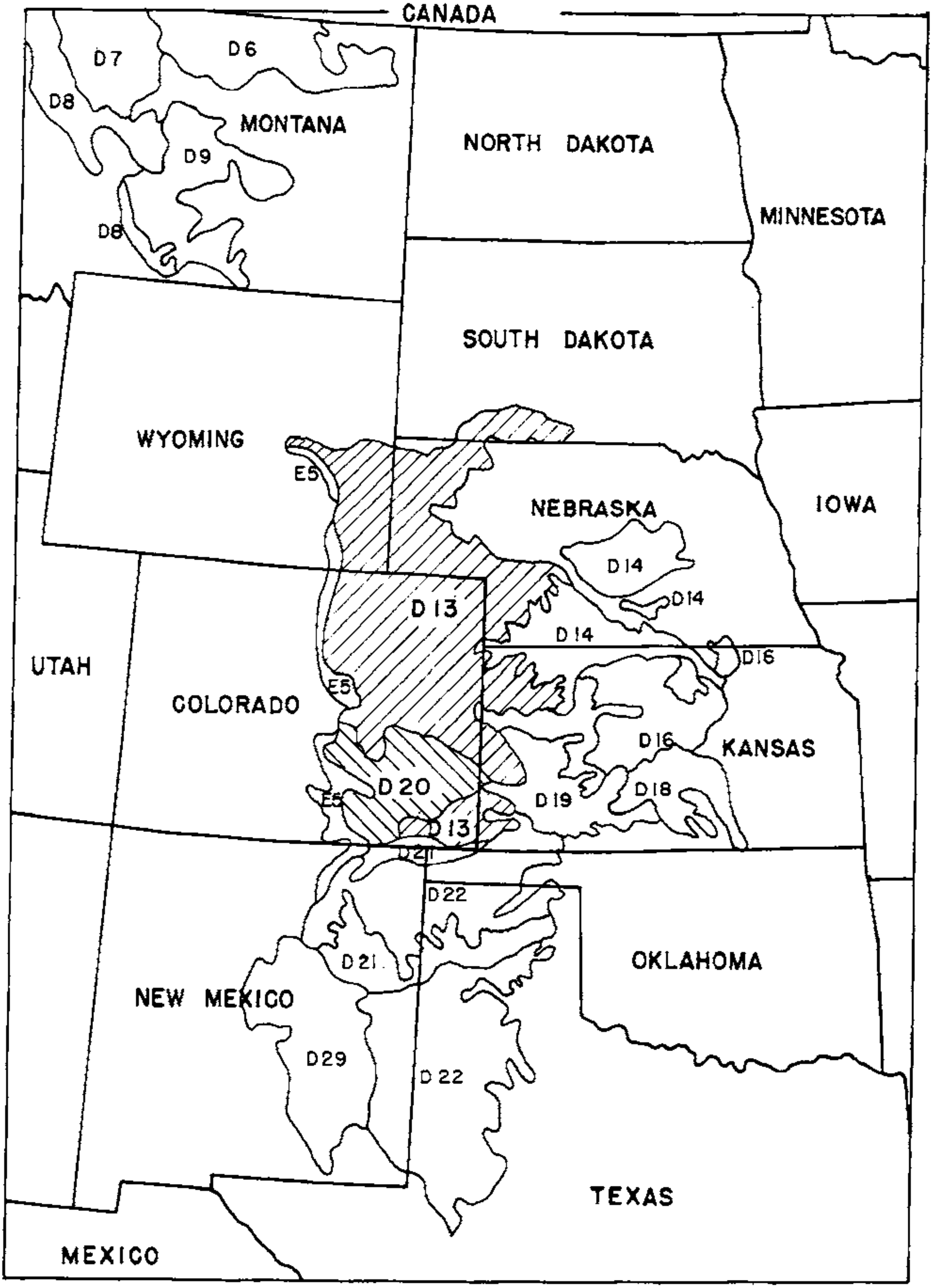


Fig. 1. Location of Study Area.

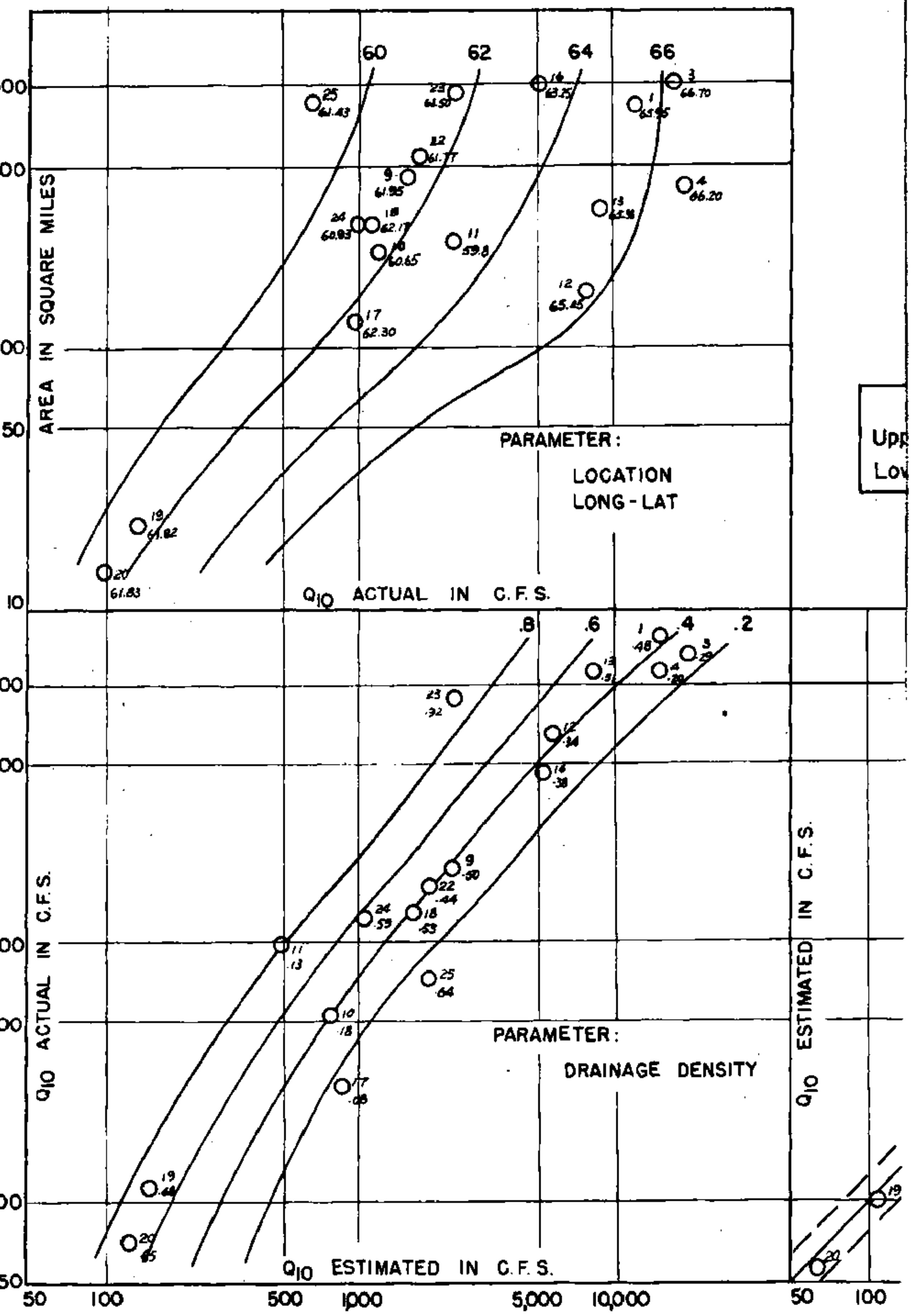
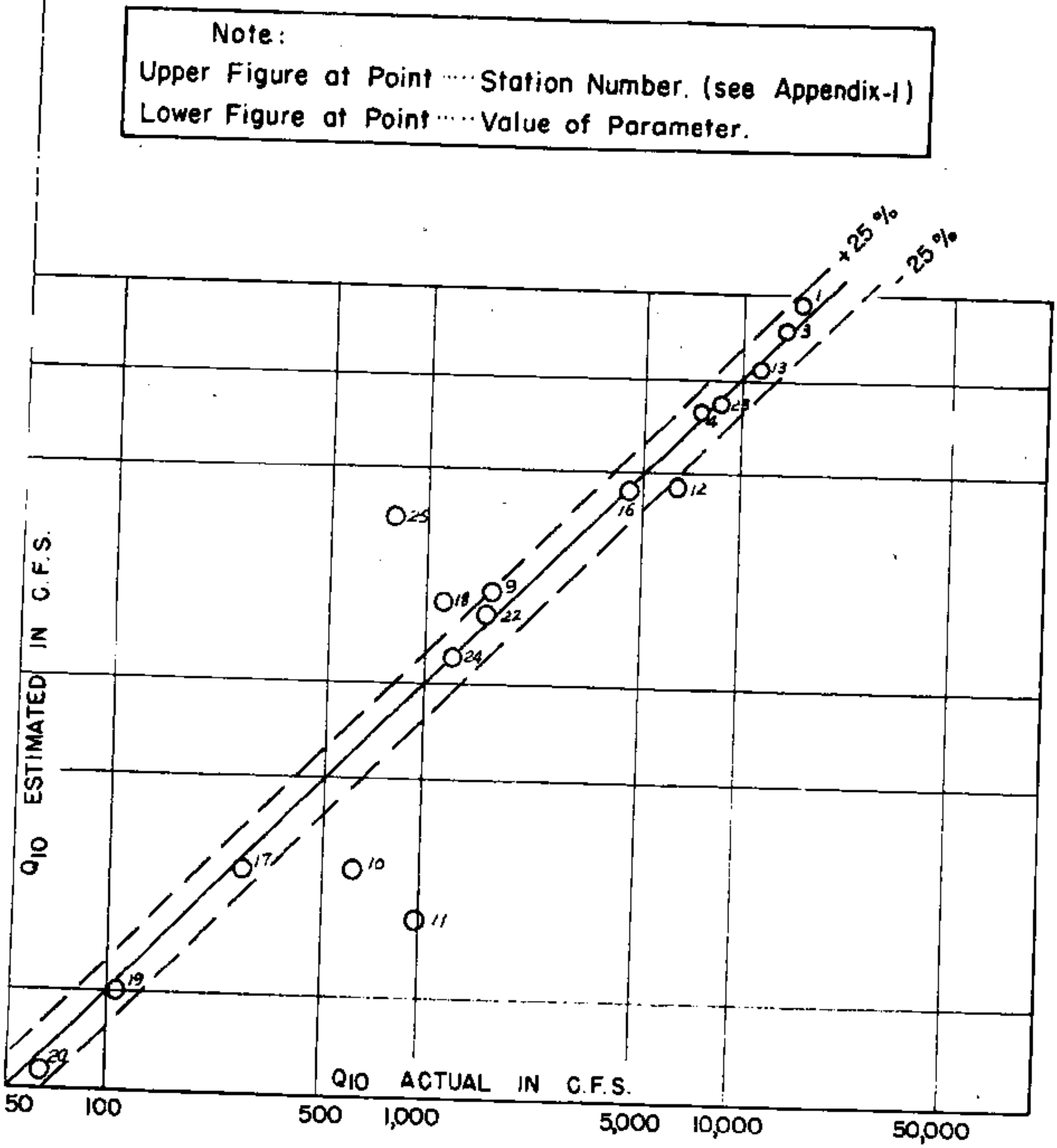


Fig. 2. Preliminary Estimate of Q_{10} from Physiographic Parameters.


Note:
Upper Figure at Point ····· Station Number. (see Appendix-I)
Lower Figure at Point ····· Value of Parameter.

meters.

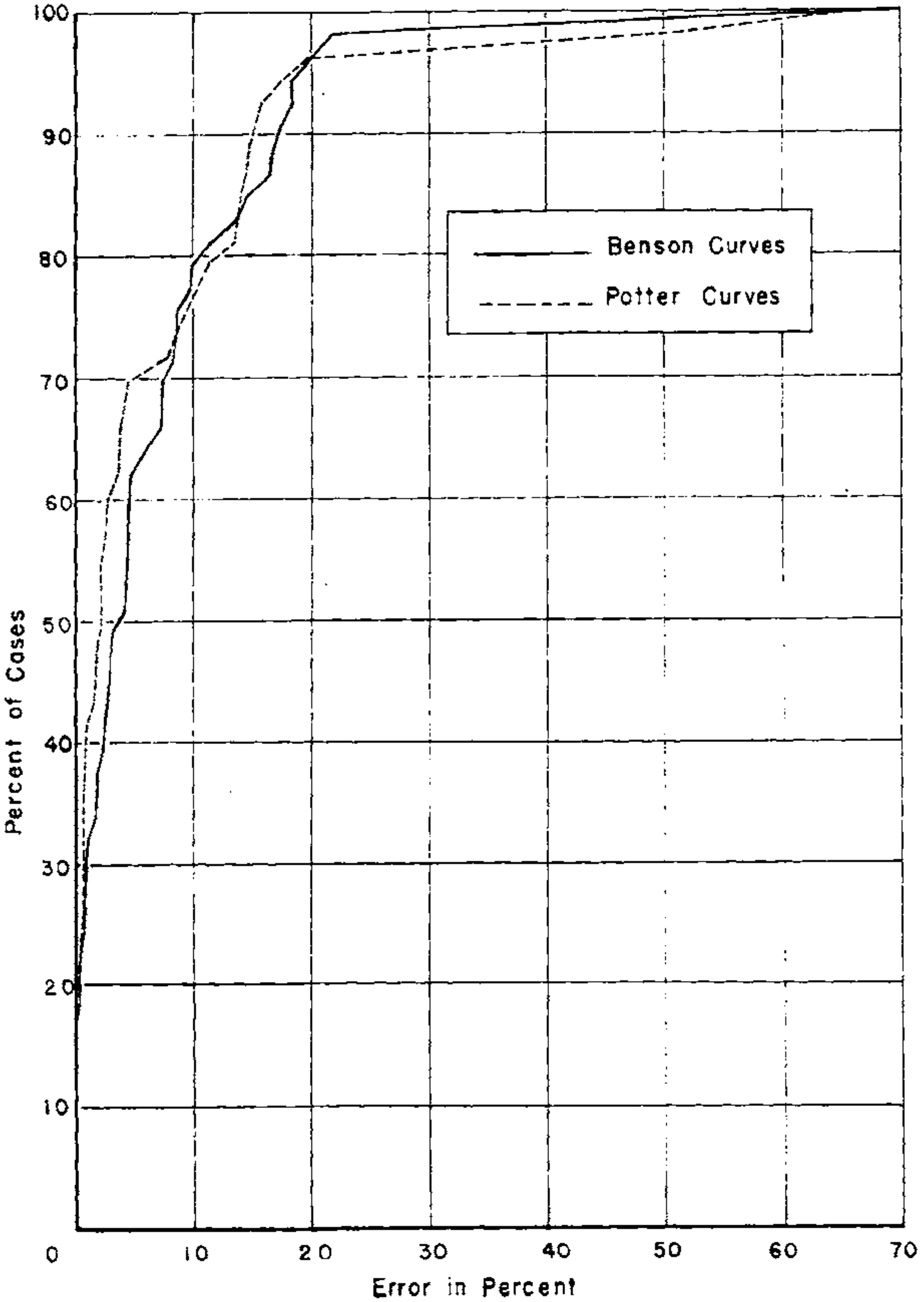


Fig. 3. **Distribution of Error Curves Showing Departure of Plotted Points for Recurrence Intervals Greater Than 10 Years From "Benson" and "Potter" Type Curves on Gumbel Frequency Paper.**

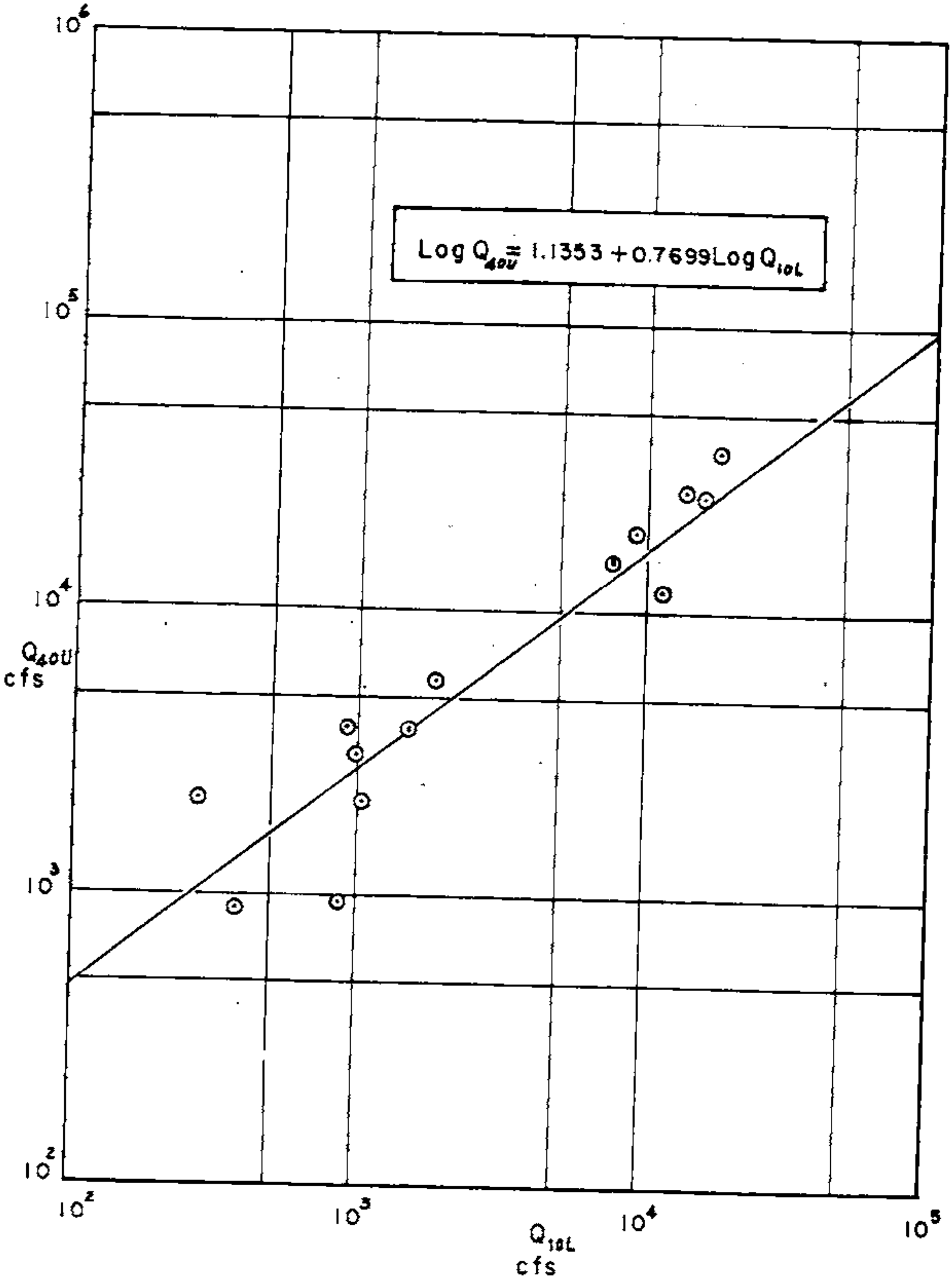
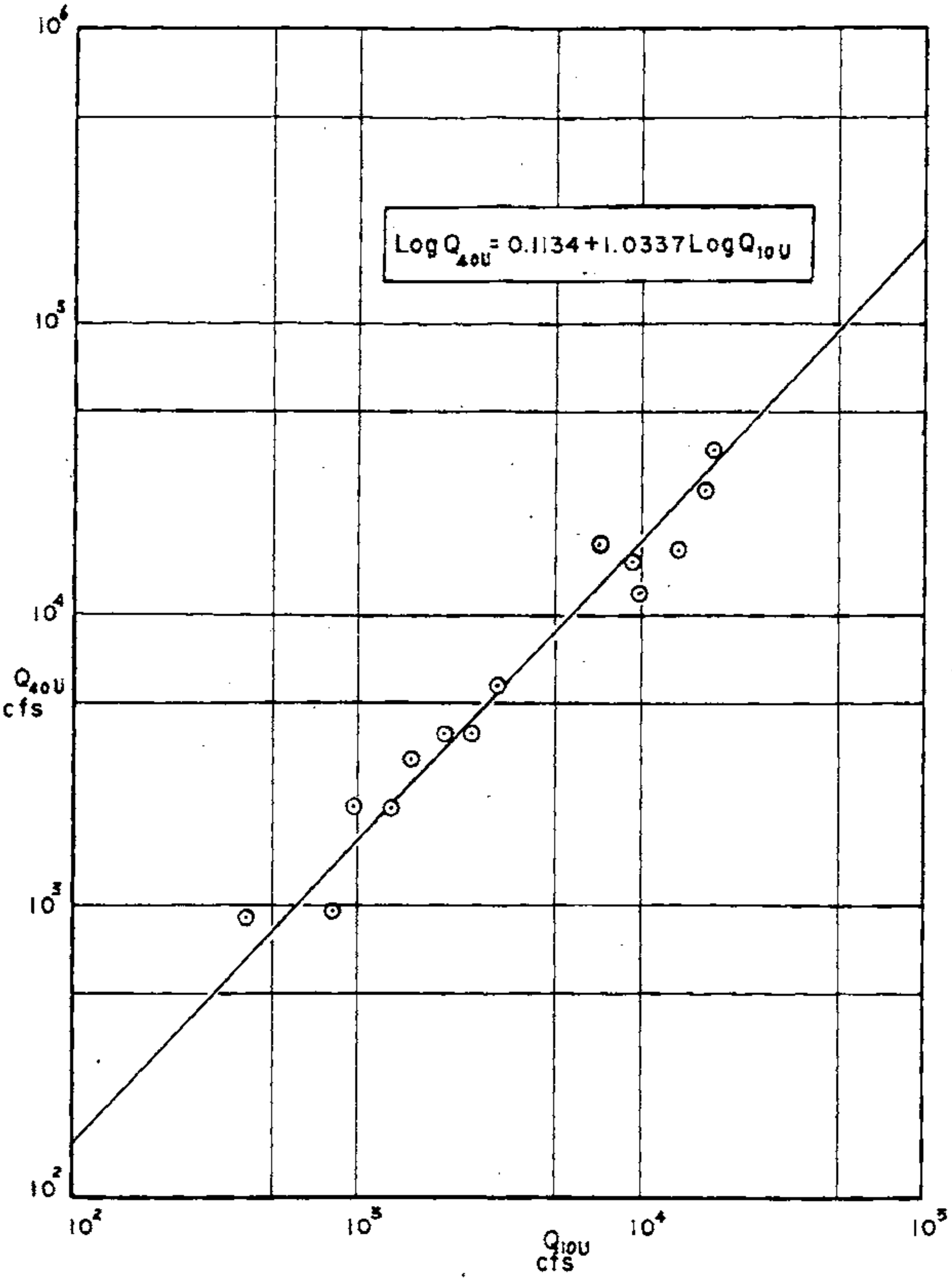


Fig. 5. Relation Between Q_{10L} and Q_{40U}, Q_{10U} and Q_{40U} (Potter method)



for Selected Stations Outside D-13 and D-20 Problem Areas.

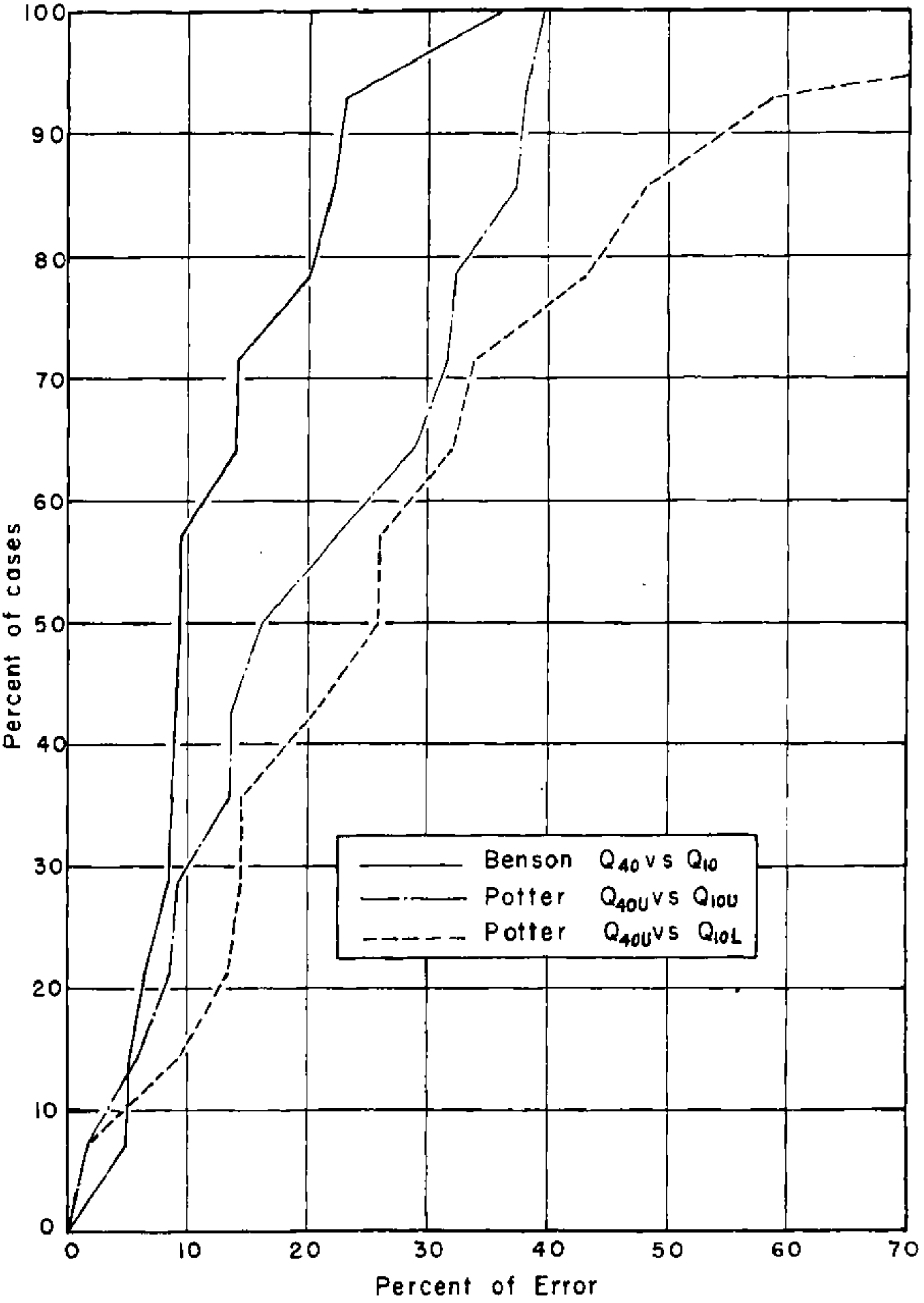


Fig. 6. Distribution of Error Curves for the Relations Shown in Figures 4 and 5.

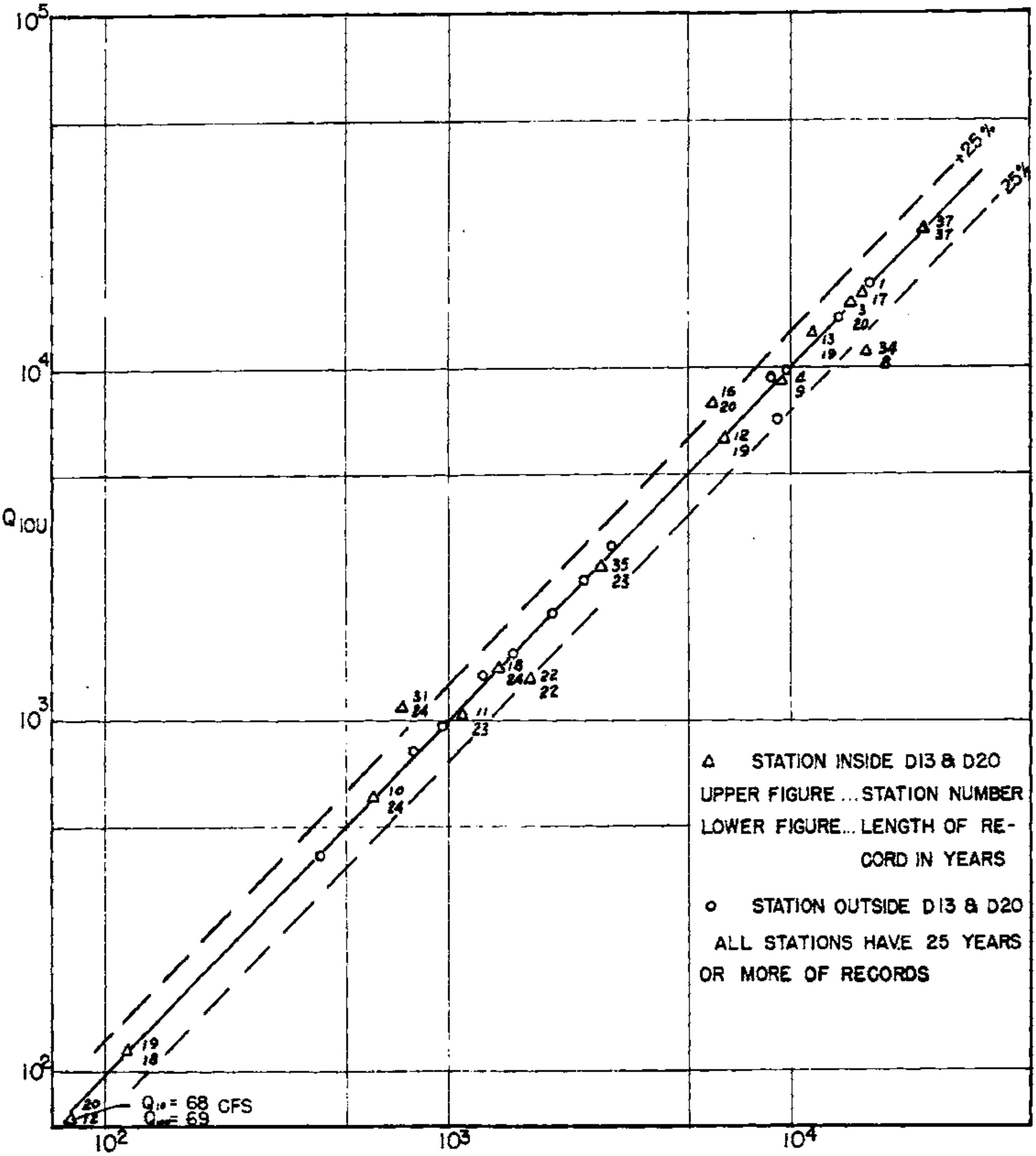


Fig. 8. Comparison of Q_{10} and Q_{10U} for Stations Inside and Outside the D-13 and D-20 Problem Areas.

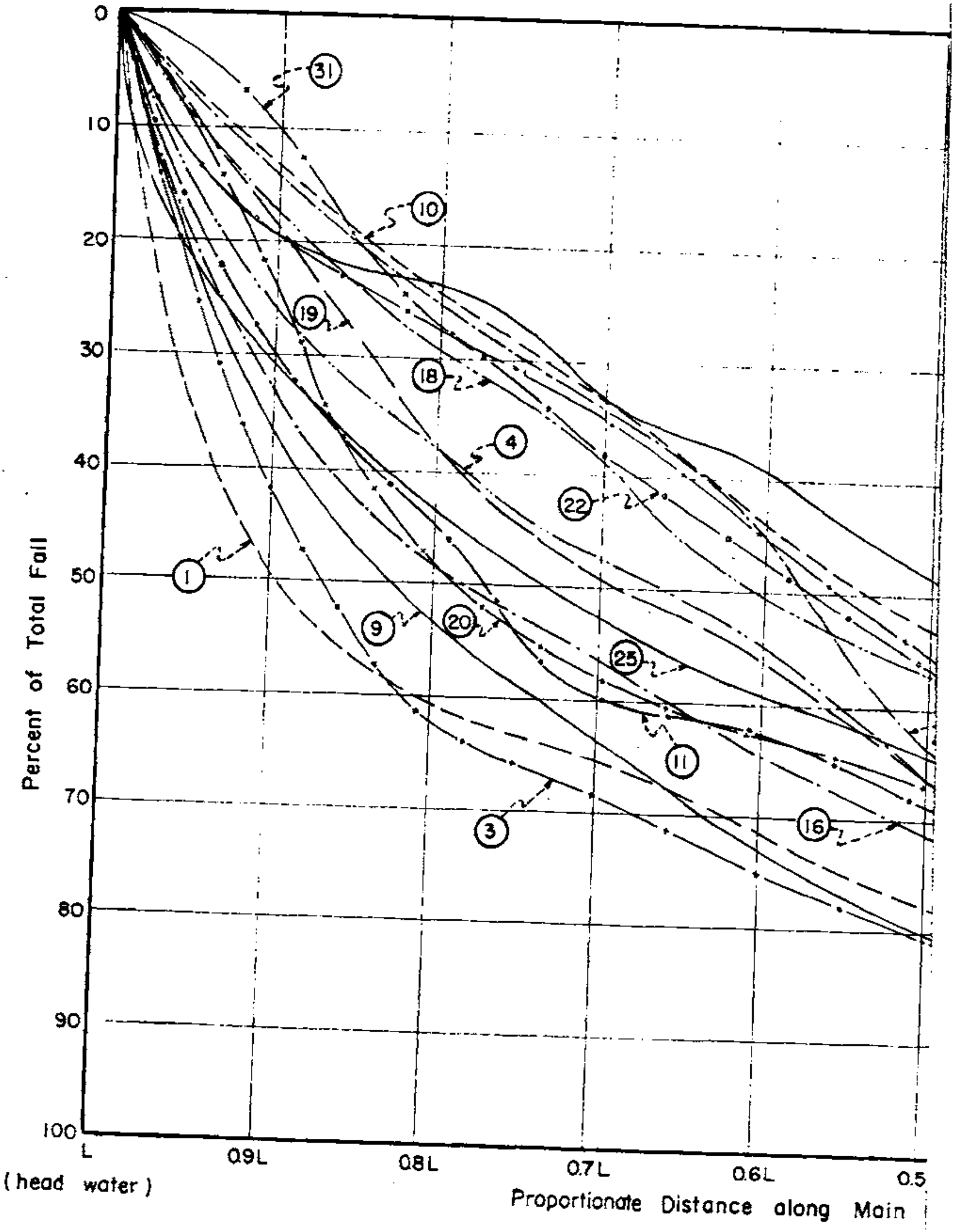
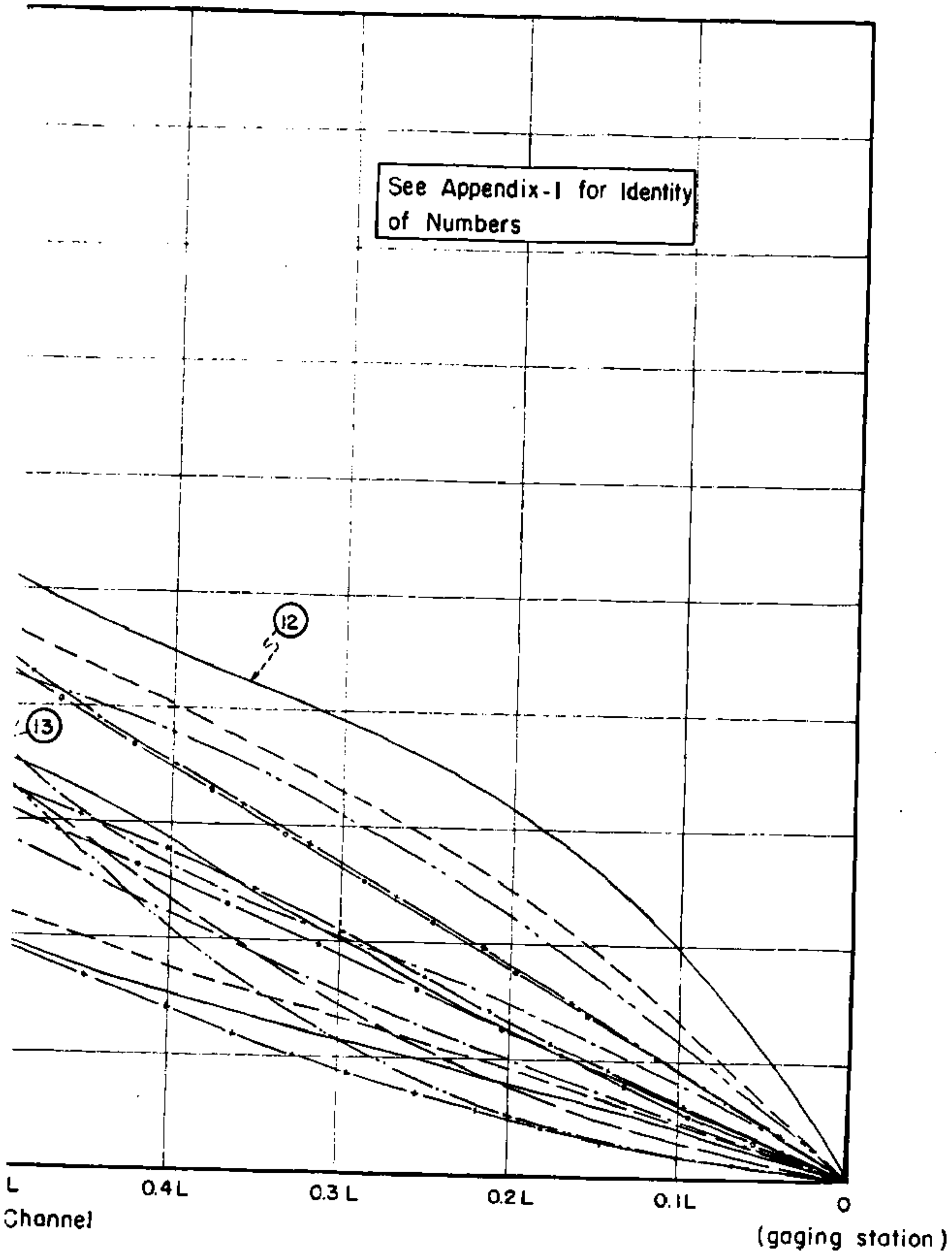


Fig. 9. Dimensionless Profiles of Main Stem of Watersheds Included



in Graphical Correlation.

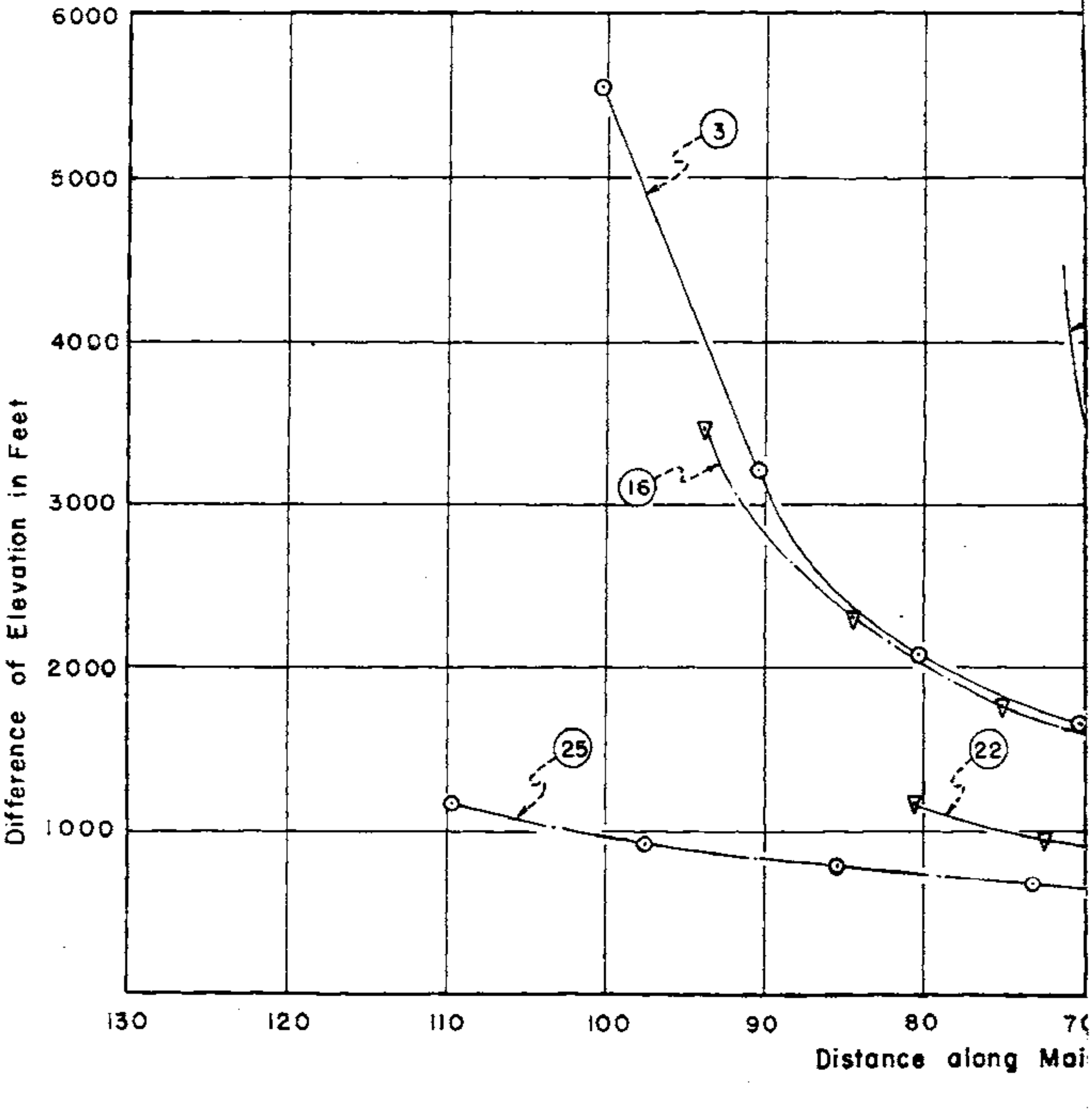
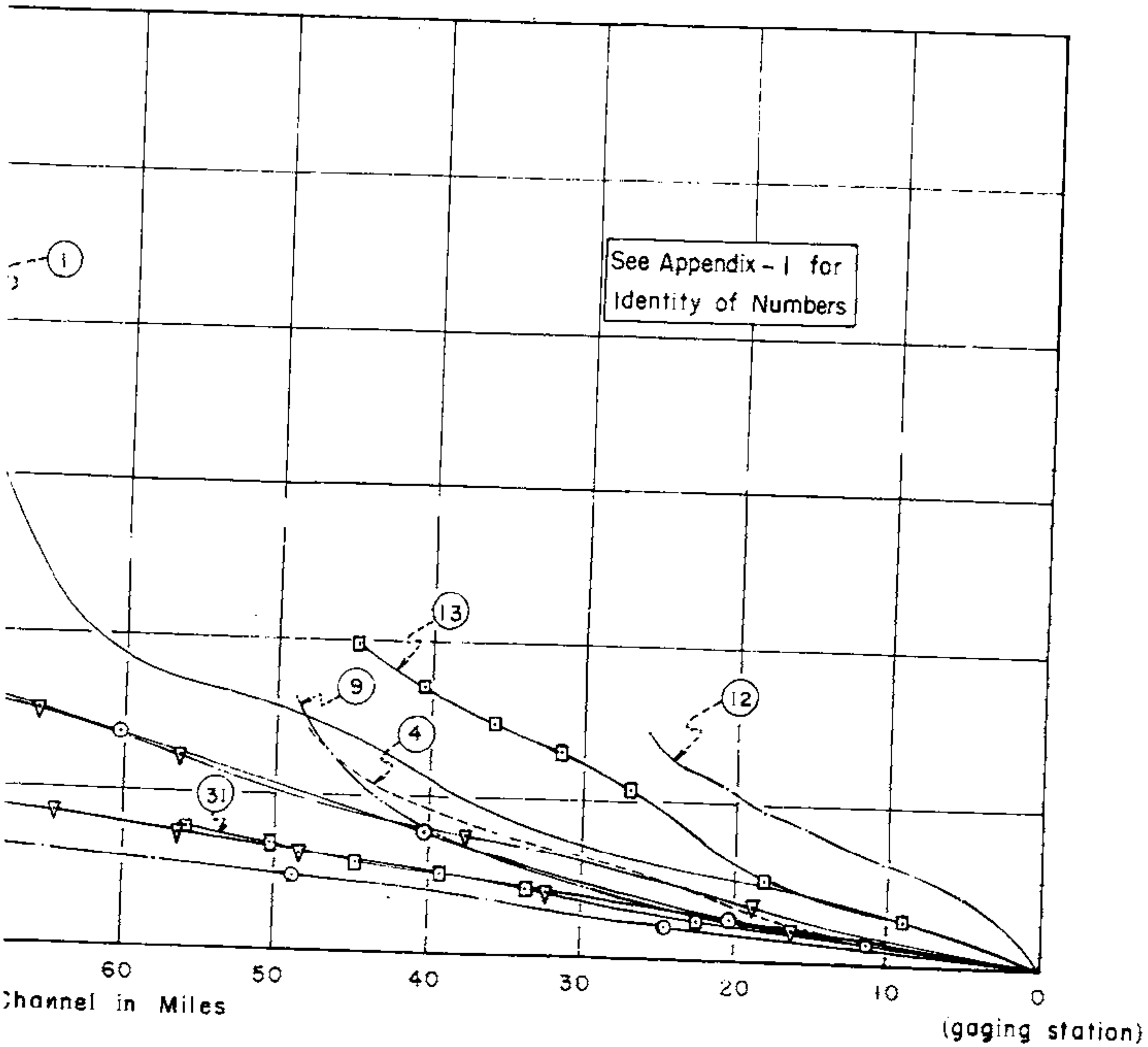


Fig. 10. Profiles of Main Stem of Watersheds Included in Graphical C


See Appendix - I for Identity of Numbers
1
13
9
12
4
31
60
50
40
30
20
10
0
Channel in Miles
(gaging station)

el[illegible]o .

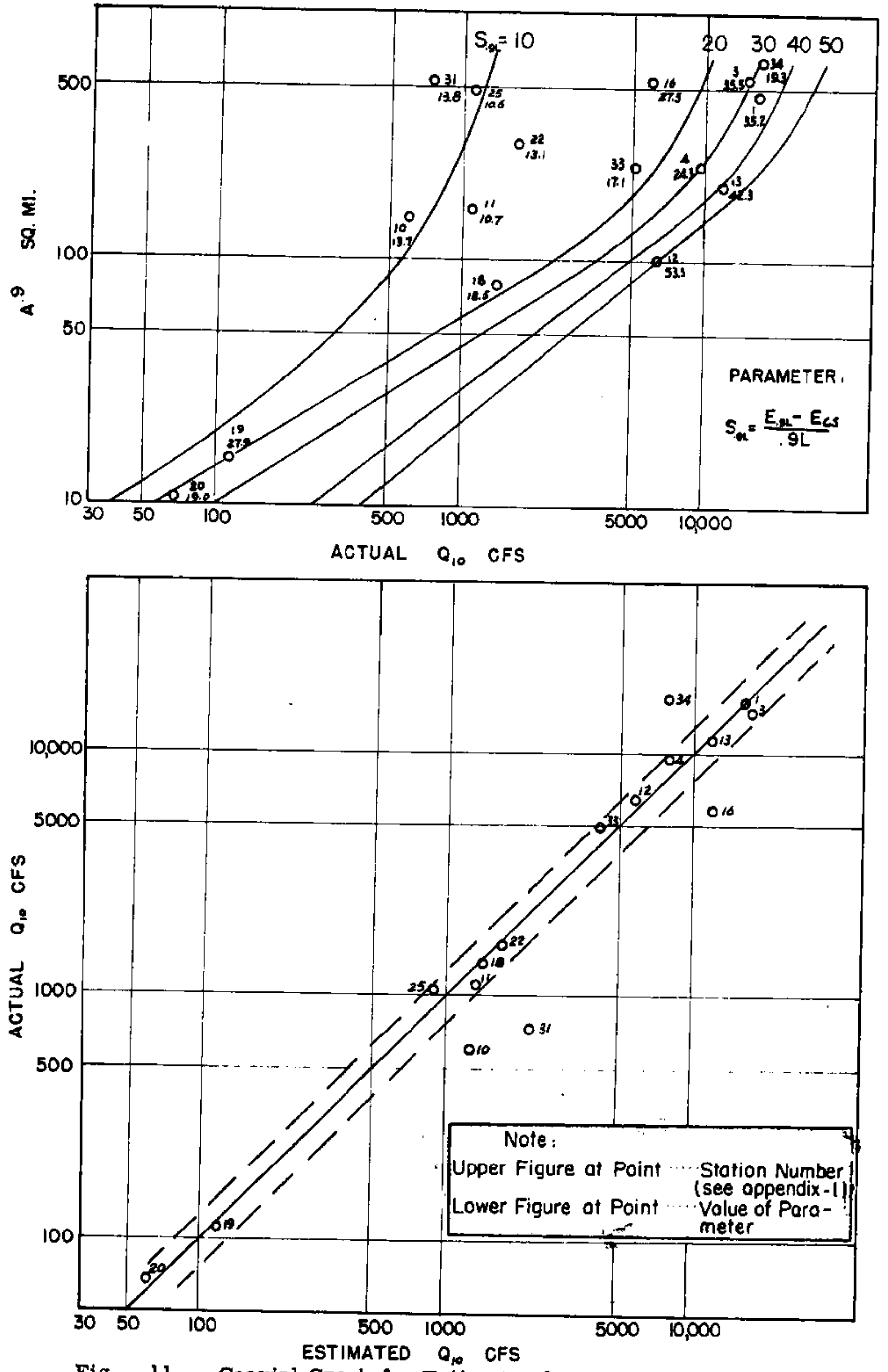


Fig. 11. Coaxial Graph for Estimate of Q_{10}.

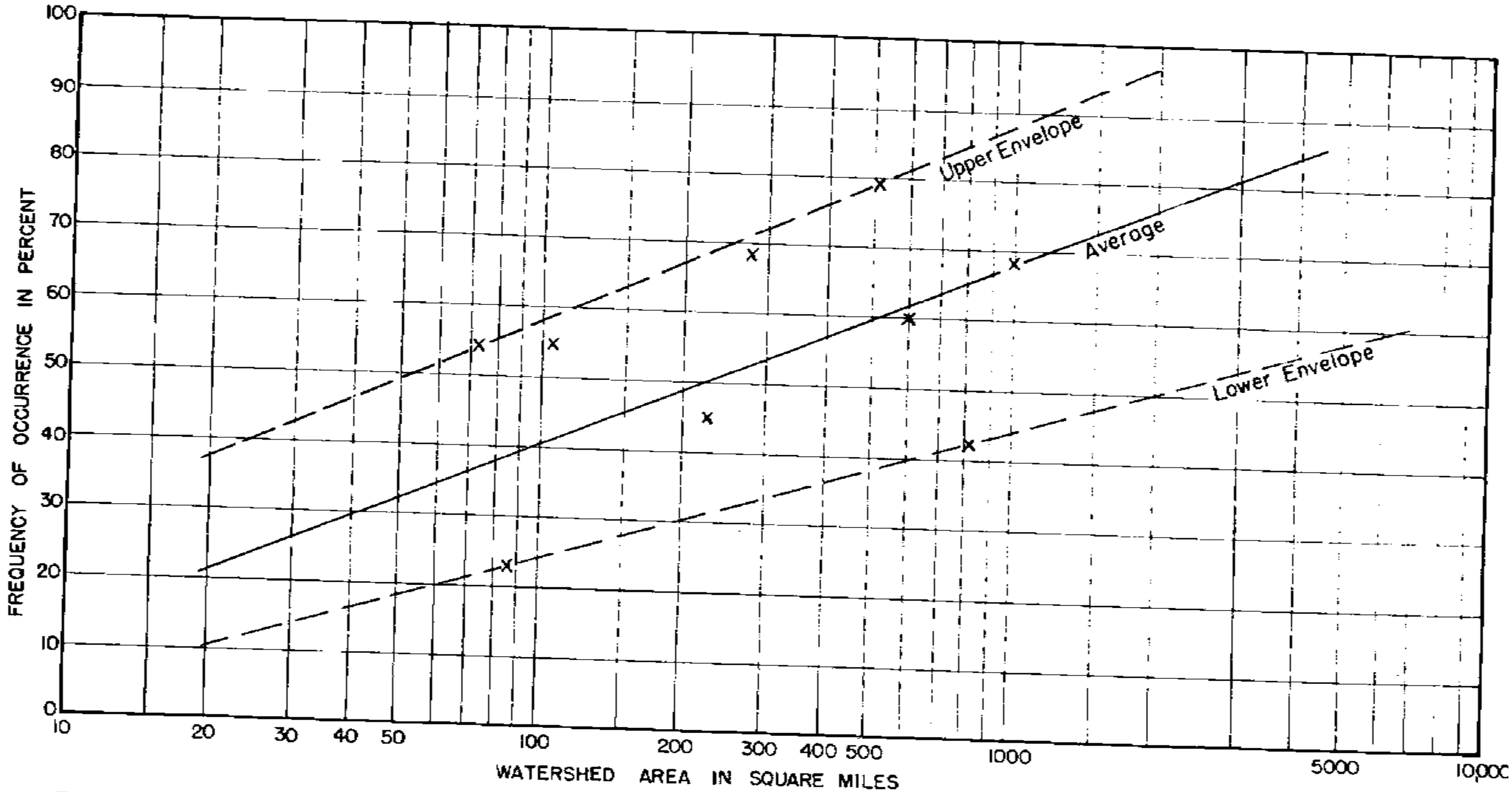


Fig. 12. Frequency of Occurrence of Complete Areal Rainfall Coverage Associated with Annual Maximum Flood Events as a Function of Area for Nine Watersheds in Eastern Colorado.

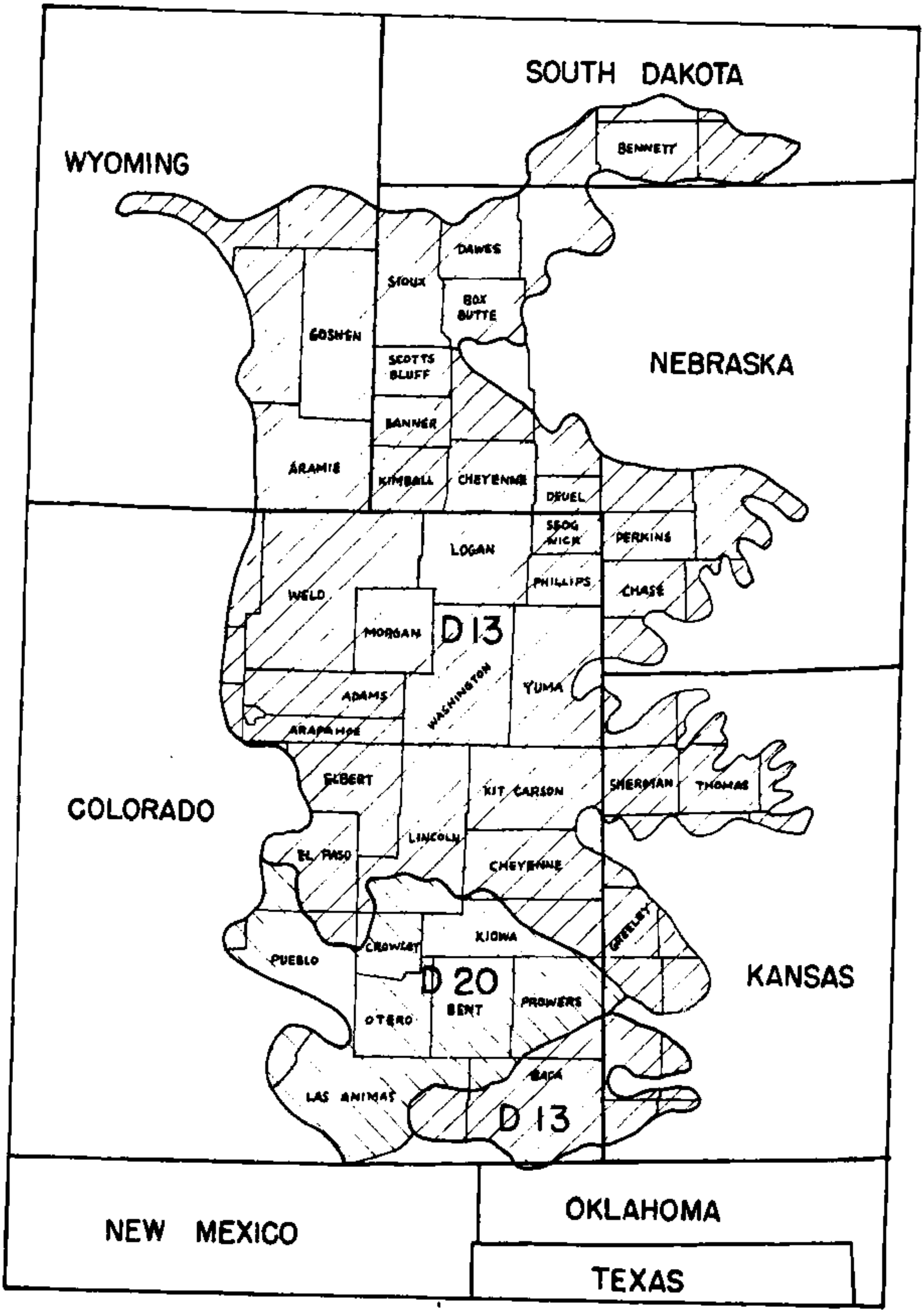
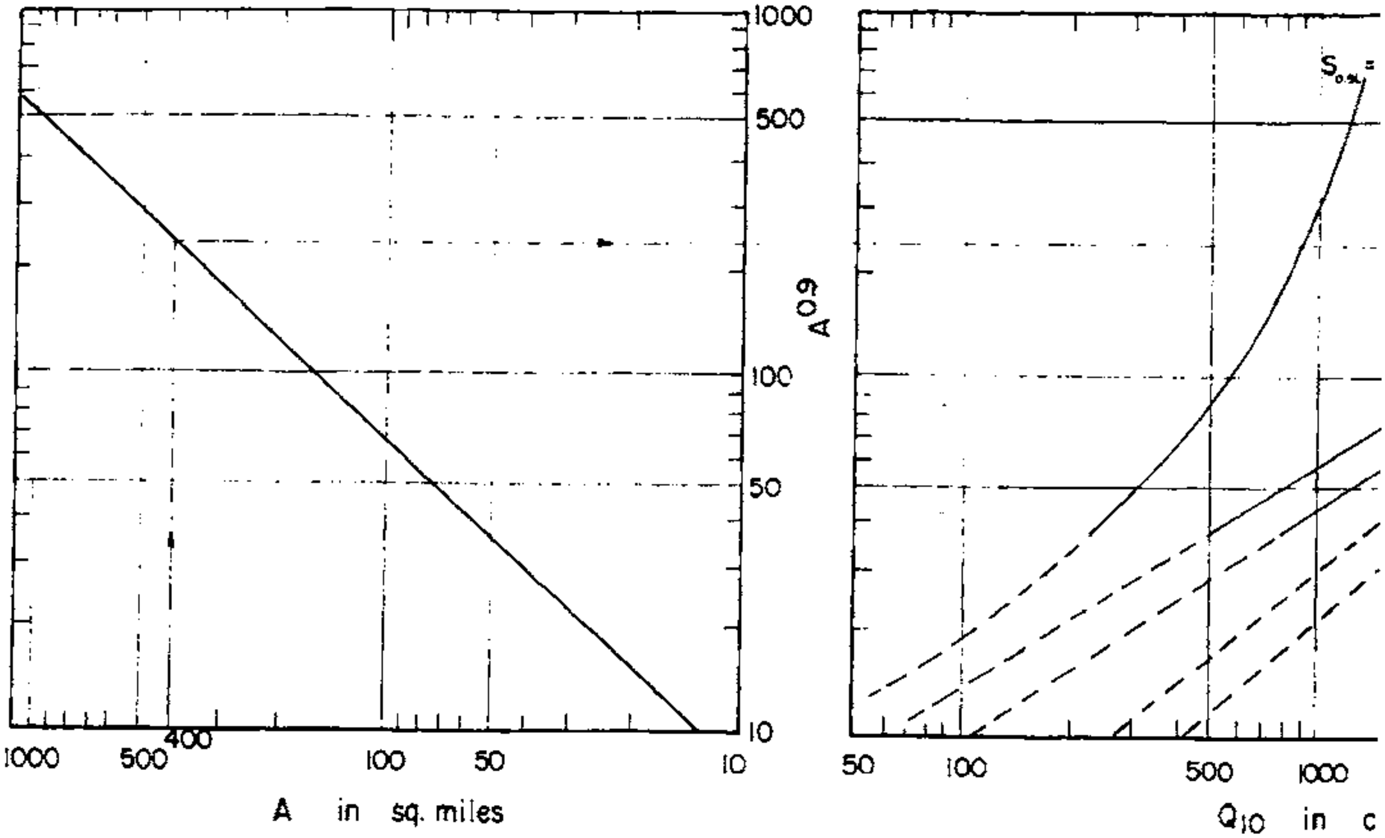


Fig. 13. Location Map.



(Example)

Given ; A = 400 sq.miles

$E_{0.9L}$ = 7320 ft.

E_{CS} = 5608 ft.

L = 45 miles

Compute ;

$$S = \frac{E_{9L} - E_{CS}}{0.9L} = \frac{1712}{40.5} = 42.3 \ \text{ft/miles}$$

Enter Graph with A = 400 , S = 42.3

Read Q_{10} = 14,000 c.f.s.

Q_{40} = 20,500 c.f.s.

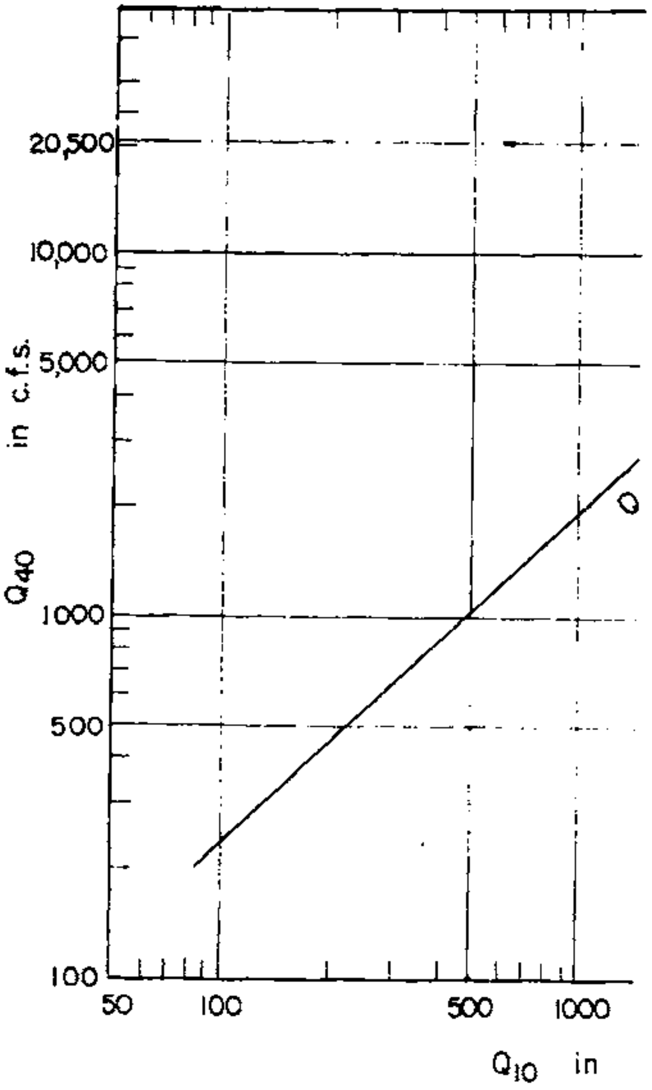
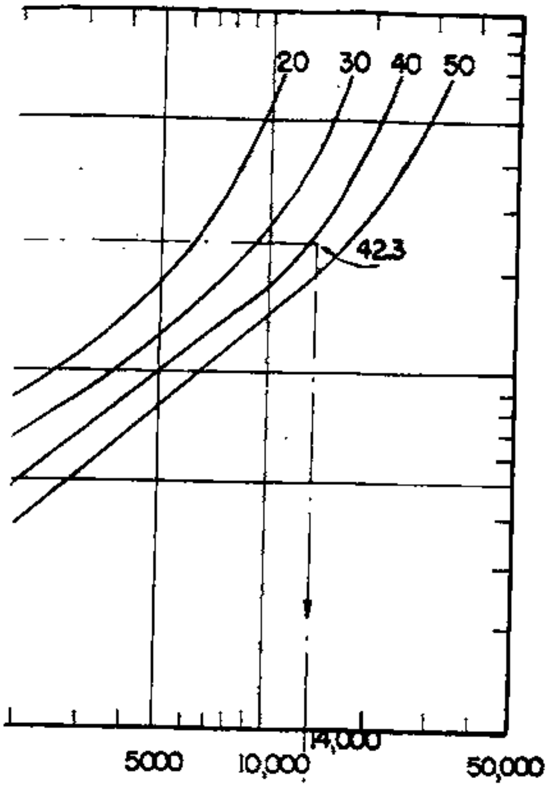
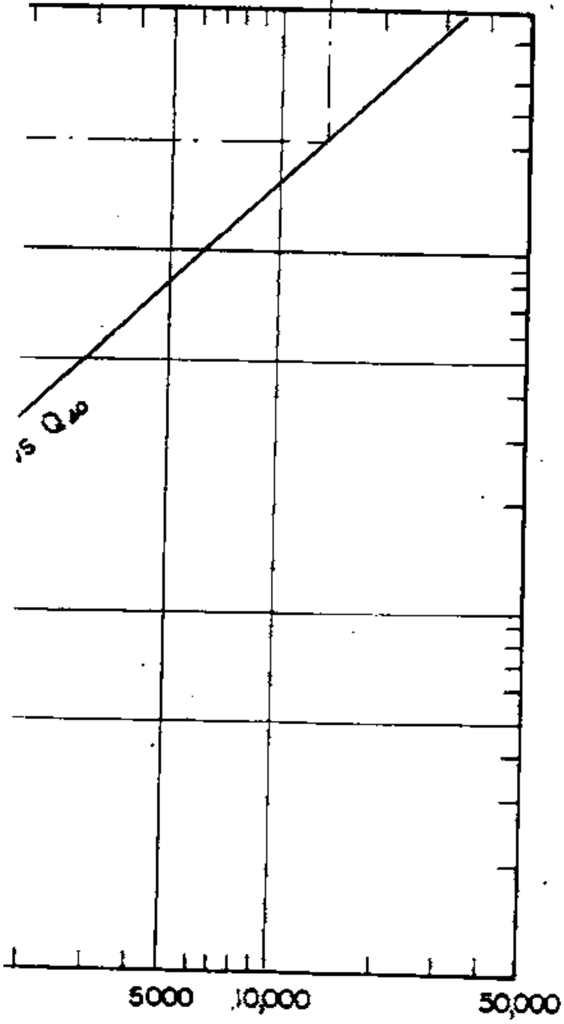


Fig. 14. Relations among Area, Slope Factor, Q_{10} and Q_{40} for the D-13 and D-2



s.



.s.

Problem Areas.

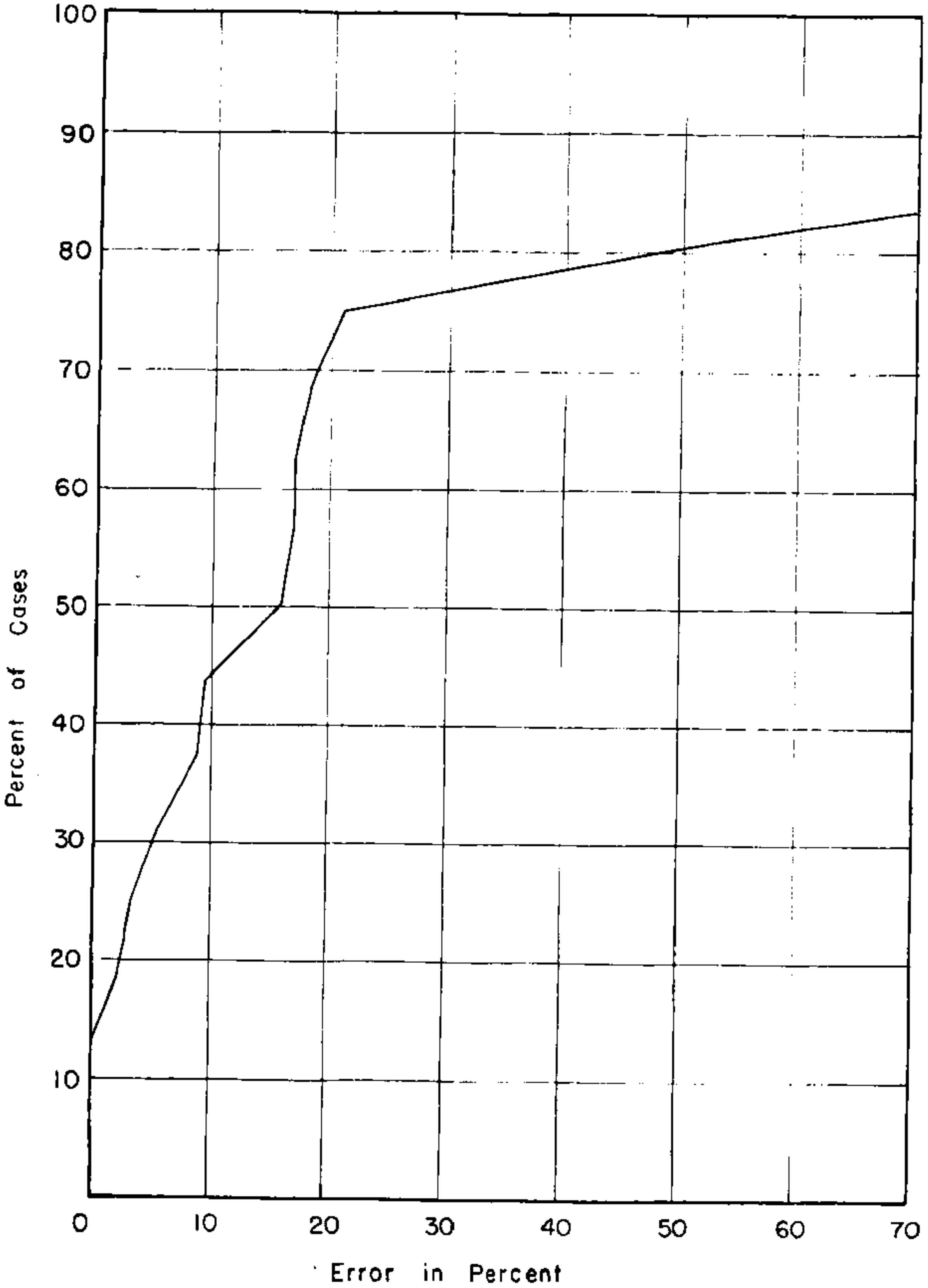


Fig. 15. Distribution of Error Curves for Estimates of Q_{10} From Fig. 14. (Dependent data.)

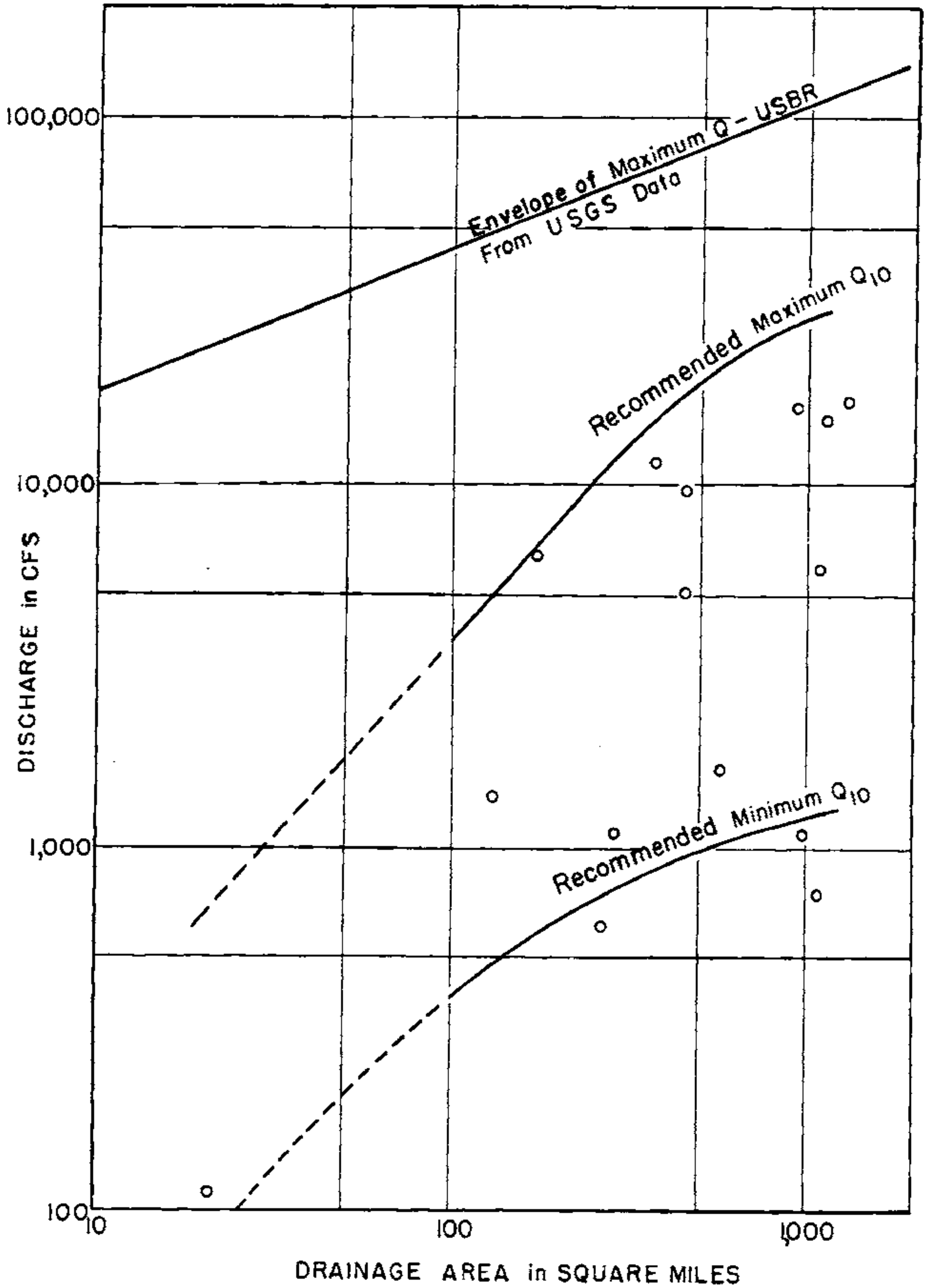


Fig. 16. Recommended Maximum and Minimum Q_{10} as a Function of Watershed Size.

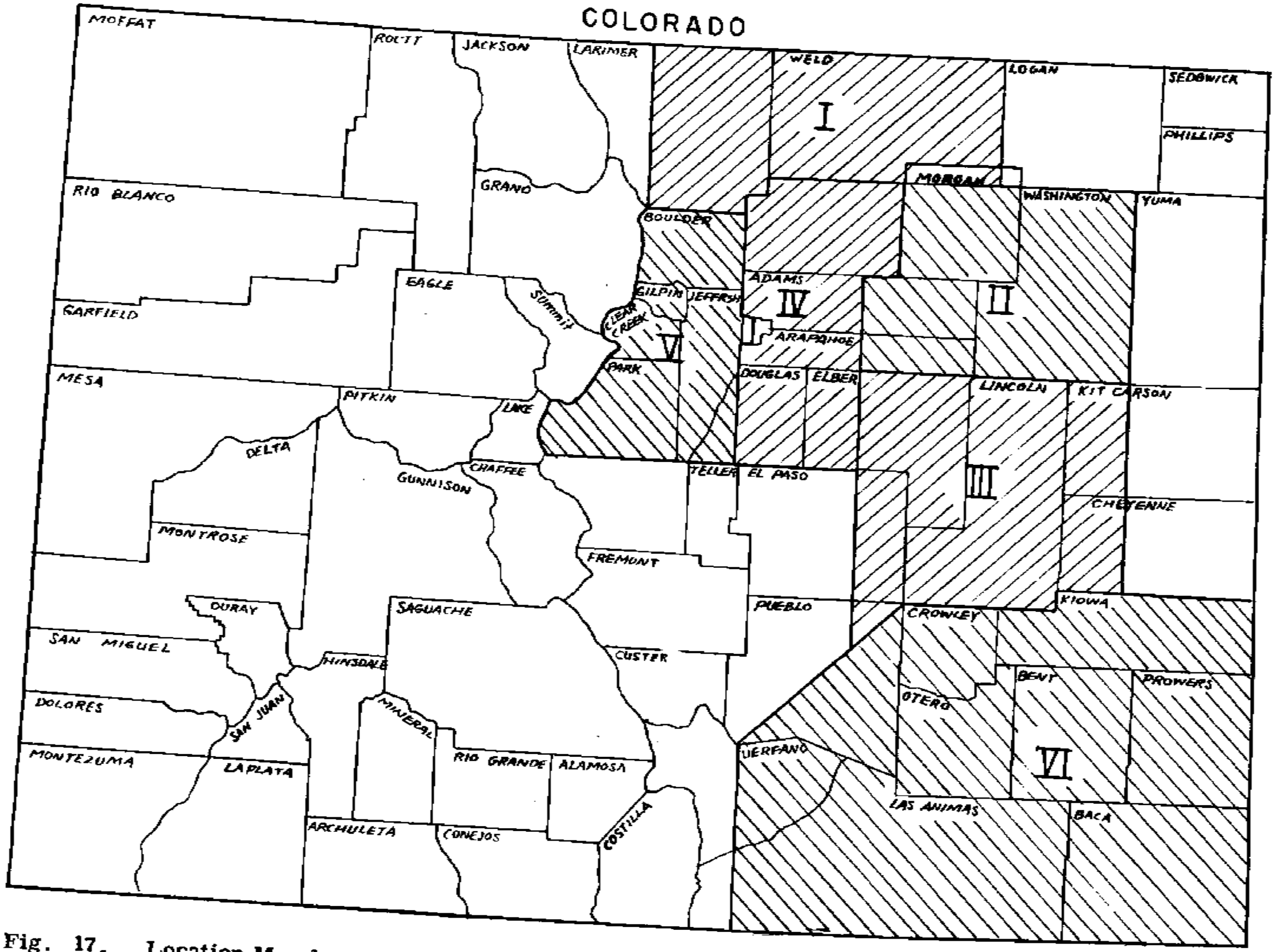


Fig. 17. Location Map for Relative Wetness Study.

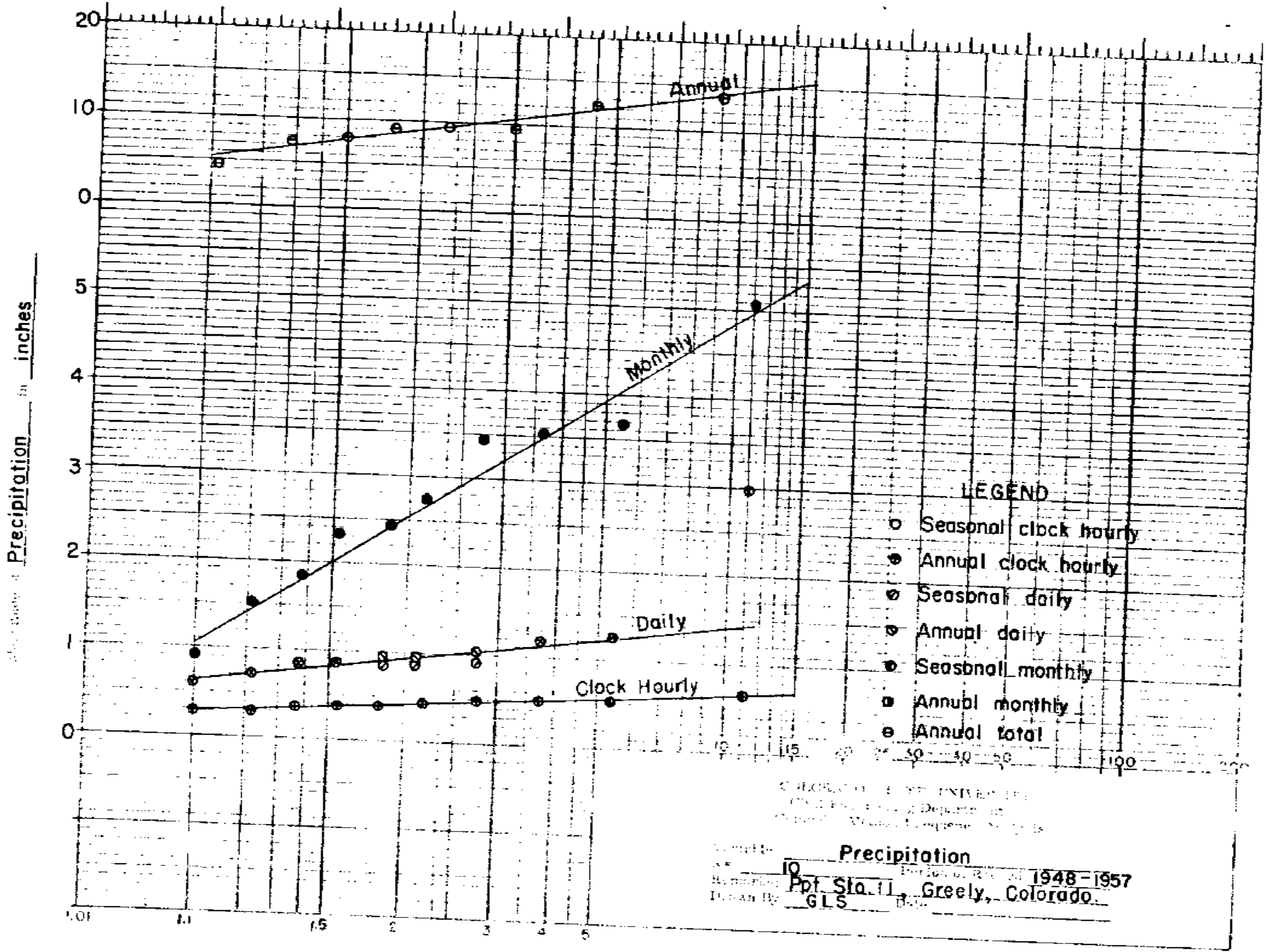


Fig. 18. Frequency Analysis of Precipitation Data at Greeley, Colorado.

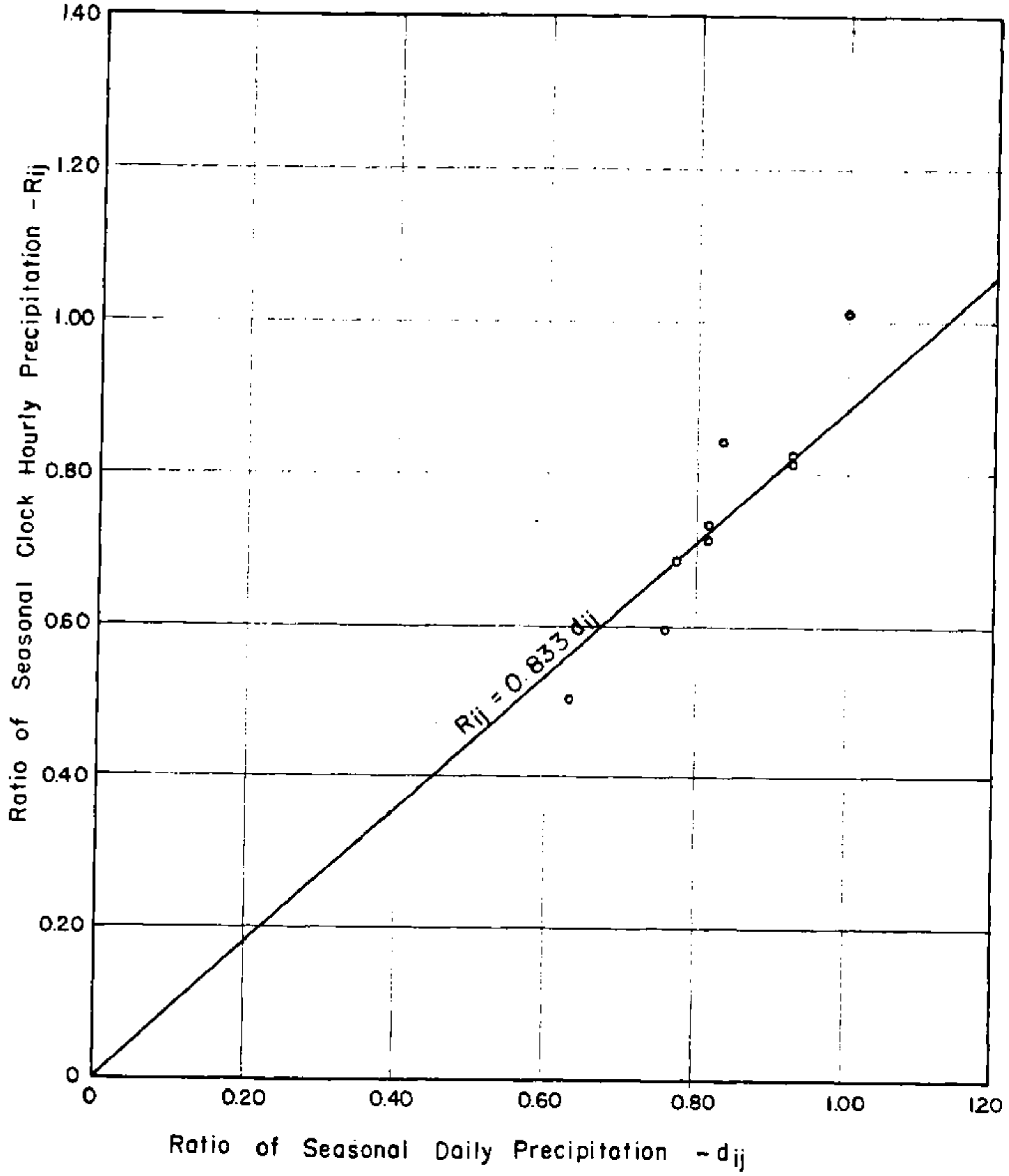
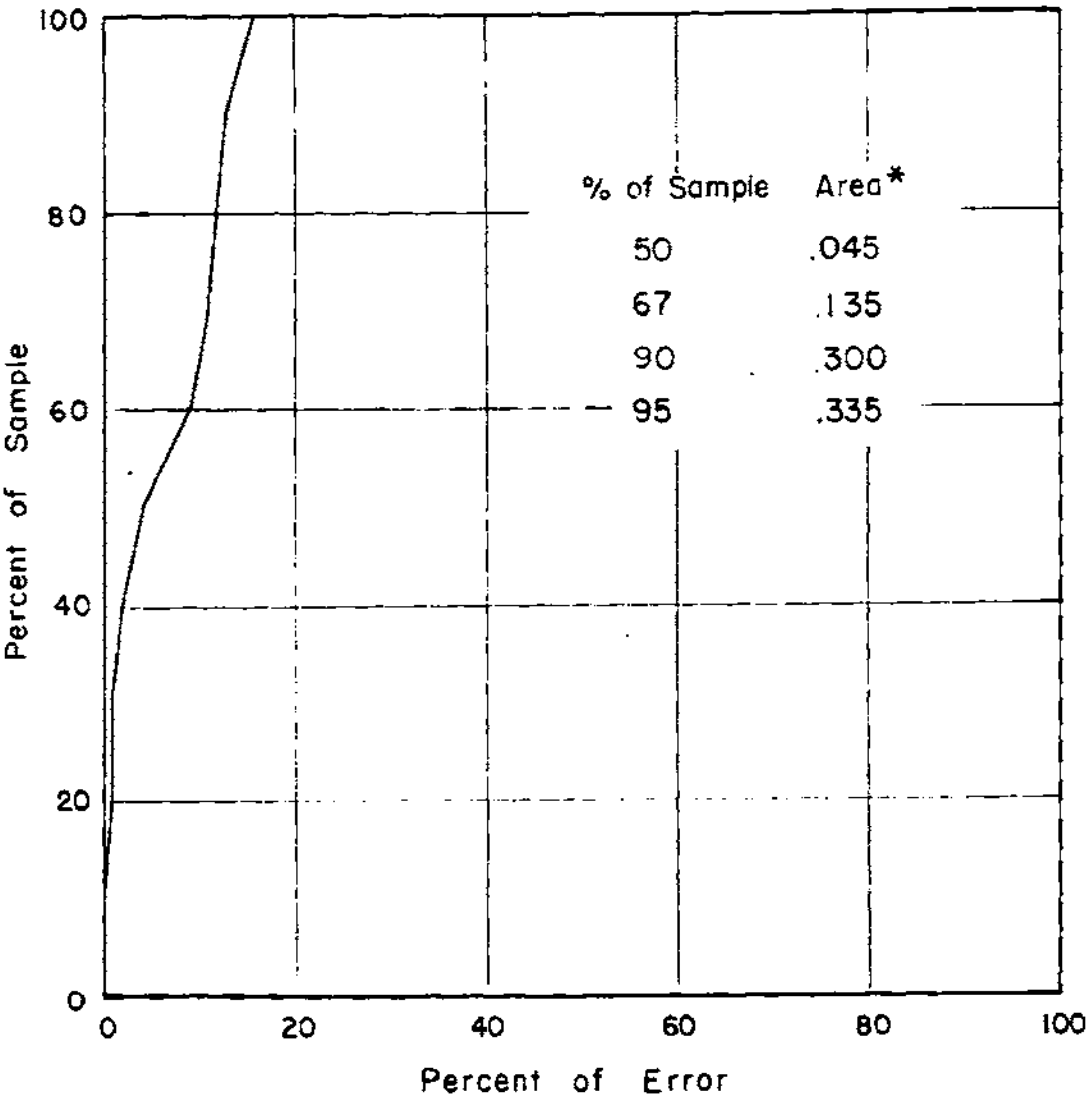


Fig. 19. **Relation Between** R_{ij} and d_{ij} for Subarea IV.(Seasonal 2 Year Values.)



% of Sample	Area*
50	.045
67	.135
90	.300
95	.335

* Area between Ordinate and Curve

Fig. 20. Distribution of Error Curve for the Relation Shown in Fig. 19.

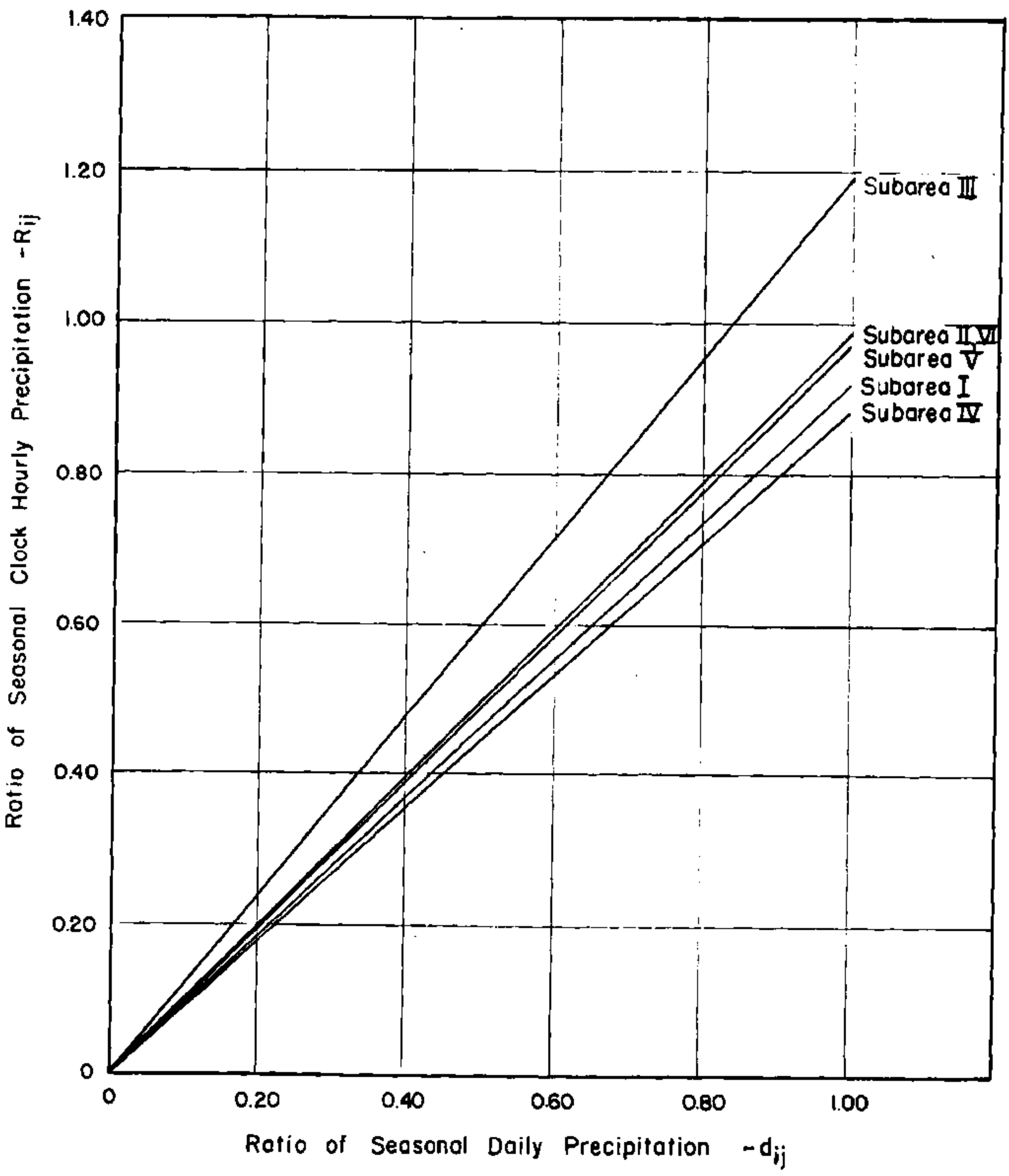


Fig. 21. Relations Between R_{ij} and d_{ij} for Subareas I-IV Shown in Fig. 17. (Seasonal 2 Year Values.)

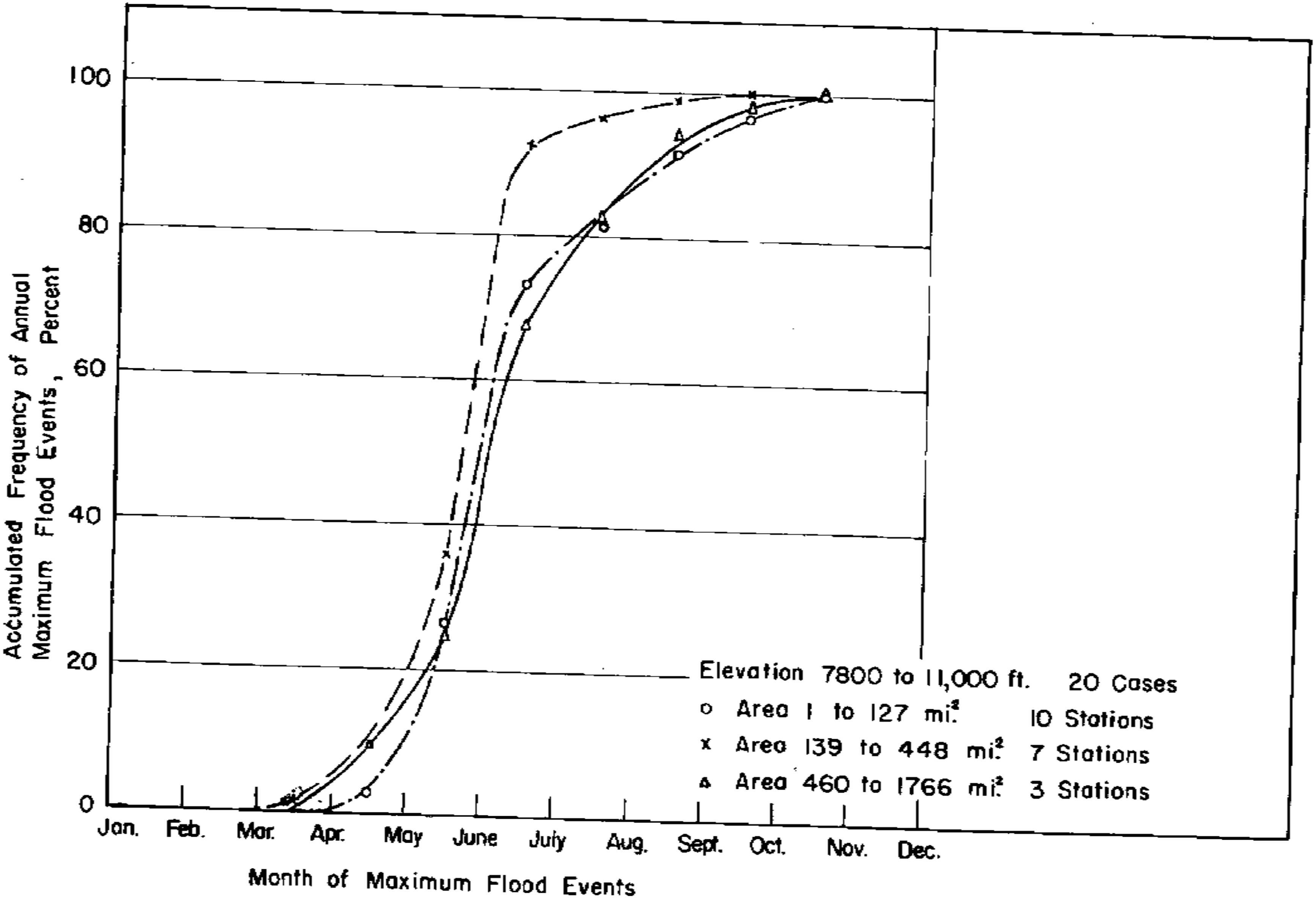


Fig. 22. Accumulated Relative Frequency of Annual Maximum Flood Events for 20 Watersheds in Colorado Between 7800 and 11,000 feet Elevation.

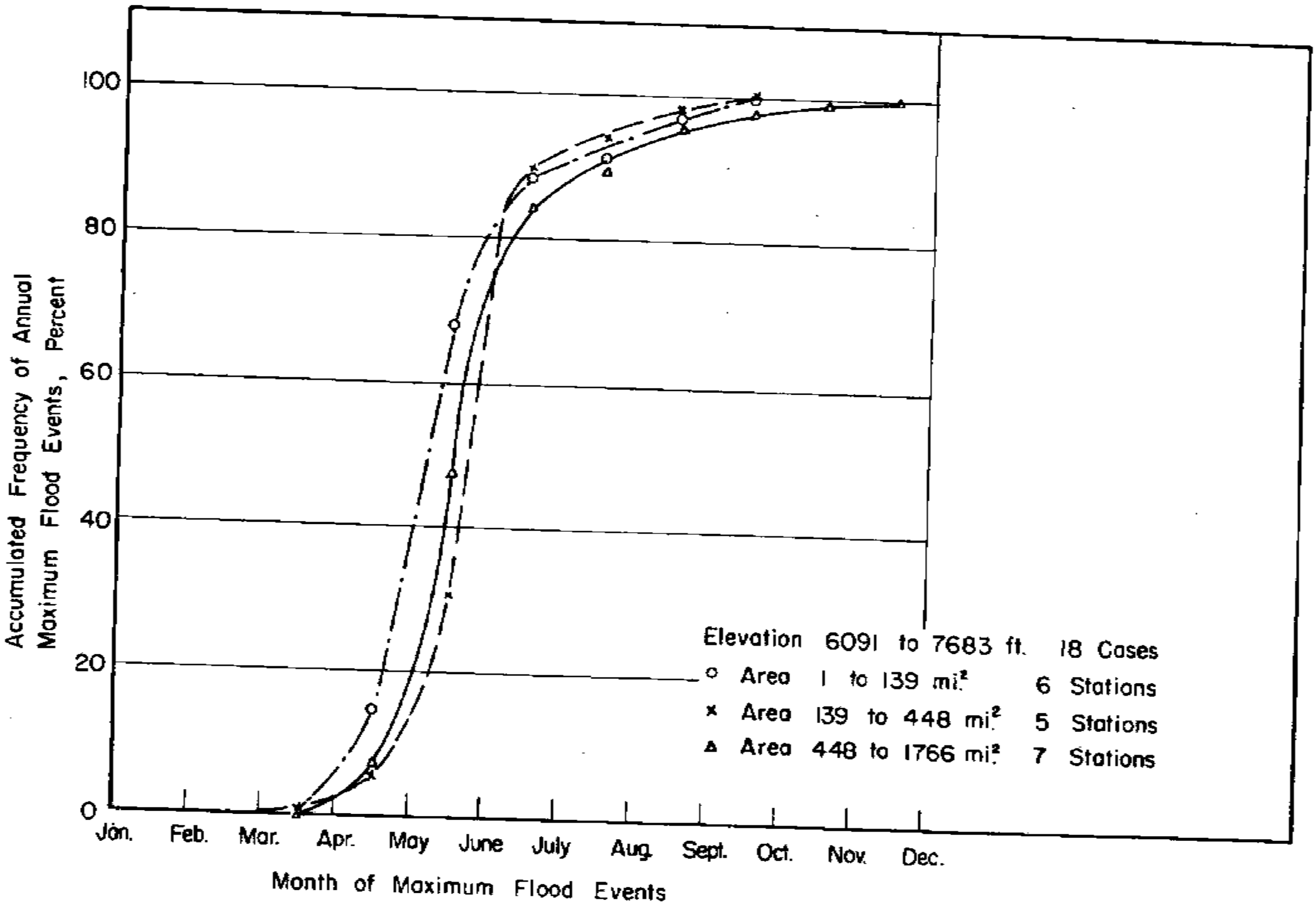


Fig. 23. Accumulated Relative Frequency of Annual Maximum Flood Events for 18 Watersheds In Colorado Between 6091 and 7683 Feet Elevation.

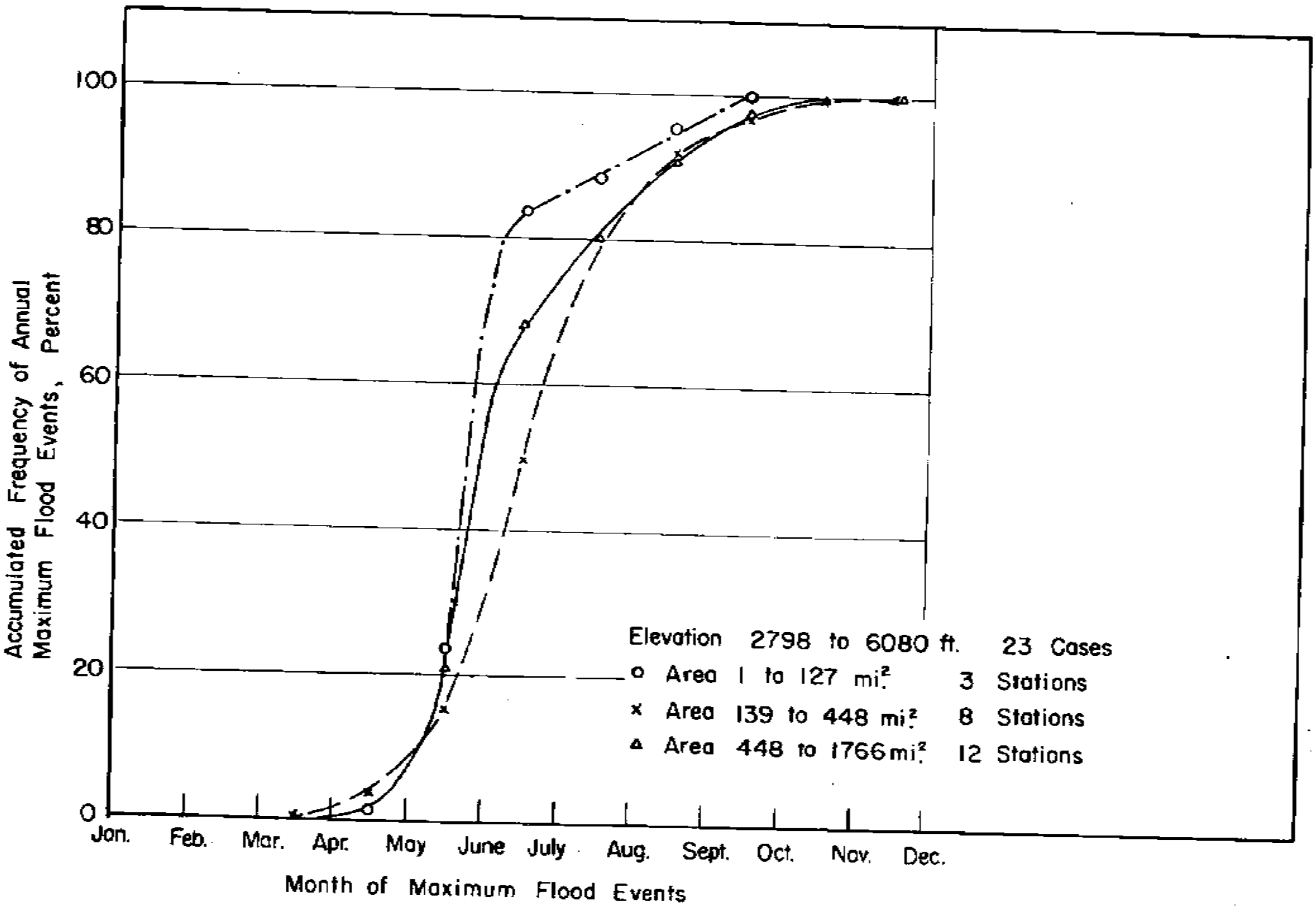


Fig. 24. Accumulated Relative Frequency of Annual Maximum Flood Events for 23 Watersheds In Colorado Between 2798 and 6080 Feet Elevation.