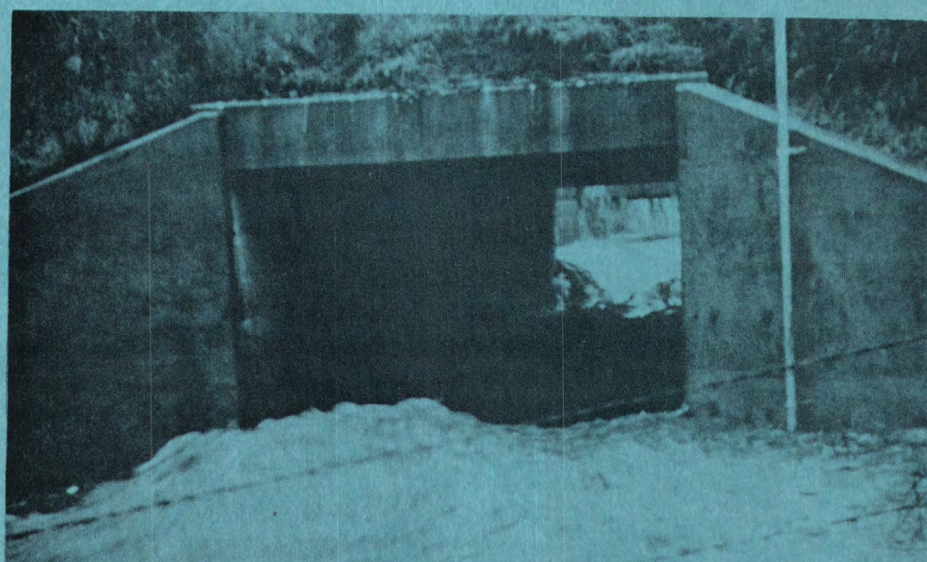
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRELIMINARY FLOOD-FREQUENCY RELATIONS FOR SMALL STREAMS IN KANSAS

T. J. Irza



Prepared in cooperation with the
State Highway Commission of Kansas

Open file report 66-67
Topeka, Kansas
February, 1966

UNITED STATES
DEPARTMENT OF THE INTERIOR
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EDWARD J. KENNEDY, District Engineer

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Prepared in cooperation with the
State Highway Commission of Kansas
WALTER G. JOHNSON, Chief Engineer

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FOR
SMALL STREAMS IN KANSAS

by T. J. Irza

ABSTRACT

Preliminary flood-frequency relations have been defined for small streams in Kansas for floods having recurrence intervals not greater than 10 years. The defined relations will be useful for the design of culverts and other hydraulic structures. The relations are expressed in terms of basin characteristics.

Peakflow records at 95 sites in Kansas for an 8-year period provided the basic data. The records were analyzed with respect to 20 basin characteristics by multiple-regression techniques. The resulting formulas relate flood magnitude and frequency to size of contributing drainage area, an index of stream-bed slope, and the average number of days per year when rainfall exceeded 1.0 inch. The other 17 factors had no statistical significance.

To illustrate a typical application of the flood-frequency relation, a step-by-step method is presented for computing a frequency curve for Rock Creek near Meriden, Kans. The frequency curve shows that a peak discharge of 3,620 cfs (cubic feet per second) can be expected once every 10 years on the average, and that the 67 percent confidence interval ranges from 1,820 cfs to 7,230 cfs. The large range results from the fact that only 8 years of record have been collected and emphasizes the need for collecting records for a longer period.

INTRODUCTION

This report describes methods for computing the magnitude and frequency of floods having recurrence intervals not greater than 10 years for drainage areas in the State of 70 square miles or less.

Knowledge of the magnitude and frequency of floods will help select the most economically feasible "design flood" for proper design of a culvert or other hydraulic structure. The use of a design flood introduces an element of risk that should be consistent with the economics and policies required in the design. When a design flood is too small, the element of risk is too great, and frequent floods greater than the design flood may cause frequent malfunction or even failure of a hydraulic structure. Thus, a low first cost will quickly be overcome by a continuing cost of repair or replacwment. When a design flood is too great, the element of risk is too small, and the probability of malfunction or failure also becomes very small; however, the assurance of sustained trouble-free operation incurs a high first cost. For both extreme conditions, the cost of the hydraulic structure may be economically excessive.

Methods for determining magnitudes and frequencies of floods for basins exceeding 150 square miles in drainage area are given by Ellis and Edelen (1960). Flood-frequency analyses for smaller basins were not attempted at that time because of lack of sufficient basic data. This deficiency was recognized, and in 1956 a program was started to provide a basis for a future analysis of flood frequency for smaller basins.

The purpose of this report is twofold: (1) To present a method for computing the magnitude and frequency of floods for drainage basins smaller than 70 square miles in Kansas; and (2) to evaluate the adequacy of the results attained.

Acknowledgments

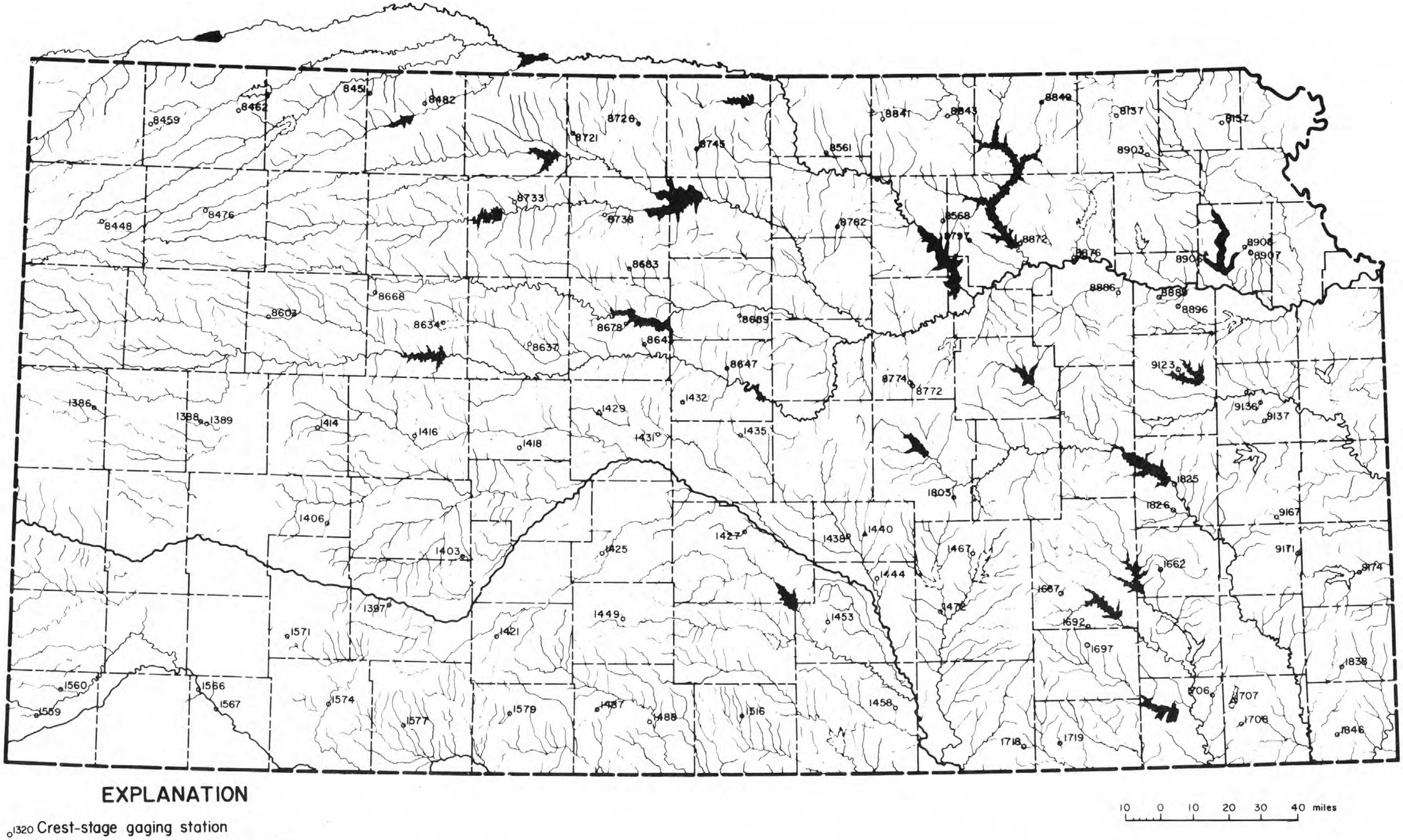
This report was prepared as a part of a cooperative program for water resources investigations in Kansas started July 1, 1956, between the State Highway Commission of Kansas, Walter G. Johnson, Chief Engineer, and the U. S. Geological Survey. The report was prepared in the Topeka district office of the Geological Survey under the administrative direction of E. J. Kennedy, district engineer, and the immediate direction of L. W. Furness, chief, Hydrologic Studies Section.

E. S. Elcock, Bridge Engineer of the State Highway Commission to September 1, 1965, and T. W. Oliver, thereafter, guided the scope of this report toward the goal of providing information useful for resolving small-area flood problems in Kansas. Aerial photography and computer facilities were supplied by the Photronics Section of the Highway Commission, directed by G. W. Anschutz, Engineer of Photronics.

RECORDS AVAILABLE

Peakflow records at 95 sites for an 8-year period in Kansas are published by the U. S. Geological Survey and provide data for the analysis. Figure 1 is a map of Kansas showing the location and identification numbers of the stations. Identification numbers are national inventory numbers used in the water-supply papers of the Geological Survey.

Table 1 includes a list of stations in downstream order where records used in this report were collected. The column headed, "Years of annual peaks", shows the years ending September 30th during which annual peak discharges have been determined. Annual peaks have been defined at most stations since the 1957 water year and for longer periods at a few stations where historical floods were known. For example, for station 6-8561, information obtained in 1958 provided a basis for the computation of the peak discharge for the flood of 1941. Other data listed in table 1 will be explained in the section, "Analysis and selection of basin hydrologic factors".



EXPLANATION

○1320 Crest-stage gaging station

△1440 Continuous record gaging station

Figure 1.- Location of small-area gaging stations in Kansas used for flood-frequency analysis.

Table 1.--Inventory of data used for flood-frequency analysis of small streams in Kansas

Identification number	Landline location		Stream and location in Kansas	Years of annual peaks (water years)	Drainage area (sq mi)		Main channel slope (ft per mi)	Wet days per year
	Township	Range			Total	Contrib.		
6-8137.0	3S	12E	Tennessee Creek tributary near Seneca	1957-64	0.90	0.90	68.8	7.0
6-8157.0	3S	18E	Buttermilk Creek near Willis	1957-64	3.74	3.74	33.3	7.0
6-8448.0	8S	39W	South Fork Sappa Creek tributary near Goodland	1957-64	4.98	4.98	17.6	4.0
6-8451.0	2S	25W	Long Branch Draw near Norcatur	1957-64	31.7	31.7	14.8	4.5
6-8459.0	3S	36W	Little Beaver Creek tributary near McDonald	1957-64	13.7	2.12	76.6	4.0
6-8462.0	3S	32W	Beaver Creek tributary near Lydell	1957-64	10.2	10.2	38.2	4.2
6-8476.0	8S	33W	Prairie Dog Creek tributary at Colby	1957-64	7.53	7.53	18.3	4.3
6-8482.0	2S	23W	Prairie Dog Creek tributary near Norton	1957-64	1.02	1.02	61.2	4.7
6-8561.0	4S	3W	West Salt Creek near Talmo	1941,57-64	42.0	42.0	10.8	5.8
6-8568.0	8S	4E	Moll Creek near Green	1957-64	3.60	3.60	27.1	8.3
6-8603.0	13S	30W	South Branch Hackberry Creek near Orion	1957-64	49.6	49.6	10.7	4.0
6-8634.0	13S	22W	Big Creek tributary near Ogallah	1957-64	4.81	4.81	19.5	5.0
6-8637.0	14S	17W	Big Creek tributary near Hays	1957-64	6.19	6.19	16.0	6.0
6-8643.0	14S	12W	Smoky Hill River tributary at Dorrance	1957-64	5.39	5.39	27.7	5.5
6-8647.0	15S	8W	Spring Creek near Kanopolis	1957-64	9.84	9.84	21.7	5.8
6-8668.0	11S	25W	Saline River tributary at Collyer	1957-64	3.13	3.13	31.9	4.8
6-8678.0	13S	13W	Cedar Creek tributary near Bunker Hill	1957-64	0.99	0.99	127.3	5.4
6-8683.0	10S	12W	Coon Creek tributary near Luray	1957-64	6.53	6.53	52.9	6.0
6-8689.0	12S	7W	Elkhorn Creek tributary near Lincoln	1957-64	2.64	2.64	63.4	5.7
6-8721.0	3S	15W	Middle Cedar Creek at Kensington	1957-64	58.9	58.9	12.0	5.1
6-8726.0	3S	12W	Oak Creek at Bellaire	1957-64	4.75	4.75	32.6	5.3
6-8733.0	7S	18W	Ash Creek tributary near Stockton	1957-64	.89	.89	59.4	5.0
6-8738.0	7S	14W	Kill Creek tributary near Bloomington	1957-64	1.45	1.45	44.2	6.0
6-8745.0	4S	9W	East Limestone Creek near Ionia	1934-37,57-64	25.6	25.6	20.8	5.5
6-8762.0	8S	2W	Middle Pipe Creek near Miltonvale	1957-64	10.2	10.2	47.8	6.0
6-8772.0	16S	2E	East Turkey Creek near Elmo	1957-64	26.6	26.6	13.0	8.3
6-8774.0	16S	2E	East Turkey Creek tributary near Elmo	1957-64	2.48	2.48	40.6	8.3
6-8797.0	9S	5E	Wild Cat Creek at Riley	1957-64	14.0	14.0	18.6	8.5
6-8841.0	3S	1E	Mill Creek tributary near Haddam	1957-64	1.64	1.64	74.0	6.8
6-8843.0	3S	4E	Mill Creek tributary near Washington	1957-64	3.20	3.20	52.9	8.0
6-8849.0	2S	9E	Robidoux Creek at Beattie	1957-64	40.0	40.0	15.7	7.5
6-8872.0	9S	8E	Cedar Creek near Manhattan	1957-64	13.4	13.4	48.6	8.5
6-8876.0	10S	10E	Kansas River tributary near Wamego	1951,57-64	.83	.83	113.8	7.9
6-8886.0	11S	12E	Dry Creek near Maple Hill	1903,57-64	15.6	15.6	33.6	7.8
6-8889.0	12S	14E	Blacksmith Creek tributary near Valencia	1957-64	1.31	1.31	77.3	7.7
6-8896.0	12S	15E	South Branch Shunganunga Creek near Pauline	1957-64	3.84	3.84	28.9	7.9
6-8903.0	5S	14E	Spring Creek near Wetmore	1957-64	21.0	21.0	19.6	6.7
6-8906.0	10S	17E	Rock Creek at Meriden	1957-64	22.0	22.0	16.3	7.7
6-8907.0	10S	19E	Slough Creek tributary near Oskaloosa	1957-64	0.83	0.83	57.2	8.0
6-8908.0	9S	19E	Slough Creek near Oskaloosa	1957-64	31.0	31.0	17.3	8.0
6-9123.0	16S	16E	Dragoon Creek tributary near Lyndon	1957-64	3.76	3.76	62.7	8.9
6-9136.0	17S	19E	Rock Creek near Ottawa	1957-64	10.2	10.2	18.1	10.0

Table 1.--Inventory of data used for flood-frequency analysis of small streams in Kansas-Continued

Identification number	Landline location Township	Landline location Range	Stream and location in Kansas	Years of annual peaks (water years)	Drainage area (sq mi) Total	Drainage area (sq mi) Contrib.	Main channel slope (ft per mi)	Wet days per year
6-9137.0	18S	19E	Middle Creek near Princeton	1951,57-64	52.0	52.0	12.1	10.2
6-9167.0	23S	20E	Middle Creek near Kincaid	1957-64	2.02	2.02	49.8	11.2
6-9171.0	25S	21E	Marmaton River tributary near Bronson	1957-64	0.88	0.88	45.8	11.3
6-9174.0	26S	24E	Marmaton River tributary near Fort Scott	1957-64	2.80	2.80	45.5	12.0
7-1386.0	17S	39W	White Woman Creek tributary near Selkirk	1957-64	38.0	7.59	20.5	4.3
7-1388.0	18S	34W	Lion Creek tributary near Modoc	1957-64	7.0	1.19	27.8	4.0
7-1389.0	18S	33W	Lion Creek near Modoc	1957-64	41.4	18.6	12.8	4.0
7-1397.0	27S	25W	Arkansas River tributary near Dodge City	1957-64	8.66	8.66	15.0	5.5
7-1403.0	24S	21W	White Woman Creek near Bellefont	1957-64	14.0	14.0	10.9	5.5
7-1406.0	23S	28W	Pawnee River tributary near Kalvesta	1957-64	6.89	6.89	14.3	5.0
7-1414.0	18S	28W	South Fork Walnut Creek tributary near Dighton	1957-64	0.81	0.81	23.	5.0
7-1416.0	18S	23W	Long Branch Creek near Ness City	1957-64	28.0	28.0	9.3	5.0
7-1418.0	19S	18W	Otter Creek near Rush Center	1957-64	17.0	17.0	16.4	5.5
7-1421.0	28S	19W	Rattlesnake Creek tributary near Mullinville	1957-64	10.3	10.3	11.6	6.1
7-1425.0	24S	14W	Spring Creek near Dillwyn	1957-64	14.3	14.3	9.8	6.0
7-1427.0	23S	7W	Salt Creek near Partridge	1957-64	85.0	72.0	7.0	7.0
7-1429.0	17S	14W	Blood Creek near Boyd	1957-64	61.0	54.0	12.3	5.7
7-1431.0	18S	11W	Cheyenne Creek tributary near Claflin	1957-64	1.48	1.48	18.4	5.8
7-1432.0	17S	10W	Plum Creek near Holyrood	1957-64	19.0	19.0	11.9	5.8
7-1435.0	18S	7W	Little Arkansas River near Geneseo	1957-64	25.0	25.0	13.0	6.0
7-1438.0	23S	2W	Black Kettle Creek tributary near Halstead	1957-64	1.65	1.65	20.5	8.2
7-1440.0	23S	1W	East Emma Creek near Halstead	1957-64	58.0	58.0	7.4	8.3
7-1444.0	25S	1E	West Fork Chisholm Creek tributary near Valley Center	1957-62	5.22	5.22	14.6	8.5
7-1449.0	27S	13W	South Fork Ninnescah River tributary near Pratt	1957-64	1.48	1.48	19.2	6.8
7-1453.0	27S	3W	Clear Creek near Garden Plain	1957-64	5.03	5.03	20.4	8.0
7-1458.0	32S	1E	Avon Creek tributary near Dalton	1957-64	0.41	0.41	56.4	8.5
7-1467.0	24S	5E	West Branch Walnut Creek tributary near De Graff	1957-64	11.0	11.0	15.0	9.0
7-1472.0	27S	4E	Indianola Creek tributary near Augusta	1957-64	0.90	0.90	55.2	9.0
7-1487.0	32S	14W	Dog Creek near Deerhead	1957-64	5.31	5.31	69.7	6.9
7-1488.0	31S	12W	Medicine Lodge River tributary near Medicine Lodge	1957-64	2.04	2.04	43.3	7.1
7-1516.0	32S	7W	Rush Creek near Harper	1957-64	12.0	12.0	21.2	7.5
7-1559.0	33S	42W	North Fork Cimarron River tributary near Elkhart	1957-64	75.0	10.0	16.9	4.5
7-1560.0	31S	41W	North Fork Cimarron River tributary near Richfield	1957-64	103.	58.9	14.7	4.5
7-1566.0	31S	34W	Cimarron River tributary near Moscow	1957-64	13.0	8.0	17.0	5.1
7-1567.0	32S	33W	Cimarron River tributary near Satanta	1957-64	2.41	2.41	42.5	5.2
7-1571.0	28S	30W	Crooked Creek near Copeland	1957-64	44.0	44.0	12.6	5.2
7-1574.0	32S	28W	Crooked Creek tributary at Meade	1957-64	6.57	6.57	39.4	5.8
7-1577.0	33S	24W	Kiger Creek near Ashland	1957-64	34.0	34.0	30.0	6.1
7-1579.0	32S	19W	Cavalry Creek near Coldwater	1957-64	46.0	46.0	9.4	6.5
7-1662.0	25S	14E	Sandy Creek near Yates Center	1957-64	6.80	6.80	30.3	10.5
7-1667.0	26S	9E	Burnt Creek at Reece	1957-64	8.85	8.85	45.5	9.9
7-1692.0	28S	11E	Salt Creek near Severy	1957-64	7.59	7.59	46.4	10.1

Table 1.--Inventory of data used for flood-frequency analysis of small streams in Kansas-Continued

Identification number	Landline location		Stream and location in Kansas	Years of annual peaks (water years)	Drainage area (sq mi)		Main channel slope (ft per mi)	Wet days per year
	Township	Range			Total	Contrib.		
7-1697.0	29S	11E	Snake Creek near Howard	1957-64	1.84	1.84	53.7	10.2
7-1706.0	31S	17E	Cherry Creek near Cherryvale	1957-64	15.0	15.0	25.3	11.2
7-1707.0			Big Hill Creek near Cherryvale	1951,58-64	37.0	37.0	10.9	10.5
7-1708.0	33S	18E	Mud Creek near Mound Valley	1957-64	4.22	4.22	28.0	11.5
7-1718.0	34S	8E	Cedar Creek tributary near Hooser	1957-64	0.56	0.56	161.5	10.1
7-1719.0	34S	9E	Grand Creek near Wauneta	1957-64	20.0	20.0	26.9	10.5
7-1803.0	21S	5E	Spring Creek tributary near Florence	1957-64	0.55	0.55	51.1	9.0
7-1825.0	21S	15E	Rock Creek at Burlington	1951,1957-64	8.27	8.27	21.9	10.0
7-1826.0	22S	15E	North Big Creek near Burlington	1957-64	46.0	46.0	9.6	10.0
7-1838.0	30S	20E	Limestone Creek near Beulah	1957-64	12.0	12.0	16.6	12.2
7-1846.0	34S	23E	Fly Creek near Faulkner	1957-64	27.0	27.0	16.0	12.4

METHOD OF FLOOD-FREQUENCY ANALYSIS

The method of computing flood-frequency relations used in this report was developed in a continuing study by engineers of the Geological Survey. In addition, an investigation was made of the applicability to this study of many hydrologic factors suggested by Benson (1962). The statistical principles and analysis outlined in the following sections follow two major steps: (1) Definition of flood-frequency relations for a specific gaging station on a stream, and (2) multiple-regression analysis to compute flood-frequency relations for any small stream in Kansas.

Flood-Frequency Relation at a Gaging Station

For each station annual peak discharges for the period October 1 to September 30 of each year were arrayed in descending order. The corresponding recurrence intervals in years were computed from the formula $\frac{N+1}{M}$, where N is the number of years of record and M is the relative order of magnitude of the flood. For a record augmented by knowledge of one or more historical floods, N is the number of years during which the relative order of magnitude of the flood is known.

Annual floods for each station were plotted at the computed recurrence interval on a special form (Powell, 1943) developed for use in the analysis of flood frequencies by the theory of extreme values (Gumbel, 1941). A plot for a sample station is shown in figure 2 where the data graphically represent flood experience at the station. A flood-frequency graph fitted to these data is not considered the best means for evaluating future flood expectancy at that particular site. The inadequacy of such a graph at a gaging station is discussed in the following section.

Limitation of a Flood-Frequency Graph at a Gaging Station

A flood-frequency graph based on records at a single station has limited value because of the manner in which flood events are distributed with respect to time. For example, a flood record of 100 years cannot be expected to include exactly one 100-year flood, two 50-year floods and so on. If a 100-year record were separated into two 50-year periods, one period may include several 50 year floods and the other may include none. Also, the frequency graph for the first 100 years of record may differ appreciably from a frequency graph for the second 100 years of record. Thus the annual flood events for a particular stream are only samples, and the frequency graph defined by these events may differ considerably and unpredictably from a frequency graph derived from an infinitely long record.

Flood magnitudes or frequencies computed from short-term records probably will differ from their true, long-term values. The differences tend to increase with the magnitude of the flood and decrease with the length of record. Possible

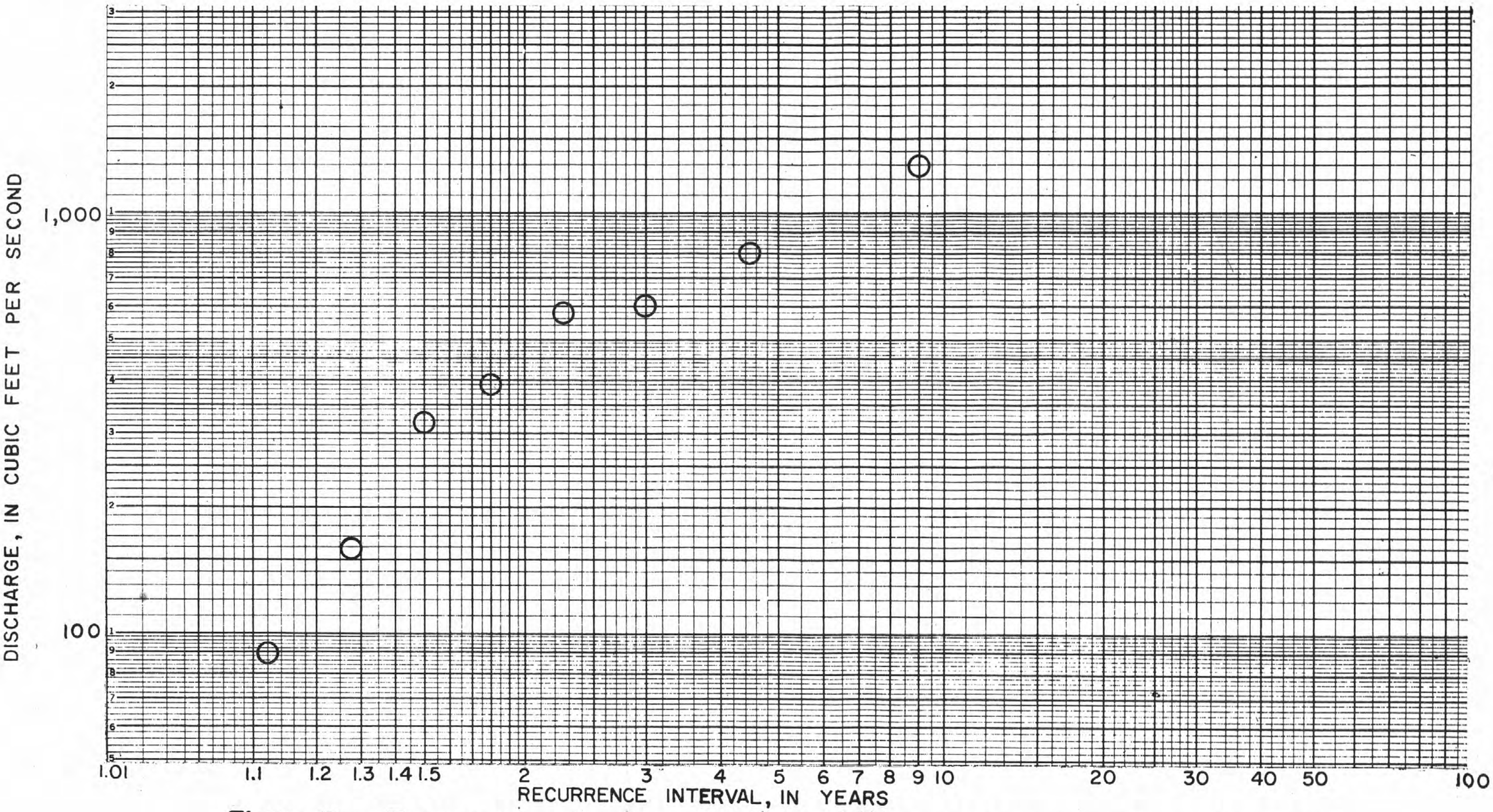


Figure 2.— Frequency of annual floods for station number 6-8603, Coon Creek tributary, near Luray, Kansas.

(Contributing drainage area, 6.53 square miles.)

variations in frequency curves computed from short records have been studied by Benson (1960) who analysed an array of 1,000 hypothetical annual floods distributed according to the theory of extreme values (Gumbel, 1941). From Benson's study the following tabulation shows the length of record required to define magnitudes and frequencies of floods:

Length of record necessary, in years, at a single station to define a flood within the indicated percentage, 19 times in 20, is as follows:

Magnitude of flood	± 25 percent	± 10 percent
2.33-year flood	12	40
10-year flood	18	90
25-year flood	31	105
50-year flood	39	110

Although the above figures are based on hypothetical rather than actual flood events, they indicate variations resulting from chance alone where frequency graphs are based on short-term records for a single station. Because of the magnitude of the variations, an average of single-station records is considered to be a better basis than a single-station record for definition of flood frequencies. Analysis on a Statewide basis is described in the section, "Statewide flood-frequency relations".

Analysis and Selection of Basin Hydrologic Factors

The problem of a Statewide flood-frequency analysis is first to choose those basin hydrologic factors which may be expected to be causally related to flood peaks, to break them down into their simplest components, to evaluate them mathemaically, and to choose factors having the least interdependence. Next, multiple regression methods are used to test the most significant factors and to define the relations between flood peaks and their causes. In the regression analysis, the hydrologic factors are the independent variables that are to be associated with the dependent variables of flood peaks.

The dependent variables were computed from plots of arrayed annual floods similar to figure 2. On these plots a flood-frequency curve was drawn for each gaging station and four values of flood magnitudes were selected as dependent variables at frequencies of recurrence of 1.2, 2.33, 5, and 10 years, respectively.

The following 14 basin hydrologic factors were selected and tested as independent variables. (1) Total drainage area. This is the area within the basin divide upstream from a gaging station. (2) Contributing drainage area. This is the area within a basin that contributes directly to runoff. Contributing drainage area is less than the total drainage area in a few parts of the State where some surface runoff is detained on flat lands or surface depressions. (3) Basin width and (4) Main channel length. Items (3) and (4) are factors of basin shape that may affect the distribution of runoff and hence the magnitude of a flood peak. (5) Main channel slope. Because the slope of one part of a stream may have the strongest influence upon the magnitude of a flood, slopes of 91 separate parts of each stream used in this report were determined by electronic computer. The computed slopes, drainage area, and mean annual precipitation were regressed with selected flood frequencies. The regression analysis indicated that the part of main channel slope statistically most significant was that between points 10 percent and 95 percent of the total distance along the main channel from the gage to the basin divide. (6) Mean flow. This is the average rate of streamflow found to be a flood-frequency factor for basins exceeding 150 square miles area in Kansas (Ellis and Edelen, 1960, fig. 9). (7) Mean annual precipitation. (8) Two-year, 24-hour rainfall intensity. (9) Number of dry periods in a 45-year period when 30 consecutive days passed with no more than 0.25 inch of precipitation (Flora, 1948). (10) Average number of "wet days" per year with 1.00 inch or more of precipitation, (Flora, 1948). (11) Minimum January temperature. (12) Heating degree days. (13) Number of days of snowfall per year. (14) Average snowfall per year. Items 9 to 14 affect antecedent soil moisture which in turn highly affects flood potential.

State-Wide Flood-Frequency Relations

Standard multiple-regression analyses were used to develop the Statewide flood-frequency relations. In the regressions, peak discharges with selected frequencies were used as dependent variables and basin hydrologic factors were used as independent variables. Because some of the independent variables were closely interrelated, they were analysed by considering 10 different combinations of the 14 variables containing seven to nine variables in each of the 10 combinations. The regression analysis to select significant variables used only the floods of 2.33-year recurrence interval as the dependent variable because floods with this recurrence interval are most accurately defined. The flood of 2.33-year recurrence interval is usually referred to as the "mean annual flood". A more rigorous expression would be "Mean of the annual floods as defined graphically on frequency graph paper".

The final equations are listed below.

(1) $Q_{1.2} = 0.050\ A^{.788}\ S^{.505}\ W^{2.45}$ +150%, -60%

(2) $Q_{2.33} = 1.72\ A^{.664}\ S^{.341}\ W^{1.82}$ + 74%, -42%

(3) $Q_{5} = 13.3\ A^{.584}\ S^{.150}\ W^{1.50}$ + 84%, -46%

(4) $Q_{10} = 39.3\ A^{.552}\ S^{.066}\ W^{1.29}$ +100%, -49%

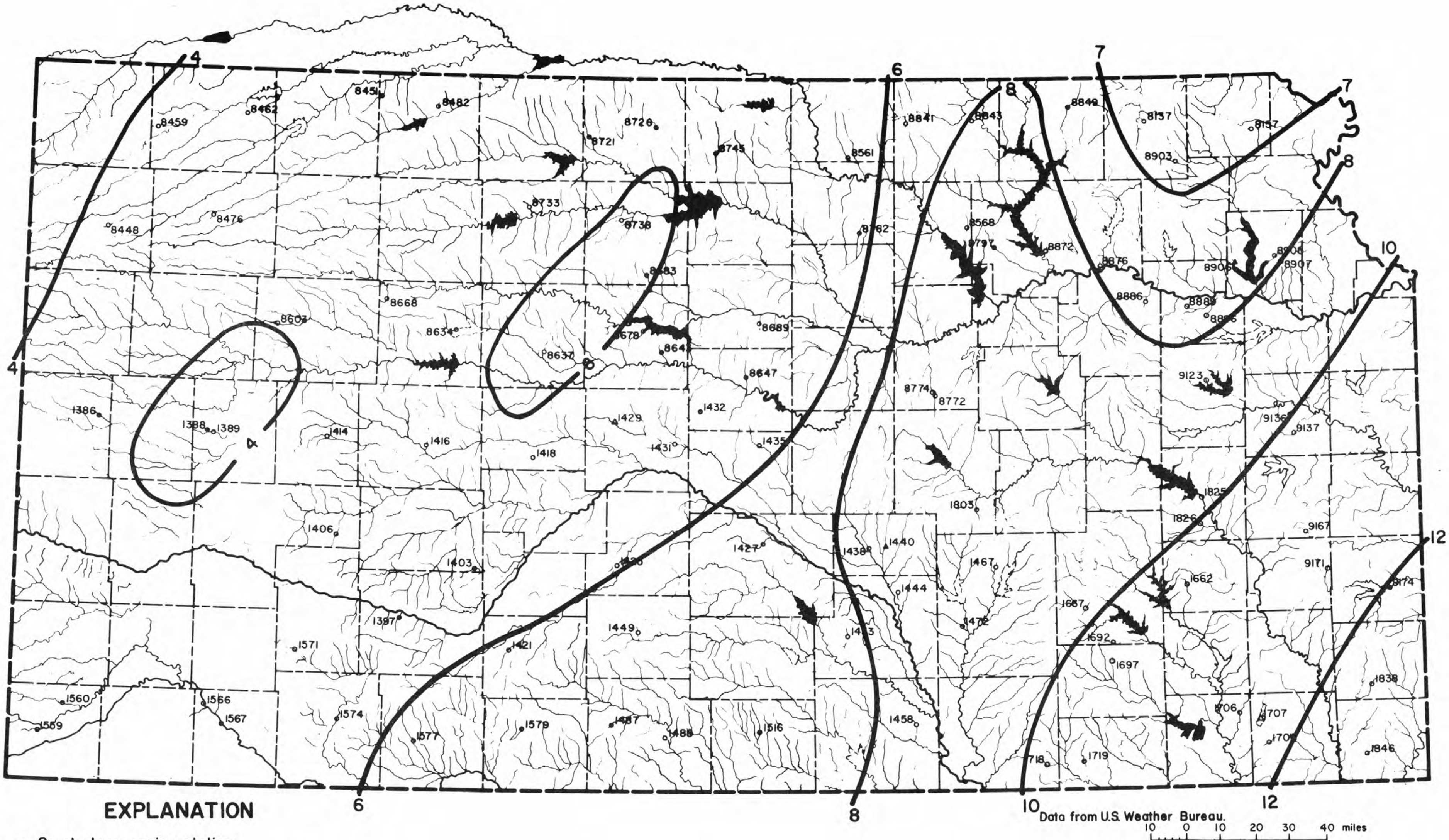
Q is the peak discharge in cubic feet per second with its subscript identifying the recurrence interval of the peak discharge in years, A is the contributing drainage area in square miles, S is the slope in feet per mile, and W is the average number of wet days per year (fig. 3). Beside each equation is the range in standard error of estimate which defines a range such that there is a two-thirds chance that the range will include the true value of the flood event.

In the above equations, the exponents of A, S and W were tested statistically using Student's t-test and found significantly different from zero showing that A, S and W are related to the dependent variables. The exponents of A and W were significantly greater than zero at more than the 99 percent confidence level of significance. The S exponent was significant above 95 percent level of significance for the $Q_{1.2}$ and $Q_{2.33}$ events and above the 60 percent and 40 percent levels of significance for the Q_5 and Q_{10} events, respectively. None of the other 11 variables investigated were found significant above the 80% level.

Analysis of Residual Errors

An analysis of the results of the computation of the Statewide flood-frequency relation was made to determine if the relation could be improved by using added factors. Accordingly, the residual error expressed as the ratio of the actual to the computed value of the 2.33-year flood was computed for each gaging station. The residual at each gaging-station location is plotted in figure 4. A ratio of 1.00 indicates exact agreement between the actual and the computed values; a large departure from 1.00 indicates a large disagreement.

If all significant hydrologic factors or variables had been considered in the regression analysis, the distribution of residuals would be random and would be attributable to sampling error. If, however, a significant variable had been omitted in the analysis, there would be a statistical relation between this variable and the residuals. Accordingly, the residuals were tested by graphical correlation against the following previously untested variables. (1) Variability index, regionally defined by Furness (1959, fig. 148), which defines the variability of streamflow as a function of the slope of duration curves; (2) Composite, soil-cover, complex number of the land resource unit encompassing each drainage basin as derived by the Soil Conservation Service (1960, table 29), as a measure of runoff potential; (3) Surface runoff from a 24-hour rainfall expected every 2 years on the average as determined for various land resource units by the Soil Conservation Service (1960, table 29). (4) Water loss during a 2-year flood expressed as the difference between a two-year, 24-hour rainfall and a surface runoff in inches with a 2-year frequency for various land resource units, by the Soil Conservation Service (1960, table 29); (5) Rainfall-runoff ratio expressed as the ratio of annual precipitation (records of the U. S. Weather Bureau) to mean runoff in that part of the State (Furness, 1960,



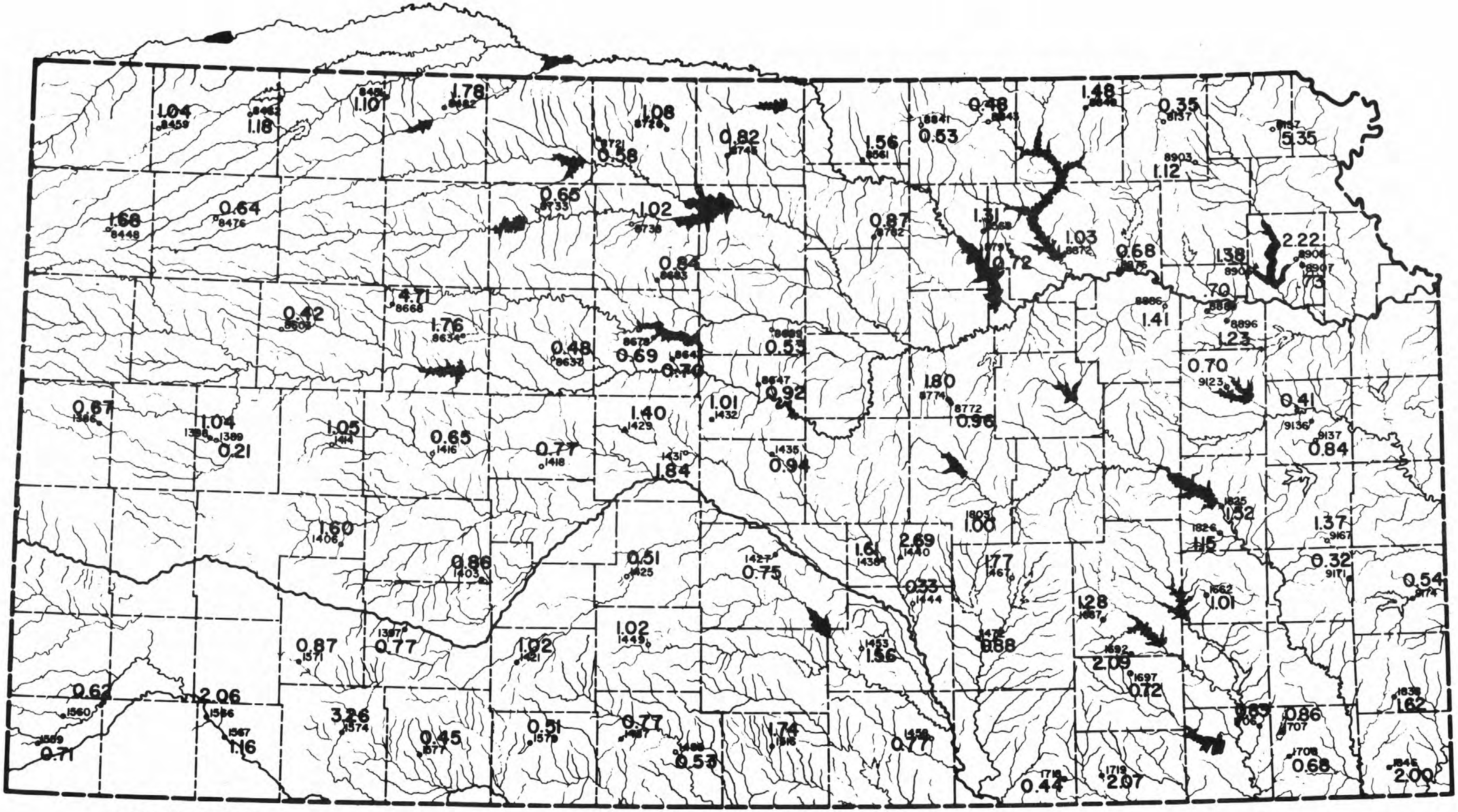
EXPLANATION

○1320 Crest-stage gaging station.

△1440 Continuous record gaging station.

4 Wet days per year.

Figure 3.- Average number of "wet days" per year when precipitation exceeds one inch per day.



EXPLANATION

○1320 Crest-stage gaging station.

▲1440 Continuous record gaging station.

1.60 Residual error expressed as the ratio of actual to computed value of mean annual flood, $Q_{2.33}$.

10 0 10 20 30 40 miles

Figure 4.—Residual error of small-area, flood-frequency relations in Kansas.

fig. 125); (6) The three physiographic zones of Kansas defined by Potter (1961, fig. B-1C). In each of the six trials no correlation was found; thus indicating that these variables do not improve the relation previously described.

APPLICATION OF A STATEWIDE FLOOD-FREQUENCY RELATION

This section gives step-by-step procedures for determining the magnitude of floods having selected recurrence intervals up to 10 years at any site in Kansas with a drainage area not greater than 70 square miles. Results should be more dependable than those obtained by considering only the experienced floods at an individual site.

(1) Determine the size of the contributing drainage area. For most basins, contributing drainage area is equivalent to total drainage area. For some, the contributing drainage area is less because surface runoff is retained on flat table-land, depressions, or closed basins. Contributing drainage area can be measured on county or topographic maps after outlining the area encompassing a continuous stream pattern.

(2) Determine slope of the streambed between the 10 percent and 95 percent points along the main channel. The elevations can be obtained from available topographic maps at points along the main stem at distances of 10 percent and 95 percent of the total distance from the site to the basin divide. When no topographic maps are available, field reconnaissance is necessary. The use of a sensitive altimeter will produce good results.

(3) Determine "wet days". "Wet days" can be determined directly from figure 3.

(4) Select applicable equation and compute flood magnitude.

The above procedure has been applied to the established gaging station at Meriden in northeastern Kansas which is identified by number 8906 in figure 1. The drainage area is 22.0 square miles, the 10 percent-95 percent channel slope is 16.3 ft per mile, and the "wet day" value is 7.7 days. By substitution in the equations, the following results are obtained:

$$Q_{1.2} = 0.050\ A^{.788}\ S^{.505}\ W^{2.45} = 340 \text{ cfs}$$

$$Q_{2.33} = 1.72\ A^{.664}\ S^{.341}\ W^{1.82} = 1,420 \text{ cfs}$$

$$Q_{5} = 13.3\ A^{.584}\ S^{.150}\ W^{1.50} = 2,620 \text{ cfs}$$

$$Q_{10} = 39.3\ A^{.552}\ S^{.066}\ W^{1.29} = 3,620 \text{ cfs}$$

The computed values have been plotted on figure 5 and connected by a smooth frequency curve between recurrence intervals of 1.2 and 10 years.

Knowledge of corresponding river stages may be required in the design of a structure and in other related studies. The stage corresponding to a given discharge must generally be obtained through the use of a stage-discharge relation. The following methods of deriving a stage-discharge relation are listed in the order of reliability. (a) If the need for data can be anticipated early enough, a series of current-meter measurements can be obtained to define the relation; (b) Computation by routing streamflow as defined in hydraulics textbooks. Also the series "Surface Water Techniques" being prepared by the U. S. Geological Survey outlines methods for determining stage-discharge relations by means other than by current-meter measurements; (the publications will soon be available from the Superintendent of Documents in Washington). (~~3~~c) A method using the values at a typical river cross section of stage, corresponding conveyance, and stream slope at selected flows. Method (c) is not recommended for streams with unstable channel beds.

ADEQUACY OF RESULTS

Using 8-year records, preliminary flood-frequency relations have been defined in this report for drainage areas ranging between 1 and 70 square miles and for floods expected to recur up to once in 10 years on the average. The adequacy of these relations are described in the following paragraphs.

The first feature to be examined is the accuracy of results obtained from the flood formulas. Only the 10-year flood will be discussed because that probably will be of most interest. A multiple-regression analysis showed that the 10-year flood would have a two-thirds chance on the average of being defined within +100 percent and -49 percent. Using the frequency curve for Rock Creek (fig. 5) as an example where the 10-year flood has been defined as 3, 620 cfs: If the prediction error were for a basin with basin characteristics representing the average for the State, the chances are 2 out of 3 that the limits of 7, 240 and 1, 850 cfs would include the true 10-year flood value. The prediction error at Rock Creek, specifically, would be larger and is represented by the enveloping lines on figure 5 for 67 percent confidence intervals. Thus at Rock Creek, the 67 percent confidence interval for the 10-year flood ranges from 1, 820 cfs to 7, 230 cfs. Such a range in limits is large primarily because of the brevity of record. It can be reduced by collecting records for additional years and by continuing the programmed search for added parameters. Such a course is recommended.

The second feature to be examined is the flood-frequency relation that has been established. In this relation, the factors of drainage area, stream slope,

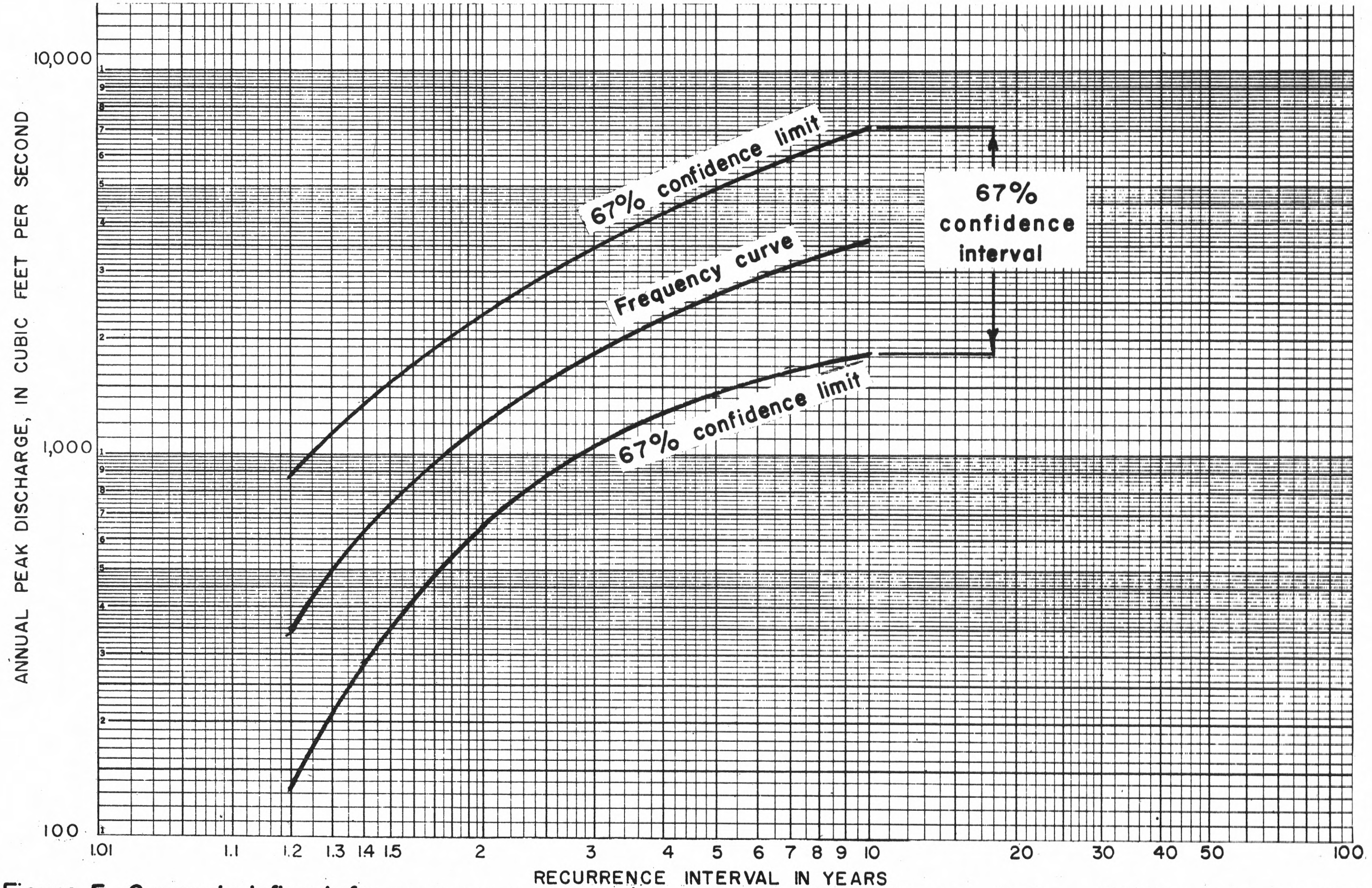


Figure 5.- Computed flood-frequency curve and its 67 percent confidence limits. Station no. 6-8906 Rock Creek near Meriden, Kans.

and "wet-days" were found to be significant. However other factors found not significant have been shown by other investigators to have an important influence on the magnitude of a flood. For example, hydrologic literature contains evidence of the effect on flood peaks of shape of basin, magnitude of rainfall, and soil characteristics; yet in spite of having considerable range in Kansas, these factors failed to improve the relations. Possibly the effect of the nonsignificant factors was obscured by an abnormal distribution of flood-producing storms during the 8-year period that might become evident in a longer period; or possibly a more specific expression of terms is needed for the nonsignificant factors. Three approaches are being attempted to resolve the latter possibility in Kansas: (1) at Rock Creek and Soldier Creek basins in northeastern Kansas the changes in characteristics of flood peaks are being studied in successive parts of the basins; (2) at selected, small-area stations throughout Kansas temporary recorders of stage and rainfall are collecting data to show variations in flood hydrographs; and (3) at seven, small-area sites near Wichita studies will be made of changes in flood peaks with respect to increase in degree of urbanization.

The third feature to be examined is the opportunity for computing the magnitude and expectancy of floods in Kansas basins ranging in size between the upper limit of data in this report of 70 square miles and the lower limit of data for the Ellis and Edelen report (1960) of 150 square miles. From a study of selected streams, the following procedure is recommended. Compute the flood discharge by methods in both reports and prorate the two answers according to difference in drainage area from the extreme values of the two reports.

CONCLUSIONS

1. A method has been presented for computing the magnitude and frequency of floods on drainage areas of 1 to 70 square miles and for estimating relations on drainage areas of 70 to 150 square miles. For areas greater than 150 square miles, one should use methods outlined by Ellis and Edelen (1960).

2. The adequacy of these methods has been evaluated, especially for predicting future flood events.

3. The results and limitations of this report show that an inadequate number of years of record are available at this time.

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