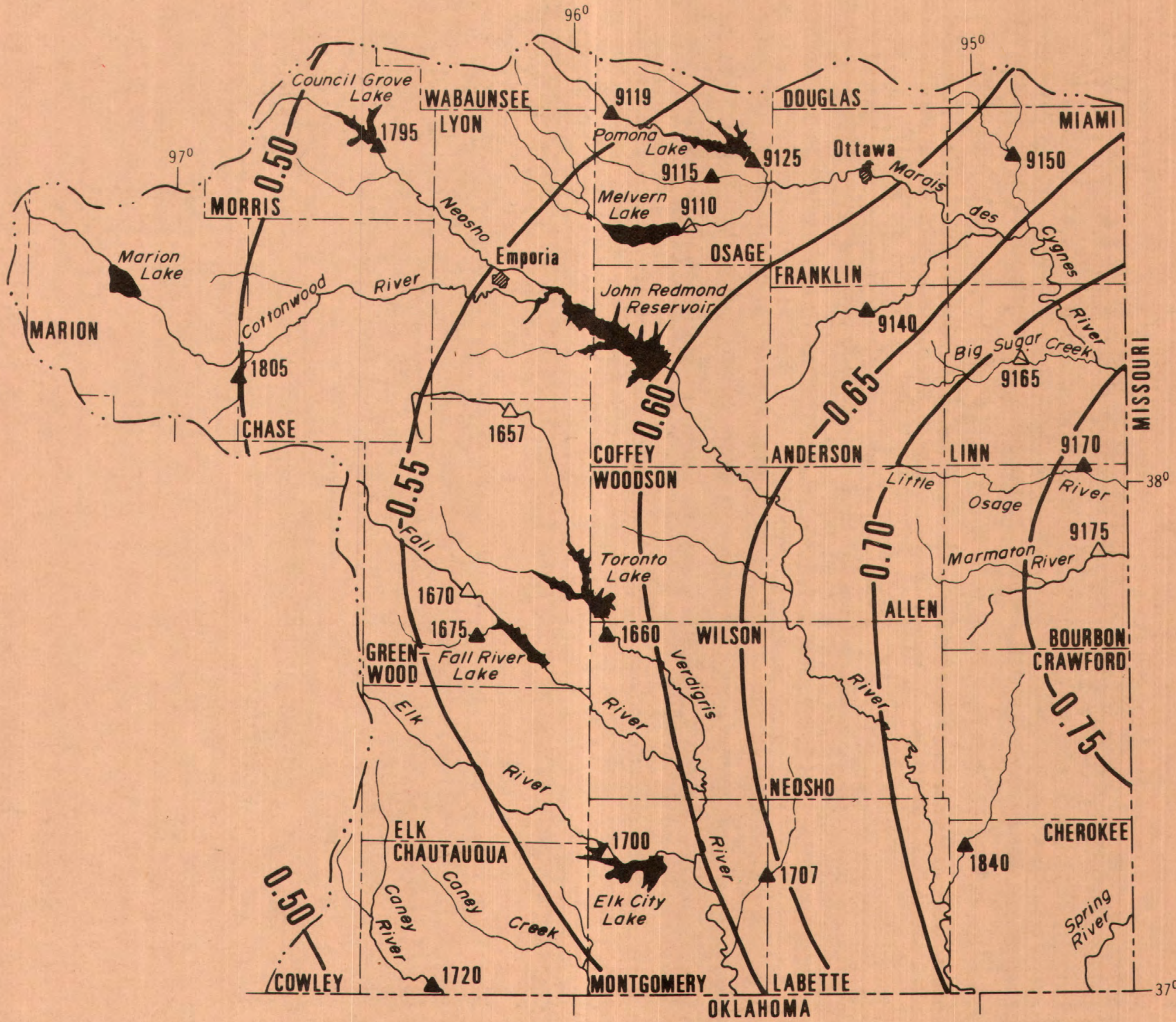
MULTIYEAR LOW FLOW IN SOUTHEASTERN KANSAS

U.S. GEOLOGICAL SURVEY

Water – Resources Investigations
Open – File Report 79 – 1288



Prepared in cooperation with
the Kansas Water Resources Board

U.S. DEPARTMENT OF THE INTERIOR
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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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By William J. Carswell, Jr.

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ABSTRACT

Many existing water supplies in southeastern Kansas are proving inadequate to meet current and expanded future needs. One of the methods in which the use of highly variable streamflow in the area can be evaluated is with the aid of multiyear low-flow frequency information. Data from 19 stream-gaging stations in the study area and a base period of 1940-77 were used to develop maps from which discharge values for the 2- and 50-year recurrence interval for durations of 12, 24, 36, and 60 months can be obtained for ungaged sites that have drainage areas of less than 1,000 square miles. Discharge values for intervening recurrence intervals can be obtained by interpolation. Extrapolation of regionalized values in this report to drainage areas smaller than 110 square miles and larger than 1,000 square miles has not been validated.

INTRODUCTION

As additional economic advances and population growth are experienced in Kansas, increased demands are placed on the limited water resources during periods of drought. Many communities and other water users experienced shortages during the drought of 1976-77. These users recognize the need for expanding water supplies by development of new ground- or surface-water sources, or by constructing new or increased reservoir storage.

Many rural areas and cities in southeastern Kansas, which experienced water shortages during the moderate and severe droughts of recent years, have a pressing need for additional water supplies. In most of the area, ground water is not available in sufficient quantity or adequate quality for municipal, industrial, or rural water district supplies. Thus, strong consideration must be given to surface-water reservoirs of adequate size to meet expanding needs.

The U.S. Soil Conservation Service, in cooperation with the Kansas Water Resources Board, is studying the potential use of small reservoirs in southeastern Kansas to satisfy water-supply needs, and comparing the results with other possible solutions. The Kansas Water Resources Board requested the U.S. Geological Survey to prepare a supplement to the report on storage requirements by Furness (1962) that will reflect subsequent streamflow data. Specifically, the purpose of this report is to provide multiyear low-flow frequency data for gaged sites and to provide a method for determining estimates of multiyear low-flow frequency curves for ungaged sites. Use of the method should be restricted to potential sites on streams in southeastern Kansas having drainage areas of less than 1,000 square miles.

CONVERSION OF INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS

For use of those readers who may prefer to use metric units rather than inch-pound units, the conversion factors and abbreviations for the terms used in this report are listed below:

Multiply inch-pound units	By	To obtain SI units
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.028	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.011	cubic meter per second per square kilometer [(m^3/s)/km^2]

ACKNOWLEDGMENTS

The information contained in this report is based on data collected by the U.S. Geological Survey in cooperation with State and Federal agencies. The report was prepared in cooperation with the Kansas Water Resources Board.

GENERAL DESCRIPTION OF STUDY AREA

As described by Schoewe (1949), southeastern Kansas lies primarily in the Osage Plains section of the Central Lowland province, as shown in figure 1. The extreme southeast corner of the State is in the Springfield Plateaus section of the Ozark Plateaus province. The topography of southeastern Kansas is gently undulating except for a few erosional remnants capped by resistant sandstone or limestone. These resistant caps vary in shape from flat-topped mesa-like forms, to rounded forms, to the form of a frustum of a cone (Schoewe, 1949, p. 280-286).

The study area consists of the drainage basins of the Neosho, Verdigris, and Marais des Cygnes Rivers and their tributaries in southeast Kansas (fig. 2). This area contains approximately 15,000 square miles that includes all or most of 22 counties. The Marais des Cygnes River is in the Missouri River basin, and the Neosho and Verdigris Rivers are in the Arkansas River basin.

AVAILABILITY OF STREAMFLOW DATA

Analyses in this report are based on records of streamflow that have been collected in southeastern Kansas for drainage areas of less than 1,000 square miles that have a minimum of 20 years of record of unregulated flow. Figure 2 shows the location of sites used in this report. Data are taken from reports of the U.S. Geological Survey.

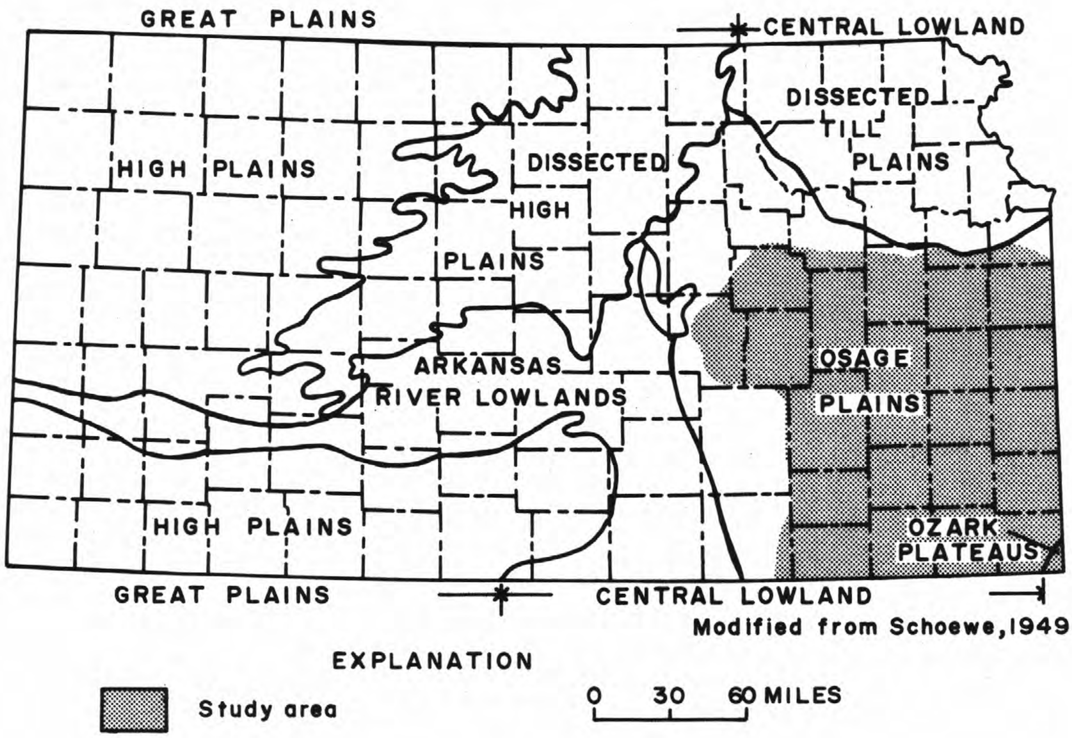

Figure 1.--Physiographic map of Kansas showing location of study area.

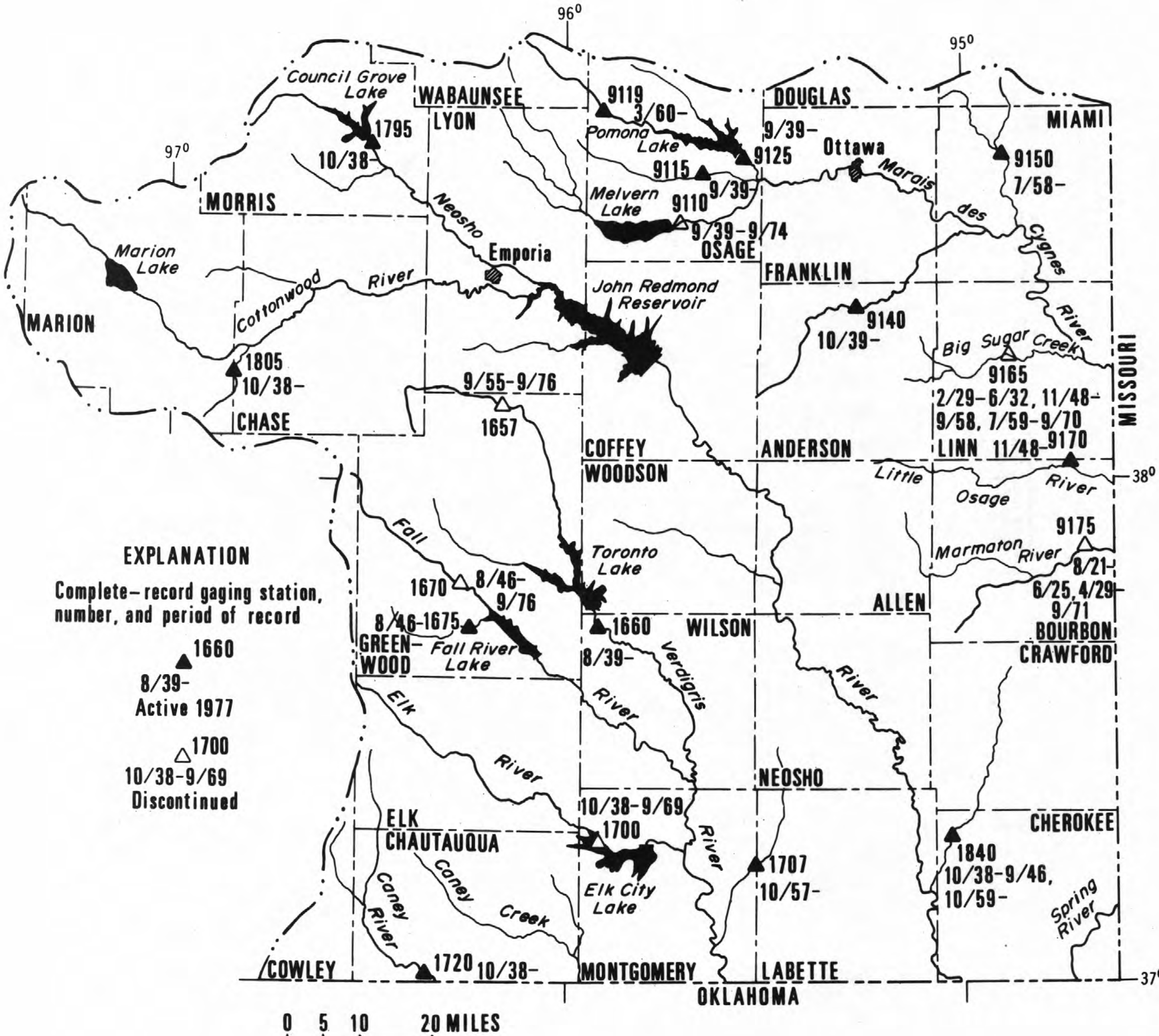

Figure 2.--Major streams draining southeastern Kansas and location of gaging stations used in the study.

LOW-FLOW FREQUENCY DATA FOR MULTIYEAR PERIODS

The storage requirement for sustaining a selected gross reservoir outflow is a function of the amount and distribution of the inflow. Therefore, the chance of deficiency in outflow from a reservoir can be evaluated from the frequency and duration of periods of natural low flow. Periods of flow of less than one year are inadequate for defining storage requirements where long periods of storage are needed to develop the optimum use of the water. Therefore, drought flows for longer periods of consecutive months must be evaluated. The frequency characteristics of multiyear low flows may be developed by an extensive process of applying statistical principles to streamflow records.

Because the period of record can have a significant impact on the flow characteristics for an individual stream or many streams in a region, a base period of 1940-77 was selected. Four stations in southeastern Kansas had drainage areas of less than 1,000 square miles and streamflow records encompassing this period. These stations were Salt Creek near Lyndon (9115), Pottawatomie Creek near Garnett (9140), Caney River near Elgin (1720), and Cedar Creek near Cedar Point (1805). Another station, Marmaton River at Fort Scott (9175), had a longer total record but was discontinued in 1970. The record at this station was extended through the 1977 water year by correlation with data from Marmaton River near Marmaton (9173.8). Thus, there was a total of five stations available with long-term records. An additional 14 stations having record lengths of less than the base period also were selected for inclusion in this study.

The frequency curves and regionalizations developed in this study are for the specified base period (1940-77); therefore, frequency values for a specific gaged site may not coincide with frequency values obtained using a different base period. Mean annual precipitation and runoff were greater for the base period (1940-77) used in this study than for the base period (1921-56) used by Furness (1962). Therefore, frequency values in this study would not be coincident with those determined by Furness.

The period 1940-77 was selected as the base period because it was the longest period of concurrent record for the stations in the study area having drainage areas less than 1,000 square miles. The Marmaton River at Fort Scott station had the longest period of record (1929-69). However, the use of 1929-77 as a base period would require that all extensions in time prior to 1940 for other station records would be based solely on the Fort Scott record. A comparison of multiyear low-flow frequency curves for Fort Scott, developed using base periods 1929-77 and 1940-77, indicated little change in the low-flow frequency curves resulted from using the shorter period of record.

METHODS OF ANALYSIS

Hydrologists do not agree on any one method for determining frequency of low flows for multiyear durations because various interpretations and assumptions are possible and no method has been shown to be clearly better than the others. The frequency determinations in this study were made by using the method described by Furness (1962, p. 165-175) in order to provide the type of data needed for the method of storage analysis used by the Soil Conservation Service. First, low-flow data for independent 12-, 24-, 36-, 48-, and 60-month periods were determined using a digital-computer program based on the method developed by Hudson and Roberts (1955). In this procedure, the lowest 12-month moving average is selected, and overlapping moving averages are eliminated from further consideration. This process is continued until the data set is exhausted. Other durations are handled in a similar manner. The discharge values are then divided by the drainage area to convert the discharges to cubic feet per second per square mile.

The recurrence interval (RI) against which the discharge values were plotted was determined by the following formula (Furness, 1962):

$$RI = \frac{N-t+2}{m} , \qquad (1)$$

in which N is the number of years of record; t is the duration of the period in years; and m is the rank order of the discharge starting with the lowest as number 1. This formula is similar to that for 1-year events

$$RI = \frac{N+1}{m} , \qquad (2)$$

but acknowledges that in a 50-year period, for example, there are only forty-seven 4-year means.

Considerable judgment was exercised in drawing the trial frequency curves for the five long-term stations. Of most concern were the extremely low plotting positions of the minimum discharge values, which commonly occurred during the extreme drought of the mid-1950's. Weather records indicate that this drought may have been the worst in 100 years or more. Thus, the curves were generally drawn above the minimum values. Sets of multiyear low-flow frequency curves were developed for each long-term gaging station. An example of the curves developed for Pottawatomie Creek near Garnett is shown in figure 3.

The curves were adjusted for position with respect to mean flow and for statistical distribution as described by Furness (1962). For continuous-record stations where the record was shorter than the base period, annual flows for missing years were estimated by graphic comparison with the nearest long-term station to compute the mean discharge for the base period. The same long-term station was then used in the manner described by Furness (1962, p. 165-175) to develop multiyear low-flow frequency curves for each short-term station. Frequency values are then representative of the flows at each site that could be expected for the base period. The frequency values are presented for selected recurrence intervals and durations in table 1.

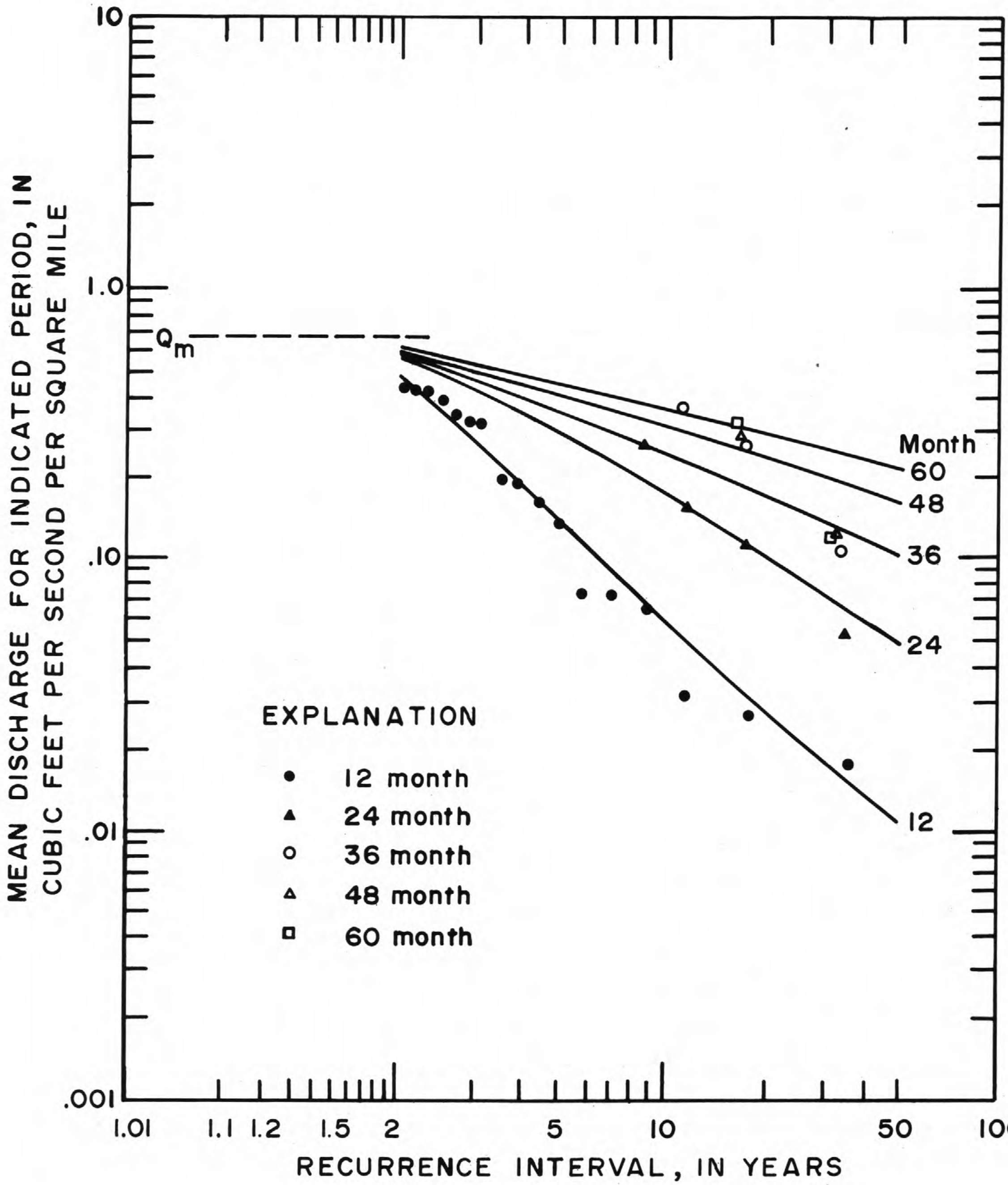

Figure 3.--Multiyear low-flow curves for Pottawatomie Creek near Garnett, 1940-77.

Table 1.--Minimum multiyear discharges expected at selected streamflow gaging stations in southeastern Kansas.

Gaging station	Drainage area (mi^2)	Average recurrence interval (yr)	Lowest mean discharge for indicated number of consecutive months [$(ft^3/s)mi^2$]				
			12	24	36	48	60
06911000	351	2	0.433	0.492	0.521	0.545	0.562
MARAIS DES CYGNES RIVER		5	.067	.132	.213	.283	.337
at Melvern		10	.020	.054	.118	.182	.240
(unregulated)		20	.0057	.023	.064	.118	.172
Records analyzed 1940-72		50	.0015	.007	.029	.064	.108
06911500	111	2	.373	.435	.460	.475	.495
SALT CREEK		5	.070	.151	.205	.259	.318
near Lyndon		10	.016	.062	.108	.163	.218
Records analyzed 1940-77		20	.0035	.024	.057	.102	.152
		50	.0003	.006	.024	.055	.094
06911900	114	2	.435	.463	.492	.505	.518
DRAGOON CREEK		5	.081	.152	.218	.269	.317
near Burlingame		10	.026	.071	.128	.179	.229
Records analyzed 1960-77		20	.0082	.033	.073	.121	.168
		50	.0015	.011	.034	.068	.110
06912500	322	2	.385	.435	.462	.478	.495
HUNDRED AND TEN MILE CREEK		5	.070	.148	.210	.258	.308
near Quenemo		10	.022	.069	.124	.173	.227
(unregulated)		20	.0069	.032	.072	.117	.168
Records analyzed 1940-63		50	.0014	.010	.034	.064	.110
06914000	334	2	.485	.562	.585	.595	.615
POTTAWATOMIE CREEK		5	.138	.287	.348	.405	.445
near Garnett		10	.057	.171	.245	.313	.363
Records analyzed 1940-77		20	.027	.099	.170	.238	.290
		50	.011	.049	.104	.163	.218
06915000	147	2	.382	.442	.483	.505	.525
BIG BULL CREEK		5	.119	.194	.256	.305	.343
near Hillsdale		10	.063	.117	.176	.226	.269
Records analyzed 1958-77		20	.039	.075	.126	.173	.217
		50	.027	.049	.088	.129	.168

Table 1.--Minimum multiyear discharges expected at selected streamflow gaging stations in southeastern Kansas (continued).

Gaging station	Drainage area (mi^2)	Average recurrence interval (yr)	Lowest mean discharge for indicated number of consecutive months [$(ft^3/s)mi^2$]				
			12	24	36	48	60
06916500	198	2	.505	.560	.585	.615	.637
BIG SUGAR CREEK		5	.147	.260	.338	.405	.465
at Farlinville		10	.066	.162	.240	.314	.375
Records analyzed 1940-70		20	.032	.106	.178	.248	.307
		50	.013	.061	.124	.189	.238
06917000	295	2	.435	.503	.540	.590	.630
LITTLE OSAGE RIVER		5	.127	.243	.318	.395	.475
at Fulton		10	.060	.158	.232	.306	.395
Records analyzed 1949-77		20	.032	.106	.172	.240	.330
		50	.017	.064	.118	.178	.265
06917500	408	2	.443	.557	.615	.640	.670
MARMATON RIVER		5	.153	.277	.355	.430	.480
near Fort Scott		10	.068	.175	.250	.330	.387
Records analyzed 1940-77*		20	.031	.112	.177	.257	.320
		50	.011	.060	.112	.186	.242
07165700	181	2	.490	.520	.545	.565	.590
VERDIGRIS RIVER		5	.057	.128	.163	.214	.275
near Madison		10	.017	.053	.075	.118	.169
Records analyzed 1956-76		20	.0069	.0239	.0375	.066	.107
		50	.0031	.0092	.0158	.032	.056
07166000	747	2	.311	.390	.438	.467	.495
VERDIGRIS RIVER		5	.091	.156	.228	.289	.337
near Coyville		10	.042	.084	.149	.213	.263
Records analyzed 1940-60		20	.021	.048	.100	.162	.213
		50	.0096	.025	.062	.115	.163
07167000	307	2	.425	.475	.540	.565	.605
FALL RIVER		5	.072	.159	.273	.349	.413
near Eureka		10	.025	.080	.180	.259	.322
Records analyzed 1947-76		20	.0096	.043	.123	.198	.260
		50	.0034	.022	.076	.145	.200

* Record extended by correlation with Marmaton River near Marmaton

Table 1.--Minimum multiyear discharges expected at selected streamflow gaging stations in southeastern Kansas (continued).

Gaging station	Drainage area (mi^2)	Average recurrence interval (yr)	Lowest mean discharge for indicated number of consecutive months [$(ft^3/s)mi^2$]				
			12	24	36	48	60
07167500	129	2	.330	.375	.410	.445	.475
OTTER CREEK		5	.0345	.097	.182	.265	.308
at Climax		10	.0097	.0435	.110	.190	.237
Records analyzed 1947-77		20	.0037	.0215	.070	.140	.185
		50	.0015	.0100	.042	.094	.138
07170000	575	2	.295	.405	.445	.470	.493
ELK RIVER		5	.064	.161	.237	.295	.340
near Elk City		10	.026	.090	.162	.223	.273
Records analyzed 1940-69		20	.0132	.054	.116	.173	.223
		50	.0067	.031	.081	.127	.173
07170700	37	2	.420	.465	.495	.530	.565
BIG HILL CREEK		5	.180	.257	.325	.383	.455
near Cherryvale		10	.108	.181	.250	.315	.390
Records analyzed 1958-77		20	.069	.137	.205	.265	.340
		50	.044	.105	.160	.219	.285
07172000	445	2	.245	.350	.390	.425	.440
CANEY RIVER		5	.067	.143	.210	.260	.295
near Elgin		10	.0295	.082	.140	.190	.232
Records analyzed 1940-77		20	.014	.049	.096	.146	.186
		50	.0055	.027	.062	.103	.140
07179500	250	2	.380	.400	.425	.435	.454
NEOSHO RIVER		5	.075	.151	.202	.240	.281
at Council Grove		10	.0162	.076	.123	.159	.205
(unregulated)		20	.0030	.038	.074	.108	.151
Records analyzed 1940-64		50	.0003	.016	.038	.062	.100
07180500	110	2	.363	.400	.433	.445	.450
CEDAR CREEK		5	.098	.152	.194	.231	.265
near Cedar Point		10	.034	.074	.112	.150	.185
Records analyzed 1940-77		20	.011	.036	.063	.097	.133
		50	.0024	.0135	.030	.054	.082

Table 1.--Minimum multiyear discharges expected at selected streamflow gaging stations in southeastern Kansas (concluded).

Gaging station	Drainage area (mi^2)	Average recurrence interval (yr)	Lowest mean discharge for indicated number of consecutive months [$(ft^3/s)mi^2$]				
			12	24	36	48	60
07184000	197	2	.475	.510	.535	.585	.630
LIGHTNING CREEK		5	.165	.245	.315	.393	.475
near McCune		10	.090	.158	.227	.305	.395
Records analyzed 1940-45,		20	.057	.105	.169	.245	.335
1960-77		50	.038	.066	.122	.189	.268

REGIONALIZATION OF RESULTS

When frequency curves had been determined at each station for the base period, the average discharge values and the 2-year and 50-year discharge values for each duration were plotted on separate base maps. The values were plotted at the centroid of the drainage for each station. Then equal flow lines were developed in southeastern Kansas for specified frequencies and durations (figs. 4-14). These figures can be used to estimate multiyear low-flow frequency curves at ungaged sites. Discharge values for the 2- and 50-year recurrence interval for each duration can be obtained by interpolation for the site of interest. The values can then be plotted on a log-Gumbel extreme-probability graph, and the points for like durations connected by a straight line.

With one exception, the data represent drainage areas of 110 to 747 square miles. Within this range, average discharge per square mile appeared to have no consistent variation with size of drainage area. Therefore, the presentation of discharges in units of cubic feet per second per square mile seems to be a valid aid to generalization and extrapolation to ungaged sites. However, extrapolation to drainage areas smaller than 110 square miles has not been validated; the record of the station gaging 37 square miles of drainage is too short to provide a reliable indication.

SUMMARY

Many existing water supplies in southeastern Kansas are proving inadequate to meet current and expanded future needs. Estimates of multiyear low-flow frequency values can be used as one of the methods to evaluate the highly variable streamflow for water supply use.

Presented in this report are maps from which discharge values for the 2- and 50-year recurrence interval for durations of 12, 24, 36, and 60 months can be obtained for ungaged sites. Discharge values for intervening recurrence intervals may be obtained by interpolation on a log-Gumbel plot. These maps were developed using data from 19 stream-gaging stations in the study area and a base period of 1940-77. Stations that did not have streamflow record for the entire base period were extended by correlation techniques.

The user is cautioned that extrapolation of regionalized values in this report to drainage areas smaller than 110 square miles and larger than 1,000 square miles has not been validated.

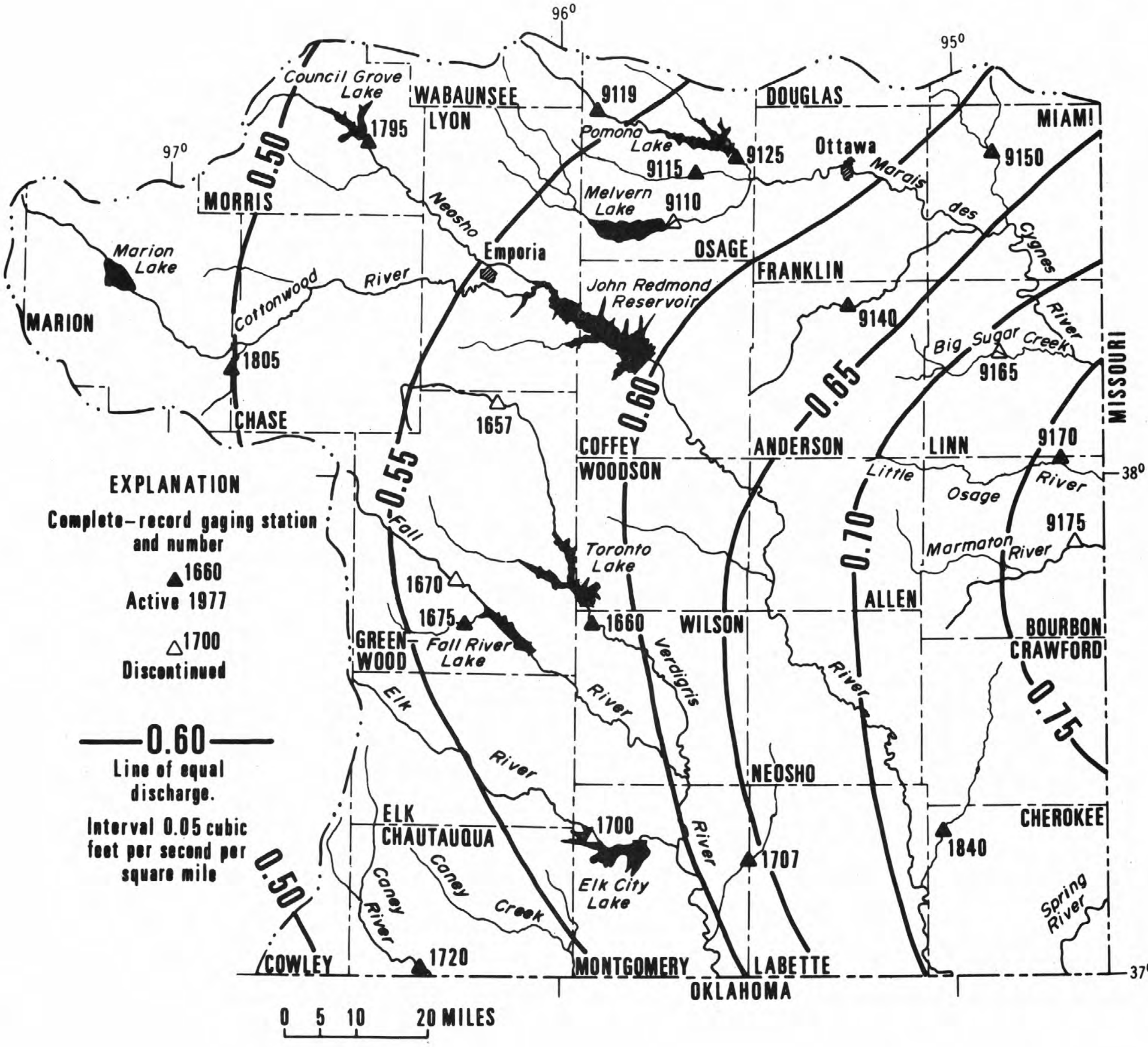

Figure 4.--Regional trend of mean streamflow, 1940-77.

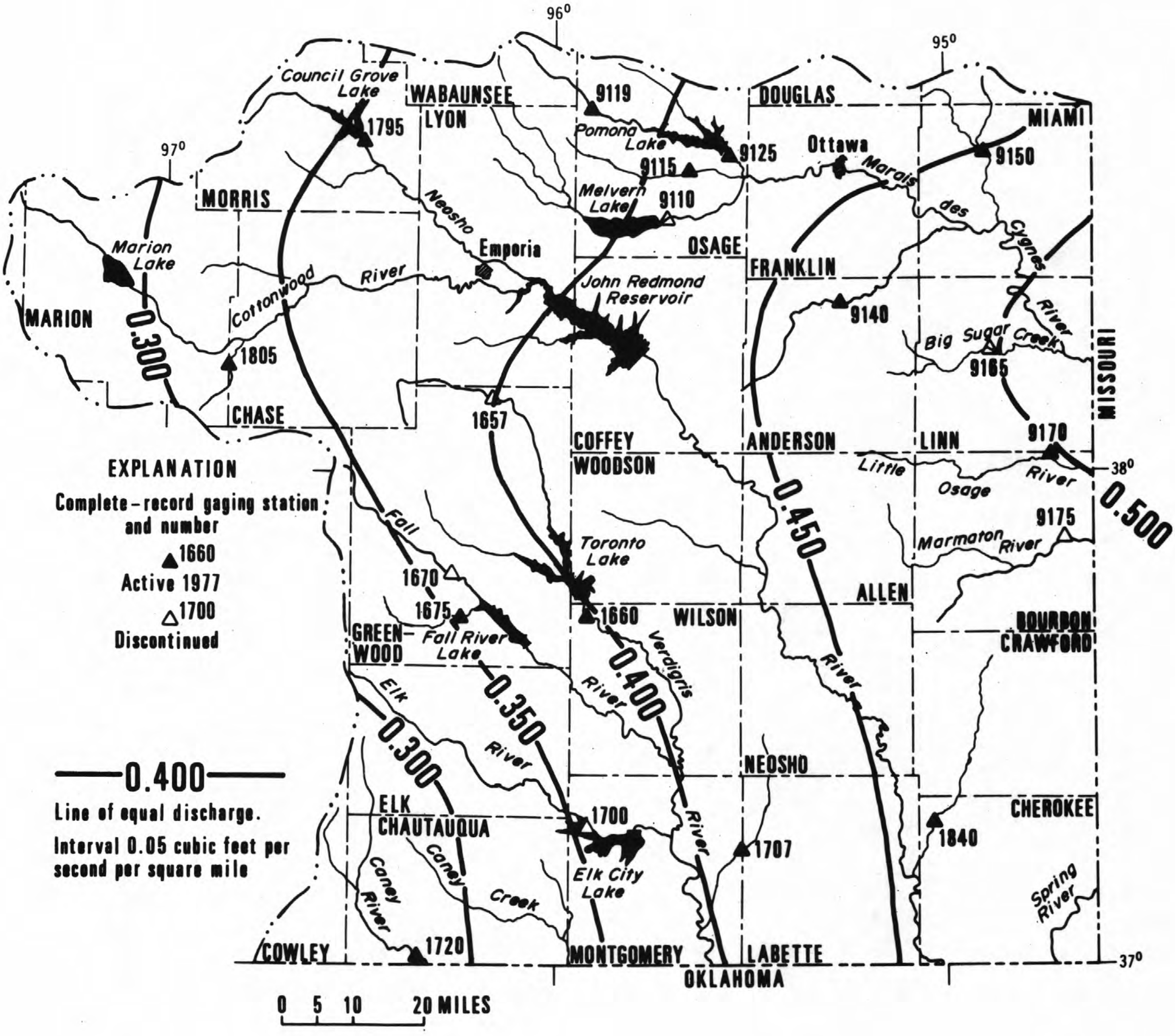

Figure 5.--Regional trend of lowest mean discharge for 12 consecutive months expected to recur once in 2 years.

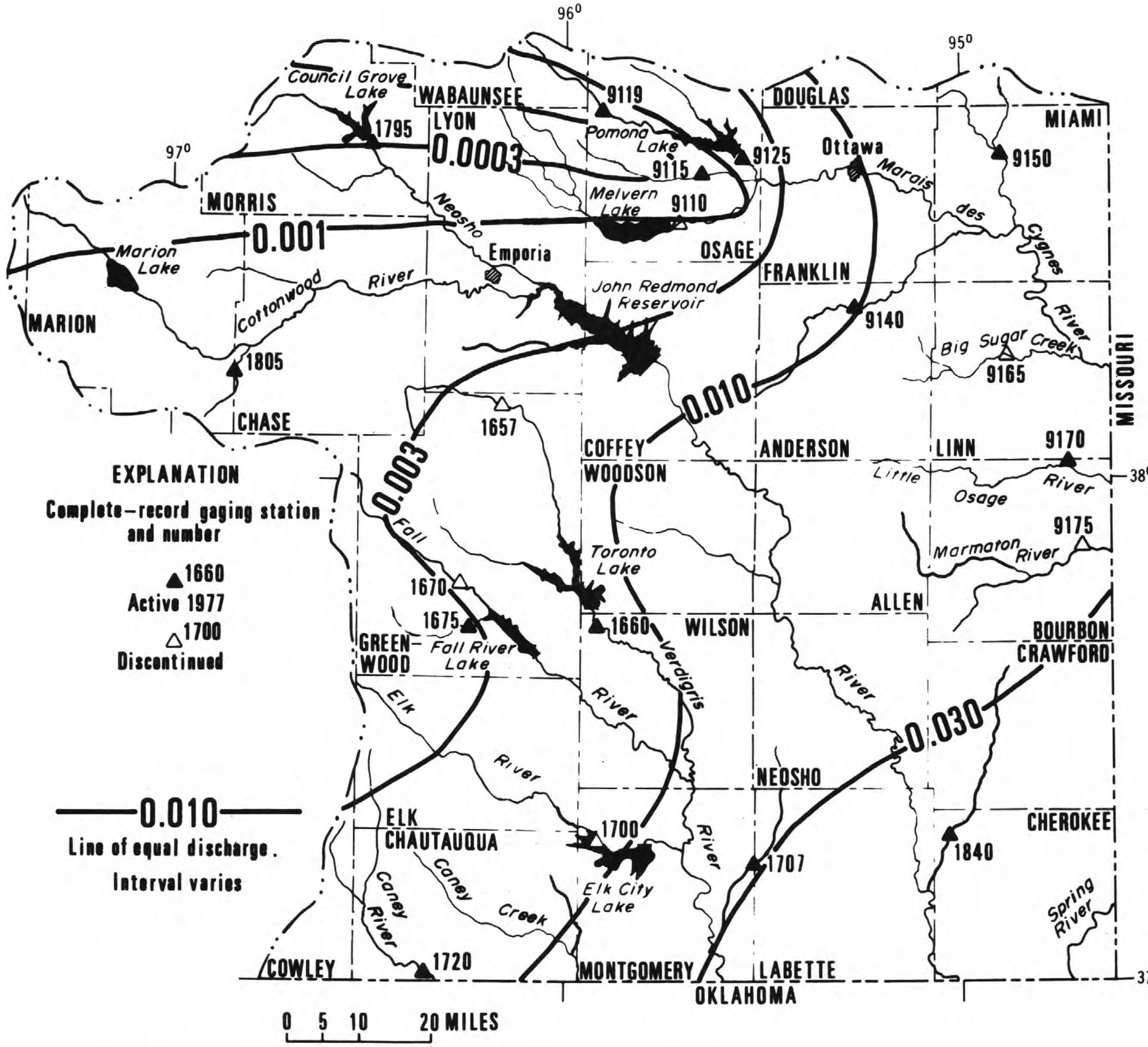

Figure 6.--Regional trend of lowest mean discharge for 12 consecutive months expected to recur once in 50 years.

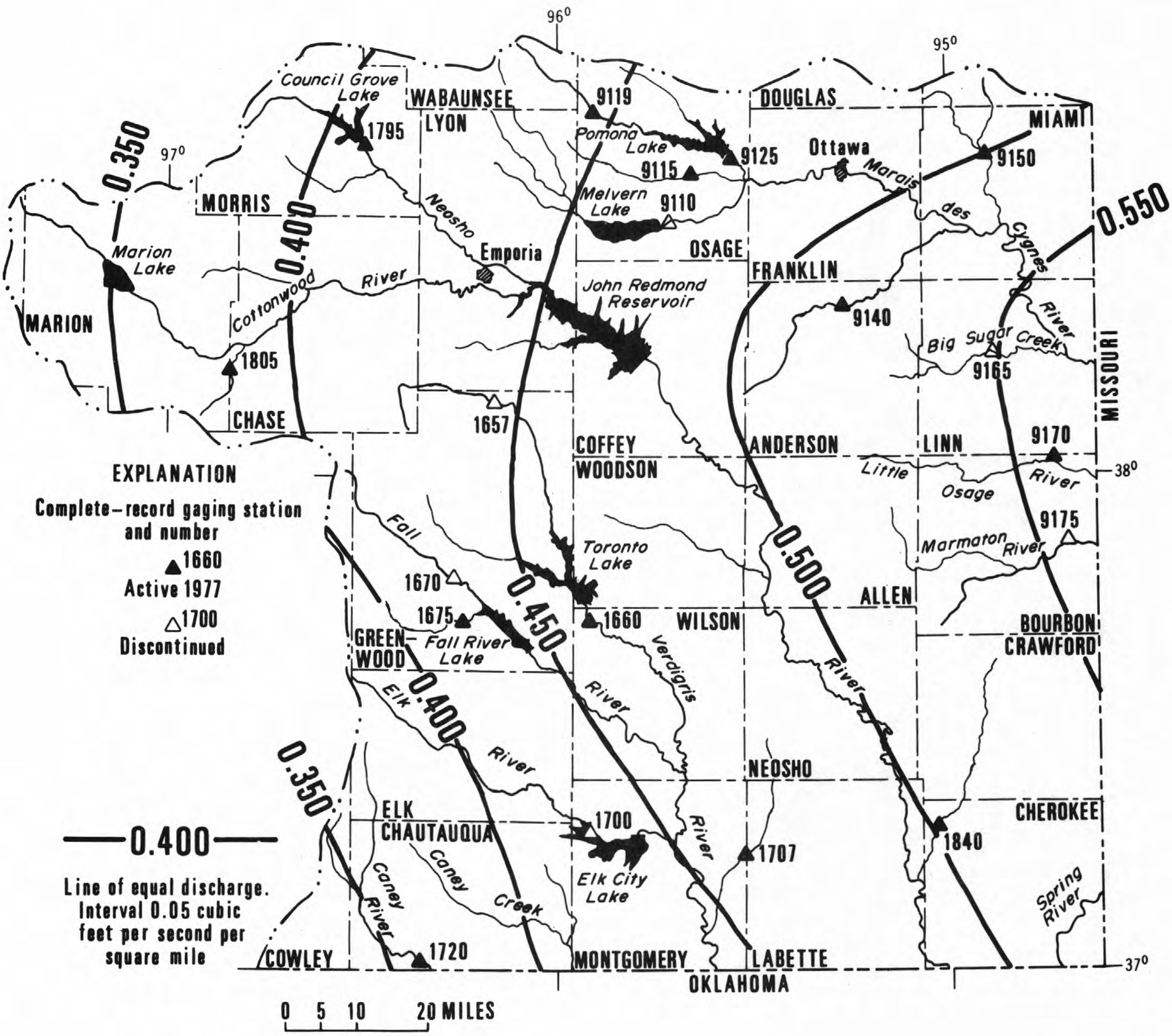

Figure 7.--Regional trend of lowest mean discharge for 24 consecutive months expected to recur once in 2 years.

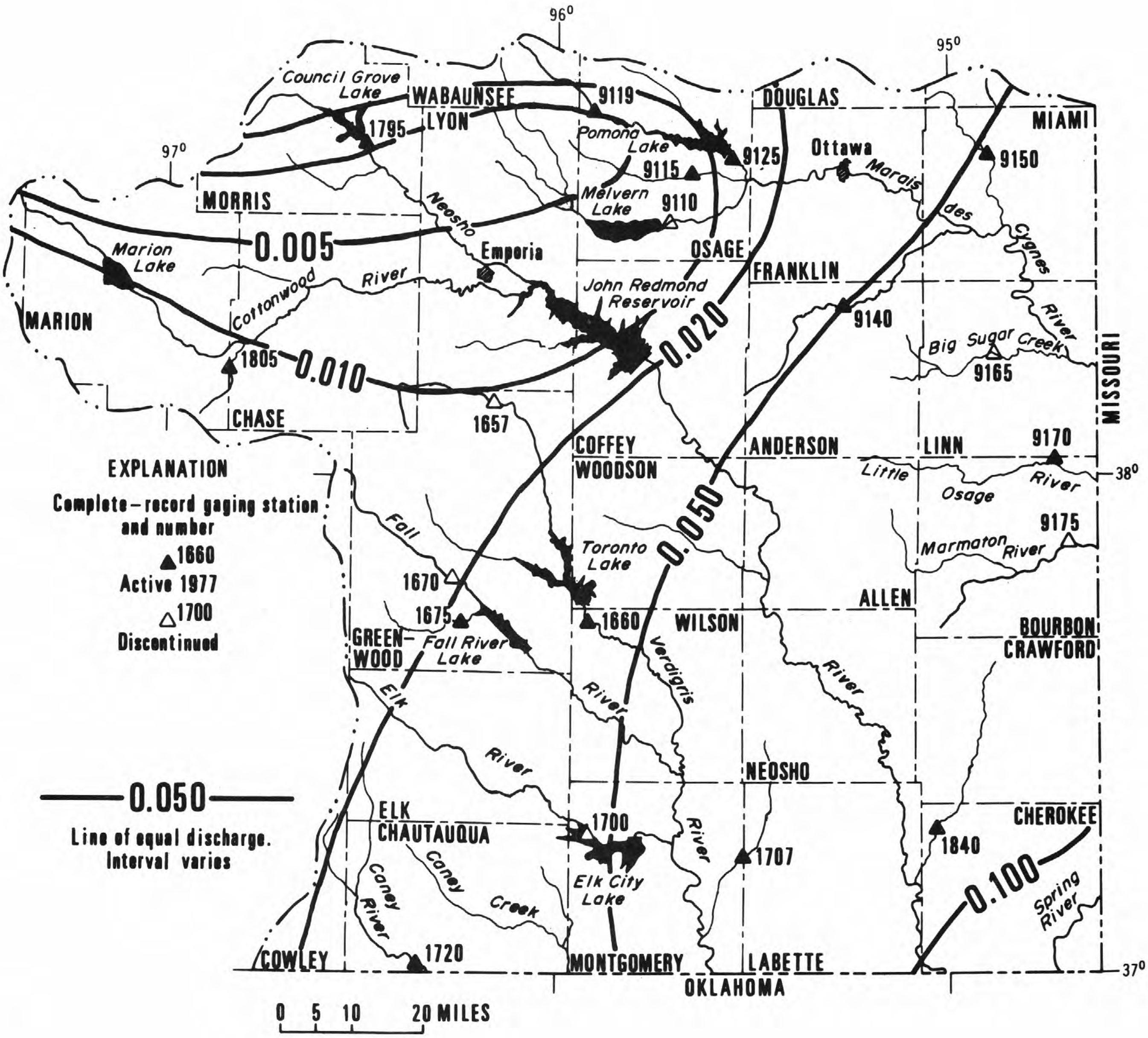

Figure 8.--Regional trend of lowest mean discharge for 24 consecutive months expected to recur once in 50 years.

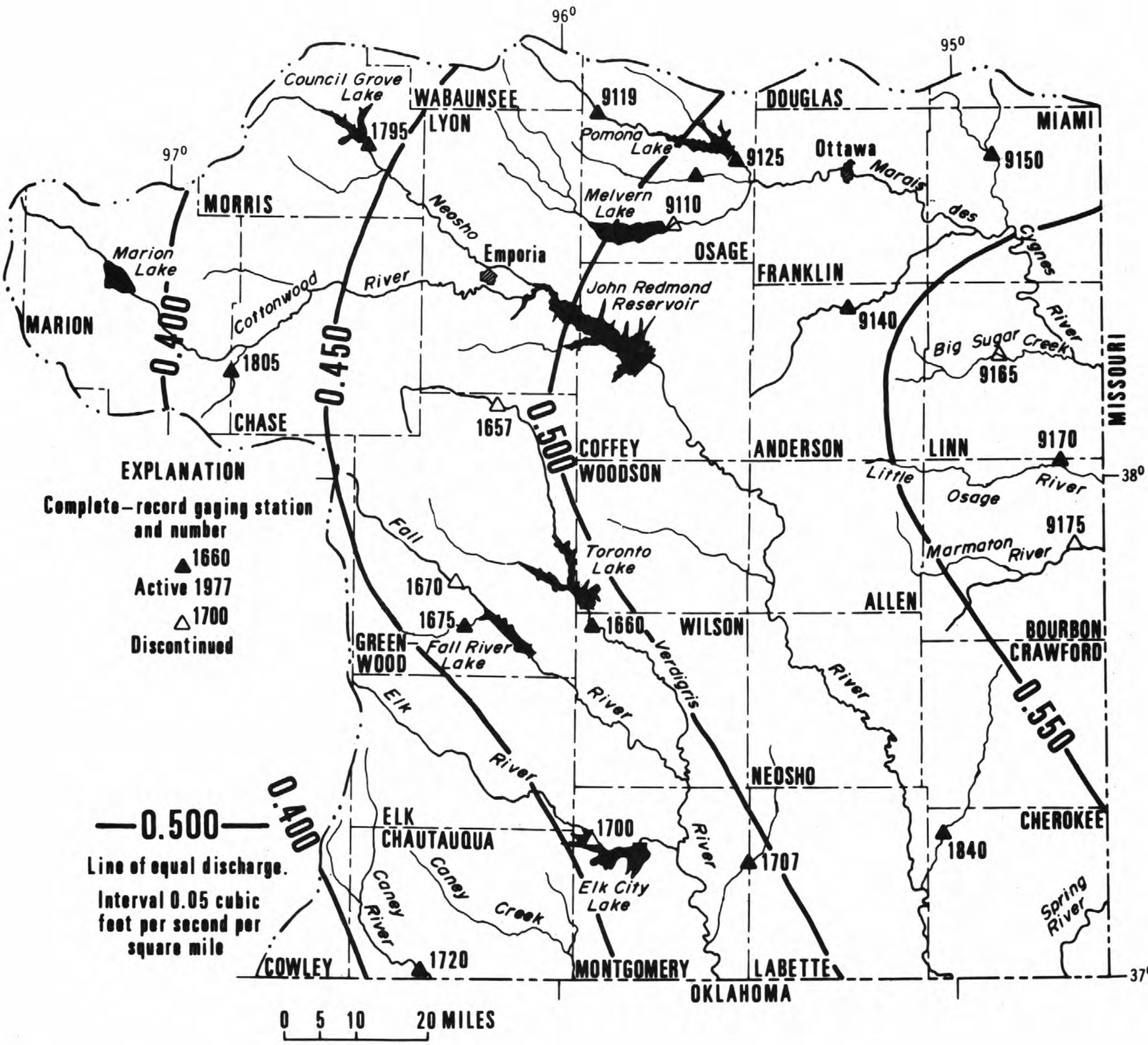

Figure 9.--Regional trend of lowest mean discharge for 36 consecutive months expected to recur once in 2 years.

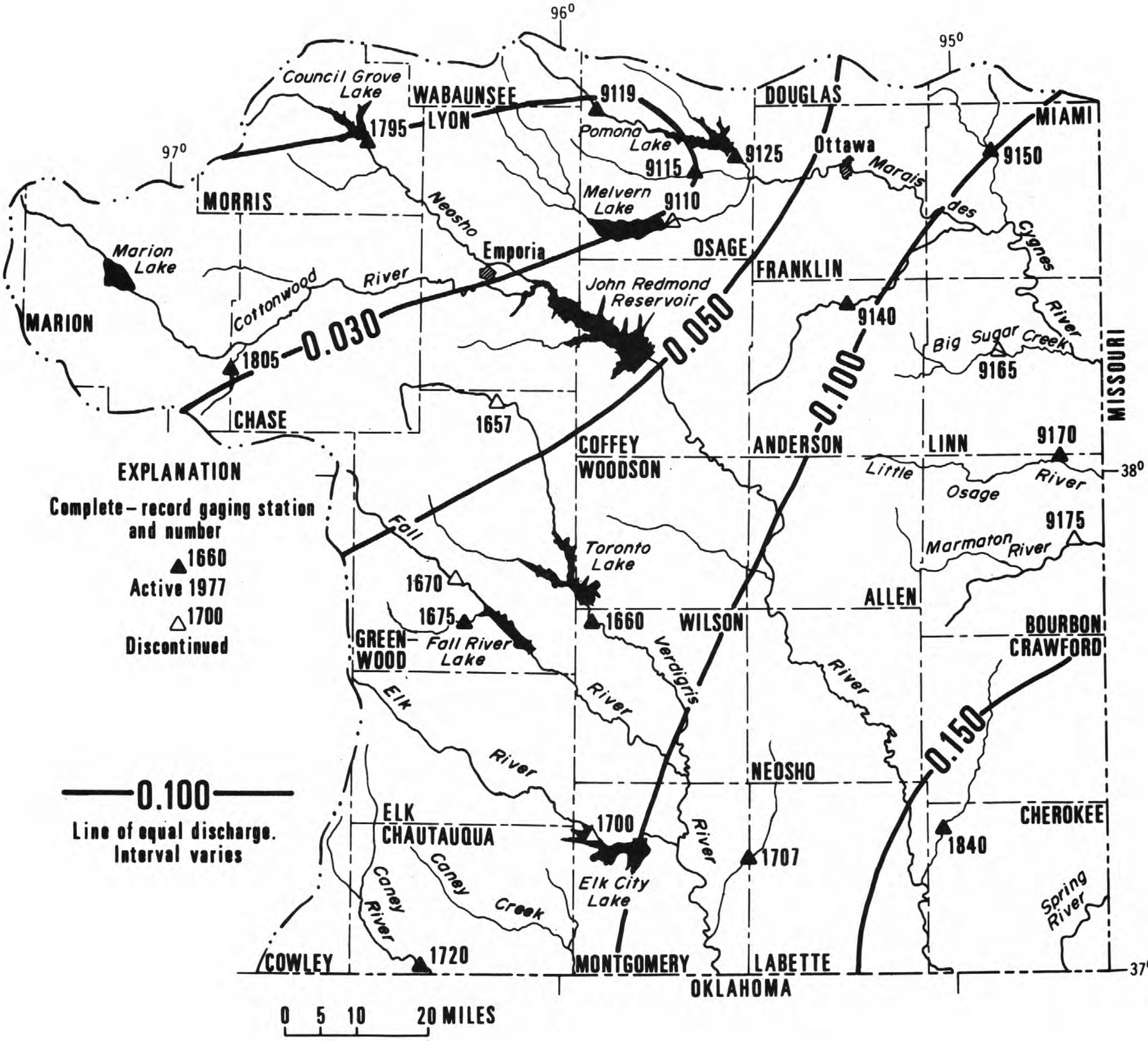

Figure 10.--Regional trend of lowest mean discharge for 36 consecutive months expected to recur once in 50 years.

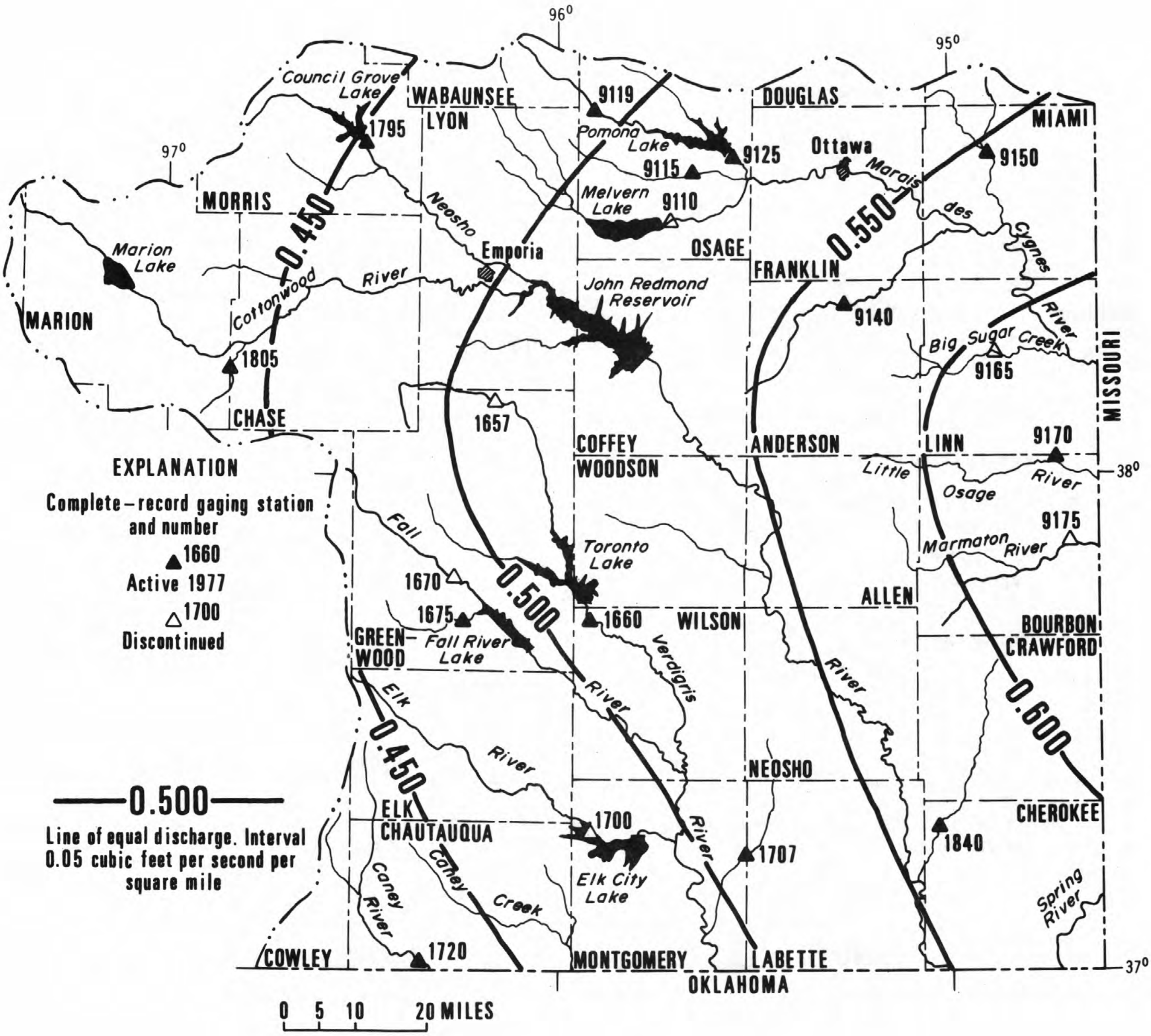

Figure 11.--Regional trend of lowest mean discharge for 48 consecutive months expected to recur once in 2 years.

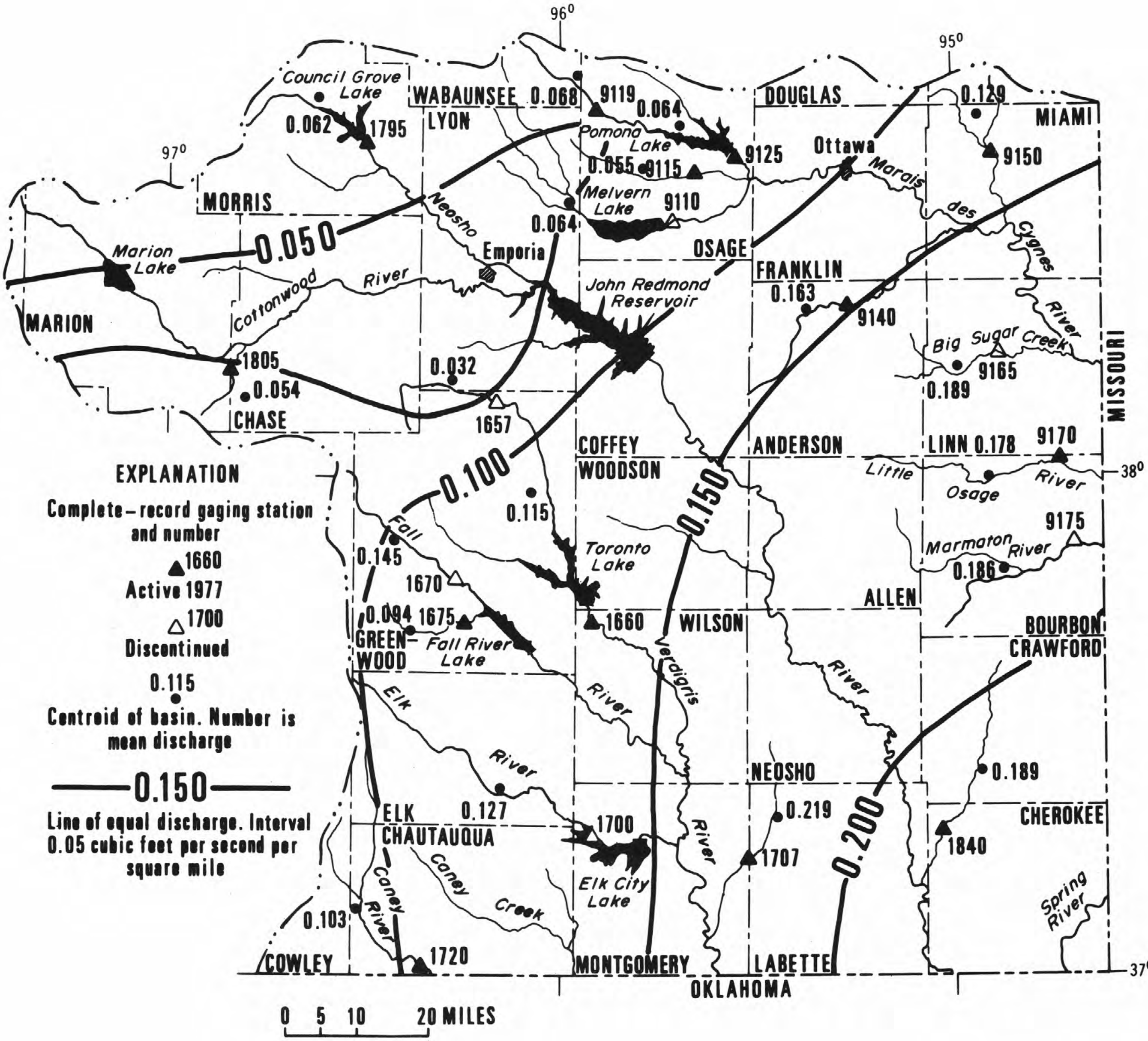

Figure 12.--Regional trend of lowest mean discharge for 48 consecutive months expected to recur once in 50 years.

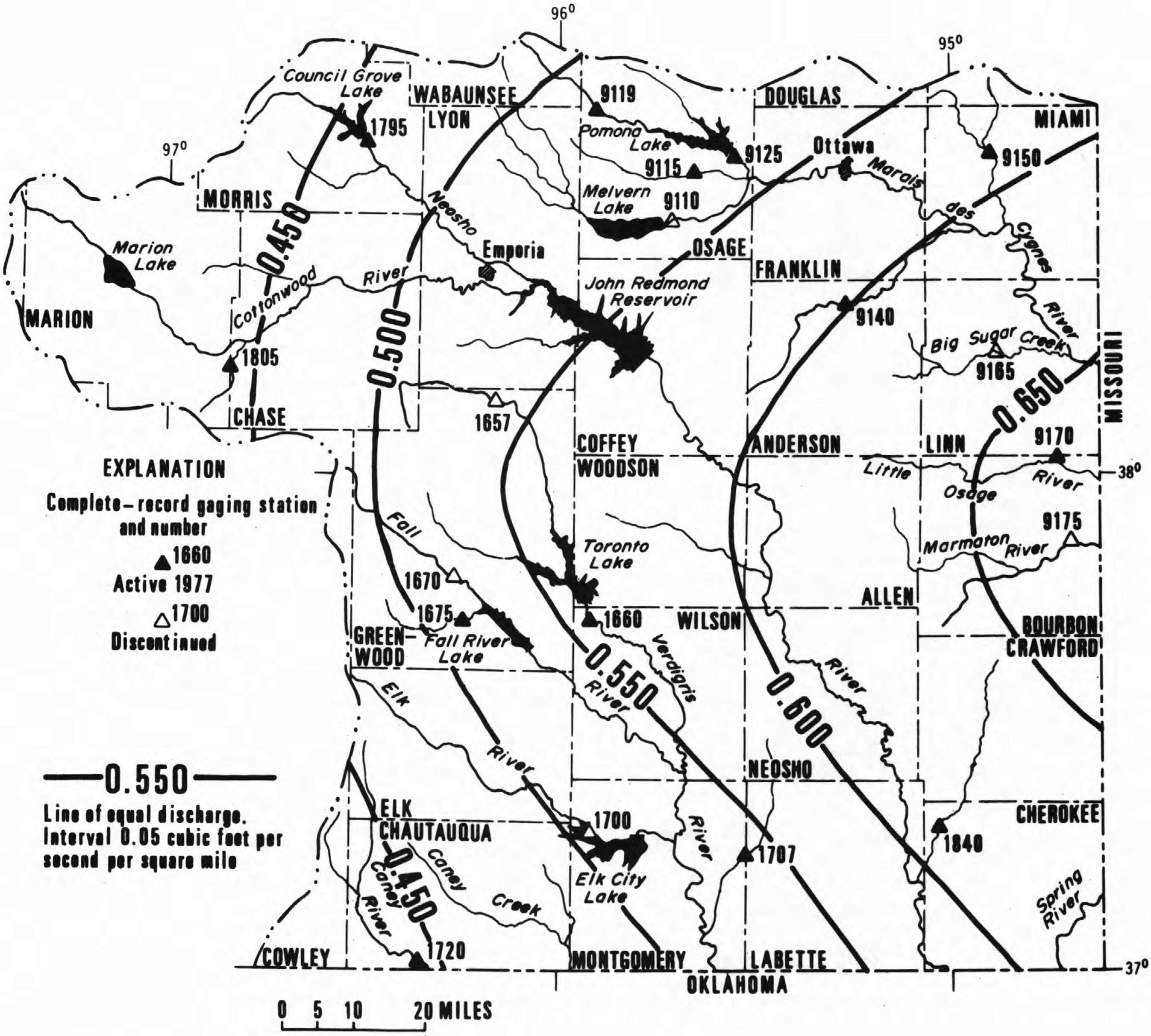

Figure 13.--Regional trend of lowest mean discharge for 60 consecutive months expected to recur once in 2 years.

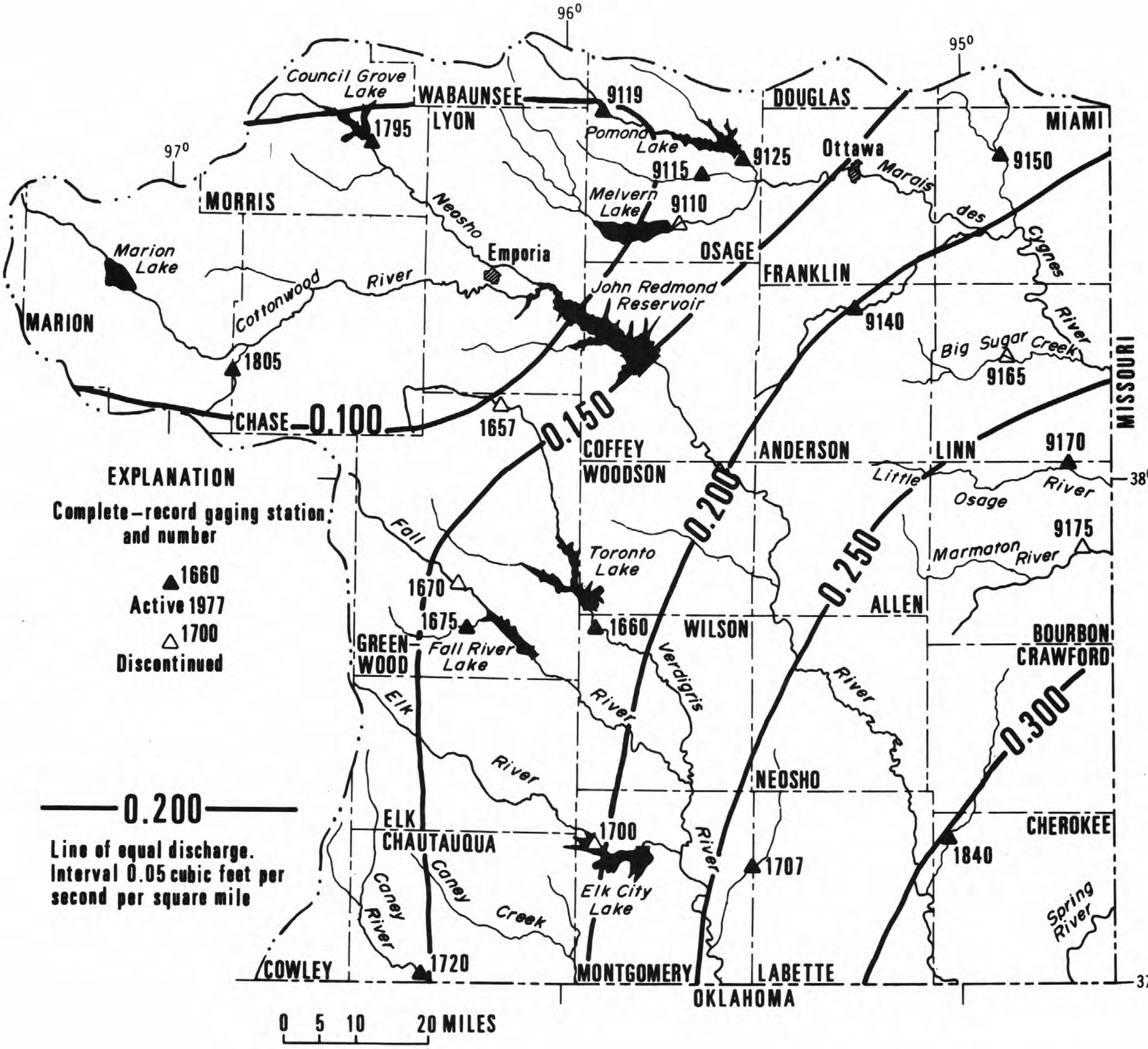

Figure 14.--Regional trend of lowest mean discharge for 60 consecutive months expected to recur once in 50 years.

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