SPILLWAY DESIGN FLOODS

FOR

SMALL DAMS IN RURAL MISSOURI

by

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ABSTRACT

At present, 1970, over 1500 small dams exist within the boundaries of the state of Missouri. Estimates indicate the number is growing at the rate of one hundred to two hundred per year. The main factor in possible failure of these existing dams is an inadequate spillway resulting from poor hydraulic practice and or lack of accurate hydrologic design information.

This report presents the result of a state wide analysis of all existing hydrologic data for rural watersheds less than twenty square miles. The results are presented in nomograph form for the 25 and 50 year frequency floods. The report also contains equations for other frequencies at two accuracy levels. The results of this investigation should provide designers of spillways, culverts and bridges with the latest hydrologic flood frequency data for small rural Missouri watersheds.

Keywords - Flood Frequency*, multiple regression, small dams, spillways*, hydrology, dam safety.

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INTRODUCTION

Demands by society for recreational areas lead to an alarming increase in the construction of small lakes and reservoirs. Presently, 1970, Missouri has over 1500 lakes with surface areas of greater than 5 acres, and of these, 410 are larger than 15 acres in size. The location of these lakes is such that approximately 1150 lie in the rural areas of Missouri. For comparative purposes the national average of lakes per state is approximately 600, thus Missouri ranks high in the number of small lakes. Analysis of the number of lakes in individual states show that the recreational oriented state of California has only approximately 1052 lakes greater than 5 acres in size.

Lakes in rural Missouri are placed in varied terrain. The location of small recreation lakes generally draws small business and vacation type housing in and around the lake sites. Often the areas below the site of the dam are utilized for homesite and business locations. It is this potentially hazardous condition that has alarmed the engineering profession.

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Present information relative to existing hazardous design of small dams is based primarily upon recent studies by the Missouri Geological Survey and Water Resources. According to the most recent information [1*] 24 dam failures have occurred in Missouri in the past 10 years. Of these failures, 17 are attributed to inadequate spillway design. Potential failures are now placed at 46. The potential cause of dam failure for 30 of these sites, or approximately 65%, is attributed to inadequate spillway design.

The design procedures relative to determining the emergency spillway design flood are varied in nature. Possibly the method most in use when the dam undergoes an engineering design is the method currently employed by the Soil Conservation Service[2]. This procedure is based however upon frequency analysis of existing rainfall data. The frequency level of the runoff calculated by this method remains unknown.

The need for a regional flood frequency analysis for streams in the state of Missouri has been recognized. The Water Resources Division of the U.S. Geological Survey in cooperation with the Bureau of Public Roads and the Missouri Geological Survey and Water Resources,[3] recently issued a publication dealing with this subject. The publication presents a single multiple regression equation for all watershed sizes in the state of Missouri at several frequency levels. Unfortunately, the variations of flooding potential due to widely scattered geographic location in the state are not adequately incorporated into these equations. The report states, in regard to small areas:

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* Raised numbers refer to list of references

> "fifty-year flood-frequency estimates at gaging stations were obtained from data for drainage areas in excess of 50 square miles. There is no evidence to support the use of the 50-year equation for drainage areas less than 50 square miles."

Thus the useful range of both frequency and drainage area size is severely hampered insofar as the usefulness of this report in the determination of spillway design floods for small dams.

OBJECTIVES

The status of hydrologic analysis of small watershed hydrology in the state of Missouri warrants an initial study into the flood frequency relationships which might exist on the small watershed areas. The objective of this study are threefold.

1. To assemble all existing hydrologic, physiographic, and climatological data for small rural watersheds less than 20 square miles in rural Missouri.
2. To utilize multiple regression techniques to establish the functional relationship between peak flow of selected frequencies and the physiographic and climatological factors.
3. To regionalize the flood frequency relationships to obtain the most accurate prediction equation for hydrologically similar areas.

ANALYSIS

Streamflow data are available from over 130 small watersheds in the state of Missouri. These data are a result of a cooperative program between the U.S. Geological Survey Water Resources Division and the Missouri State Highway Commission. These data are published annually in the U.S. Geological survey publication "Water Resources Data for Missouri." Data in this report were extracted for 107 small watersheds less than or equal to 20 square miles in size, all lying in rural undeveloped areas. A frequency analysis was performed for each watershed by a log Pearson III method advocated by the Water Resources Council[4].

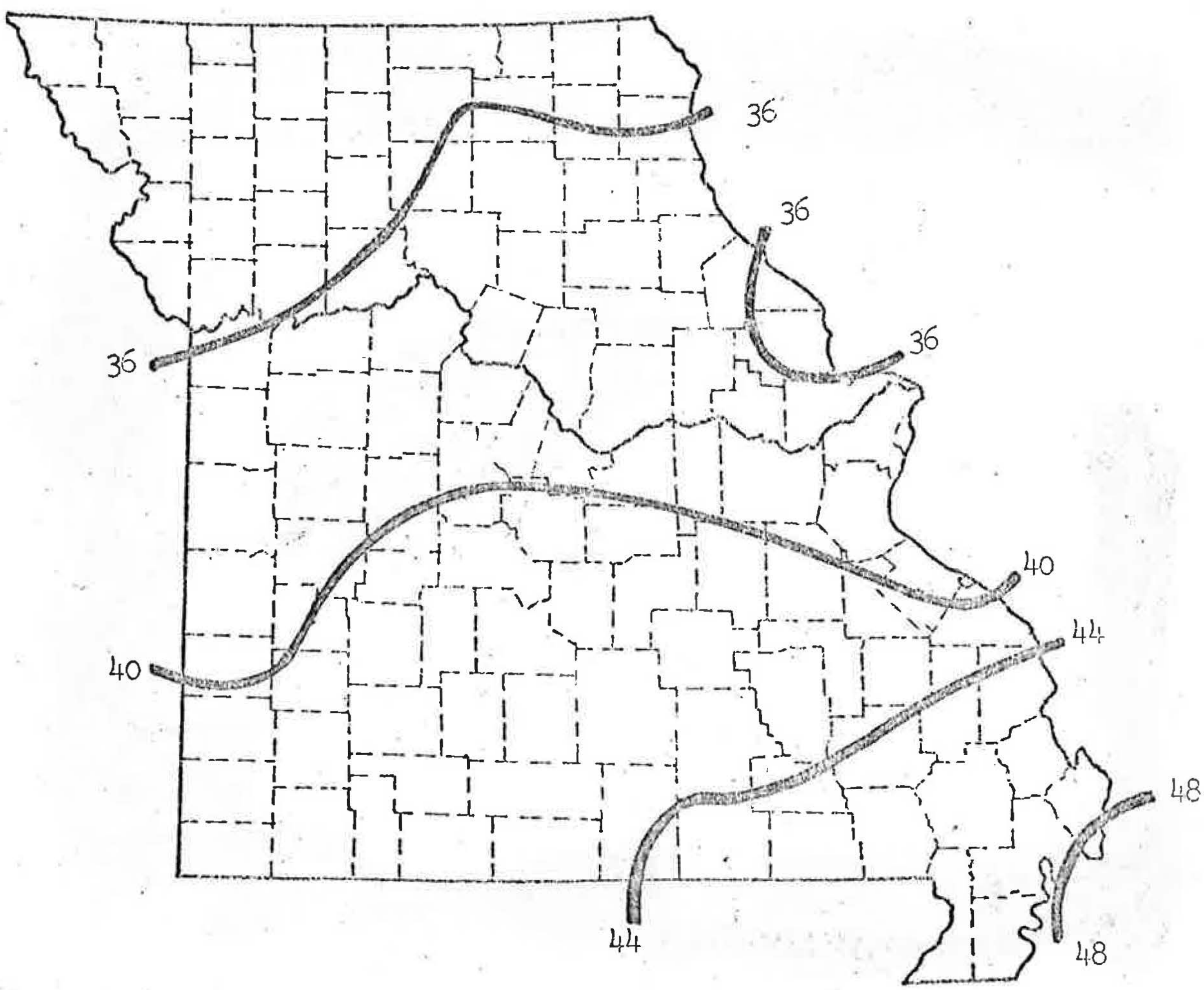

Figure 1.--Average Annual Rainfall in Missouri

Physiographic data were obtained from U.S. Geological Survey topographic maps available at the Missouri Geological Survey and Water Resources Division. These data consist of watershed area, stream length, average basin elevation, circumference, and stream slope*. An additional climatological factor of mean annual rainfall was utilized as obtained from Figure 1. This rainfall value is a result of a twenty-four year average of Missouri rainfall station data compiled by the Environmental Science Service Administration.

Multiple Regression:

A forward step-wise multiple regression technique was employed to determine the most significant variables at the 95% level for flood frequencies at the 5,10,25,50, and 100 year level for the entire state. The form of the multiple regression equation resulting from this study is of the form

$$Q_T = f(A,S,R,E,C)$$

where

Q_T = peak discharge at given recurrance intervals in cfs

A = drainage area size in square miles

S = slope of stream in percent

R = mean annual rainfall in inches

E = average basin elevation in feet

C = watershed circumference in miles

Additional variables which were included but found not to be significant or highly interrelated were: L_c, or length to centroid of watershed, F, percent forest cover, H, total change in basin elevation, and L, length of

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* The stream slope is defined as the difference between the highest elevation on the watershed less the outlet elevation divided by the length of the stream in feet, expressed in percent.

watershed. Two additional measures of slope were also tested: A definition of average slope obtained by plotting the stream profile and equating the area below a straight line through the outlet elevation to area above; a measure of slope obtained by dividing the elevations at the 10% and 85% of the stream length by the distance between these two points. These two definitions of slope did not demonstrate as much significance as the slope utilized in the final regression. Measures of watershed shape were also tested and the use of circumference was selected from L_c, A/L, C/L_c, and C.

Regionalization:

An internal statistical homogeneity test was performed on all stations within the state to define areas of similar hydrologic behavior. The boundaries of these regions are shown in Figure 2. Adjustments have been made in the boundary lines to insure that those data points within the region limits produce the lowest standard error of estimate for the final multiple regression equation. The results of the regional multiple regression equations with all variables significant at the 95% level are shown in Table 1.

The use of hydrologic regions significantly improves the level of accuracy for predicting floods at a given frequency level. The state wide equation, without the hydrologic regions produced a standard error* of 52% for the 25 year frequency flood. This compares to a 58% standard error for watersheds less than 20 square miles as computed by a multiple regression equation in a recent report[3]. Use of the hydrologic regions, however, result

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* The standard error indicates that the value calculated with the suggested equation will be correct within one standard error two out of three times.

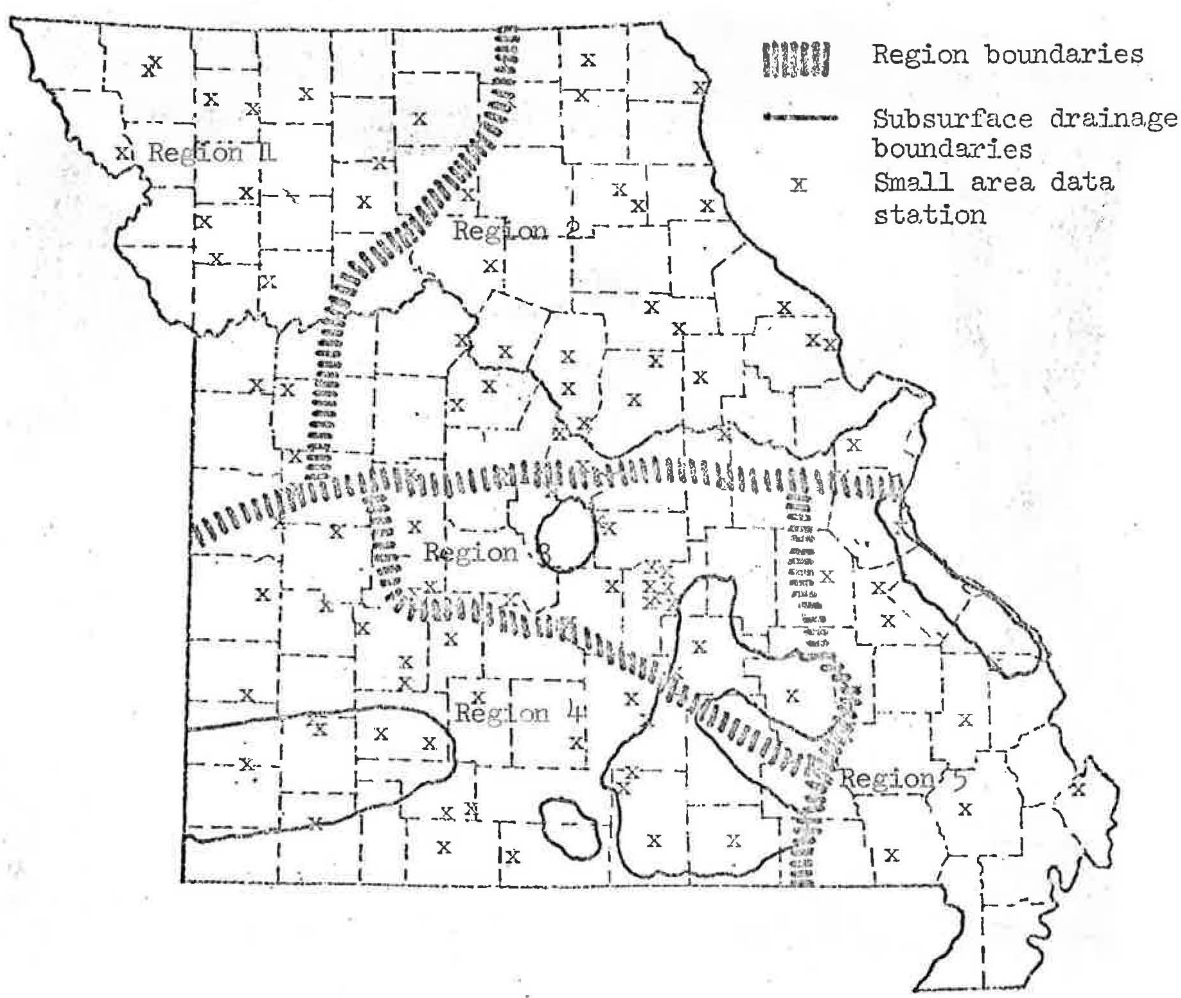

Figure 2.--Hydrologic Regions for Missouri

in standard errors of 22%, 42%, 83%, 41% and 56% for hydrologic regions 1 through 5 respectively. This is a significant improvement in all regions except regions 3 and 5.

As may be noted in Figure 2, regions 3,4, and 5 are subjected to zones of extensive subsurface drainage. Region 5 also has areas of high ground water and is interlaced with an extensive network of drainage ditches in the southern "bootheel" areas. These conditions lead to some difficult problems in attempting to define the relative influence of these factors on the flood producing characteristics. Due to the limited time available on the project the further investigation necessary to evaluate this effect

TABLE I. -- Multiple Regression Equations at 95% Significance Level

Region 1

$$Q_5=1.15\cdot10^{15}A^{-.742}E^{-2.046}S^{.094}R^{-5.104}C^{2.590}\ (26\%)$$

$$Q_{10}=2.33\cdot10^{11}A^{-.426}E^{-1.335}R^{-3.712}C^{1.991}\ (18\%)$$

$$Q_{25}=7.79\cdot10^{5}A^{-.179}E^{-.325}R^{-1.843}C^{1.570}\ (22\%)$$

$$Q_{50}=19E^{.451}C^{1.256}\ (26\%)$$

$$Q_{100}=.087E^{.969}R^{.973}C^{1.271}\ (35\%)$$

Region 2

$$Q_5=.438A^{1.499}E^{1.378}S^{.646}C^{-1.149}\ (35\%)$$

$$Q_{10}=.308A^{1.494}E^{1.368}S^{.696}C^{-1.181}\ (38\%)$$

$$Q_{25}=92.5A^{1.423}E^{1.236}S^{.708}R^{-1.280}C^{-1.129}\ (42\%)$$

$$Q_{50}=802A^{1.383}E^{1.139}S^{.710}R^{-1.667}C^{-1.111}\ (52\%)$$

$$Q_{100}=4.89\cdot10^{4}A^{1.342}E^{1.034}S^{.706}R^{-1.947}C^{-1.091}\ (58\%)$$

Region 3

$$Q_5=6.86\cdot10^{6}A^{1.261}E^{-2.215}R^{1.790}C^{-.738}\ (70\%)$$

$$Q_{10}=6.03\cdot10^{10}A^{1.456}E^{-2.466}C^{-.994}\ (74\%)$$

$$Q_{25}=2.05\cdot10^{12}A^{1.558}E^{-2.904}C^{-1.109}\ (83\%)$$

$$Q_{50}=2.41\cdot10^{13}A^{1.610}E^{-3.221}C^{-1.157}\ (89\%)$$

$$Q_{100}=2.59\cdot10^{14}A^{1.647}E^{-3.532}C^{-1.183}\ (97\%)$$

Region 4

$$Q_5=1.22\cdot10^{10}A^{.479}E^{.107}S^{.170}R^{-5.029}C^{.423}\ (35\%)$$

$$Q_{10}=8.72\cdot10^{7}A^{.468}E^{.147}S^{.172}R^{-3.692}C^{.414}\ (35\%)$$

$$Q_{25}=3.28\cdot10^{5}A^{.472}E^{.149}S^{.168}R^{-2.102}C^{.378}\ (41\%)$$

$$Q_{50}=526A^{.503}S^{.133}C^{.272}\ (45\%)$$

$$Q_{100}=600A^{.504}S^{.151}C^{.294}\ (51\%)$$

Region 5

$$Q_5=456A^{.807}E^{-.823}R^{1.456}\ (59\%)$$

$$Q_{10}=5.16\cdot10^{4}A^{.787}E^{-.663}\ (46\%)$$

$$Q_{25}=7.98\cdot10^{7}A^{1.130}E^{-.524}R^{-1.846}C^{-.688}\ (56\%)$$

$$Q_{50}=5.67\cdot10^{9}A^{1.180}E^{-.377}S^{.086}R^{-3.150}C^{-.783}\ (66\%)$$

$$Q_{100}=4.45\cdot10^{9}A^{.756}S^{.326}R^{-4.042}\ (60\%)$$

Note:

Numbers in parentheses represent standard error of estimate in percent. Correlation coefficients are generally above 0.90

was not undertaken. The problem areas of prime concern are properly noted on Figure 2 and extreme care should be taken in computing peak discharge rates in these regions.

In order to simplify the calculations involved in determining peak discharge rates for a given frequency level, a reduced form of the multiple regression equation was employed. These equations involve only the area of the watershed and the slope of the watershed. These equations and their standard errors of estimate are shown in Table II. Little accuracy is sacrificed in this simplification.

Flood frequencies generally encountered in spillway design floods were prepared in nomograph form for the 25 and 50 year flood for each region based on the simplified multiple regression equation. The nomographs are presented in Figures 3 to 12. These nomographs will allow a rapid calculation of the peak discharge normally encountered on small dams which might be designed in rural unpopulated areas.

APPLICATION

The nomograph based on the simplified multiple regression equations can be used after determining the area of the watershed in square miles and the slope of the watershed in percent. A straight line connecting these two points intersects the line for the selected flood frequency at a point equal to the flood magnitude for that particular watershed.

Example:

Find the 25 and 50 year flood peak for the West Branch of Crawford Creek.

TABLE II. -- Simplified Multiple Regression Equations

Region 1	Region 2	Region 3
$Q_5=665A^{.623}S^{.017}$ (30%) $Q_{10}=942A^{.625}S^{-.066}$ (23%) $Q_{25}=1332A^{.629}S^{-.149}$ (23%) $Q_{50}=1651A^{.633}S^{-.198}$ (29%) $Q_{100}=1990A^{.636}S^{-.239}$ (37%)	$Q_5=382A^{.860}S^{.456}$ (41%) $Q_{10}=481A^{.840}S^{.507}$ (44%) $Q_{25}=606A^{.811}S^{.548}$ (49%) $Q_{50}=704A^{.788}S^{.567}$ (54%) $Q_{100}=799A^{.764}S^{.581}$ (60%)	$Q_5=325A^{.925}S^{.433}$ (73%) $Q_{10}=429A^{.969}S^{.499}$ (81%) $Q_{25}=570A^{1.018}S^{.581}$ (91%) $Q_{50}=680A^{1.051}S^{.642}$ (100%) $Q_{100}=793A^{1.082}S^{.702}$ (114%)
Region 4	Region 5	Note:
$Q_5=362A^{.605}S^{.050}$ (36%) $Q_{10}=481A^{.621}S^{.085}$ (35%) $Q_{25}=648A^{.640}S^{.121}$ (39%) $Q_{50}=778A^{.652}S^{.142}$ (44%) $Q_{100}=915A^{.665}S^{.160}$ (50%)	$Q_5=560A^{.632}S^{-.054}$ (53%) $Q_{10}=680A^{.681}S^{.082}$ (49%) $Q_{25}=795A^{.741}S^{.284}$ (51%) $Q_{50}=861A^{.783}S^{.442}$ (55%) $Q_{100}=919A^{.822}S^{.597}$ (62%)	Numbers in parentheses represent standard error of estimate in percent. Correlation coefficients are generally above 0.90.

Solution:

The watershed is located on the West Branch of Crawford Creek about 8.5 miles southeast of Lees Summit. The drainage area determined from a topographic map is 0.80 square miles. The slope is obtained by noting the highest elevation equals 1045 feet and the outlet elevation equals 945 feet. The measured map length of the stream to the boundary of the watershed is 1.46 miles. The slope is calculated to be (1045-945)÷(5280)(1.46)-1.3%. The nomographs of Figures 3 and 4 produce:

Q_{25} = 1150 cfs

Q_{50} = 1580 cfs

A complete frequency curve can be constructed using the equations in Table II.

CONCLUSIONS

The results presented in this report allow a more reliable estimate of flood flow frequency predictions for small rural watersheds within the state of Missouri. Hydrologic regions 3, 4, and 5 exhibit hydrologic prediction problems as a result of subsurface drainage conditions. The bootheel area of region 5 exhibits an accuracy problem which though not as severe, should be taken into consideration in determining hydrologic design information.

Reasonable accuracy can be obtained for most small rural watersheds by use of a simplified multiple regression equation. This simplified multiple regression equation is presented in nomograph form for ease in computing the 25 and 50 year flood peaks for watersheds less than 20 square miles.

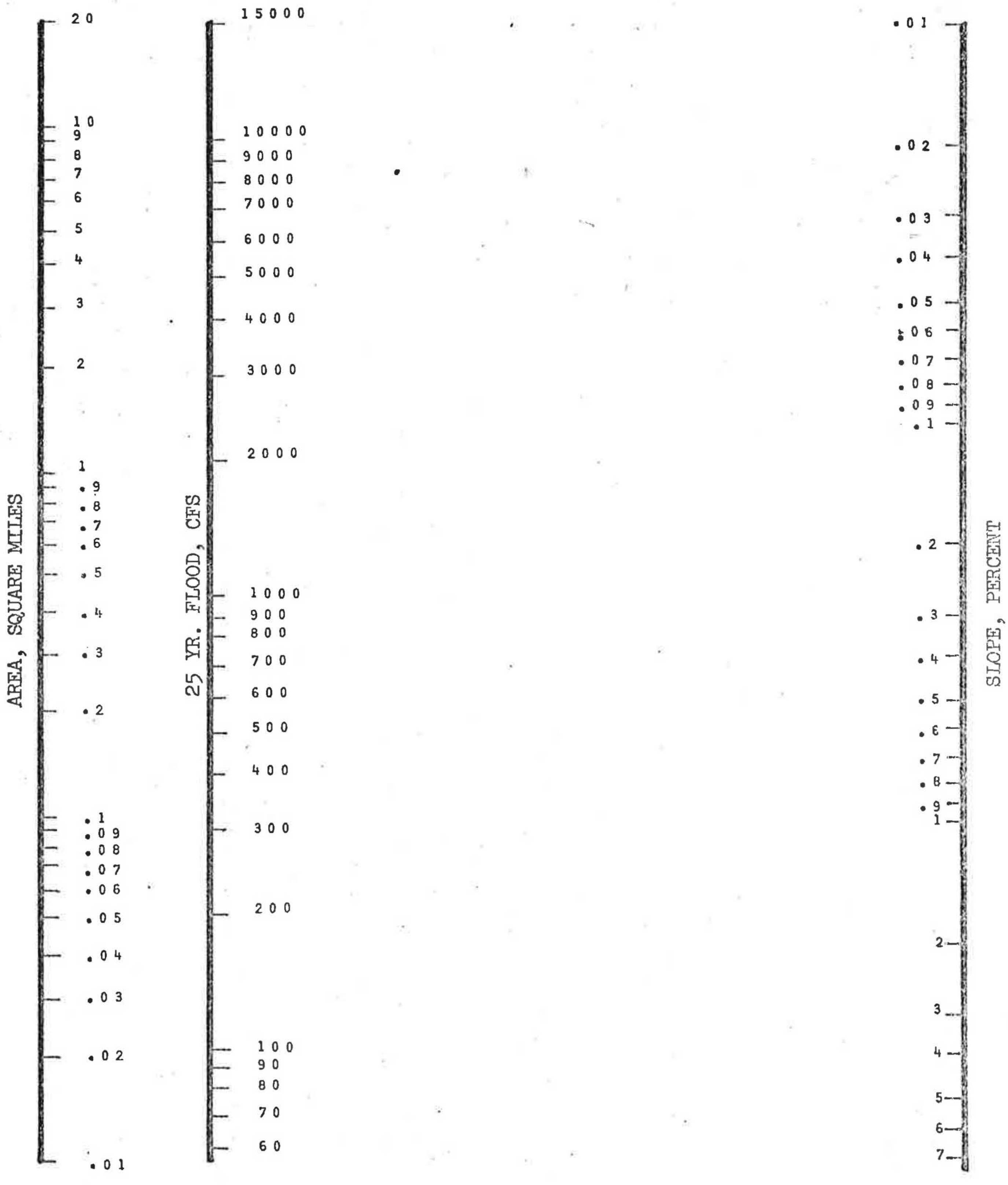

Figure 3.--25 year Flood Frequency for Region 1

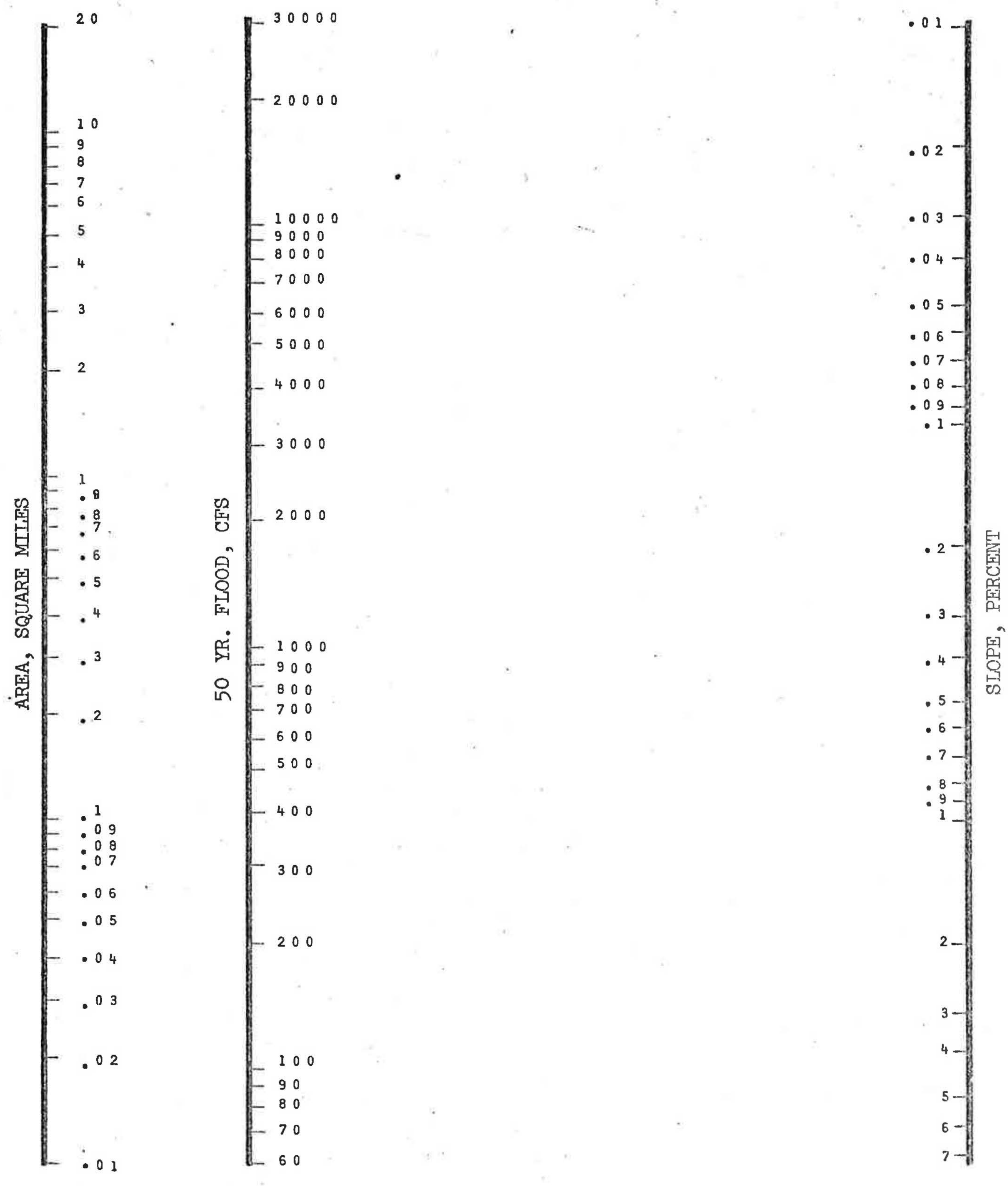

Figure 4.--50 year Flood Frequency for Region 1

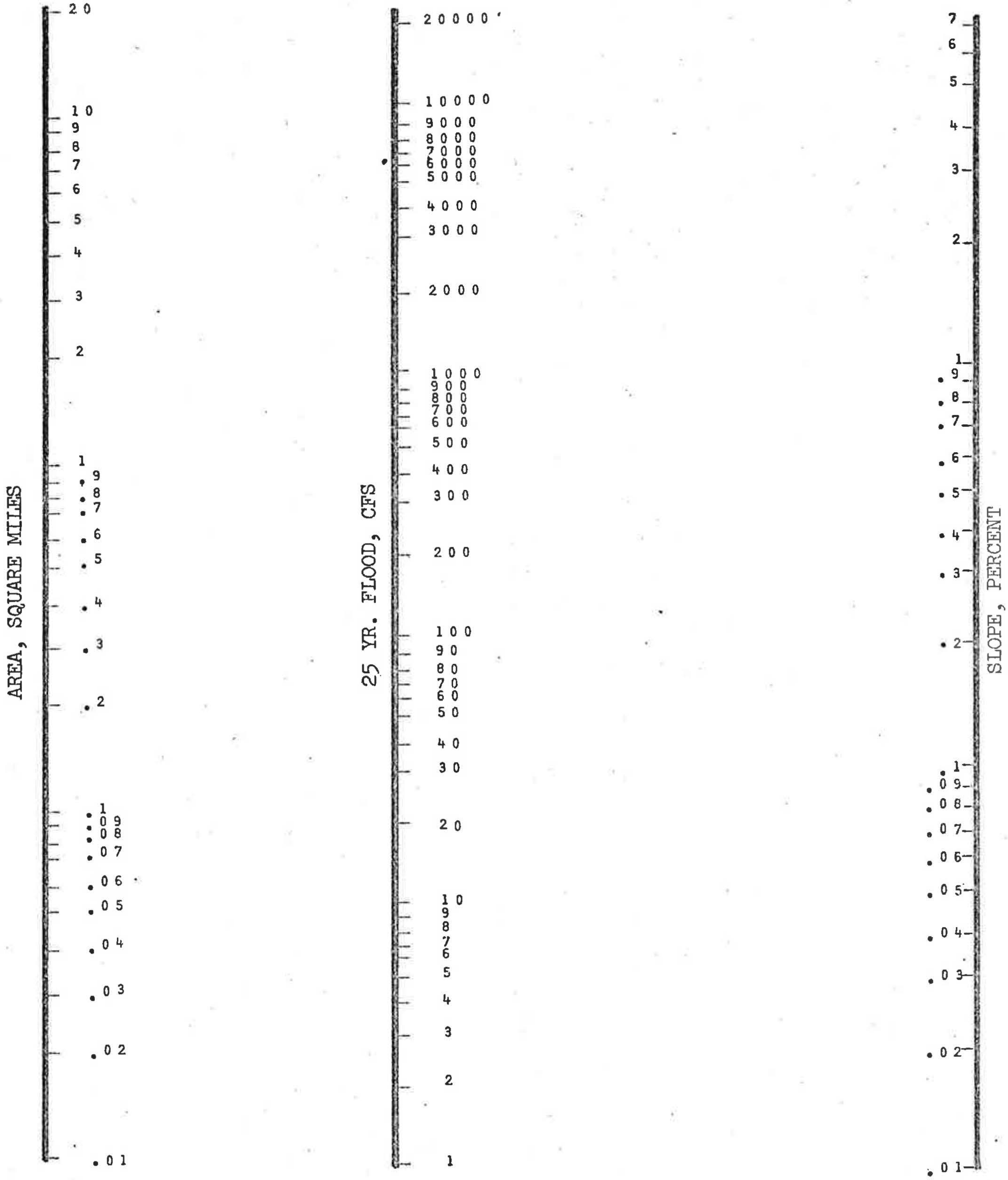

Figure 5.--25 year Flood Frequency for Region 2

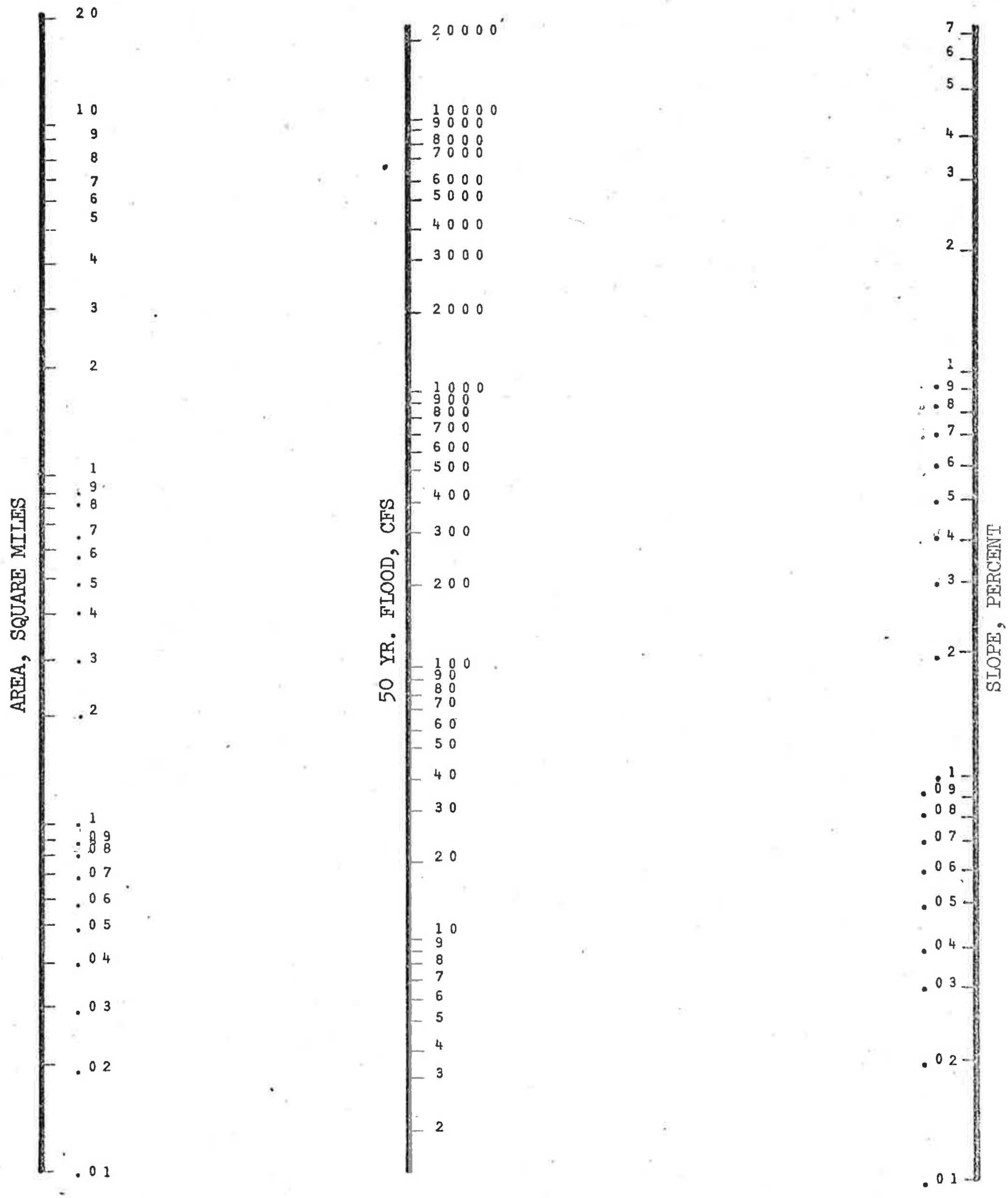

Figure 6.--50 year Flood Frequency for Region 2

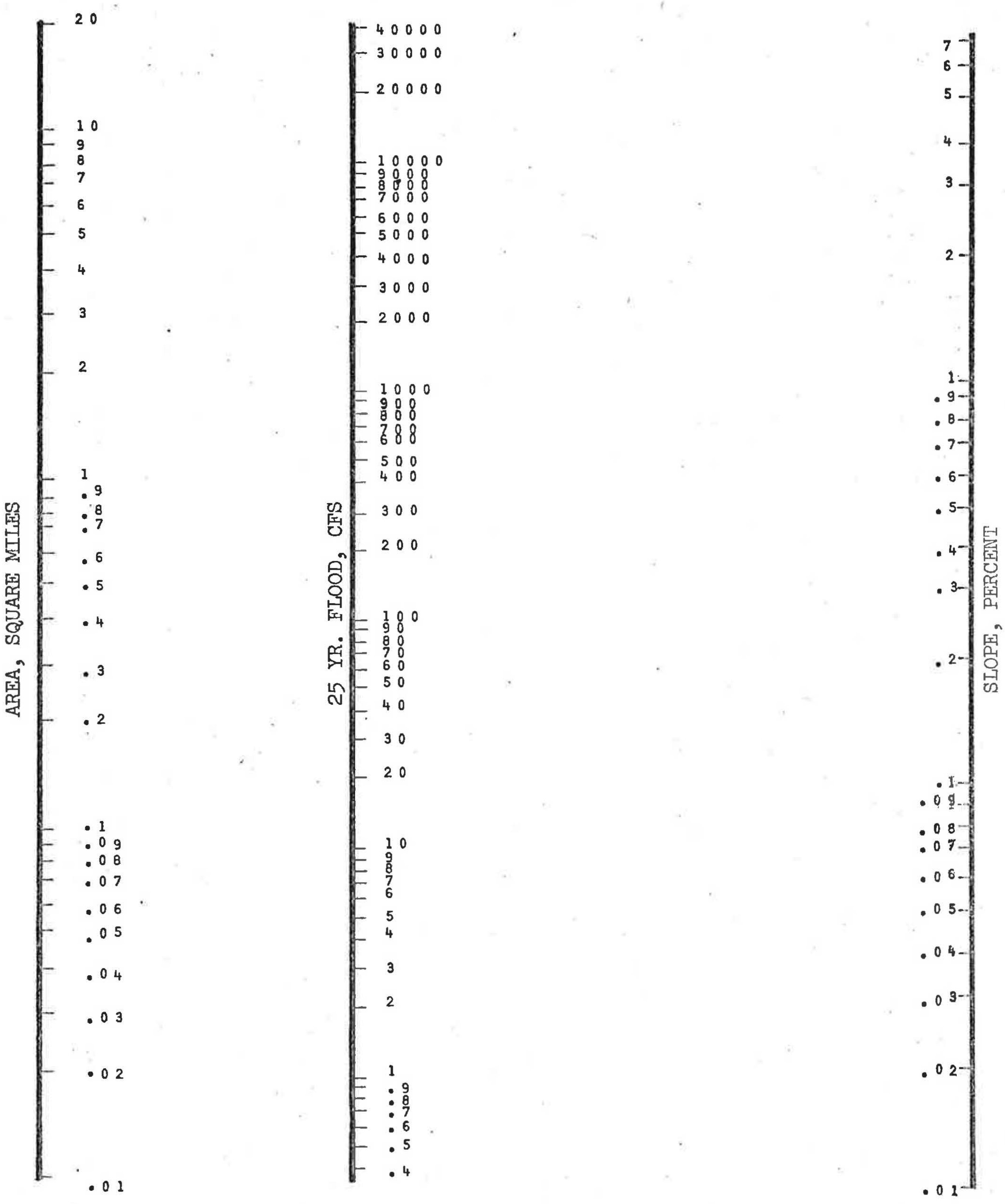

Figure 7.--25 year Flood Frequency for Region 3

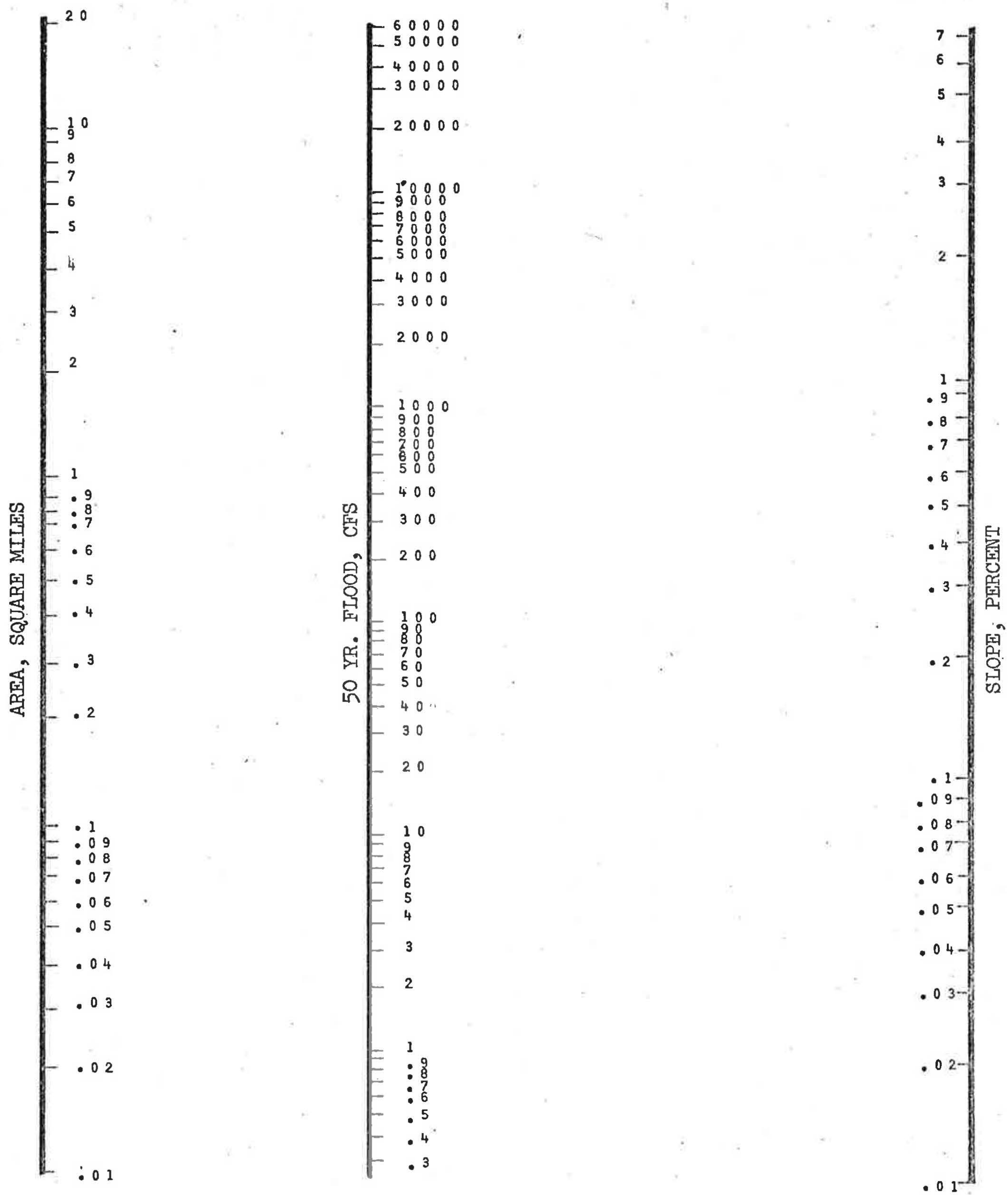

Figure 8.--50 year Flood Frequency for Region 3

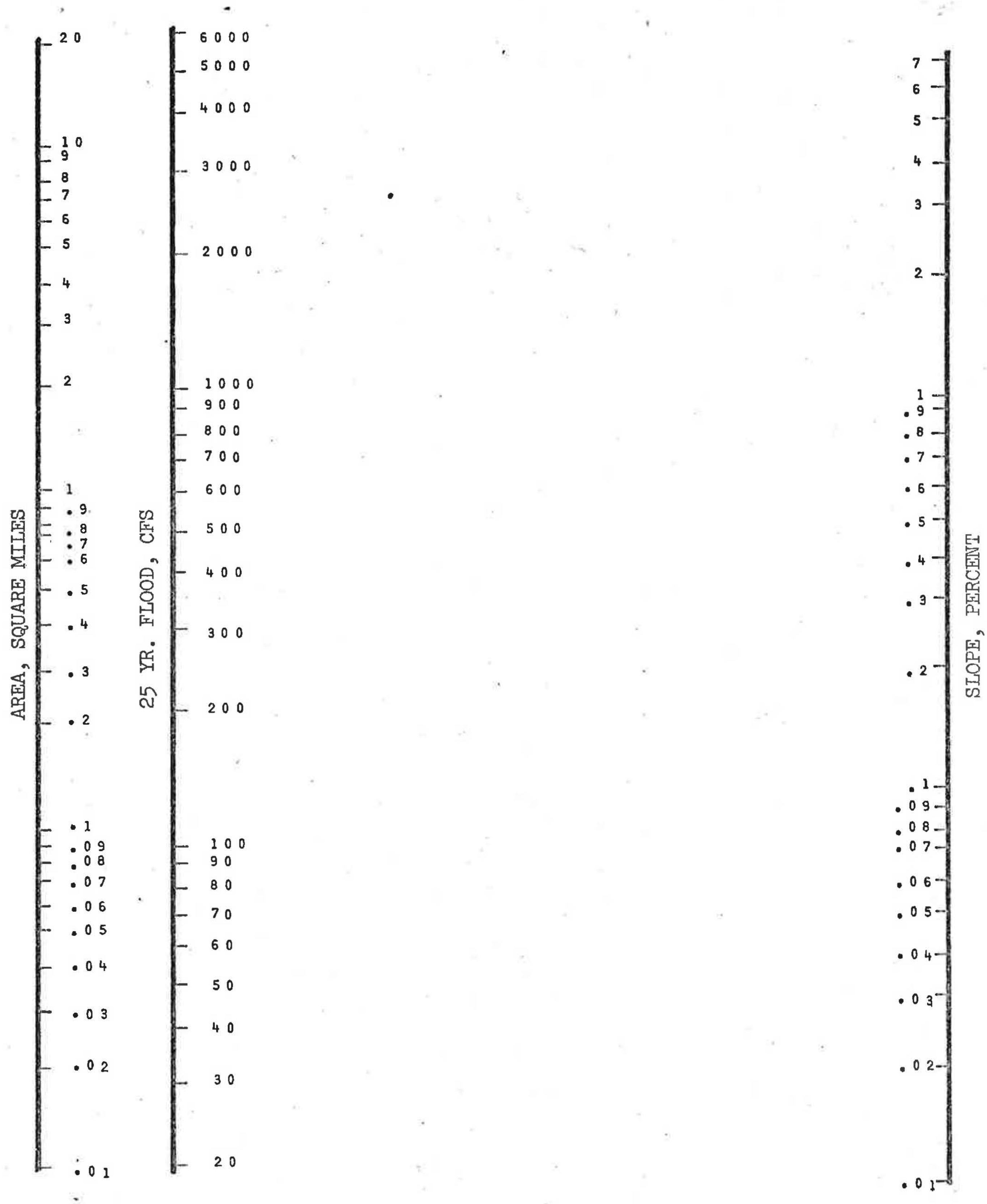

Figure 9.--25 year Flood Frequency for Region 4

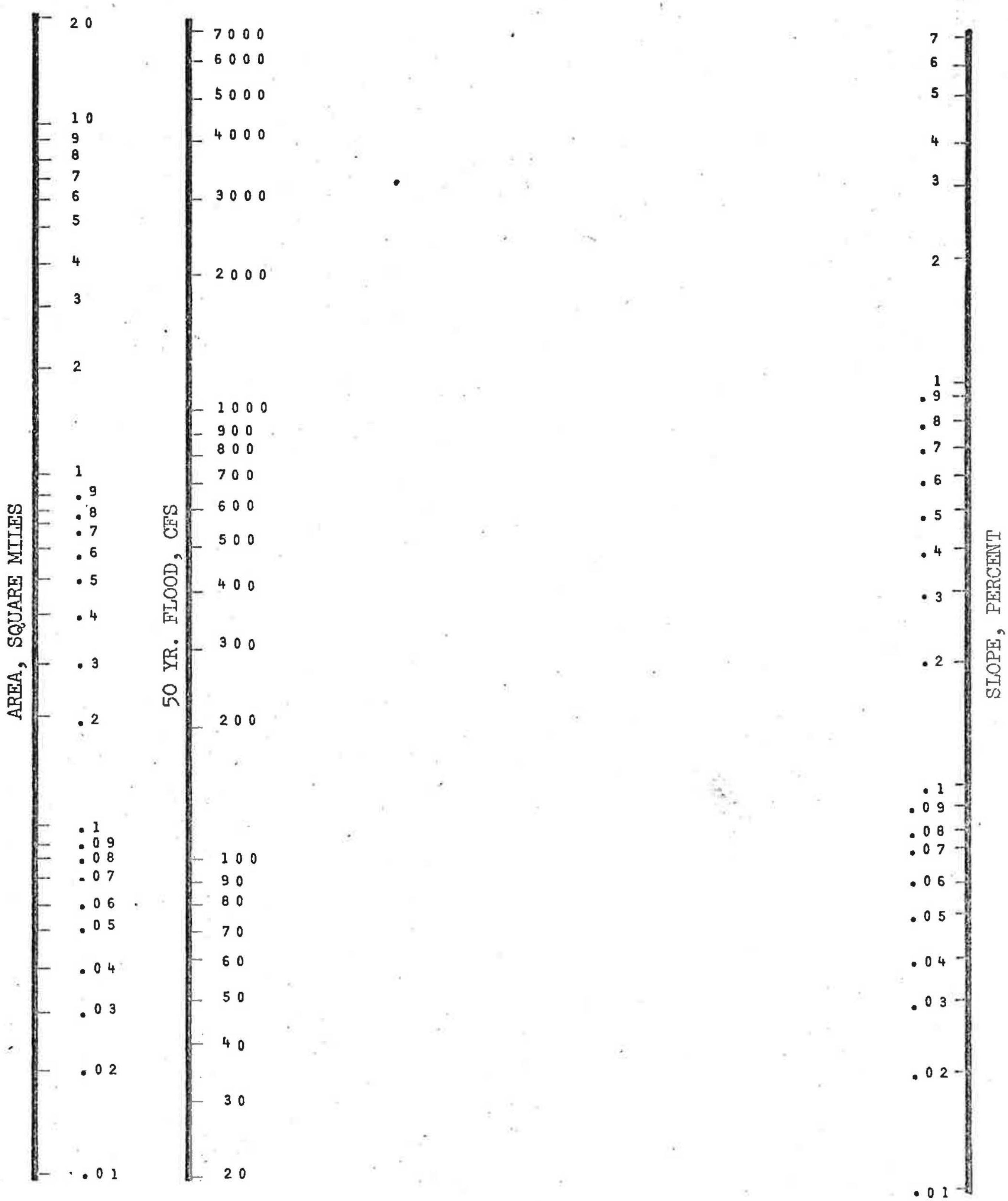

Figure 10.--50 year Flood Frequency for Region 4

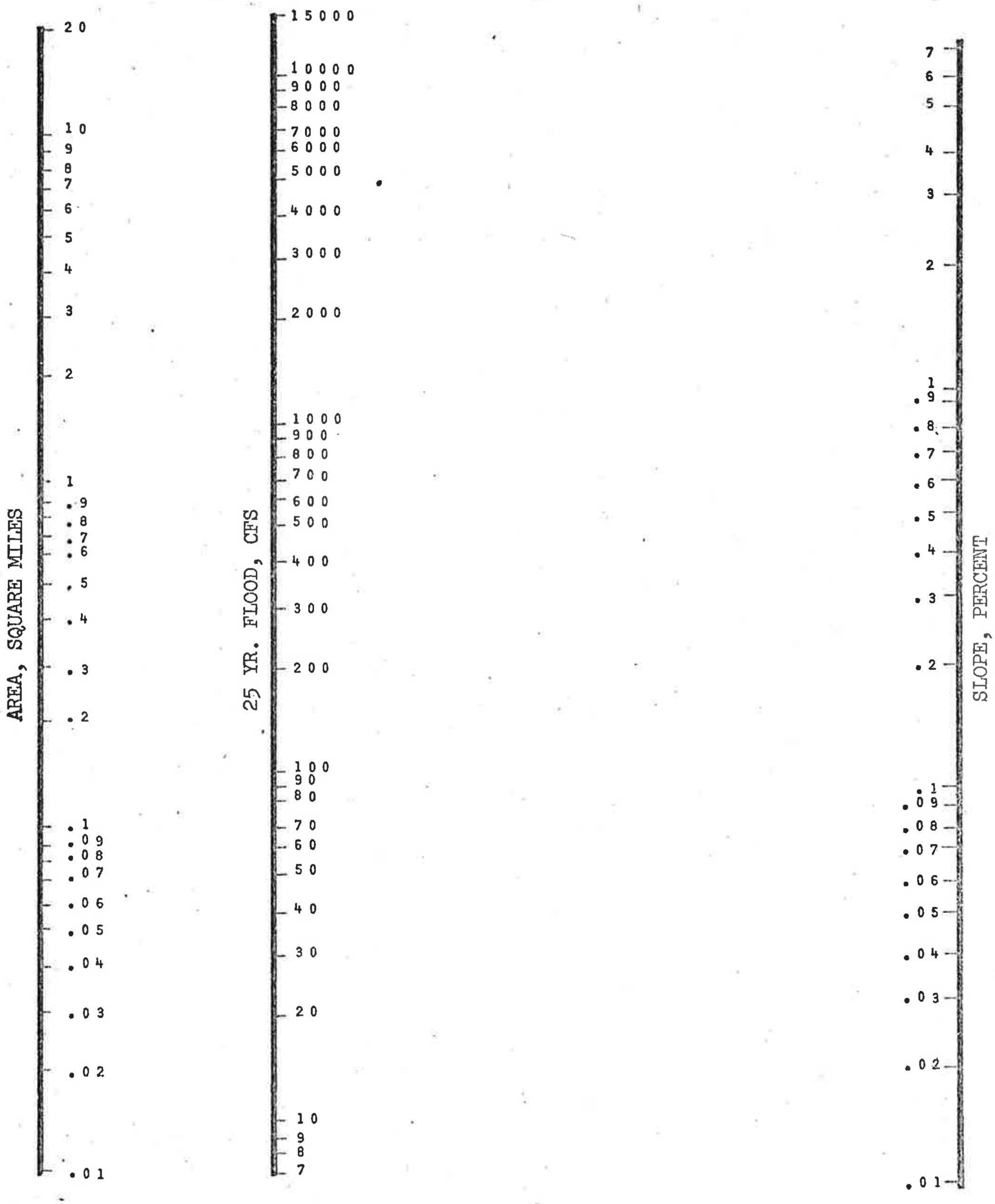

Figure 11.--25 year Flood Frequency for Region 5

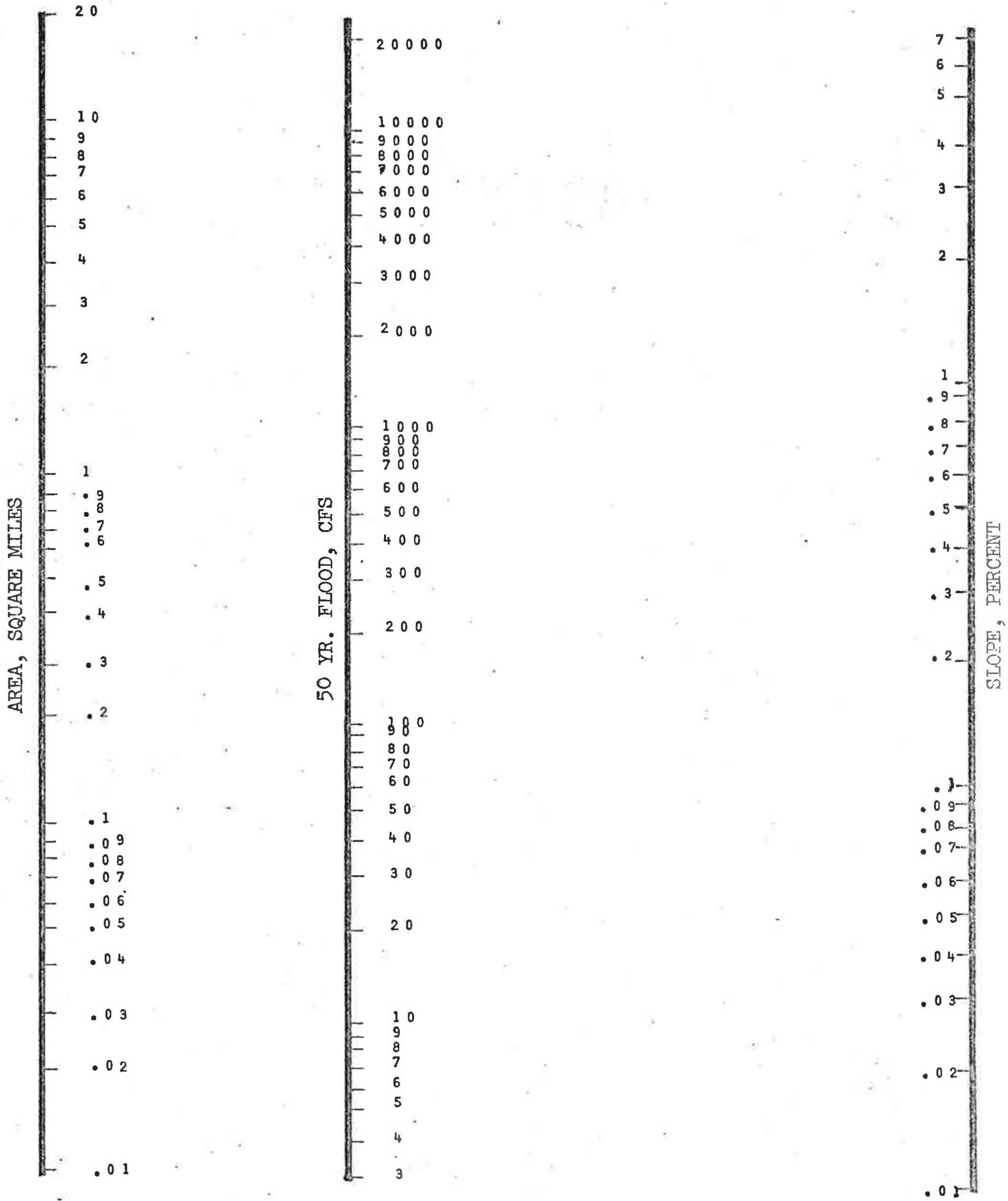

Figure 12.--50 year Flood Frequency for Region 5

PUBLICATIONS

"Spillway Design Floods for Small Dams in Rural Missouri," T.E. Harbaugh and J.E. Thompson, Civil Engineering Studies, UMR, Hydrologic Series Bulletin, June, 1970.

This publication was distributed to Missouri state and federal agencies and consultants for their use in designing small hydraulic structures.

TALKS PRESENTED

May 1969 - Annual Water Resources Research Center Meeting, Rolla, Mo.

May 1970 - Annual Water Resources Research Center Meeting, Rolla, Mo.

TRAINING ACCOMPLISHED

This project has provided the support for one M.S. candidate in Civil Engineering. In addition the material developed is used to explain the procedures of developing regional flood frequency estimates to a total of over 200 undergraduate and 25 graduate students in Civil Engineering.

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