UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

# History of Natural Flows--Kansas River

by Elwood R. Leeson

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# HISTORY OF NATURAL FLOWS - KANSAS RIVER 1/

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Streamflow history is of major importance to those responsible for planning the development and management of our water resources. Historic water-supply records provide the basis for the prediction of the future supply. Also, the best means of evaluating proposed water-resources projects is the superimposition of the planned projects in theory on the historic records to determine what the history would have been had some or all of the projects been in operation.

Through its Water Resources Division, the United States Geological Survey has become the major water-resources historian for the nation. The Geological Survey's collection of streamflow records in Kansas began on a very small scale in 1895 in response to some early irrigation interest. Since that time the program has grown, as shown in Figure 1, and we now have about 2,350 station-years of record accumulated. A station-year of record is defined as a continuous record of flow collected at a fixed point for a period of one year. Figure 1, then, is a graphical indication of the mass of historical data which has been accumulated in Kansas. Volume of data at hand, however, is not in itself an adequate measure of its usefullness. An important element in historical streamflow data which enhances its value as a tool for the prediction of the future is the length of continuous records available in the area being studied. The records should be of sufficient length that they may be regarded as a reasonable sample of what has gone before and may be expected in the future. Table 1 gives a graphical inventory of the available streamflow records in Kansas. It shows that, in general, there is a fair coverage of stations with records of about thirty-seven years in length. This is not a long period as history goes but it does include considerable experience with floods and droughts.

Although a large quantity of data on Kansas streamflow has been accumulated, hydrologists and planning engineers find that stream flow information for many areas of the State is considerably less than adequate. The problem of obtaining adequate coverage has been given careful study by the Kansas Water Resources Board in cooperation with the U. S. Geological Survey and a report entitled "Development of A Balanced Stream-Gaging Program For Kansas", has been published by the Board as Bulletin No. 4. That report presents an analysis of the existing stream-gaging program and recommendations for a program to meet the rapidly expanding needs for more comprehensive basic data.

The Kansas River is formed near Junction City, Kansas, by the confluence of the Smoky Hill and Republican Rivers. From that point the river flows eastward about 175 miles to Kansas City where it empties into the Missouri River. The basic history of its natural flow can be depicted in general by the records from three gaging stations. The one at Bonner Springs, about 21 miles upstream from the mouth, may be considered as representing the total outflow from the basin; the one at Ogden, about 8 miles downstream

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from the confluence of the Smoky Hill and Republican Rivers, may be considered as representing the combined contribution of those streams to the Kansas River flow; and the one at Topeka, being only about 16 river miles nearer to Ogden than to Bonner Springs, may be considered as representing flows at the mid-point along the river.

Figure 2 is a graphical description of the historical flow of the river at Ogden. This graph is defined by the plotting of the average flow in cubic feet per second for each month of record in chronological sequence. Here in one diagram are 34 years of river history beginning with July 1917 and ending with September 1951, when as an aftermath of the great 1951 floods, the gaging station site became untenable for operation. Figures 3 and 4 show similar historical data for the stations at Topeka and Bonner Springs. The records for these stations also begin in 1917 but are continuous to date.

The great spread between the extremes of high and low flows makes it difficult to select a suitable scale for these graphs. The use of a scale large enough to properly illustrate the normal variations at low and medium-flow periods would cause the data for months in which major floods occurred to run completely off the sheets, or would require sheets of unmanageable size. To avoid these difficulties two scales are used with the change made at the 10,000 cfs (cubic feet per second) level. The scale below this point is magnified 10 times. Thus in true scale the flows in excess of 10,000 would extend much higher. Some comparisons based on the Bonner Springs records will give an indication of the great spread in the rates of natural flow. Out of 39 years of record, in only three years -- 1944, 1945, and 1949 -- was the total volume of discharge in a whole calendar year as much as that which occurred in the single month of July 1951. During the drought of the thirties it would have been necessary to accumulate all the streamflow from December 1, 1931, until early June 1935, when a substantial flood occurred, to equal the volume of flow in the month of July 1951 alone. On an annual basis the total flow for the water year ending September 30, 1951, was slightly more than twice as great as the second largest of record, water year 1945, and more than twenty times as great as the smallest annual flow of record, that for water year 1956.

The Geological Survey acts as the nation's water resources historian in the fullest sense of the word. It is not enough to simply chronicle the day-by-day water record. Much as a true historian of human events evaluates such events and interprets their significance, so does the Geological Survey analyze and interpret the accumulated water facts.

If we were to attempt a portrayal of the history of the natural flow of the Kansas River by using all of the accumulated flow records in their raw form the picture would be distorted by the indiscriminate mixture of records covering periods ranging from long to short. Therefore we have applied hydrologic and statistical techniques to adjust as many of the records as possible to common periods. Figure 5 shows the distribution of the average rate of natural flow in the Kansas River. It is based on records adjusted to a standard 36-year period extending from October 1920 through September 1956 and is a schematic diagram of the river and its major tributaries. The width of the stream at the indicated points is proportional to the average flow at those points. These widths also refer to the discharge scale shown at the mouth of the river. For example, the width at Bonner Springs referred to the scale shows the average flow to be about 6,600 cfs at that point. At Ogden the width indicates an average flow of about 2,800 cfs, or about 42 percent of the flow at Bonner Springs. This means that, on the average, about 42 percent of the outflow from the Kansas River basin originates in the drainage area above the Ogden gaging station, although this drainage area comprises about 75 percent of the total area in the basin. Similarly, about 26 percent of the average flow at Bonner Springs comes from the Big Blue River and a little over 8 percent from the Delaware River. It is important to note that these percentages apply to the average flows at the various points in the basin and include the flood discharges as well as the drought-affected low flows. It should not be assumed that during any selected month the discharge of the Big Blue River would be 26 percent of that at Bonner Springs. To illustrate this, we have computed the minimum 30-day average rate of flow that might be expected to occur on an average of once every 50 years at the various points over the basin. These minimum 30-day averages have been diagrammed in Figure 6 in the same manner as in Figure 5. Figure 6 shows that the expected minimum 30-day rate of flow from the drainage area above Ogden is 34 percent of that at Bonner Springs. Comparison of this figure with the 42 percent obtained from Figure 5 shows that the unregulated natural flow of the upper basin will not supply as great a percentage of the downstream low flows as it does to the overall supply. In a like manner, the minimum 30-day rate of 37 percent for the Big Blue River, when compared with the long term 26 percent, indicates that this stream may be expected to furnish a larger percentage of the downstream flow during periods of low flow. For the Delaware River the minimum rate is only one-half of one percent as compared with 8 percent of the total flow.

Additional comparisons of flows from the streams in the upper basin are of interest in that many of the present and planned programs will affect the contributions of these streams to the flow of the Kansas River. The Republican River has contributed 17 percent of the long-term average flow at Bonner Springs but only 6 percent of the 30-day minimum; the Solomon River, 9 percent of the average and 3 percent of the minimum. The Saline River and the Smoky Hill River above the mouth of the Saline have each contributed 4 percent of the long-term average flow but, contrary to the situation for the Republican and Solomon Rivers, these streams have contributed larger percentages of the 30-day minimum flows, those percentages being 6 and 7, respectively. Another interesting comparison is that on the average the Republican River has contributed over four times as much to the flow at Bonner Springs as has either the Saline River or the Smoky Hill River above the mouth of the Saline, but the contributions from the three streams have been almost equal during the 30-day minimum period that may be expected to recur on the average of once every 50 years.

Figure 7 shows the results of similar studies based on the minimum 24-month average rates of flow that might be expected to recur on an average of once every 50 years. It is shown primarily to suggest the many ways the history of flows may be presented to meet various planning needs.

The graphs shown in Figures 2, 3, and 4 indicate the great variability in the natural flow rates of the Kansas River but give no indication, except in a very general way, of how often selected rates of flow have been equalled or exceeded. Figure 8 is a graphical presentation of such information for five points along the Kansas River. These graphs are known to hydrologists as flow duration curves. One use of such graphs might be as follows: Suppose we were studying a proposed use or combination of uses of water which would require a minimum daily streamflow rate of 1,000 cfs. If we were dependent for our supply on the unregulated natural flow of the Kansas River at Ogden, the curves indicate that during the standard period the daily flow would have been equal to or greater than our requirements 59 percent of the time or we would have had an insufficient supply 41 percent of the time. However, if we could move downstream to Bonner Springs the daily flow would have been equal to or greater than our requirements more than 89 percent of the time. If our requirements were for only 500 cfs, the flow at Bonner Springs would have been adequate more than 98 percent of the time. Flow duration curves have many other uses, usually in water-supply problems much more complicated than this example.

Sometimes a planned use of water would permit occasional shut-downs or temporary reductions in use when flows were inadequate if the frequency and duration of such flows could be predicted. Flow duration curves like those in Figure 8 show what percent of the time selected rates of flow occurred during the 36-year period but give no indication as to how the periods of deficient flow were distributed with respect to time. We probably will want to know whether these low flows occurred on widely scattered days or persisted for a week, a month, or longer periods. Figure 9 shows by a series of curves the frequency of low flows for various periods at the Ogden gaging station. These curves cover a wide range of flows and periods. An example of how we might use these curves is as follows: Assume we are interested in a minimum daily flow of 100 cfs at Ogden. The one-day curve shows that a minimum daily flow of 100 cfs could be expected to recur on an average of once in about every 10 years. The 7-day curve shows that an average minimum flow of 100 cfs lasting for 7 days could be expected to recur once in 14 years, the 30-day curve an average minimum of 100 cfs for 30 days once in 28 years, and so on. Figures 10 and 11 show the low-flow frequency curves for the stations at Topeka and Bonner Springs. These curves, along with those for the various other points in the basin, were used in defining the distribution of minimum flows in the Kansas River as shown earlier in Figures 6 and 7. Also, such curves provide a basis for determining the storage required to maintain selected minimum flows.

It should be understood that references to recurrence intervals in years does not mean the event in question will occur regularly at those intervals. An expected recurrence of once in fifty years indicates that the expected chance of the event occurring in any one year is 1 in 50, or 2 percent. Furthermore, they are applicable only for hydrologic conditions similar to those for the base period used for these low-flow analyses, April 1920 through March 1957.

It is only quite recently that the Kansas streamflow data program has provided for interpretive presentation of streamflow history. Perhaps the greatest single deterrent to programming of this kind has been the tremendous work load imposed by the required sifting and sorting of amassed data. For example, the preparation of a flow duration curve for one gaging station with 37 years of records involves going through the record and tabulating more than 13,500 individual days of record in the order of their magnitude -- a huge undertaking if done by human hands. Electronic data processing equipment has now eliminated this formidable hurdle.

In cooperation with the Kansas Water Resources Board, the Geological Survey has placed all available daily discharge data for streams in Kansas on punch tape for use in electronic computers. Using this punch tape record of the data and the electronic computer, a flow duration tabulation may be accomplished in a matter of minutes.

Table 1.--Inventory of streamflow records in Kansas and immediately adjoining areas

| Stream and location | Contributive drainage area (sq mi) | 1955 Regulation |
|---|---|---|
| **Nemaha River basin:** | | |
| Turkey Creek near Seneca, Kans. | 276 | slight |
| Nemaha River at Falls City, Nebr. | 1,340 | slight |
| **Kansas River basin:** | | |
| Arikaree River at Haigler, Nebr. | 1,330 | some |
| Landsman Creek near Hale, Colo. | 450 | small |
| South Fork Republican River near Colorado-Kansas Line | 1,860 | reg. |
| South Fork Republican River near Benkleman, Nebr. | 2,550 | reg. |
| Sappa Creek near Oberlin, Kans. | 1,050 | small |
| Sappa Creek near Beaver City, Nebr. | 1,500 | small |
| Beaver Creek at Ludell, Kans. | 1,460 | slight |
| Beaver Creek at Cedar Bluffs, Kans. | 1,710 | slight |
| Beaver Creek near Beaver City, Nebr. | 2,060 | slight |
| Prairie Dog Creek at Norton, Kans. | 721 | small |
| Prairie Dog Creek near Woodruff, Kans. | 1,050 | some |
| Republican River near Hardy, Nebr. | 16,700 | reg. |
| White Rock Creek at Lovewell, Kans. | 358 | slight |
| Republican River at Scandia, Kans. | 17,230 | reg. |
| West Buffalo Creek near Jewell, Kans. | 15.2 | --- |
| West Buffalo Creek at Jewell, Kans. | 16.8 | --- |
| Republican River at Concordia, Kans. | 17,840 | reg. |
| Republican River at Clay Center, Kans. | 18,870 | reg. |
| Republican River at Milford (Junction City), Kans. | 19,200 | reg. |
| Rose Creek near Wallace, Kans. | 28.5 | slight |
| North Fork Smoky Hill River near McAllaster, Kans. | 670 | slight |
| Ladder Creek below Chalk Creek near Scott City, Kans. | 1,460 | slight |
| Smoky Hill River at Elkader, Kans. | 3,55[illegible] | slight |
| Hackberry Creek at Gove, Kans. | 426 | slight |
| Smoky Hill River near Arnold (Ransom), Kans. | 5,220 | slight |
| Smoky Hill River at Cedar Bluff Dam, Kans. | 5,300 | reg. |
| Smoky Hill River near Ellis, Kans. | 5,630 | --- |
| Smoky Hill River at Pfeifer, Kans. | 6,070 | --- |
| Big Creek near Hays, Kans. | 594 | slight |
| Smoky Hill River near Russell, Kans. | 6,965 | reg. |
| Smoky Hill River at Ellsworth, Kans. | 7,580 | reg. |
| Smoky Hill River near Langley, Kans. | 7,857 | reg. |
| Smoky Hill River at Lindsborg, Kans. | 8,110 | reg. |
| Smoky Hill River near Mentor (Salina), Kans. | 8,230 | reg. |
| Saline River near Russell, Kans. | 1,502 | slight |
| Paradise Creek near Paradise, Kans. | 212 | slight |
| Saline River near Wilson, Kans. | 1,900 | slight |
| Wolf Creek near Sylvan Grove, Kans. | 261 | slight |
| Saline River at Tescott, [illegible] | 2,820 | slight |
| Saline River near Salina, Kans. | 3,311 | --- |
| Smoky Hill River near New Cambria, Kans. | 11,980 | reg. |
| North Fork Solomon River near Glade, Kans. | 849 | slight |
| Bow Creek near Stockton, Kans. | 337 | slight |
| North Fork Solomon River at Kirwin, Kans. | 1,290 | reg. |
| North Fork Solomon River near Downs, Kans. | 2,390 | reg. |

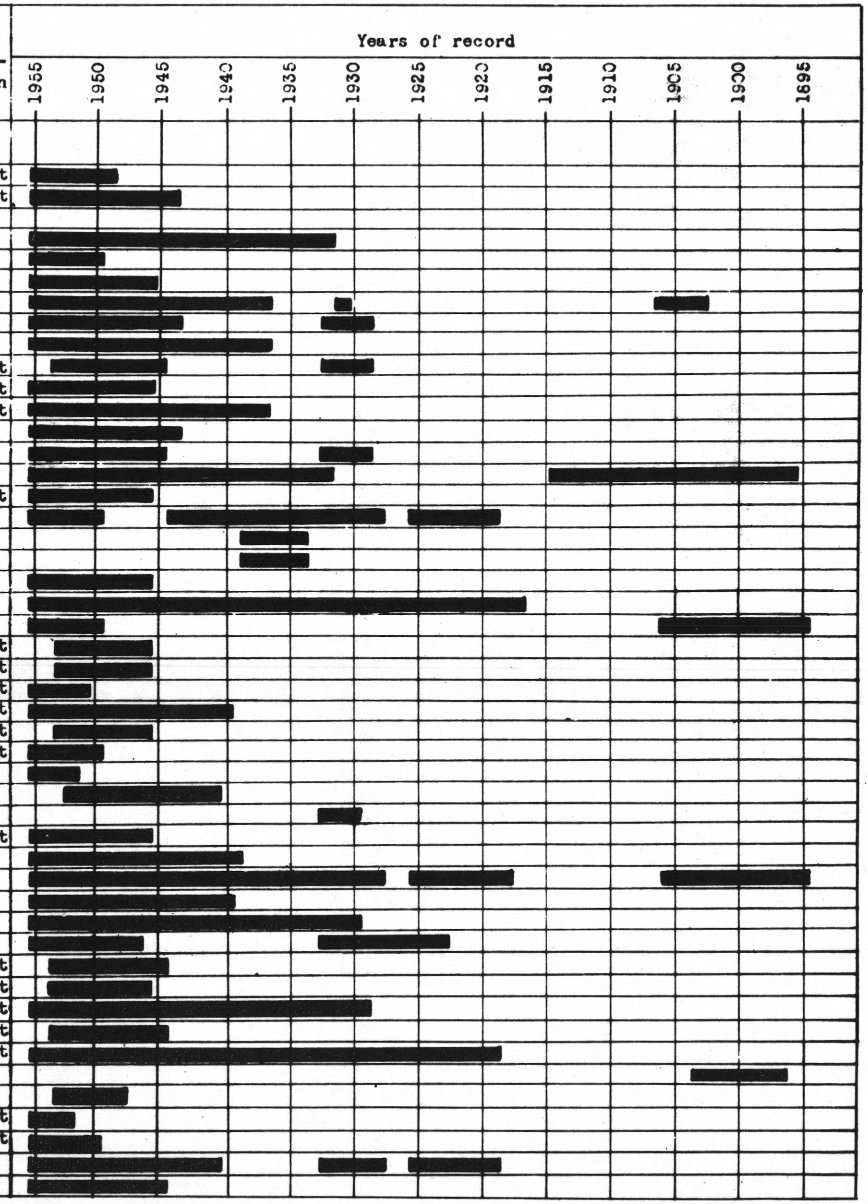


Table 1.--Inventory of streamflow records in Kansas and immediately adjoining areas--Continued

| Stream and location | Contributive drainage area (sq mi) | 1955 Regulation |
|---|---|---|
| South Fork Solomon River above Webster Reservoir (at Webster), Kans. | 1,036 | slight |
| South Fork Solomon River at Alton, Kans. | 1,720 | slight |
| South Fork Solomon River at Osborne, Kans. | 2,024 | slight |
| East Limestone Creek near Ionia, Kans. | 27.3 | --- |
| Elm Creek near Ionia, Kans. | 22.7 | --- |
| East Limestone Creek at Ionia, Kans. | 51.6 | --- |
| Solomon River at Beloit, Kans. | 5,430 | slight |
| Solomon River at Niles, Kans. | 6,770 | same |
| Smoky Hill River at Solomon, Kans. | 18,830 | --- |
| Smoky Hill River at Enterprise, Kans. | 19,200 | reg. |
| Chapman Creek near Chapman, Kans. | 300 | slight |
| Lyon Creek near Woodbine | 230 | slight |
| Smoky Hill River at Junction City, Kans. | 19,900 | reg. |
| Kansas River at Ogden, Kans. | 39,540 | --- |
| Big Blue River at Hull, Kans. | 4,540 | --- |
| Little Blue River at Waterville, Kans. | 3,440 | slight |
| Snipe Creek near Beattie, Kans. | 18 | reg. |
| Black Vermillion Creek near Frankfort, Kans. | 412 | slight |
| Big Blue River at Randolph, Kans. | 9,100 | slight |
| Fancy Creek at Winkler, Kans. | 176 | slight |
| Big Blue River near Manhattan, Kans. | 9,563 | slight |
| Kansas River at Wamego, Kans. | 49,540 | reg. |
| Vermillion Creek near Wamego, Kans. | 243 | some |
| Mill Creek near Paxico, Kans. | 316 | slight |
| Kansas River at Topeka, Kans. | 51,010 | reg. |
| Soldier Creek near Topeka, Kans. | 268 | slight |
| Little Delaware River near Horton, Kans. | 19.3 | reg. |
| Delaware River at Valley Falls, Kans. | 922 | slight |
| Kansas River at Lecompton, Kans. | 52,720 | reg. |
| Wakarusa River near Lawrence, Kans. | 458 | slight |
| Stranger Creek near Tonganoxie, Kans. | 406 | slight |
| Kansas River at Bonner Springs, Kans. | 54,190 | reg. |
| Blue River near Kansas City, Mo. | 180 | some |
| Marais des Cygnes River at Melvern, Kans. | 363 | slight |
| Salt Creek near Lyndon, Kans. | 111. | slight |
| Switzler Creek at Burlingame, Kans. | 26.3 | reg. |
| Hundred and Ten Mile Creek near Quenemo, Kans. | 321 | slight |
| Marais des Cygnes River near Quenemo, Kans. | 1,030 | --- |
| Marais des Cygnes River near Ottawa, Kans. | 1,260 | slight |
| Pottowatomie Creek near Garnet, Kans. | 334 | slight |
| Pottowatomie Creek at Lane, Kans. | 513 | --- |
| Marais des Cygnes River at Trading Post, Kans. | 2,910 | slight |
| Big Sugar Creek at Farlingville, Kans. | 198 | slight |
| Little Osage River at Fulton, Kans. | 295 | slight |
| Marmaton River near Fort Scott, Kans. | 411 | slight |
| Arkansas River at Holly, Colo. | ----- | reg. |
| Arkansas River near Coolidge, Kans. | ----- | reg. |
| Arkansas River at Syracuse, Kans. | 23,906 | reg. |

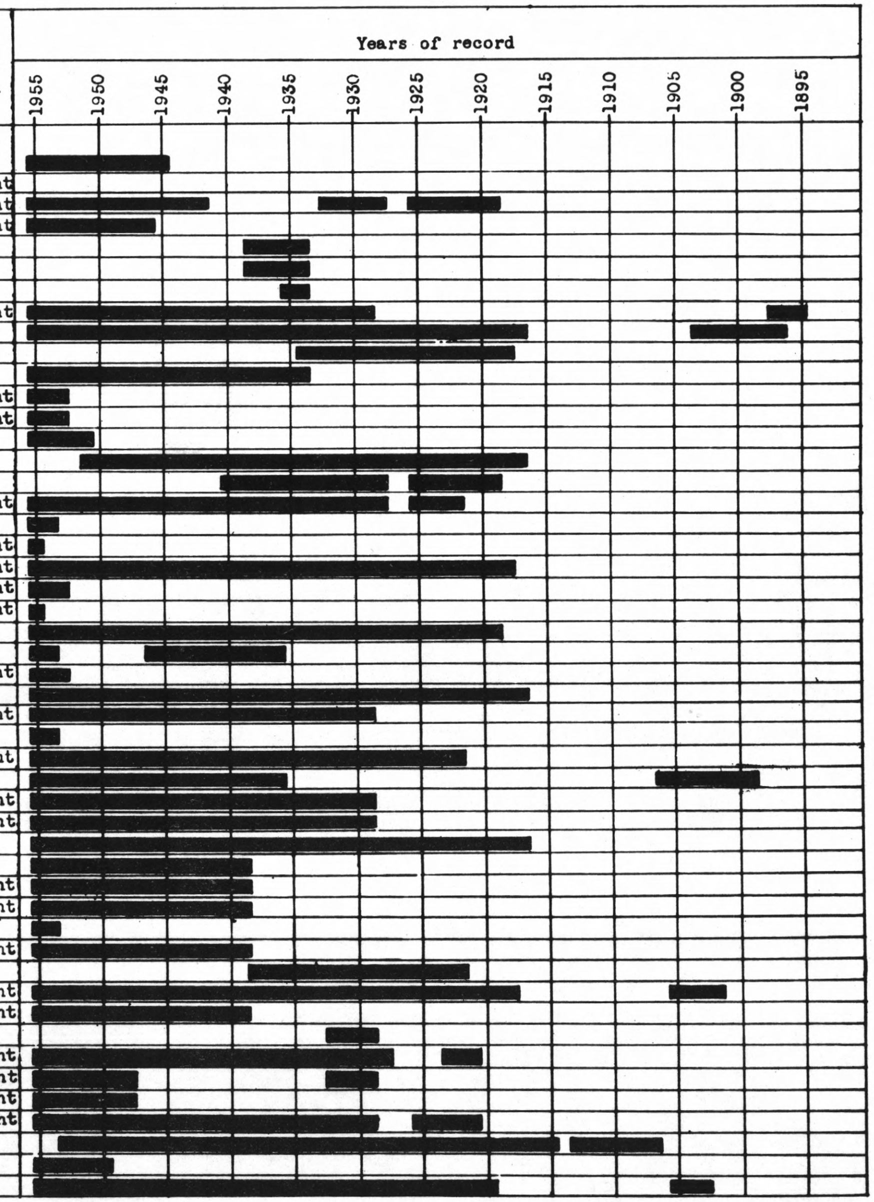
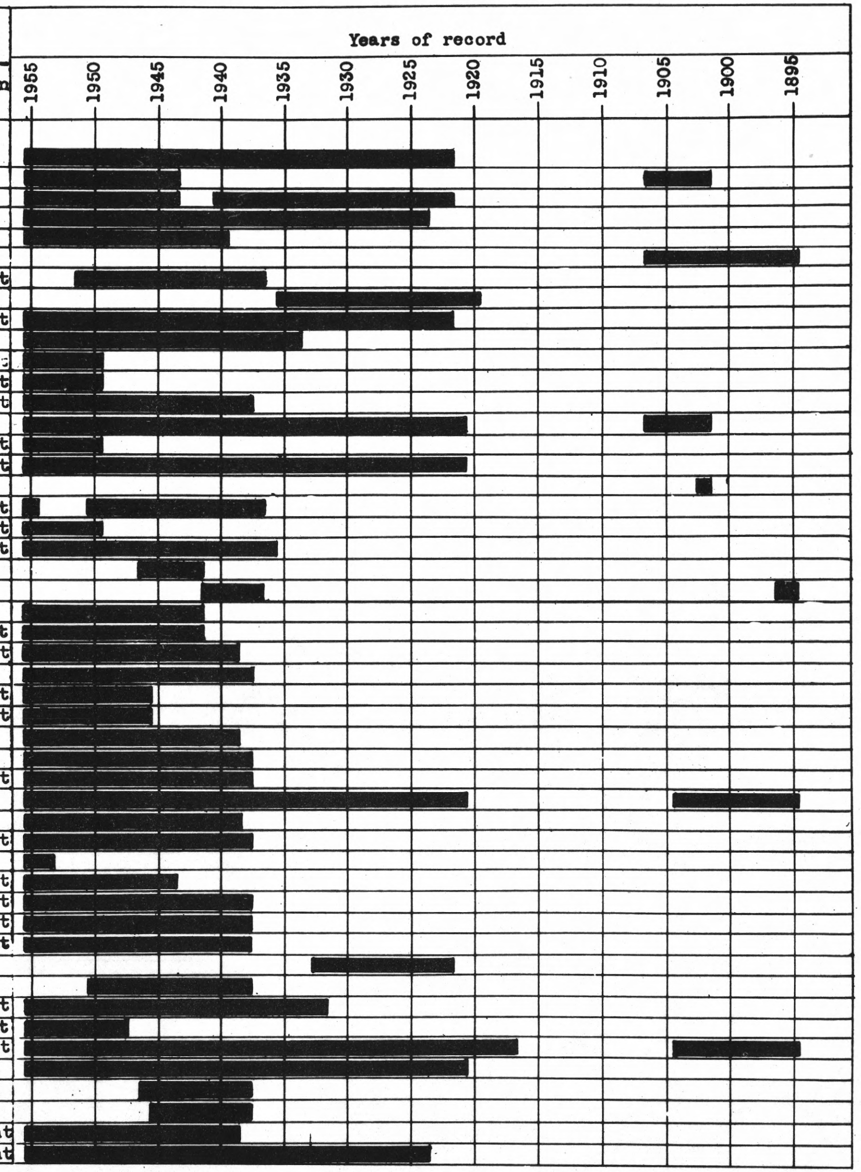


Table 1.--Inventory of stream-flow records in Kansas and immediately adjoining areas--Continued

| Stream and location | Contributive drainage area (sq mi) | 1955 Regulation |
|---|---|---|
| Arkansas River at Garden City, Kans. | 24,703 | reg. |
| Arkansas River at Dodge City, Kans. | 25,017 | reg. |
| Arkansas River near Kinsley (Larned), Kans. | 25,406 | reg. |
| Pawnee River near Larned, Kans. | 2,010 | div. |
| Arkansas River at Great Bend, Kans. | 28,354 | reg. |
| Arkansas River at Hutchinson, Kans. | 30,930 | --- |
| Cow Creek near Lyons, Kans. | 489 | slight |
| Arkansas River near Wichita, Kans. | 31,890 | --- |
| Little Arkansas River at Valley Center, Kans. | 1,250 | slight |
| Arkansas River at Wichita, Kans. | 33,157 | reg. |
| North Fork Ninnescah River near Cheney, Kans. | 693 | slight |
| South Fork Ninnescah River near Murdock, Kans. | 543 | slight |
| Ninnescah River near Peck, Kans. | 1,785 | slight |
| Arkansas River at Arkansas City, Kans. | 36,106 | reg. |
| Whitewater River at Augusta, Kans. | 456 | slight |
| Walnut River at Winfield, Kans. | 1,840 | slight |
| Walnut River near Arkansas City, Kans. | 1,952 | --- |
| Medicine Lodge River near Kiowa, Kans. | 914 | slight |
| Chikaskia River near Corbin, Kans. | 794 | slight |
| Chikaskia River near Blackwell, Okla. | 1,859 | slight |
| Cimarron River near Satanta, Kans. | 3,922 | div. |
| Cimarron River near Liberal, Kans. | 4,107 | div. |
| Cimarron River near Mocane, Okla. | 8,653 | div. |
| Crooked Creek near Nye, Kans. | 357 | slight |
| Verdigris River near Coyville, Kans. | 747 | slight |
| Verdigris River near Altoona, Kans. | 1,138 | reg. |
| Fall River near Eureka, Kans. | 336 | slight |
| Otter Creek at Climax, Kans. | 129 | slight |
| Fall River near Fall River, Kans. | 591 | reg. |
| Fall River at Fredonia, Kans. | 827 | reg. |
| Elk River near Elk City, Kans. | 575 | slight |
| Verdigris River at Independence (near Liberal), Kans. | 2,892 | reg. |
| Verdigris River near Lenapah, Okla. | 3,639 | reg. |
| Caney River near Elgin, Kans. | 445 | slight |
| Bee Creek near Havana, Kans. | 11 | reg. |
| Caney Creek near Copan, Okla. | 424 | slight |
| Neosho River at Council Grove, Kans. | 250 | slight |
| Cottonwood River near Marion, Kans. | 329 | slight |
| Cedar Creek near Cedar Point, Kans. | 110 | slight |
| Cottonwood River at Elmdale, Kans. | 1,045 | --- |
| Middle Creek near Elmdale, Kans. | 92 | --- |
| Cottonwood River at Cottonwood Falls, Kans. | 1,402 | slight |
| Neosho River at Strawn, Kans. | 2,933 | slight |
| Neosho River near Iola, Kans. | 3,818 | slight |
| Neosho River near Parsons, Kans. | 4,905 | small |
| Lightning Creek near McCune, Kans. | 197 | --- |
| Labette Creek near Oswego, Kans. | 211 | --- |
| Neosho River near Commerce, Okla. | 5,876 | slight |
| Spring River near Waco, Missouri | 1,164 | slight |



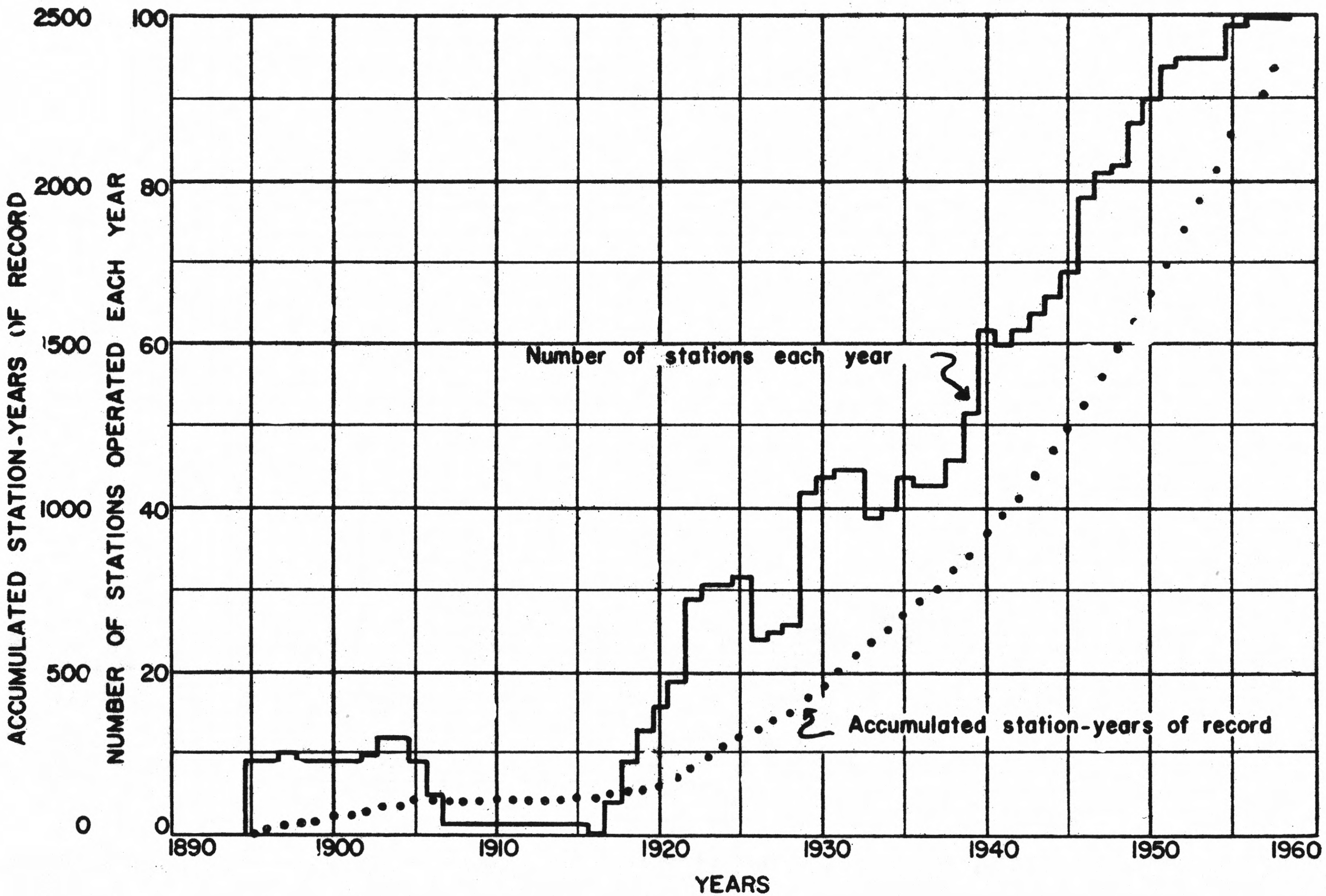



Figure 1.--Number of gaging stations operated each year within Kansas and station years of record accumulated.

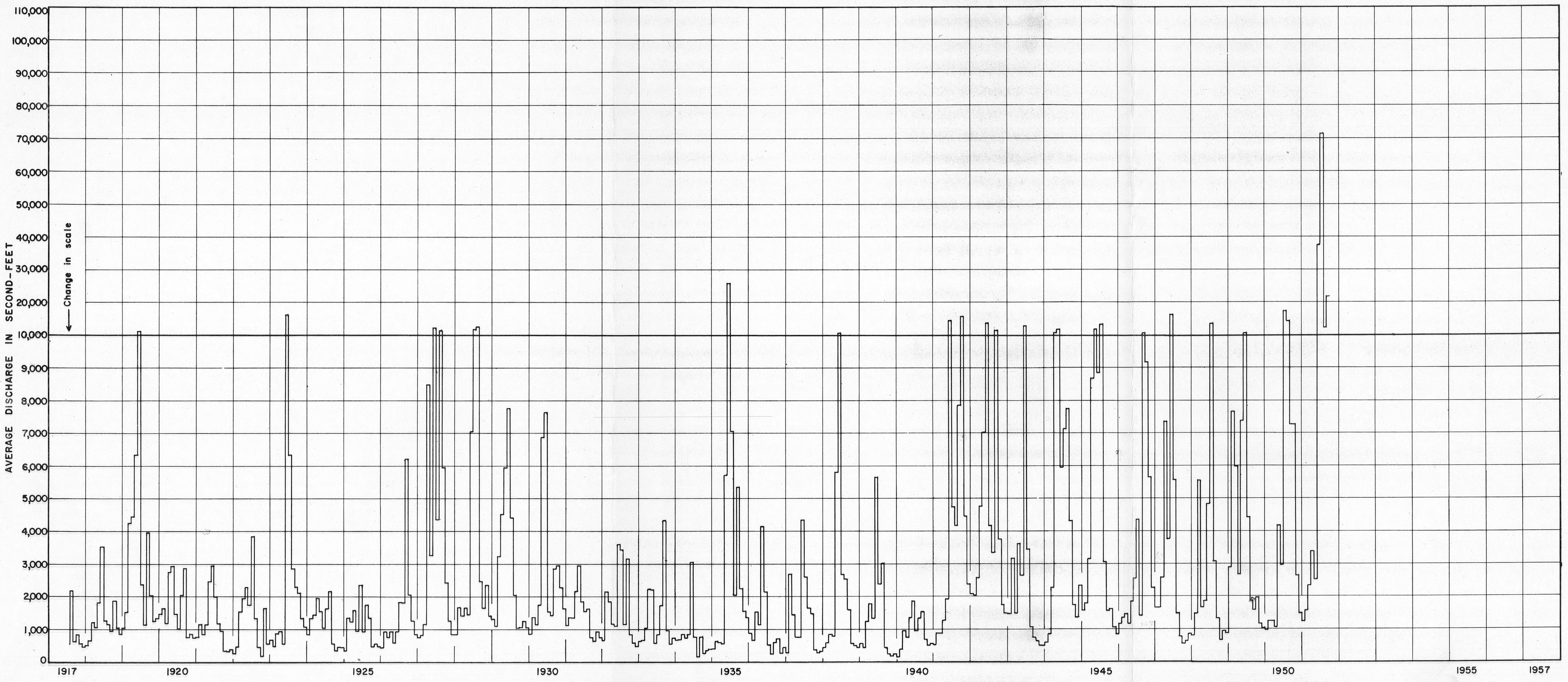



Figure 2.- Monthly discharges of Kansas River at Ogden, Kansas

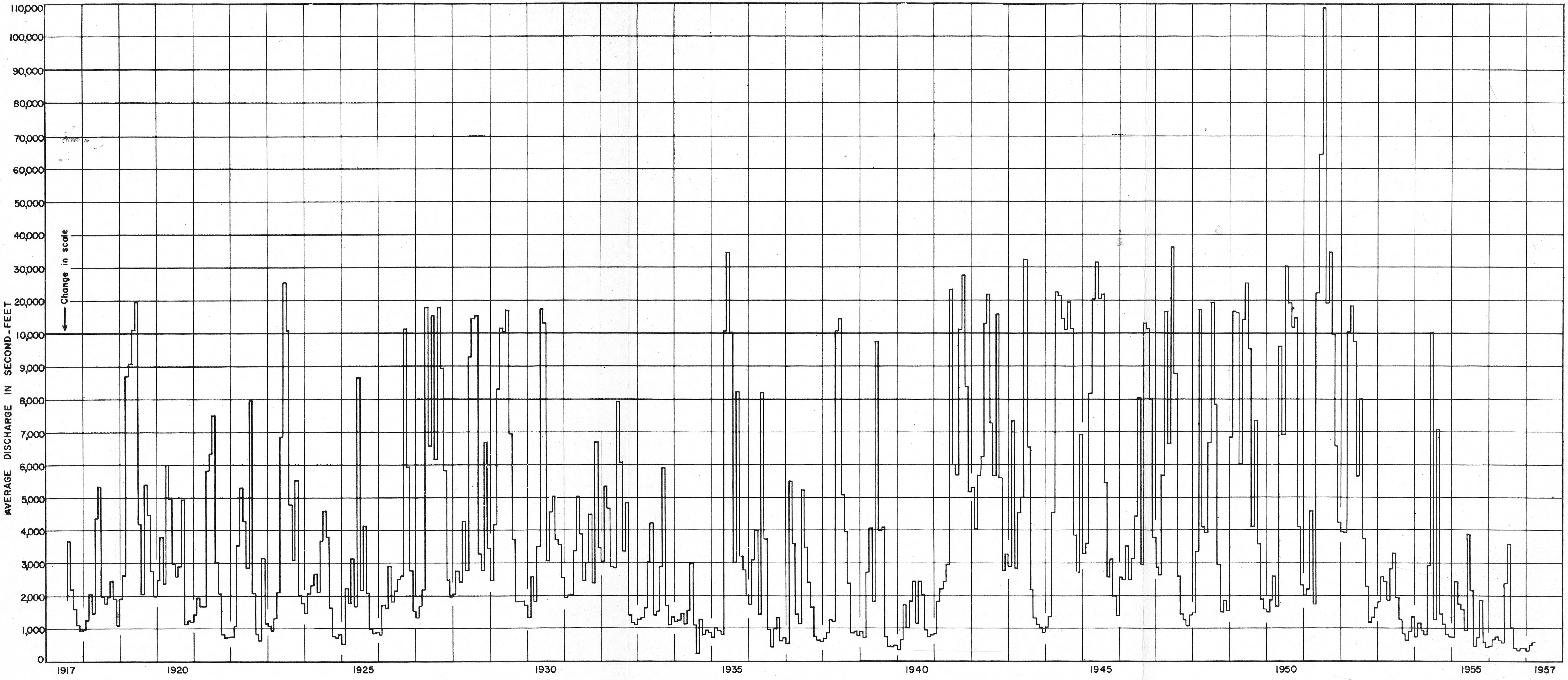



Figure 3.- Monthly discharges of Kansas River at Topeka, Kansas

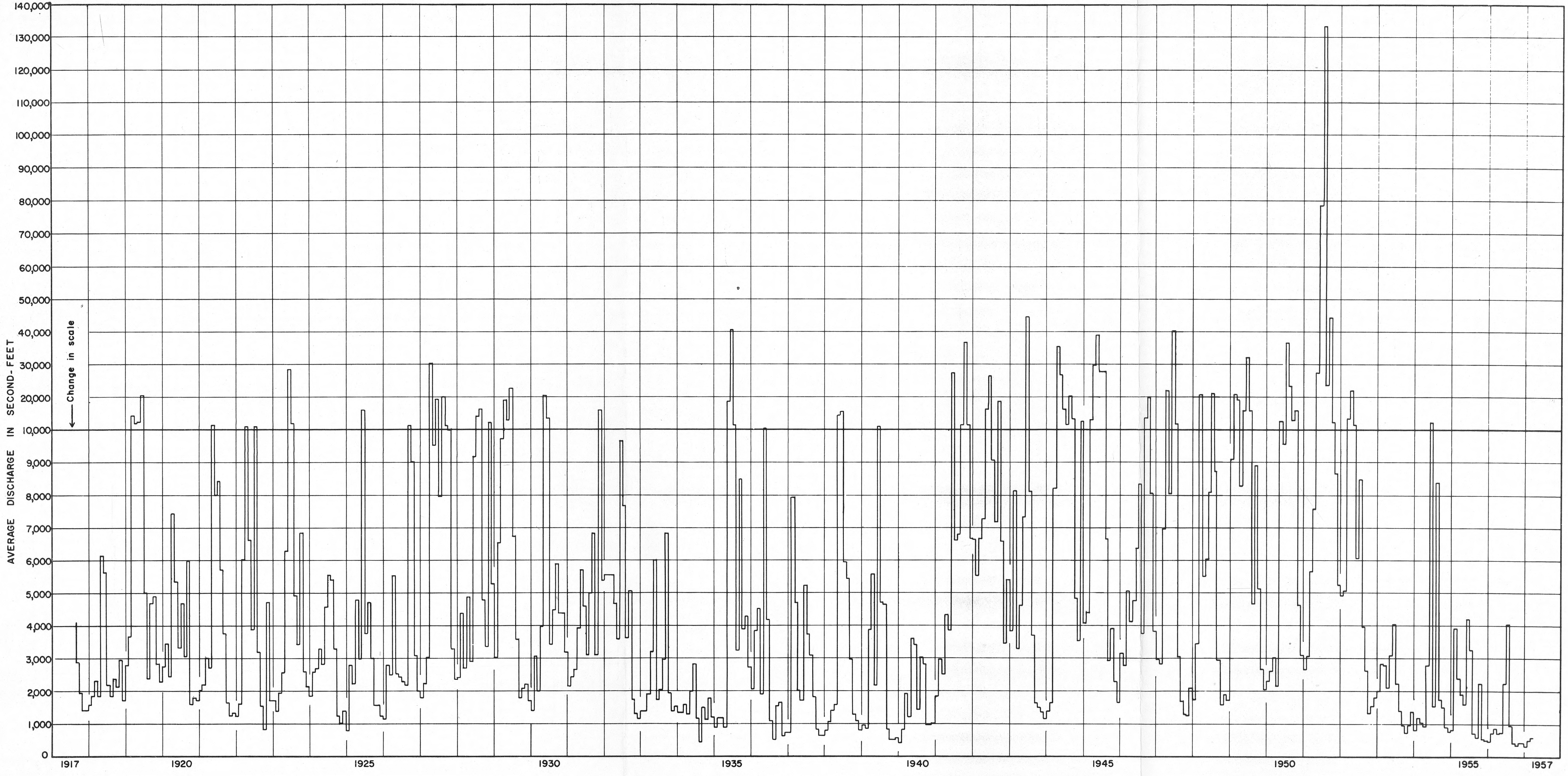
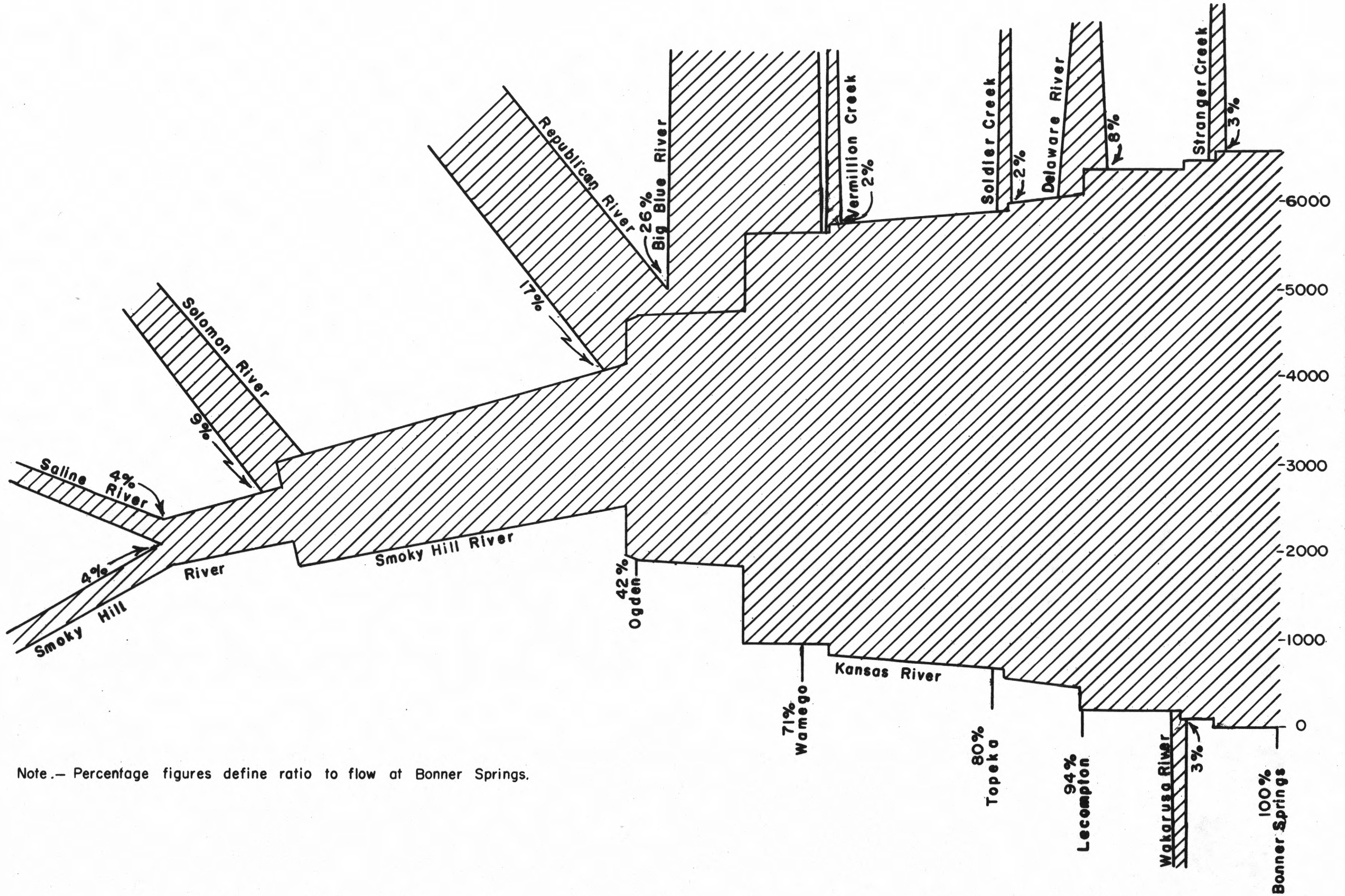



Figure 4.- Monthly discharges of Kansas River at Bonner Springs, Kansas




Note.— Percentage figures define ratio to flow at Bonner Springs.

MILES ABOVE MISSOURI RIVER

Figure 5.- Distribution of average flow in the Kansas River

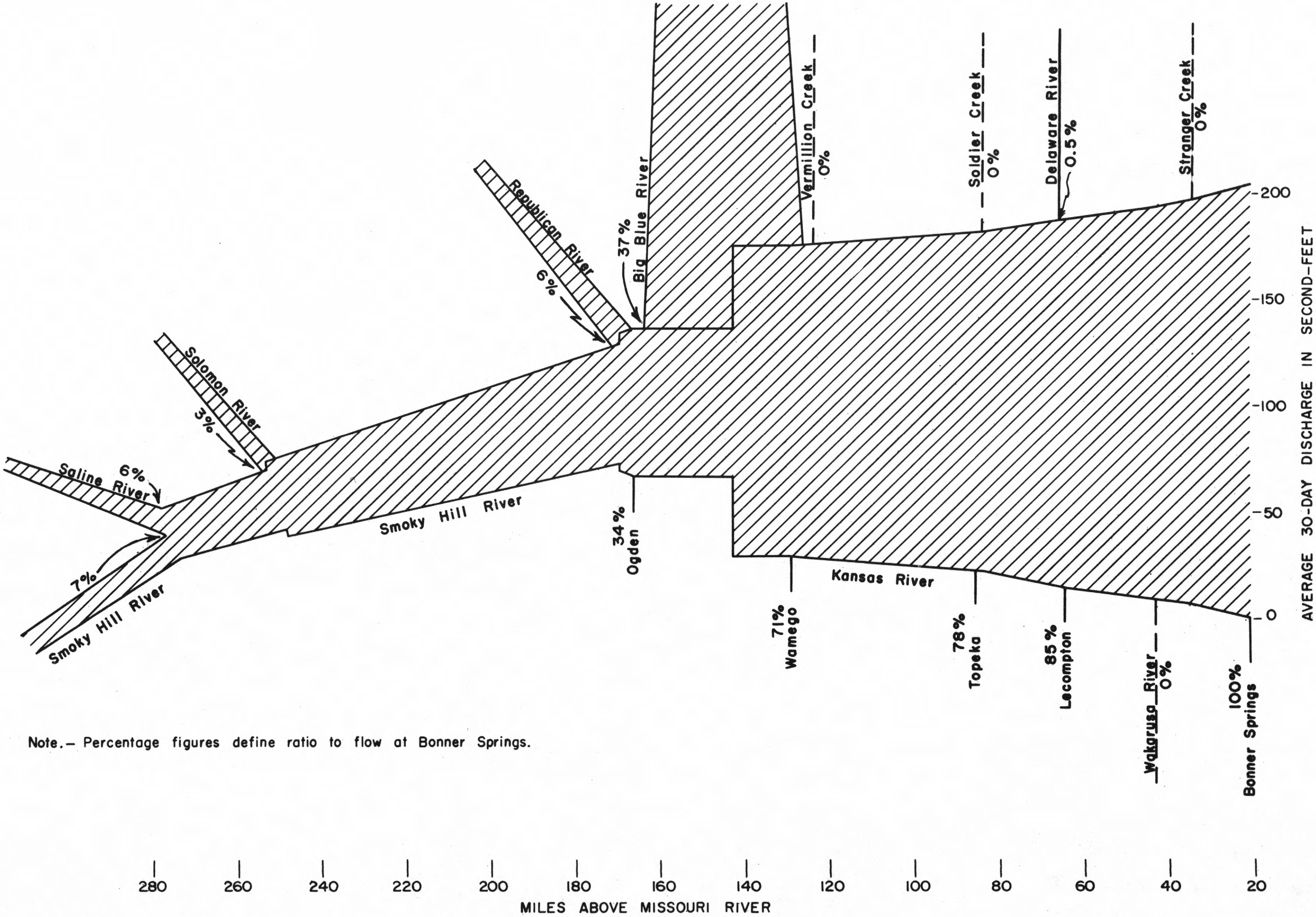
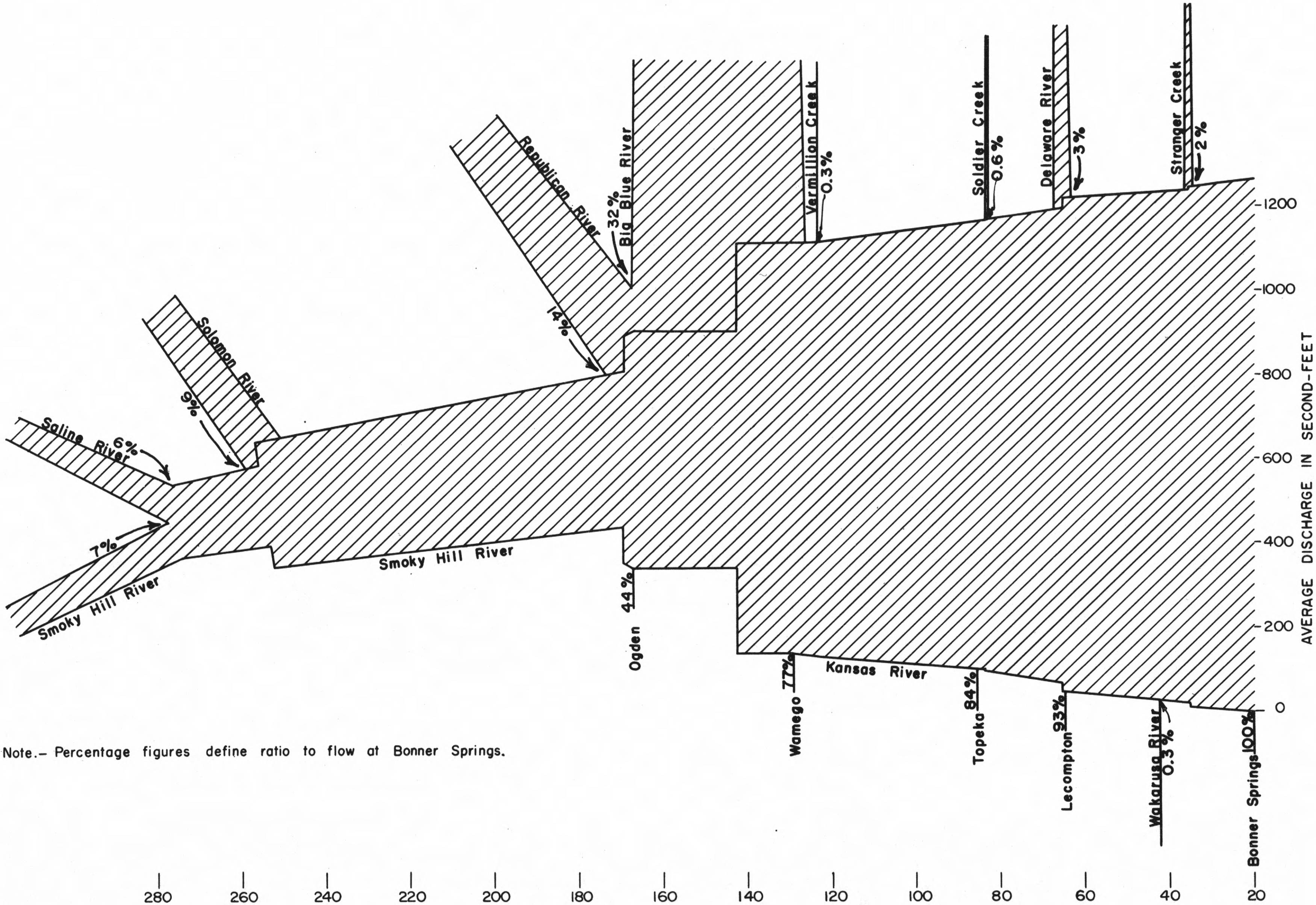



Figure 6.- Distribution of minimum 30-day rate of flow in the Kansas River that may be expected to recur on the average of once every 50 years




Note.- Percentage figures define ratio to flow at Bonner Springs.

Figure 7.- Distribution of minimum 24-month rate of flow in the Kansas River that may be expected to recur on the average of once every 50 years.

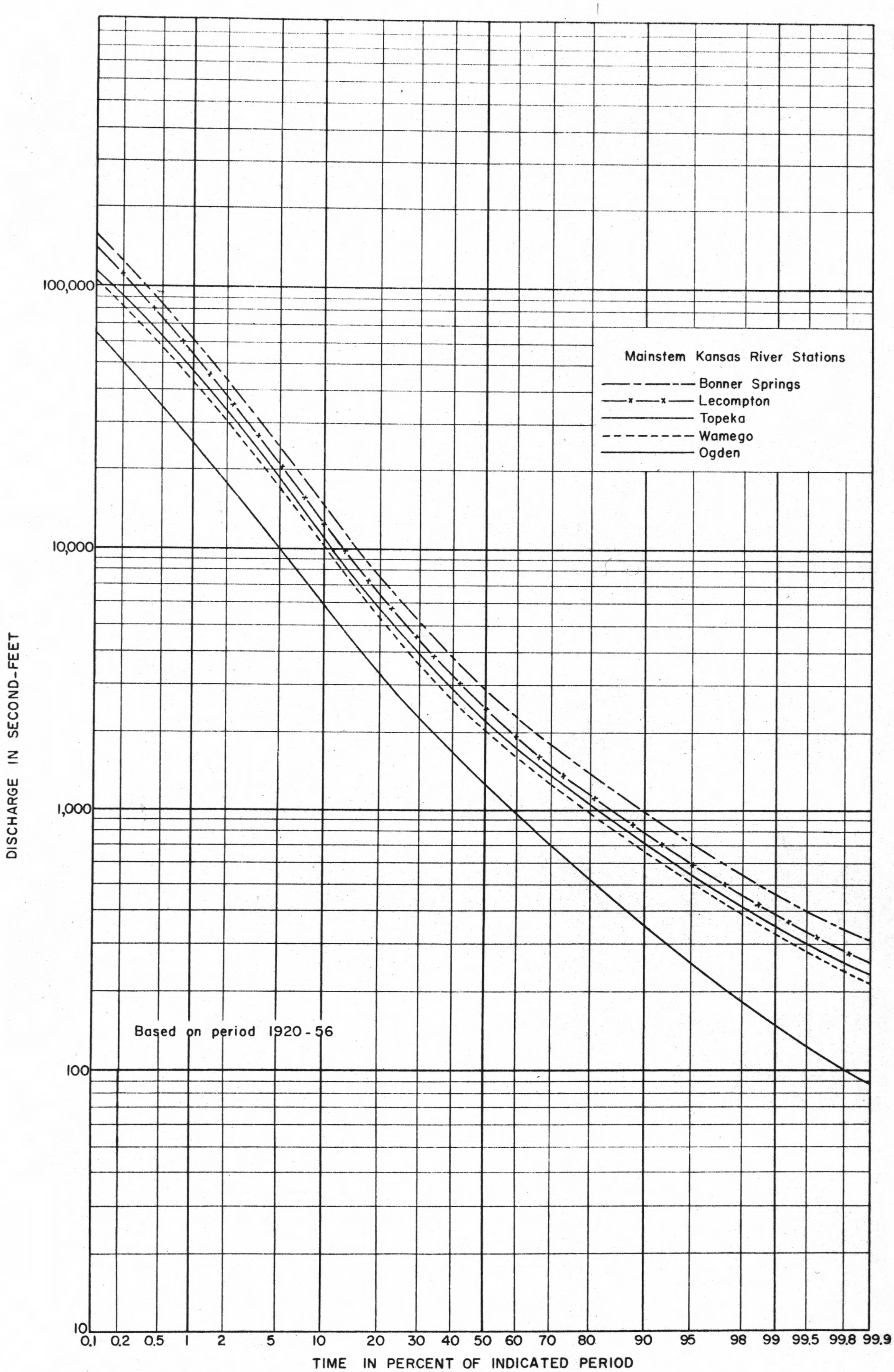



Figure 8.- Duration curves for daily flows of Kansas River from Ogden to Bonner Springs

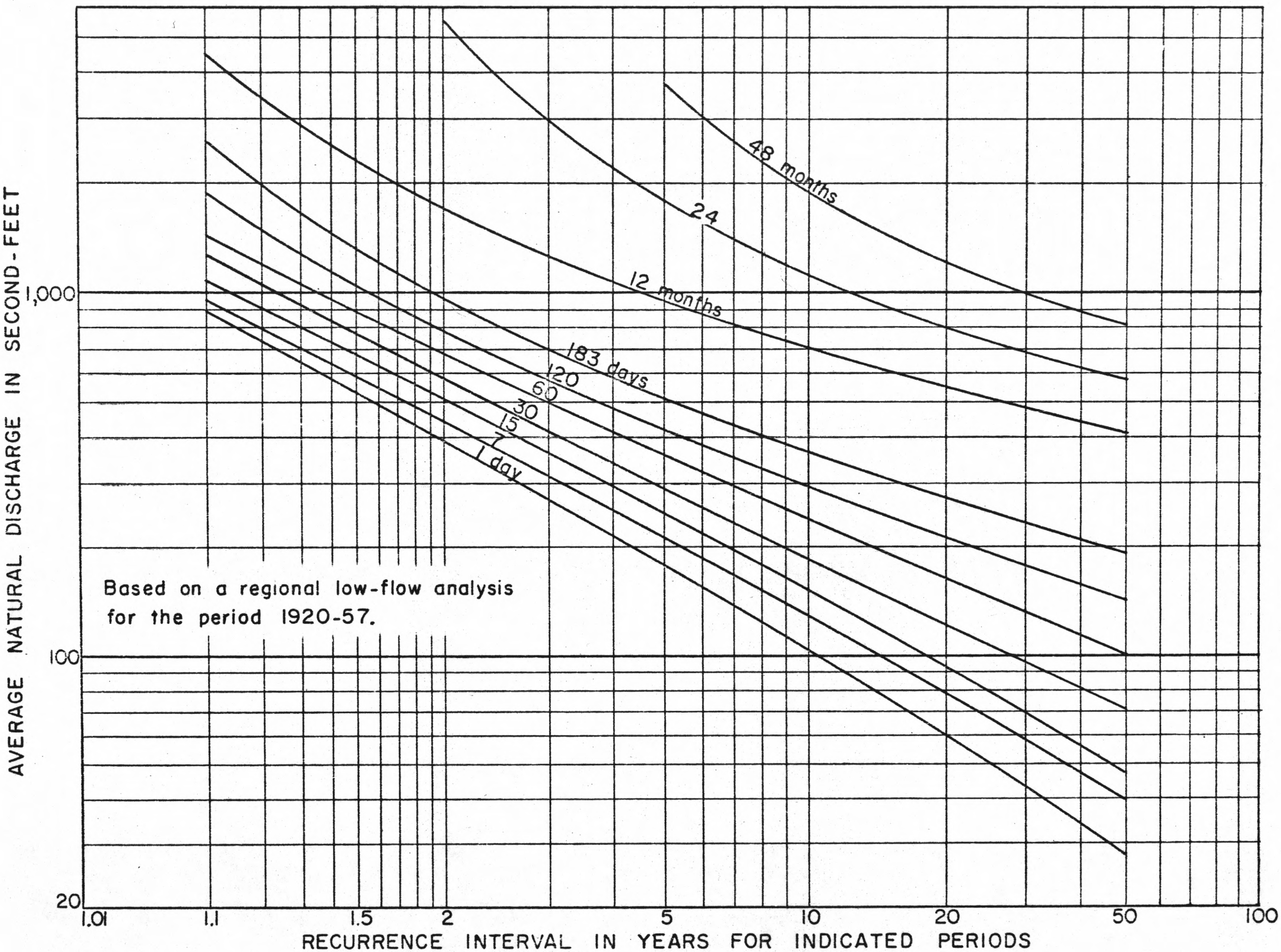



Figure 9.- Low-flow frequency curves for Kansas River at Ogden, Kans.
(Total drainage area, 45,240 sq mi)

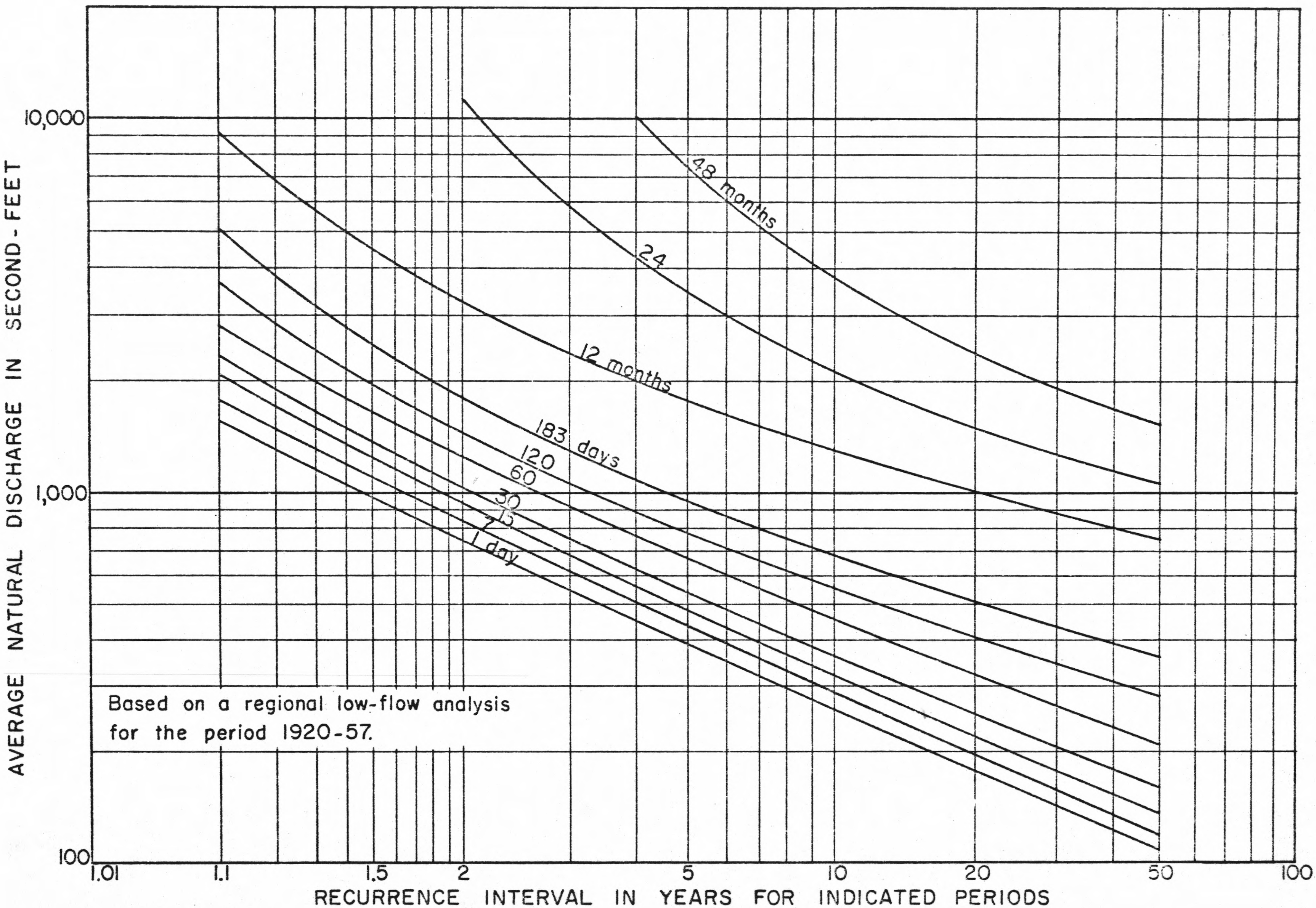



Figure 10.- Low-flow frequency curves for Kansas River at Topeka, Kans.

(Total drainage area, 56,710 sq mi)

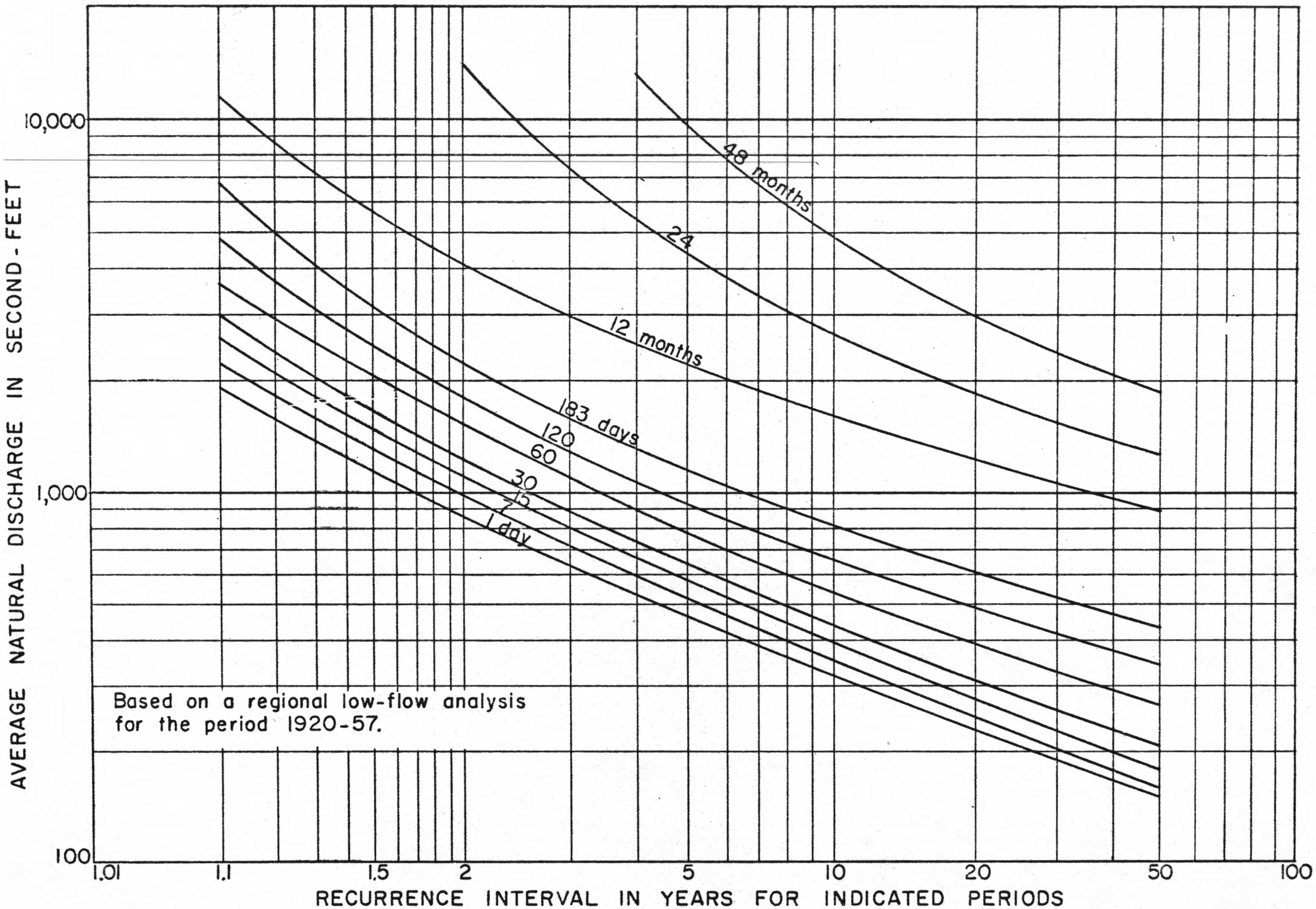



Figure 11.- Low-flow frequency curves for Kansas River at Bonner Springs, Kans.

(Total drainage area, 59,890 sq mi)