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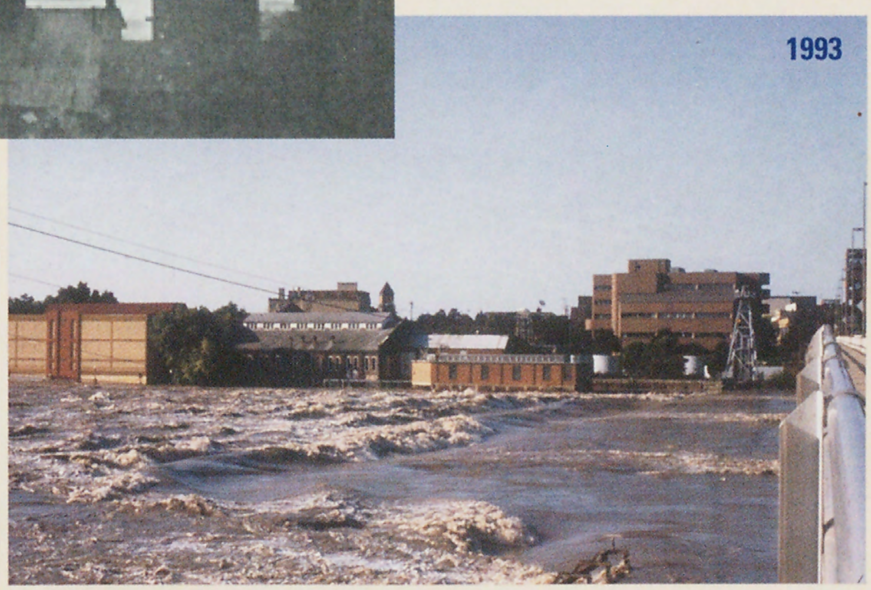
Trends in Peak Flows of Selected Streams in Kansas

Water-Resources Investigations Report 01–4203



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Cover photographs—peak flows on the Kansas River at Massachusetts Street bridge, Lawrence, Kansas, 1903 and 1993.

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By TERESA J. RASMUSSEN and CHARLES A. PERRY

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Lawrence, Kansas
2001

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
4821 Quail Crest Place
Lawrence, KS 66049–3839

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Building 810
Box 25286, Federal Center
Denver, CO 80225–0286

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per year [(ft^3/s)/yr]	0.02832	cubic meter per second per year
foot (ft)	0.3048	meter
inch (in.)	2.54	centimeter
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
square mile (mi^2)	2.590	square kilometer

Trends in Peak Flows of Selected Streams in Kansas

By Teresa J. Rasmussen *and* Charles A. Perry

Abstract

The possibility of a systematic change in flood potential led to an investigation of trends in the magnitude of annual peak flows in Kansas. Efficient design of highway bridges and other flood-plain structures depends on accurate understanding of flood characteristics. The Kendall's tau test was used to identify trends at 40 stream-gaging stations during the 40-year period 1958–97. Records from 13 (32 percent) of the stations showed significant trends at the 95-percent confidence level. Only three of the records (8 percent) analyzed had increasing trends, whereas 10 records (25 percent) had decreasing trends, all of which were for stations located in the western one-half of the State. An analysis of flow volume using mean annual discharge at 29 stations in Kansas resulted in 6 stations (21 percent) with significant trends in flow volumes. All six trends were decreasing and occurred in the western one-half of the State.

The Kendall's tau test also was used to identify peak-flow trends over the entire period of record for 54 stream-gaging stations in Kansas. Of the 23 records (43 percent) showing significant trends, 16 (30 percent) were decreasing, and 7 (13 percent) were increasing. The trend test then was applied to 30-year periods moving in 5-year increments to identify time periods within each station record when trends were occurring.

Systematic changes in precipitation patterns and long-term declines in ground-water levels in some stream basins may be contributing to peak-flow trends. To help explain the cause of the streamflow trends, the Kendall's tau test was applied to total annual precipitation and ground-water levels in Kansas. In western Kansas, the lack of precipitation and presence of decreasing trends in ground-water levels indicated that declining water tables are contributing to decreasing trends in peak streamflow. Declining water tables are caused by ground-water withdrawals and other factors such as construction of ponds and terraces.

Peak-flow records containing trends introduce statistical error into flood-frequency analysis. To examine the effect of trends on flood-frequency analysis, statistically significant trends were added systematically to four nontrending station records. Flood magnitudes estimated on the basis of each data series were compared. The added trends resulted in changes in the 100-year flood magnitudes of as much as 70 percent.

INTRODUCTION

There is evidence that the magnitudes of the annual peak flow for some streams in Kansas are changing. For example, annual peak-flow records for the Marmaton River in east-central Kansas (fig. 1) indicated that during the 13-year period, 1985–97, the annual peak flow exceeded the 2-year flood in 9 years, the 5-year flood in 5 years, and the 25-year flood in 3 years. During the previous 13-year period, 1972–84, the annual peak flow exceeded the 2-year flood in only 4 years and the 5-year flood only once. The recurrence intervals of annual peak flows for the Marmaton River near Marmaton were estimated using the Bulletin 17B guidelines for flood-frequency analysis established by the Interagency Advisory Committee on Water Data (1982) and were based on 26 years of record from 1972–97. Recurrence interval, commonly used in hydrology to express the probability of an event, is the time interval in which an event will occur once on the average (Bedient and Huber, 1992). Conversely, in southwest Kansas, annual peak-flow records (1943–98) for Crooked Creek (fig. 1) showed that the creek was frequently dry with no peak flows exceeding the 2-year flood magnitude in the last 13 years.

Trends in peak streamflow are of particular interest to State and Federal highway departments as they design highway structures in flood plains. Routine flood-frequency analysis on streams with gaging stations, as well as regional frequency-analysis procedures used at ungaged sites, rely on historical peak-flow records to estimate flood magnitudes. Frequency analysis is based on the assumption that floods are independent and identically distributed in time—that is, temporally uncorrelated and stationary. A trend in streamflow could indicate that floods are not independent, not stationary, or both, introducing an element of error into the flood-frequency analysis.

The purposes of this report, prepared by the U.S. Geological Survey (USGS) in cooperation with the Kansas Department of Transportation, are to: (1) document whether significant trends exist in the magnitudes of annual peak flows at selected stream-gaging stations in Kansas, (2) evaluate possible causes of the trends, and (3) document if these trends have a significant effect on flood magnitudes as indicated by flood-frequency analyses. For the purpose of this report, a

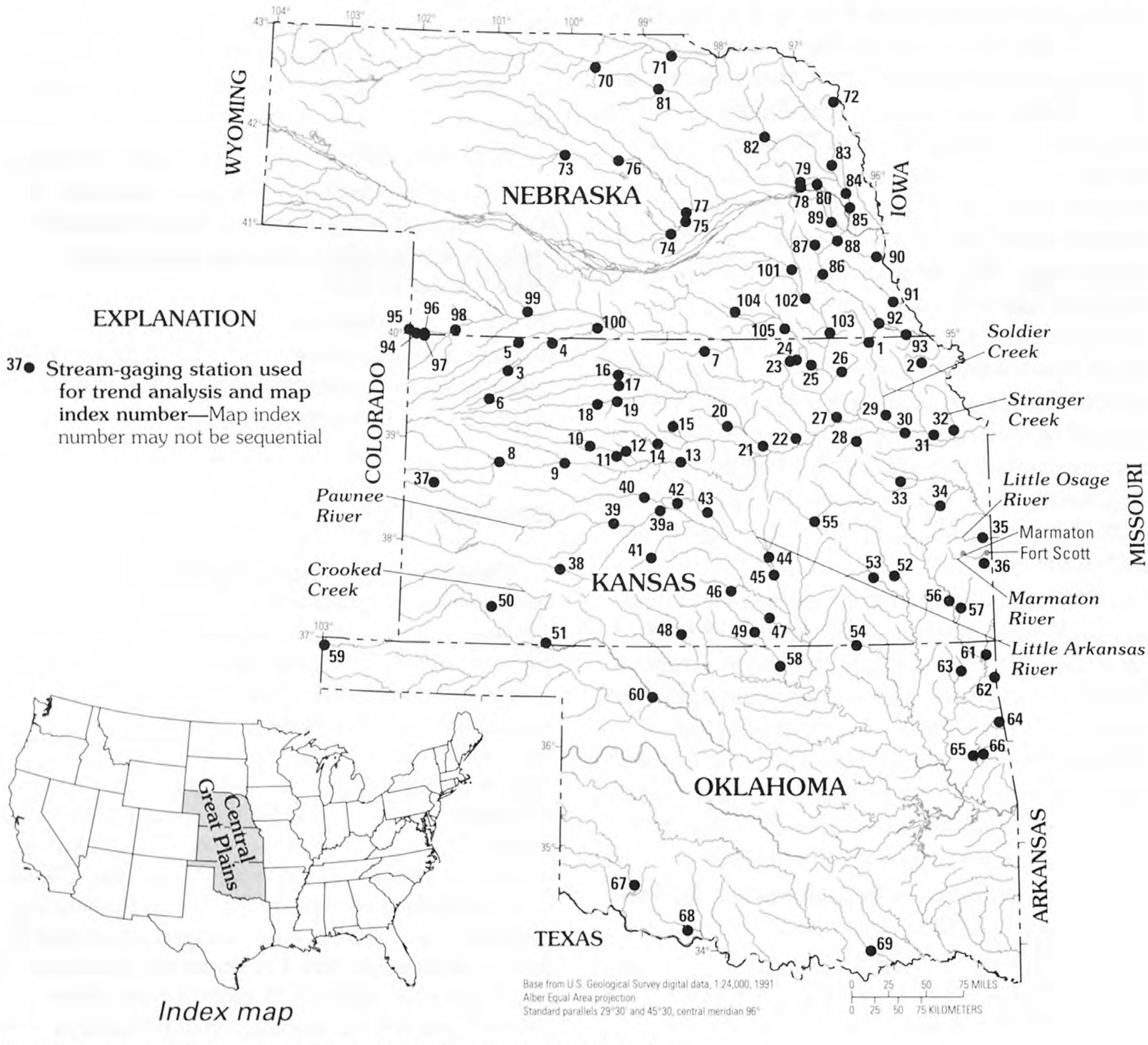


Figure 1. Location of study area and stream-gaging stations used in trend analyses.

trend is considered to be a smooth upward or downward change over several (three to six) decades. This is a relatively small window in time, representing only a part of what actually may be, over a longer period, a continuing trend or a fluctuating or cyclic pattern.

This report focuses primarily on Kansas peak-flow trends and their causes. However, peak-flow records were analyzed for stream-gaging stations in the adjoining States of Oklahoma and Nebraska to improve understanding of the regional pattern associated with trends in Kansas. Several different categories of analysis were used to identify regional and temporal trends in streamflow. First, peak flows from the same 40-year period of record, 1958-97, were considered for selected streams in Kansas, Oklahoma, and Nebraska. Then peak flows over the entire available period of record for Kansas streams were analyzed. In addition, the complete periods of record were divided into moving 30-year blocks to recognize trending cycles in peak flow. Finally, flow volumes at selected Kansas stream-gaging stations were analyzed using mean annual discharge values.

STREAMFLOW TREND ANALYSES

Kendall's Tau Test

Kendall's tau (Kendall and Gibbons, 1990) served as the statistical basis for the trend analyses presented in this report. It is a nonparametric test that can be used to indicate the likelihood of an increasing or decreasing trend over time. A nonparametric test is one that does not require a known or assumed probability distribution for the variables in question. A parametric test, like linear regression, was not considered appropriate for this report because streamflow characteristics are not normally distributed. The Kendall's tau test is rank based and does not depend specifically on the magnitudes of the data values. It is effective for identifying trends in streamflow because extreme values and skewness in the data have little effect on the outcome (Helsel and Hirsch, 1992).

Using the Kendall's tau test, the rank of each peak-flow value is compared to the rank of the values following it in the series. If the second value is consistently higher than the first, the tau coefficient is positive. If the second value is consistently lower, the tau coefficient is negative. An equal number of negative and positive values would suggest that a trend does not exist. Therefore, the tau value is a measure of the correlation between the series and time. In this report, a trend was considered to be significant if the probability (p) value (probability that a true null hypothesis of no trend is erroneously rejected) was less than or equal to 0.05. This represents a 95-percent confidence level. The slope is a measure of the magnitude of the trend.

Past studies suggest that statistically significant trends in streamflow can be difficult to detect due to relatively short periods of record (Chiew and McMahon, 1993). Furthermore, Wahl (1998) showed that, although Kendall's tau test is relatively insensitive to the presence of individual outliers, a sequence of extreme occurrences near the beginning or the end of the period of record could have a significant effect on the outcome of the Kendall's tau test. Therefore, stream-gaging-station records used in this report were examined for multiyear sequences that were wetter or dryer than normal at either end of the period of record. Although several sequences were found, they were minor and did not appear to significantly alter the overall results of the trend analysis.

Peak Flow

All the stations used in the trend analyses are listed in table 1. The first part of the peak-flow analysis used the same 40-year period of record, 1958–97, from 88 stations in Kansas, Oklahoma, and Nebraska (table 2). The second part of the peak-flow analysis used the entire period of record from all stations in Kansas that had more than 38 years of record.

Peak-flow trends were analyzed by first applying the Kendall's tau test to the instantaneous (occurring at a particular instant in time) annual peak-flow values from 40 stream-gaging stations in Kansas, 12 stations in Oklahoma, and 36 stations in Nebraska. Peak-flow data were obtained from the USGS, which operates a stream-gaging-station network throughout the United States. Data are published in annual USGS water-data reports for each State and are available on the Internet (http://water.usgs.gov). This report considered all the stream-gaging stations in the three-State area that measured flows that were unregulated (less than 10 percent of the basin is regulated by a dam) and that provided an uninterrupted 40-year peak-flow record from 1958 through 1997. The 40-year period of record is nearly twice the length of the suspected drought cycle, which is estimated to be 22 years in the Great Plains (Mitchell and others, 1979). The drought of the

Table 1. Stream-gaging stations used in trend analyses

[mi^2, square miles]

Map index number (fig. 1)	Station number	Station name	Total drainage area (mi^2)
		Kansas	
1	06814000	Turkey Creek near Seneca, KS	276
2	06815700	Buttermilk Creek near Willis, KS	3.74
3	06844900	South Fork Sappa Creek near Achilles, KS	446
4	06845100	Long Branch Draw near Norcatur, KS	31.7
5	06846500	Beaver Creek at Cedar Bluffs, KS	1,618
6	06847600	Prairie Dog Creek tributary at Colby, KS	7.5
7	06853800	White Rock Creek near Burr Oak, KS	2.3
8	06860000	Smoky Hill River at Elkader, KS	3,555
9	06861000	Smoky Hill River near Arnold, KS	5,220
10	06863400	Big Creek tributary near Ogallah, KS	4.8
11	06863500	Big Creek near Hays, KS	594
12	06863700	Big Creek tributary near Hays, KS	6.2
13	06864300	Smoky Hill River tributary at Dorrance, KS	5.4
14	06867000	Saline River near Russell, KS	1,502
15	06868300	Coon Creek tributary near Luray, KS	6.5
16	06871000	North Fork Solomon River at Glade, KS	849
17	06871500	Bow Creek near Stockton, KS	341
18	06873000	South Fork Solomon River above Webster Reservoir, KS	1,040
19	06873300	Ash Creek tributary near Stockton, KS	0.89
20	06876700	Salt Creek near Ada, KS	384
21	06876900	Solomon River at Niles, KS	6,770
22	06878000	Chapman Creek near Chapman, KS	300
23	06884200	Mill Creek at Washington, KS	344
24	06884300	Mill Creek tributary near Washington, KS	3.2
25	06884400	Little Blue River near Barnes, KS	3,324
26	06885500	Black Vermillion River near Frankfort, KS	410
27	06887200	Cedar Creek near Manhattan, KS	13.4
28	06888500	Mill Creek near Paxico, KS	316
29	06889200	Soldier Creek near Delia, KS	157
30	06889500	Soldier Creek near Topeka, KS	290
31	06891000	Kansas River at Lecompton, KS	58,460
32	06892000	Stranger Creek near Tonganoxie, KS	406
33	06911500	Salt Creek near Lyndon, KS	111
34	06914000	Pottawatomie Creek near Garnett, KS	334
35	06917000	Little Osage River at Fulton, KS	295
36	06917400	Marmaton River tributary near Fort Scott, KS	2.8

Table 1. Stream-gaging stations used in trend analyses—Continued

Map index number (fig. 1)	Station number	Station name	Total drainage area (mi^2)
		Kansas—Continued	
37	07138600	White Woman Creek tributary near Selkirk, KS	38
38	07139700	Arkansas River tributary near Dodge City, KS	8.7
39	07141200	Pawnee River at Rozel, KS	2,148
39a	07141300	Arkansas River at Great Bend, KS	34,356
40	07141900	Walnut Creek at Albert, KS	1,410
41	07142300	Rattlesnake Creek near Macksville, KS	784
42	07143100	Little Cheyenne Creek tributary near Claflin, KS	1.5
43	07143300	Cow Creek near Lyons, KS	728
44	07144200	Little Arkansas River at Valley Center, KS	1,327
45	07144300	Arkansas River at Wichita, KS	40,490
46	07145200	South Fork Ninnescah River near Murdock, KS	650
47	07145700	Slate Creek at Wellington, KS	154
48	07149000	Medicine Lodge River near Kiowa, KS	903
49	07151500	Chikaskia River near Corbin, KS	794
50	07156700	Cimarron River tributary near Satanta, KS	2.41
51	07157500	Crooked Creek near Englewood, KS	1,157
52	07166200	Sandy Creek near Yates Center, KS	6.8
53	07167500	Otter Creek at Climax, KS	129
54	07172000	Caney River near Elgin, KS	445
55	07180500	Cedar Creek near Cedar Point, KS	110
56	07183500	Neosho River near Parsons, KS	4,905
57	07184000	Lightning Creek near McCune, KS	197
		Oklahoma	
58	07152000	Chikaskia River near Blackwell, OK	1,859
59	07154500	Cimarron River near Kenton, OK	1,106
60	07158000	Cimarron River near Waynoka, OK	13,334
61	07188000	Spring River near Quapaw, OK	2,510
62	07189000	Elk River near Tiff City, MO	872
63	07191000	Big Cabin Creek near Big Cabin, OK	450
64	07195500	Illinois River near Watts, OK	635
65	07196500	Illinois River near Tahlequah, OK	959
66	07197000	Baron Fork at Eldon, OK	307
67	07300500	Salt Fork Red River at Mangum, OK	1,566
68	07311500	Deep Red Creek near Randlett, OK	617
69	07332500	Blue River near Blue, OK	476
		Nebraska	
70	06463500	Long Pine Creek near Riverview, NE	458
71	06465000	Niobrara River near Spencer, NE	11,070
72	06601000	Omaha Creek at Homer, NE	174

Table 1. Stream-gaging stations used in trend analyses—Continued

Map index number (fig. 1)	Station number	Station name	Total drainage area (mi^2)
		Nebraska—Continued	
73	06775500	Middle Loup River at Dunning, NE	1,830
74	06784000	South Loup River at St. Michael, NE	2,320
75	06785000	Middle Loup River at St. Paul, NE	8,075
76	06786000	North Loup River at Taylor, NE	2,350
77	06790500	North Loup River near St. Paul, NE	4,302
78	06793000	Loup River near Genoa, NE	14,320
79	06794000	Beaver Creek at Genoa, NE	677
80	06795500	Shell Creek near Columbus, NE	294
81	06797500	Elkhorn River at Ewing, NE	1,400
82	06799000	Elkhorn River at Norfolk, NE	2,790
83	06799500	Logan Creek near Uehling, NE	1,015
84	06800000	Maple Creek near Nickerson, NE	450
85	06800500	Elkhorn River at Waterloo, NE	6,900
86	06803000	Salt Creek at Roca, NE	167
87	06803500	Salt Creek at Lincoln, NE	685
88	06803555	Salt Creek at Greenwood, NE	1,050
89	06804000	Wahoo Creek at Ithaca, NE	273
90	06806500	Weeping Water Creek at Union, NE	241
91	06811500	Little Nemaha River at Auburn, NE	792
92	06814500	North Fork Big Nemaha River at Humboldt, NE	548
93	06815000	Big Nemaha River at Falls City, NE	1,339
94	06821500	Arikaree River at Haigler, NE	1,700
95	06823000	North Fork Rebublican River at Colorado-Nebraska State line	2,370
96	06823500	Buffalo Creek near Haigler, NE	172
97	06824000	Rock Creek at Parks, NE	24
98	06828500	Republican River at Statton, NE	8,200
99	06836500	Driftwood Creek near McCook, NE	361
100	06847500	Beaver Creek near Beaver City, NE	2,080
101	06880800	West Fork Big Blue River near Dorchester, NE	1,192
102	06881000	Big Blue River near Crete, NE	2,710
103	06882000	Big Blue River at Barneston, NE	4,447
104	06883000	Little Blue River near Deweese, NE	979
105	06884000	Little Blue River near Fairbury, NE	2,350

Table 2. Results of trend analyses of annual peak flows in Kansas, Oklahoma, and Nebraska, 1958–97

[Shading indicates statistically significant at the 95-percent level (probability value less than or equal to 0.05). mi^2, square miles; <, less than]

Map index number (fig. 1)	Station number	Station name	Total drainage area (mi^2)	Kendall's tau	Probability value	Increasing (+) or decreasing (-) trend
		Kansas				
1	06814000	Turkey Creek near Seneca, KS	276	0.15	0.180	+
4	06845100	Long Branch Draw near Norcatur, KS	31.7	-.22	.049	-
5	06846500	Beaver Creek at Cedar Bluffs, KS	1,618	-.33	.003	-
6	06847600	Prairie Dog Creek tributary at Colby, KS	7.5	.19	.080	+
7	06853800	White Rock Creek near Burr Oak, KS	2.3	-.02	.860	-
8	06860000	Smoky Hill River at Elkader, KS	3,555	-.15	.180	-
9	06861000	Smoky Hill River near Arnold, KS	5,220	-.41	.002	-
10	06863400	Big Creek tributary near Ogallah, KS	4.8	-.03	.790	-
11	06863500	Big Creek near Hays, KS	594	-.31	.005	-
12	06863700	Big Creek tributary near Hays, KS	6.2	-.22	.050	-
13	06864300	Smoky Hill River tributary at Dorrance, KS	5.4	.16	.150	+
14	06867000	Saline River near Russell, KS	1,502	-.23	.042	-
15	06868300	Coon Creek tributary near Luray, KS	6.5	.00	1.000	+
16	06871000	North Fork Solomon River at Glade, KS	849	-.22	.046	-
17	06871500	Bow Creek near Stockton, KS	341	-.16	.150	-
18	06873000	South Fork Solomon River above Webster Reservoir, KS	1,040	-.21	.055	-
19	06873300	Ash Creek tributary near Stockton, KS	.89	-.01	.970	-
22	06878000	Chapman Creek near Chapman, KS	300	-.10	.360	-
24	06884300	Mill Creek tributary near Washington, KS	3.2	.29	.010	+
25	06884400	Little Blue River near Barnes, KS	3,324	.13	.240	+
26	06885500	Black Vermillion River near Frankfort, KS	410	-.10	.360	-
27	06887200	Cedar Creek near Manhattan, KS	13.4	-.03	.810	-
28	06888500	Mill Creek near Paxico, KS	316	.20	.069	+
30	06889500	Soldier Creek near Topeka, KS	290	.25	.024	+
32	06892000	Stranger Creek near Tonganoxie, KS	406	.02	.843	+
33	06911500	Salt Creek near Lyndon, KS	111	.13	.240	+
34	06914000	Pottawatomie Creek near Garnett, KS	334	-.01	.944	-
35	06917000	Little Osage River at Fulton, KS	295	.25	.023	+
36	06917400	Marmaton River tributary near Fort Scott, KS	2.8	.10	.351	+
37	07138600	White Woman Creek tributary near Selkirk, KS	38	-.16	.150	-
38	07139700	Arkansas River tributary near Dodge City, KS	8.7	-.21	.054	-
39	07141200	Pawnee River at Rozel, KS	2,148	-.22	.046	-
42	07143100	Little Cheyenne Creek tributary near Claflin, KS	1.5	-.27	.016	+
44	07144200	Little Arkansas River at Valley Center, KS	1,327	.01	.960	+
46	07145200	South Fork Ninnescah River near Murdock, KS	650	-.12	.290	-

Table 2. Results of trend analyses of annual peak flows in Kansas, Oklahoma, and Nebraska, 1958–97—Continued

Map index number (fig. 1)	Station number	Station name	Total drainage area (mi^2)	Kendall's tau	Probability value	Increasing (+) or decreasing (-) trend
		Kansas—Continued				
51	07157500	Crooked Creek near Englewood, KS	1,157	-0.48	<0.001	-
52	07166200	Sandy Creek near Yates Center, KS	6.8	-.02	.840	-
53	07167500	Otter Creek at Climax, KS	129	-.05	.641	-
54	07172000	Caney River near Elgin, KS	445	.01	.926	+
55	07180500	Cedar Creek near Cedar Point, KS	110	-.09	.400	-
		Oklahoma				
58	07152000	Chikaskia River near Blackwell, OK	1,859	.02	.870	+
59	07154500	Cimarron River near Kenton, OK	1,106	-.19	.087	-
60	07158000	Cimarron River near Waynoka, OK	13,334	-.31	.005	-
61	07188000	Spring River near Quapaw, OK	2,510	.16	.140	+
62	07189000	Elk River near Tiff City, MO	872	.13	.240	+
63	07191000	Big Cabin Creek near Big Cabin, OK	450	.06	.620	+
64	07195500	Illinois River near Watts, OK	635	.06	.600	+
65	07196500	Illinois River near Tahlequah, OK	959	.11	.330	+
66	07197000	Baron Fork at Eldon, OK	307	.14	.230	+
67	07300500	Salt Fork Red River at Mangum, OK	1,566	-.20	.073	-
68	07311500	Deep Red Creek near Randlett, OK	617	.29	.012	+
69	07332500	Blue River near Blue, OK	476	.16	.160	+
		Nebraska				
70	06463500	Long Pine Creek near Riverview, NE	458	-.06	.620	-
71	06465000	Niobrara River near Spencer, NE	11,070	-.26	.019	-
72	06601000	Omaha Creek at Homer, NE	174	-.15	.180	-
73	06775500	Middle Loup River at Dunning, NE	1,830	.00	1.000	-
74	06784000	South Loup River at St. Michael, NE	2,320	-.14	.220	-
75	06785000	Middle Loup River at St. Paul, NE	8,075	.07	.520	+
76	06786000	North Loup River at Taylor, NE	2,350	.12	.260	+
77	06790500	North Loup River near St. Paul, NE	4,302	.03	.790	+
78	06793000	Loup River near Genoa, NE	14,320	.04	.750	+
79	06794000	Beaver Creek at Genoa, NE	677	-.04	.740	-
80	06795500	Shell Creek near Columbus, NE	294	.08	.500	+
81	06797500	Elkhorn River at Ewing, NE	1,400	.13	.250	+
82	06799000	Elkhorn River at Norfolk, NE	2,790	.12	.270	+
83	06799500	Logan Creek near Uehling, NE	1,015	.06	.610	+
84	06800000	Maple Creek near Nickerson, NE	450	.16	.120	+
85	06800500	Elkhorn River at Waterloo, NE	6,900	.09	.440	+
86	06803000	Salt Creek at Roca, NE	167	-.03	.820	-
87	06803500	Salt Creek at Lincoln, NE	685	.04	.730	+
88	06803555	Salt Creek at Greenwood, NE	1,050	.07	.520	+
89	06804000	Wahoo Creek at Ithaca, NE	273	-.08	.470	-

Table 2. Results of trend analyses of annual peak flows in Kansas, Oklahoma, and Nebraska, 1958–97—Continued

Map index number (fig. 1)	Station number	Station name	Total drainage area (mi^2)	Kendall's tau	Probability value	Increasing (+) or decreasing (-) trend
		Nebraska—Continued				
90	06806500	Weeping Water Creek at Union, NE	241	0.10	0.360	+
91	06811500	Little Nemaha River at Auburn, NE	792	.01	.950	+
92	06814500	North Fork Big Nemaha River at Humboldt, NE	548	-.12	.270	-
93	06815000	Big Nemaha River at Falls City, NE	1,339	-.01	.940	-
94	06821500	Arikaree River at Haigler, NE	1,700	-.45	<.001	-
95	06823000	North Fork Rebublican River at Colorado-Nebraska State line	2,370	-.43	<.001	-
96	06823500	Buffalo Creek near Haigler, NE	172	-.42	<.001	-
97	06824000	Rock Creek at Parks, NE	24	-.11	.340	-
98	06828500	Republican River at Statton, NE	8,200	-.41	<.001	-
99	06836500	Driftwood Creek near McCook, NE	361	-.37	.001	-
100	06847500	Beaver Creek near Beaver City, NE	2,080	-.30	.007	-
101	06880800	West Fork Big Blue River near Dorchester, NE	1,192	.16	.140	+
102	06881000	Big Blue River near Crete, NE	2,710	.10	.370	+
103	06882000	Big Blue River at Barneston, NE	4,447	.28	.810	+
104	06883000	Little Blue River near Deweese, NE	979	-.20	.410	-
105	06884000	Little Blue River near Fairbury, NE	2,350	.01	.410	+
		Summary of significant trends	**Increasing trends**	**5 percent**		
			Decreasing trends	**20 percent**		
			No trend	**75 percent**		

1950s was severe from 1952 until 1957, and 1993 was an extremely wet year. Therefore, 1958 was chosen as the beginning year and 1997 the ending year for the trend analyses.

The 88 stream-gaging stations whose records were analyzed are distributed fairly well across the three States and are representative of a range of existing conditions in the central Great Plains. Drainage areas of the associated basins vary in size from 0.89 to 14,320 mi^2 (table 2). Land-surface elevations within the three States generally slope gently downward from west to east. Relatively flat topography, shallow stream channels, and ephemeral (intermittent) flow generally characterize the western parts of the three States. The eastern parts have hilly topography, deep channels, and perennial (continuous) streamflow.

Mean annual precipitation ranges from 16 in. in western Nebraska to 56 in. in southeastern Oklahoma (National Oceanic and Atmospheric Administration, 1979). Most of the precipitation is produced by summer thunderstorms, and the quantity is variable, both spatially and temporally (Paulson and others, 1991). Land is used primarily for crop production and livestock grazing, with scattered industrial uses near urbanized areas.

The Kendall's tau analysis of annual peak flow for the 88 stream-gaging stations in Kansas, Oklahoma, and Nebraska indicated both increasing and decreasing trends in peak flows across the three States during the 40-year period (table 2). Some individual station records showed significant trends, and slight regional trends in peak flows occurred as well (fig. 2). Of the

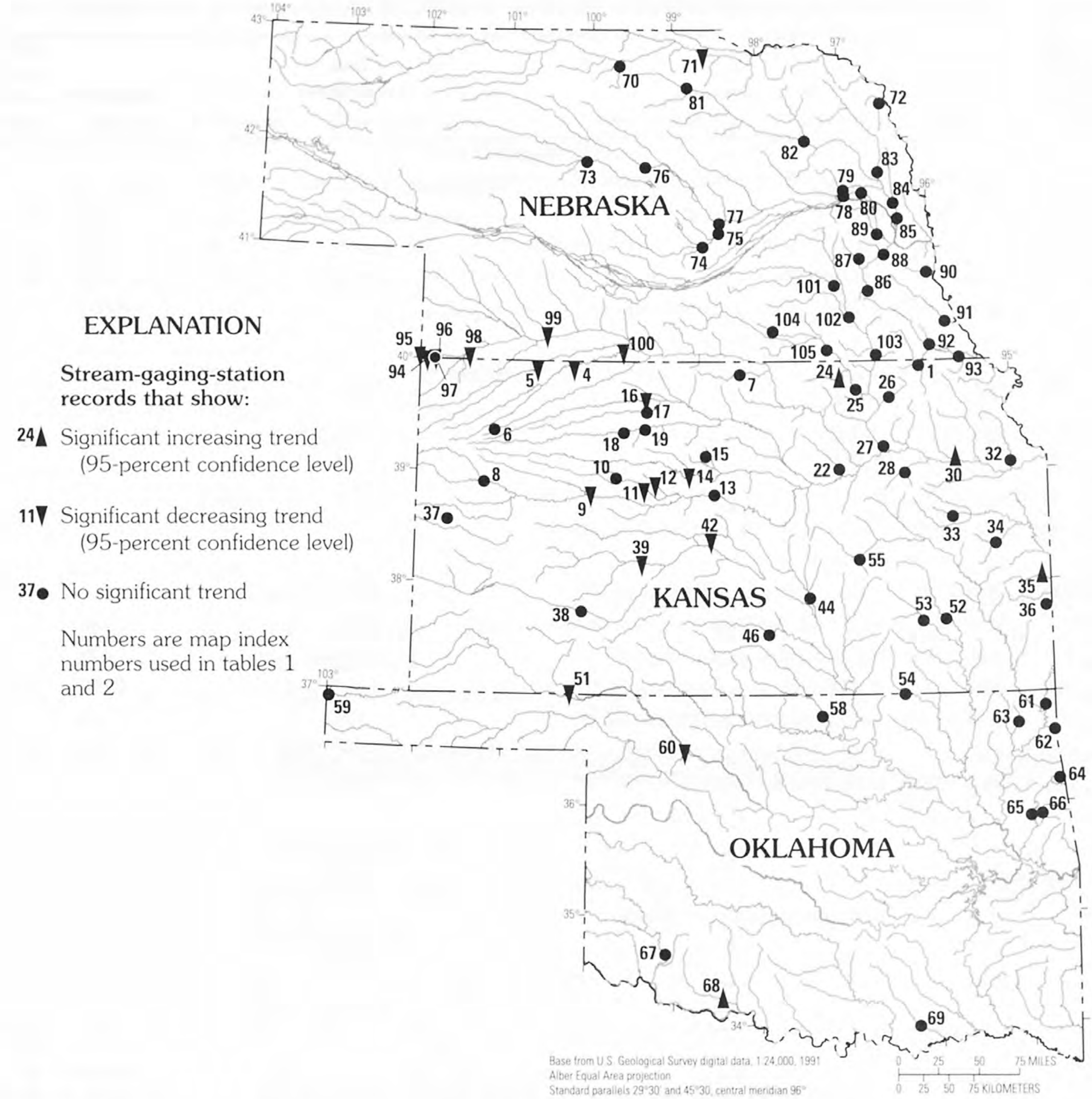


Figure 2. Results of Kendall's tau trend analysis for annual peak flows at selected stream-gaging stations in Kansas, Oklahoma, and Nebraska, 1958–97.

88 sets of records analyzed for trends in peak flow, 22 sets (25 percent) exhibited a trend at the 95-percent confidence level. Records from 4 stream-gaging stations indicated statistically significant increasing trends in peak flows, whereas records from 18 stations indicated statistically significant decreasing trends (table 2). The records with increasing trends were from gaging stations scattered in the eastern or southern part of the three-State area, whereas the decreasing-trend stations were all located in the western or northern part, particularly western Kansas and southwestern Nebraska. Considering only stream-gaging-station records in Kansas, 13 of the 40 peak-flow station records analyzed (32 percent) showed a significant trend. Of the 13 station records that showed a significant trend, 10 indicated decreasing trends occurring in the western one-half of the State, whereas the 3 increasing-trend stations were located in eastern Kansas (see fig. 2).

As the period of record is adjusted, so is the trend test result. The Kendall's tau test also was used to identify trends over the entire available record for 54 stations in Kansas with a record length of more than 38 years (table 3). Some years were missing from

Table 3. Results of Kendall's tau trend analysis of annual peak flows for all Kansas stream-gaging stations with more than 38 years of record

[Shading indicates statistically significant at the 95-percent confidence level (probability value less than or equal to 0.05). (ft^3/s)/yr, cubic feet per second per year; <, less than]

Map index number (fig. 4)	Station number	Station name	Start-end years	Number of years used	Number of years missing	Kendall's tau	Probability value	Slope [(ft^3/s)/yr]
1	06814000	Turkey Creek near Seneca	1949–98	50	0	0.193	0.048	100
2	06815700	Buttermilk Creek near Willis	1957–97	40	1	-.251	.023	-36.5
3	06844900	South Fork Sappa Creek near Achilles	1960–98	39	0	-.055	.628	-3.48
4	06845100	Long Branch Draw near Norcatur	1957–98	42	0	-.243	.024	-8.83
5	06846500	Beaver Creek at Cedar Bluffs	1946–98	53	1	-.267	.005	-7.27
6	06847600	Prairie Dog Creek tributary at Colby	1957–97	41	0	.145	.185	4.44
7	06853800	White Rock Creek near Burr Oak	1950–98	41	8	-.017	.884	-3.81
8	06860000	Smoky Hill River at Elkader	1938–98	60	1	-.212	.017	-33.3
9	06861000	Smoky Hill River near Arnold	1938–98	52	9	-.394	<.001	-131
10	06863400	Big Creek tributary near Ogallah	1957–98	42	0	-.048	.664	-1.09
11	06863500	Big Creek near Hays	1947–98	52	0	-.236	.014	-31
12	06863700	Big Creek tributary near Hays	1957–98	40	1	-.146	.187	-1.29
13	06864300	Smoky Hill River tributary at Dorrance	1957–98	42	0	.182	.091	5.82
14	06867000	Saline River near Russell	1946–98	48	5	-.241	.016	-73
15	06868300	Coon Creek tributary near Luray	1957–98	42	0	-.045	.680	-2
16	06871000	North Fork Solomon River at Glade	1953–98	46	0	-.319	.002	-66
17	06871500	Bow Creek near Stockton	1951–98	48	0	-.207	.038	-17.4
18	06873000	South Fork Solomon River above Webster Reservoir	1908–98	56	35	-.416	<.001	-163
19	06873300	Ash Creek tributary near Stockton	1957–98	41	1	.017	.884	0
20	06876700	Salt Creek near Ada	1960–98	39	0	.005	.971	2.31
22	06878000	Chapman Creek near Chapman	1951–98	46	2	.013	.910	5
23	06884200	Mill Creek at Washington	1960–98	39	0	.003	.990	2.73
24	06884300	Mill Creek tributary near Washington	1957–98	42	0	.328	.002	19.2
25	06884400	Little Blue River near Barnes	1958–98	41	0	.141	.196	116
26	06885500	Black Vermillion River near Frankfort	1948–98	46	5	.005	.970	3.75
27	06887200	Cedar Creek near Manhattan	1957–98	42	0	-.023	.837	-1.67
28	06888500	Mill Creek near Paxico	1951–98	46	2	.216	.035	206
29	06889200	Soldier Creek near Delia	1959–98	40	0	.237	.032	60
30	06889500	Soldier Creek near Topeka	1929–98	70	0	.289	<.001	88.7
32	06892000	Stranger Creek near Tonganoxie	1929–98	70	0	.146	.074	49.4
33	06911500	Salt Creek near Lyndon	1940–98	59	0	.038	.676	9.86
34	06914000	Pottawatomie Creek near Garnett	1929–98	60	10	-.04	.655	-24.4
35	06917000	Little Osage River at Fulton	1949–98	50	0	.13	.186	77.9
36	06917400	Marmaton River tributary near Fort Scott	1957–98	42	0	.166	.124	11.5
37	07138600	White Woman Creek tributary near Selkirk	1957–97	40	1	-.167	.132	-1.61

Table 3. Results of Kendall's tau trend analysis of annual peak flows for all Kansas stream-gaging stations with more than 38 years of record—Continued

Map index number (fig. 4)	Station number	Station name	Start-end years	Number of years used	Number of years missing	Kendall's tau	Probability value	Slope [(ft³/s)/yr]
38	07139700	Arkansas River tributary near Dodge City	1957–98	40	2	-0.173	0.118	-3.99
39	07141200	Pawnee River at Rozel	1925–98	74	0	-.203	.011	-18.6
40	07141900	Walnut Creek at Albert	1959–98	40	0	-.323	.003	-48.3
41	07142300	Rattlesnake Creek near Macksville	1960–98	39	0	-.031	.790	-1.08
42	07143100	Little Cheyenne Creek tributary near Claflin	1957–98	42	0	-.271	.012	-2.45
43	07143300	Cow Creek near Lyons	1929–98	54	16	-.097	.303	-12.1
44	07144200	Little Arkansas River at Valley Center	1916–98	81	2	.169	.025	58.3
[1]45	07144300	Arkansas River at Wichita	1898–1998	101	0	.183	.007	65
46	07145200	South Fork Ninnescah River near Murdock	1951–98	48	0	-.027	.797	-12.3
47	07145700	Slate Creek at Wellington	1960–98	39	0	-.004	.981	-1.05
48	07149000	Medicine Lodge River near Kiowa	1938–98	61	0	-.234	.013	-61.7
49	07151500	Chikaskia River near Corbin	1923–98	40	36	-.047	.675	-29.1
50	07156700	Cimarron River tributary near Satanta	1957–97	41	0	-.239	.028	-5.91
51	07157500	Crooked Creek near Englewood	1943–98	56	0	-.506	<.001	-59.2
52	07166200	Sandy Creek near Yates Center	1957–98	42	0	-.045	.680	-6
53	07167500	Otter Creek at Climax	1947–98	51	1	.045	.649	22.9
54	07172000	Caney River near Elgin	1939–98	60	0	.024	.794	16.8
55	07180500	Cedar Creek near Cedar Point	1939–98	60	0	-.006	.949	-2.15
57	07184000	Lightning Creek near McCune	1938–98	48	13	.123	.220	47.7

[1]Peak flows at the station are partially regulated by John Martin Reservoir in southeastern Colorado.

the peak-flow series. However, a few missing values within the series has little effect on the test outcome (Helsel and Hirsch, 1992). Of the 54 stations used, 23 station records showed significant trends over their entire record. Sixteen station records had decreasing trends (negative tau and slope), and seven records had increasing trends (positive tau and slope) (fig. 3). Four of the Kansas stations (06889500, 06892000, 07141200, and 07144200; map index numbers 30, 32, 39, and 44) had peak-flow data dating back to at least 1930. Two of these four records showed significant trends, one increasing (station 06889500, map index number 30) and the other decreasing (station 07141200, map index number 39) when tested over the 40-year period of record (table 2). Trends for the same two stations proved significant over the longer period of record as well. When the other two longer records were tested, they too showed significant trends, both increasing; however, these two increasing trends were not evident in the 40-year period (fig. 4 and table 2). Graphs showing annual peak flows and 10-year moving averages (with the value of the 10-year average plotted at the middle of the 10-year period) for each of the 54 peak-flow records are given in figures 5(*A*) through 5(*BBB*).

Table 4 shows results of a trend test on records from each of the 54 stream-gaging stations in Kansas using a 30-year period that moves in 5-year increments through the available periods of record. From this table, it is possible to identify time periods within each station record when peak-flow trends were occurring. For example, Crooked Creek near Englewood (07157500, map index number 51) showed a decreasing trend throughout its record. Pawnee River at Rozel (07141200, map index number 39) showed a variable pattern with an increasing trend from 1926–55, then shifted to a decreasing trend from 1956–85. Table 4 also shows time periods when trends were more geo-

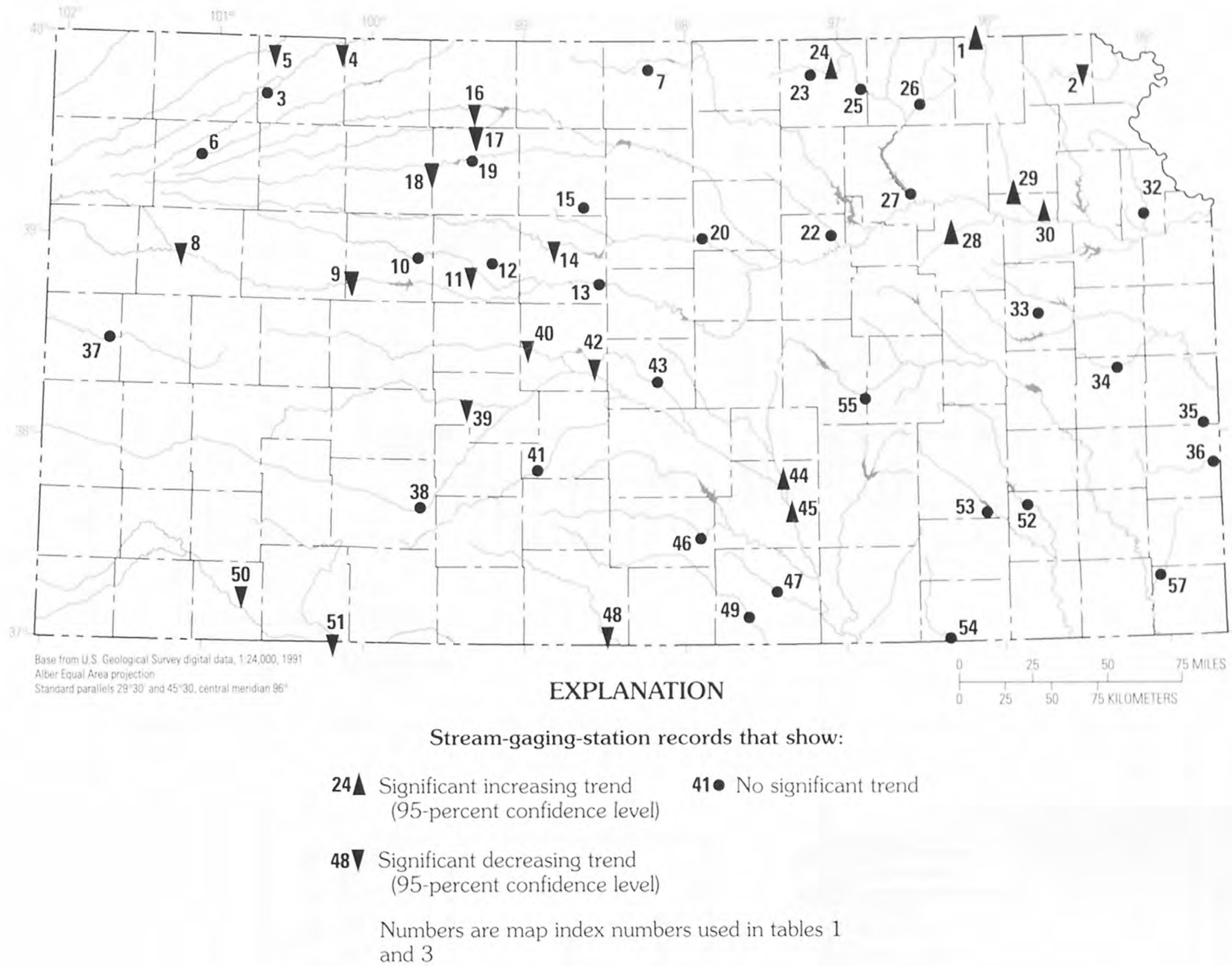


Figure 3. Results of Kendall's tau trend analysis using entire period of record for annual peak flows for all Kansas stream-gaging stations with more than 38 years of record.

graphically widespread, such as 1956–85 when 9 of 28 station records were experiencing decreasing trends.

The Marmaton River in southeast Kansas was not included in the trend analyses because the period of record for any one stream-gaging station was not completely within the 1958–97 time period. Although the Marmaton River has been gaged since the 1920s, the stream-gaging station was relocated from Fort Scott to near Marmaton, dividing the 40-year period from 1958–97 into two records. When both station records were combined and adjustments made for the difference in drainage-basin area, the Marmaton River data showed a statistically significant increasing trend in peak streamflow.

Flow Volume

In addition to the peak-flow analysis, flow volume in Kansas was analyzed for trends using mean annual discharge for 29 stream-gaging stations. Mean annual discharge is the average of the individual daily mean discharge values. Fewer stream-gaging stations were studied in this part of the analysis than for the peak-flow analysis because some of the stations had only partial records of daily mean discharge. Regulated streams were not used in the peak-flow analysis because dams and diversions significantly altered peak flows on regulated streams. However, records from four regulated stream-gaging stations with large drainage basins were used in the analysis of flow volumes. Losses from lake evaporation and diversions were not

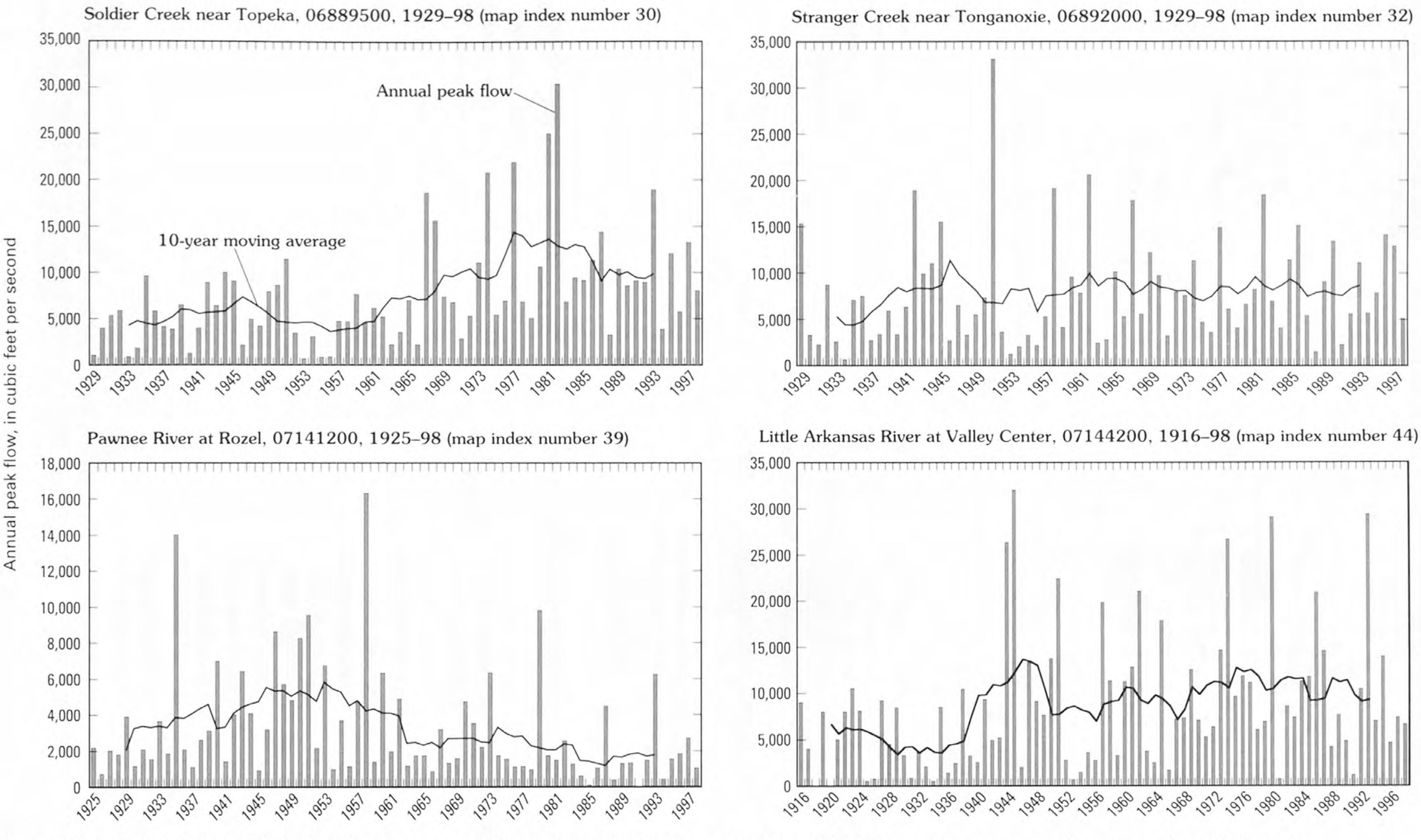


Figure 4. Annual peak-flow records for four Kansas stream-gaging stations with significant trends from 1930–97. Location of stream-gaging stations shown in figure 3.

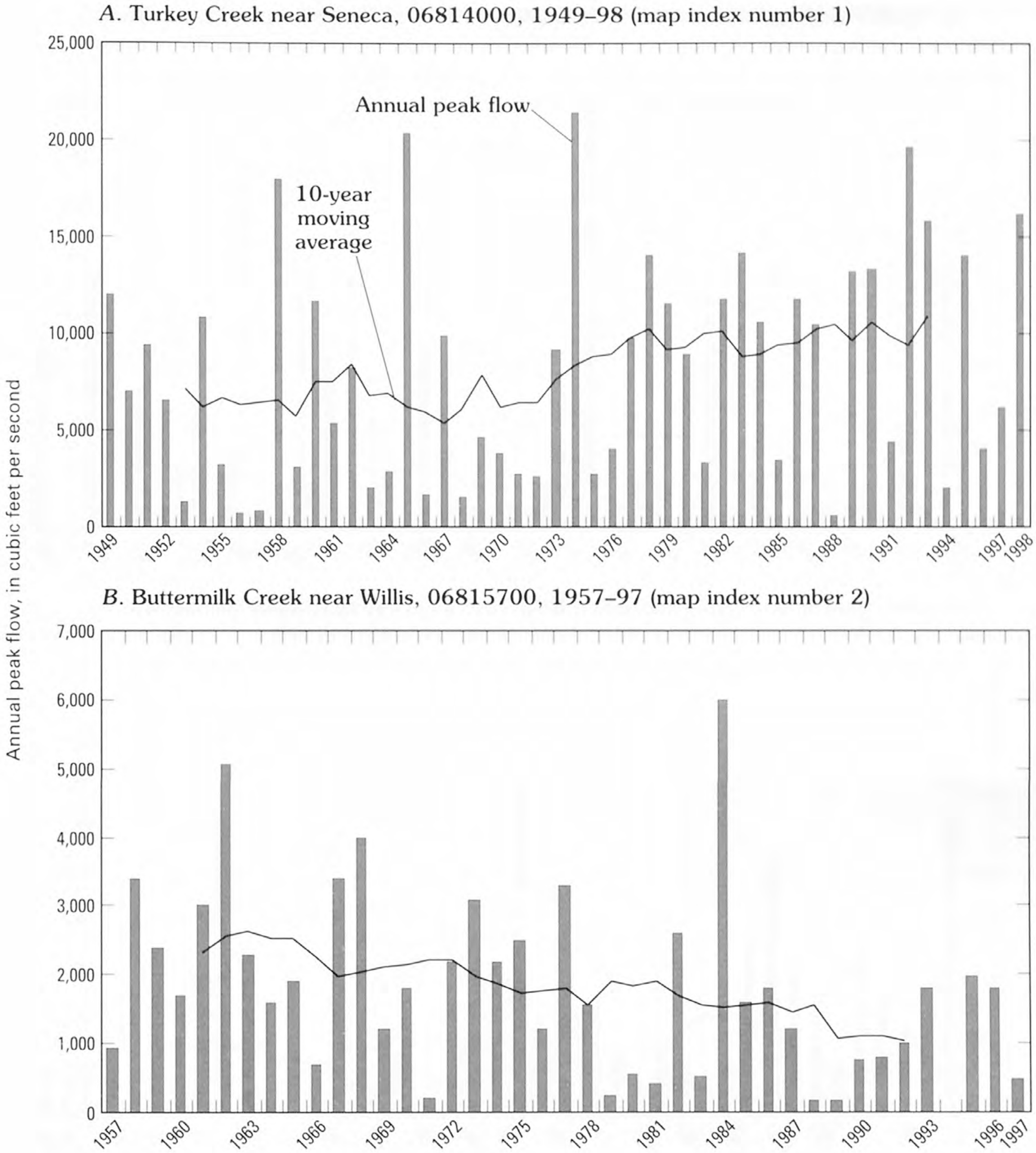


Figure 5 *(A–B)*. Annual peak flows and 10-year moving averages using available periods of record. Location of stations shown in figure 3.

C. South Fork Sappa Creek near Achilles, 06844900, 1960–98 (map index number 3)

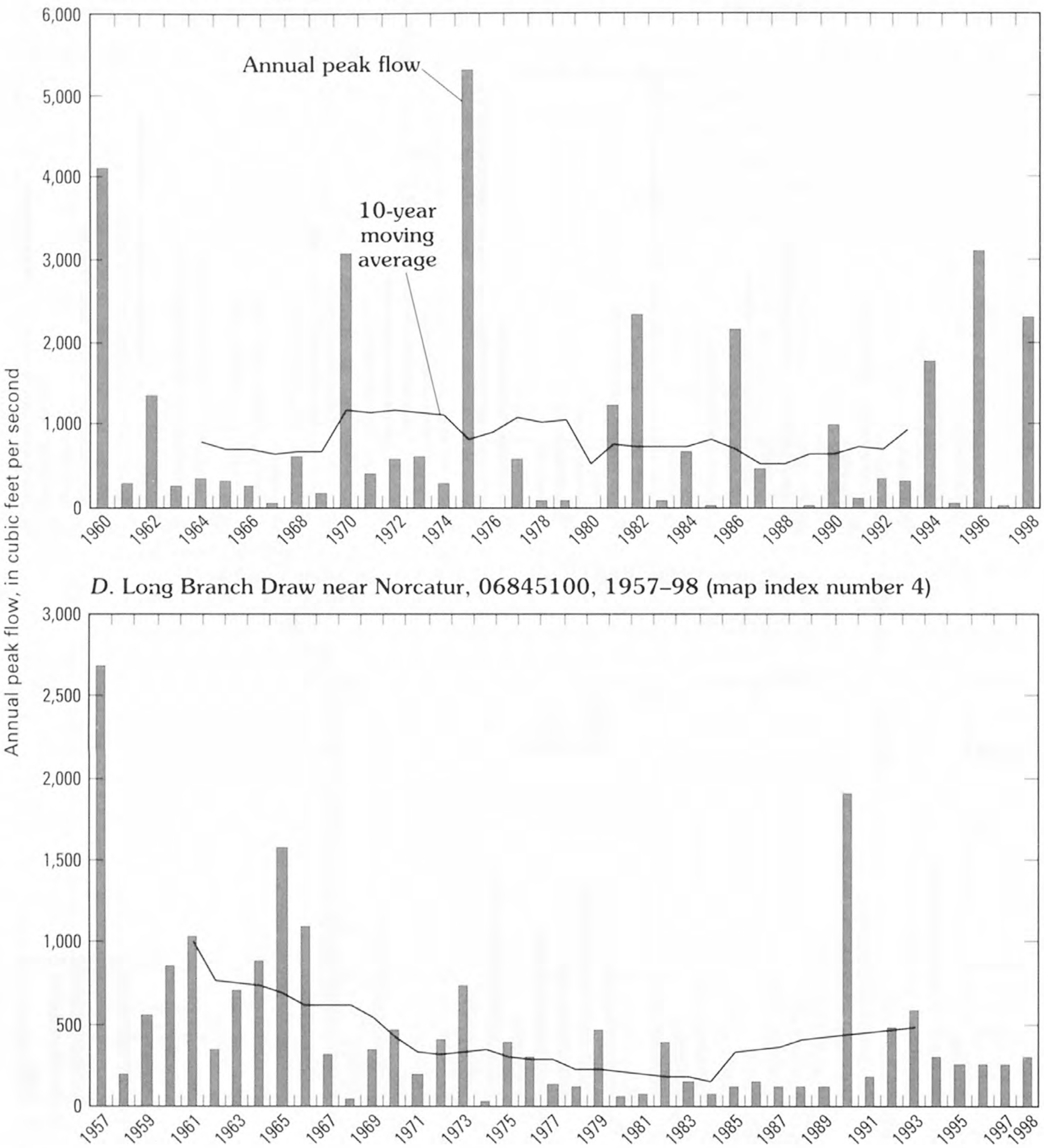


Figure 5 ***(C–D).*** **Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.**

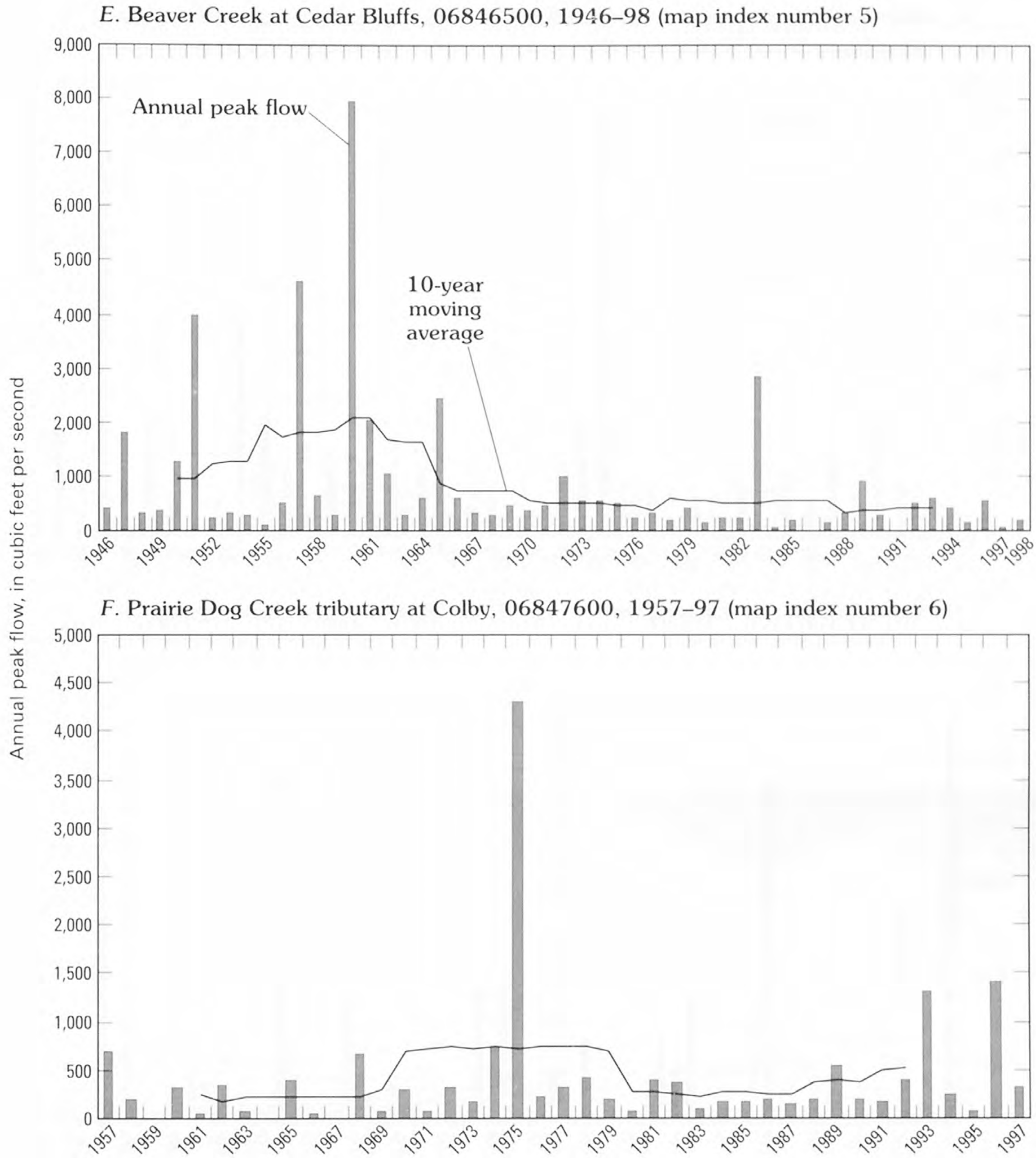


Figure 5 ***(E–F).*** **Annual peak flows and 10-year moving averages using available periods of record–Continued. Location of stations shown in figure 3.**

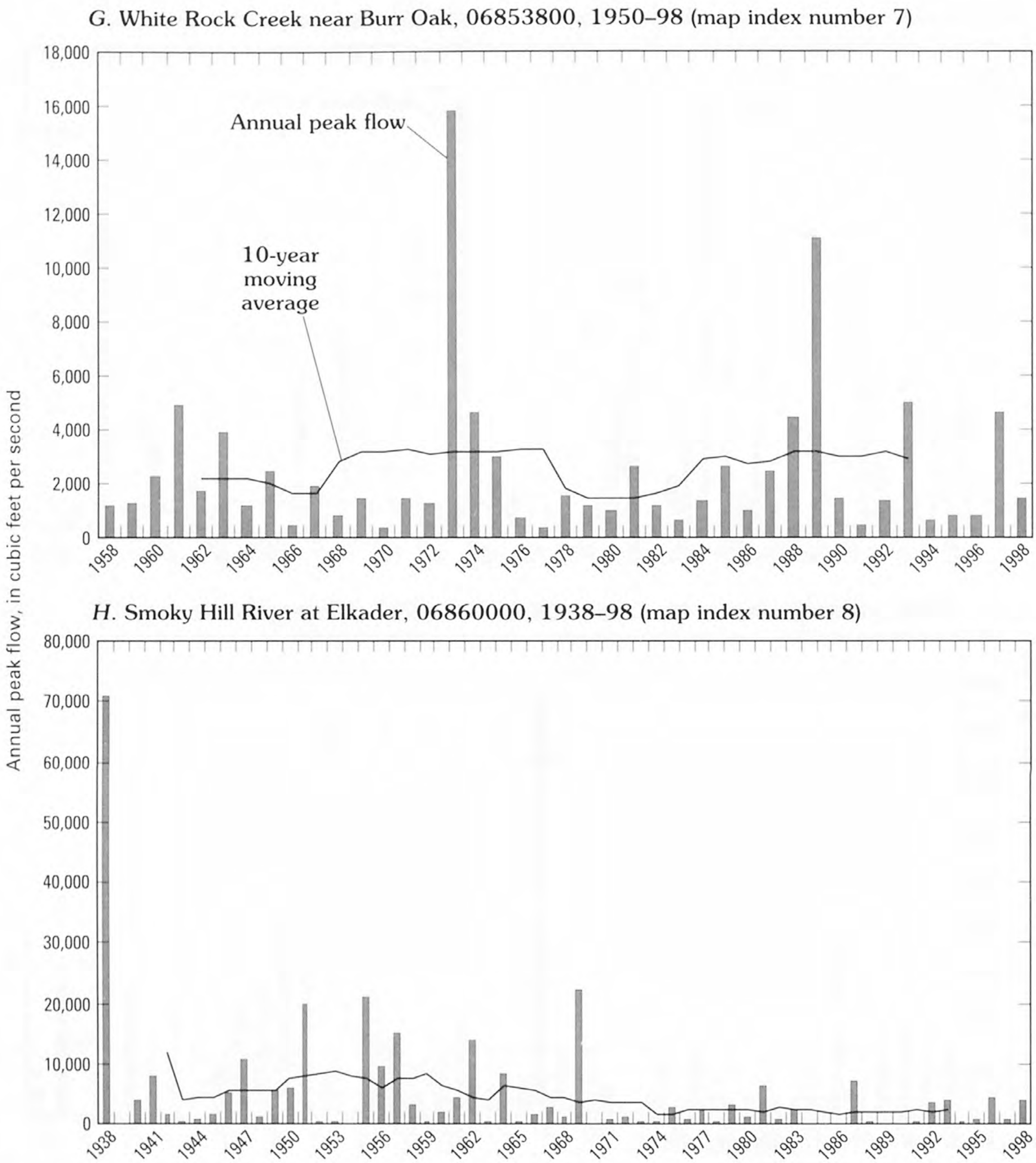
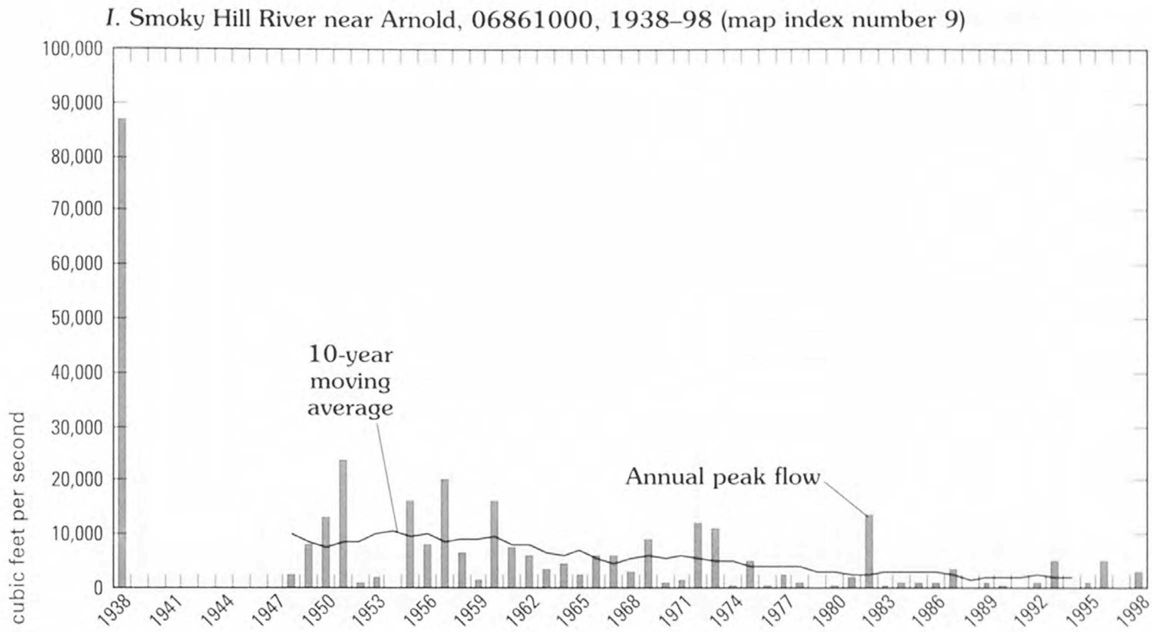


Figure 5 ***(G–H).*** **Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.**



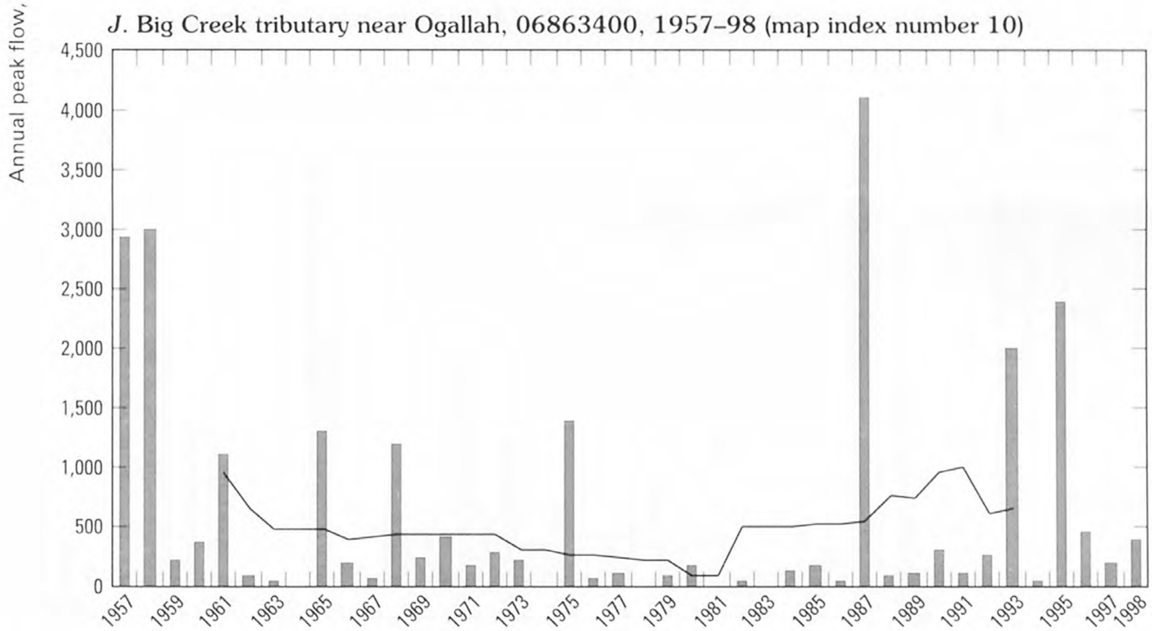


Figure 5 ***(I–J).*** **Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.**

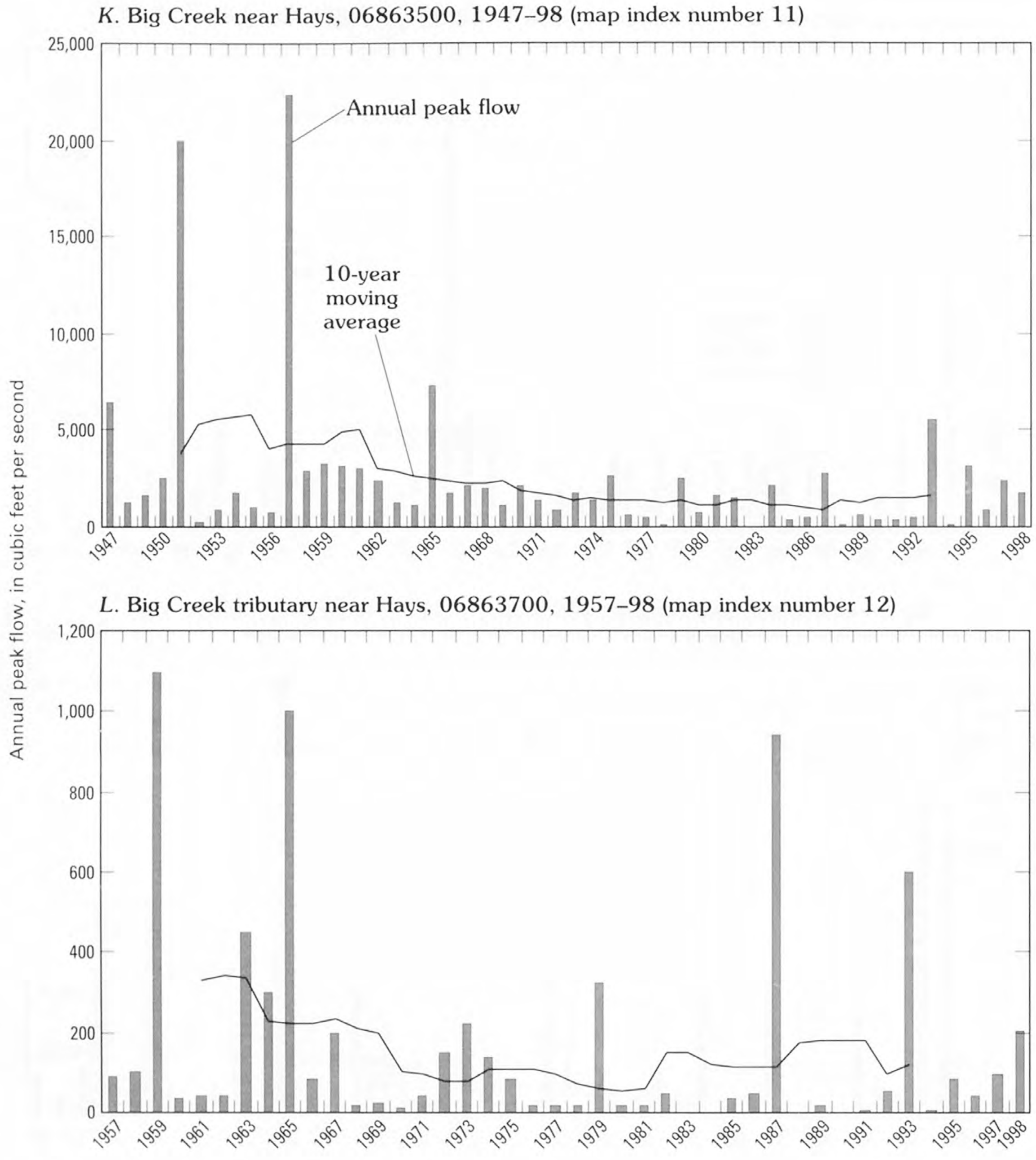


Figure 5 ***(K–L).*** **Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.**

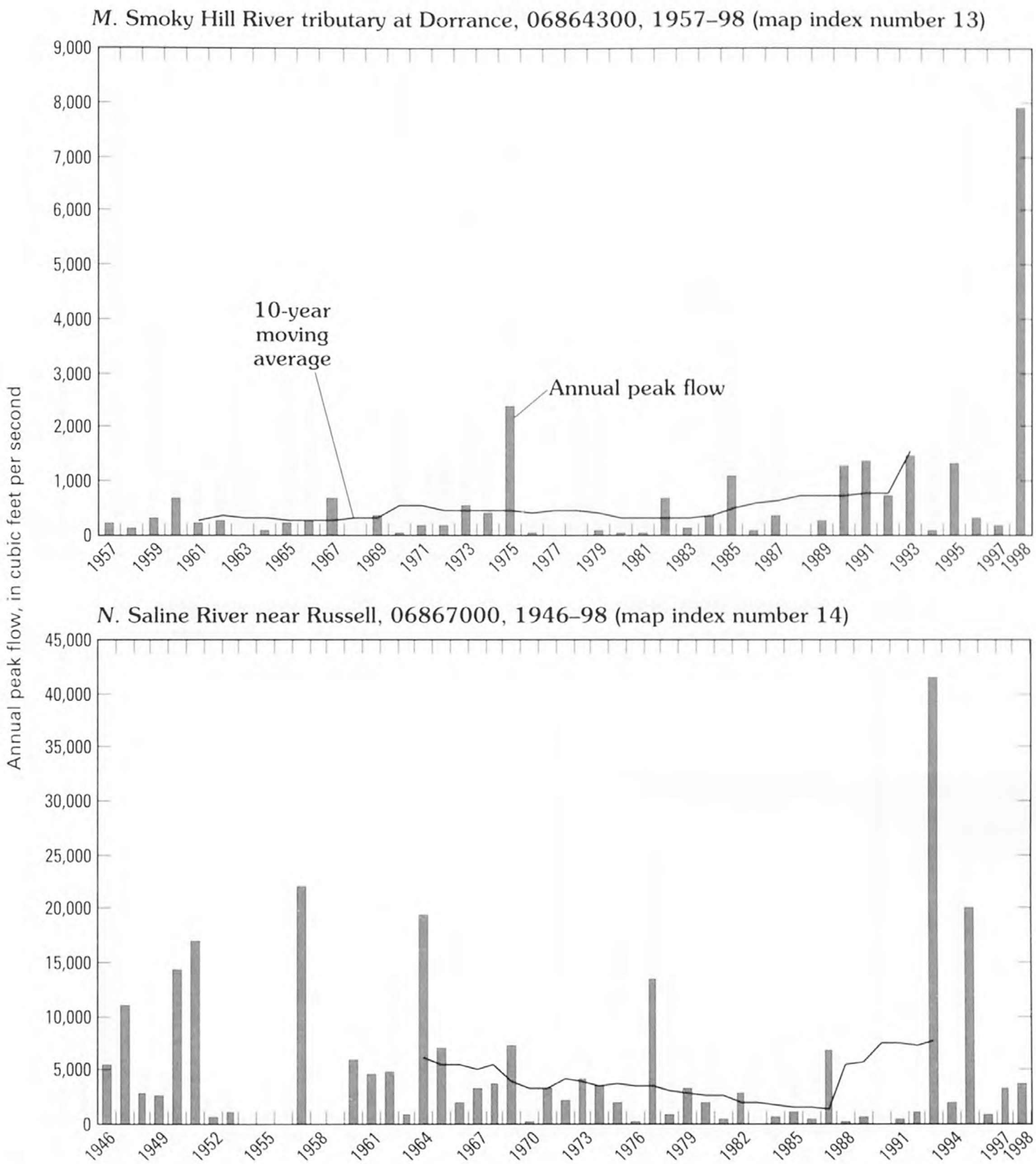
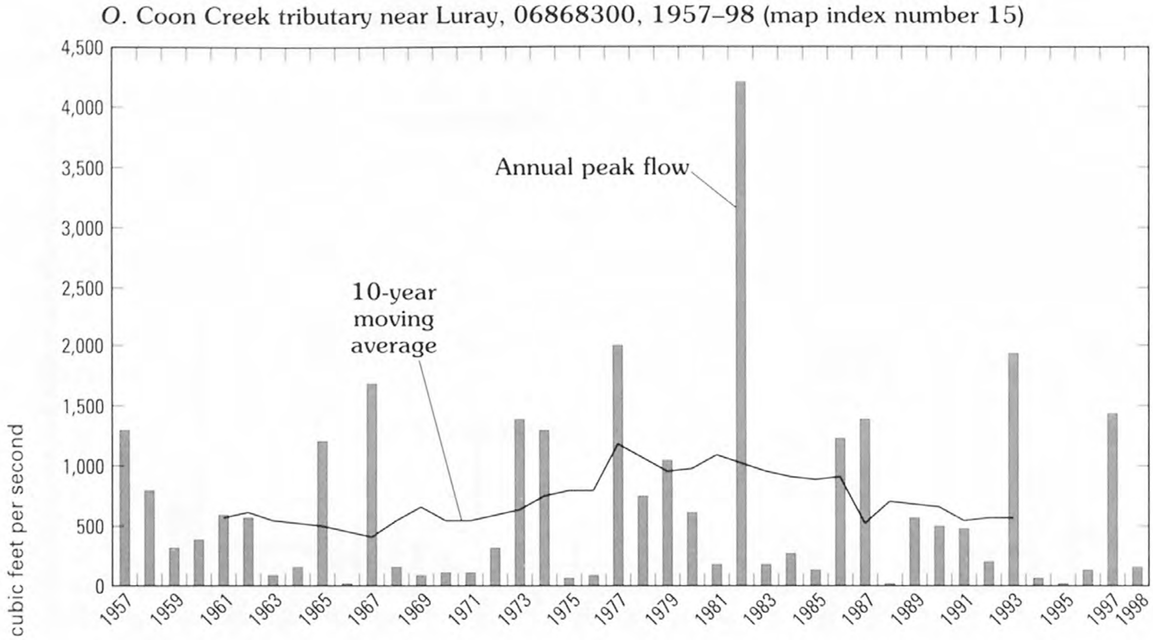


Figure 5 *(M–N).* Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.



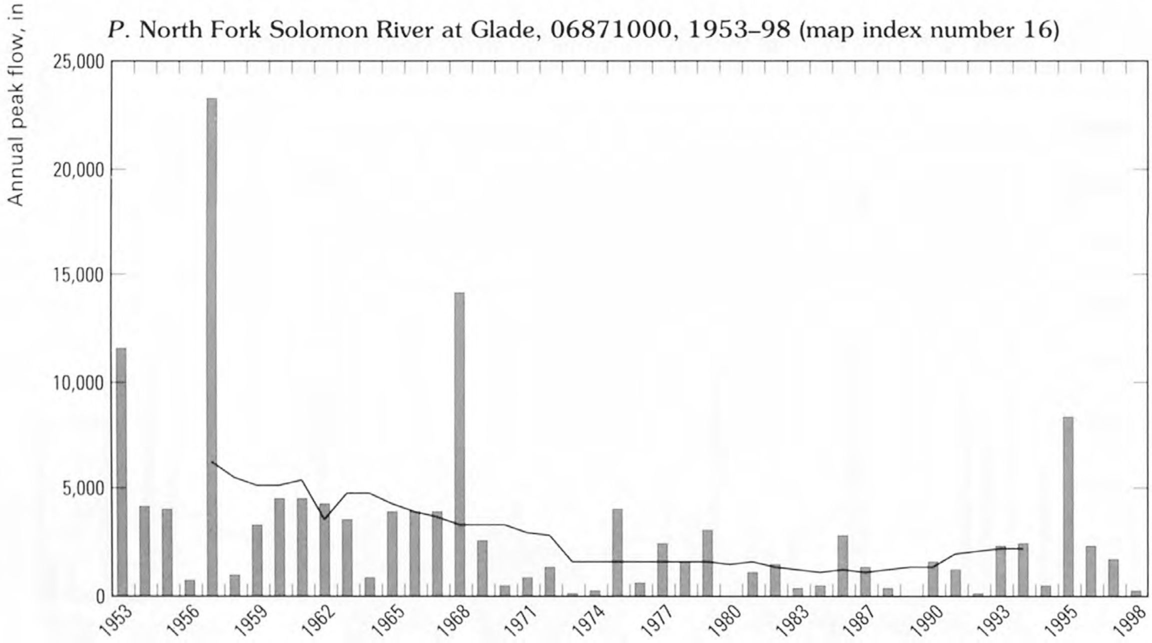
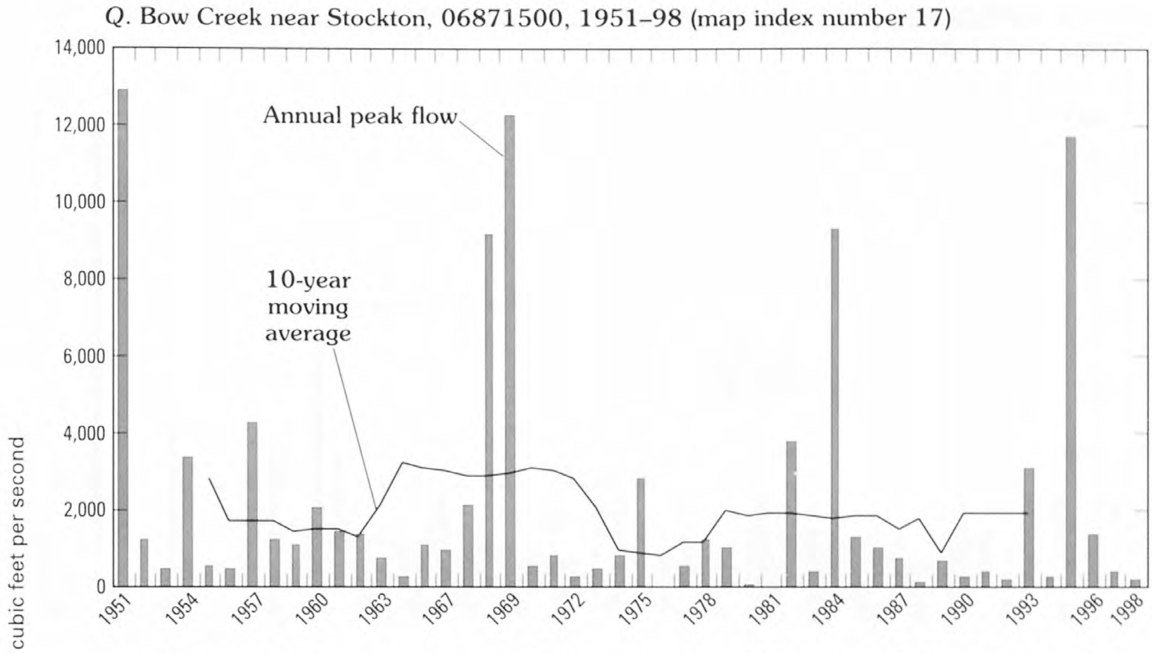


Figure 5 *(O–P)*. **Annual peak flows and 10-year moving averages using available periods of record–Continued. Location of stations shown in figure 3.**



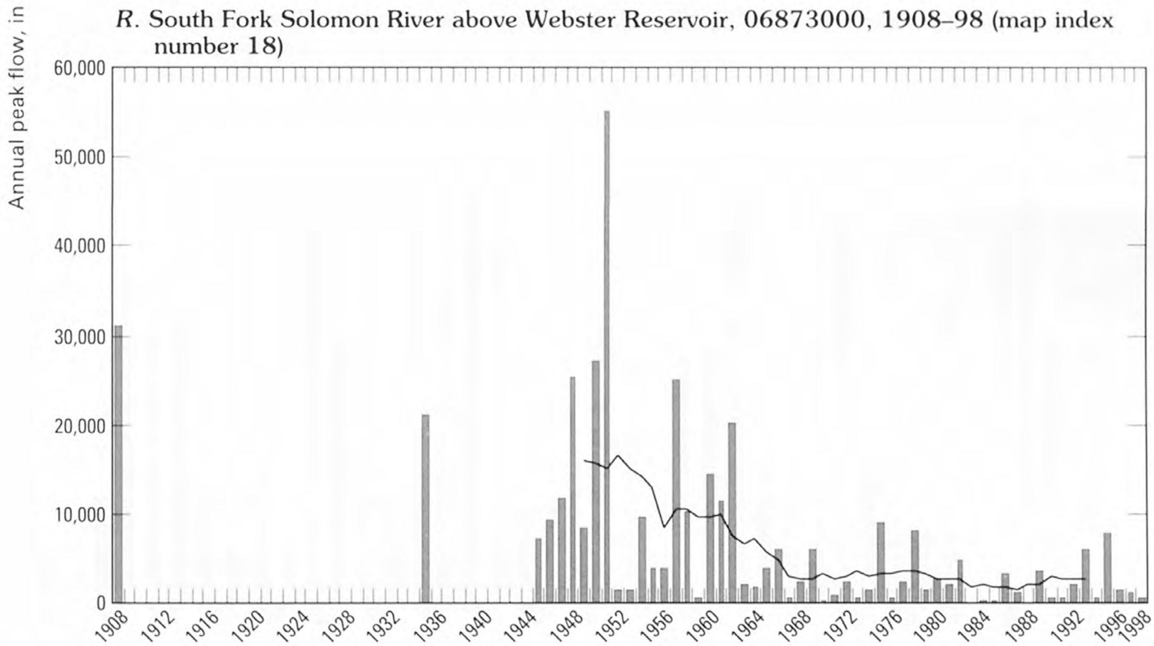


Figure 5 *(Q–R)*. Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.

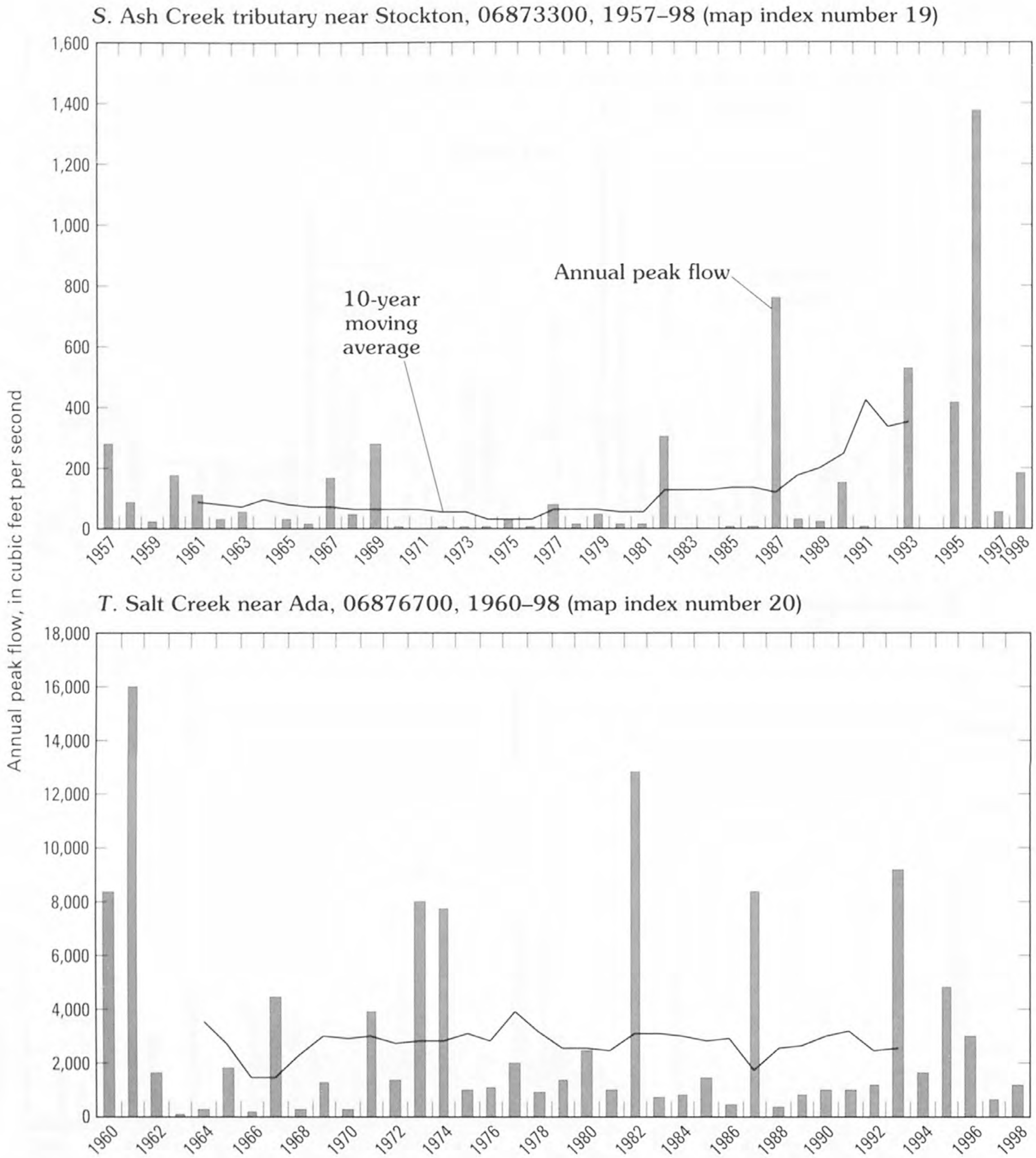


Figure 5 ***(S–T).*** **Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.**

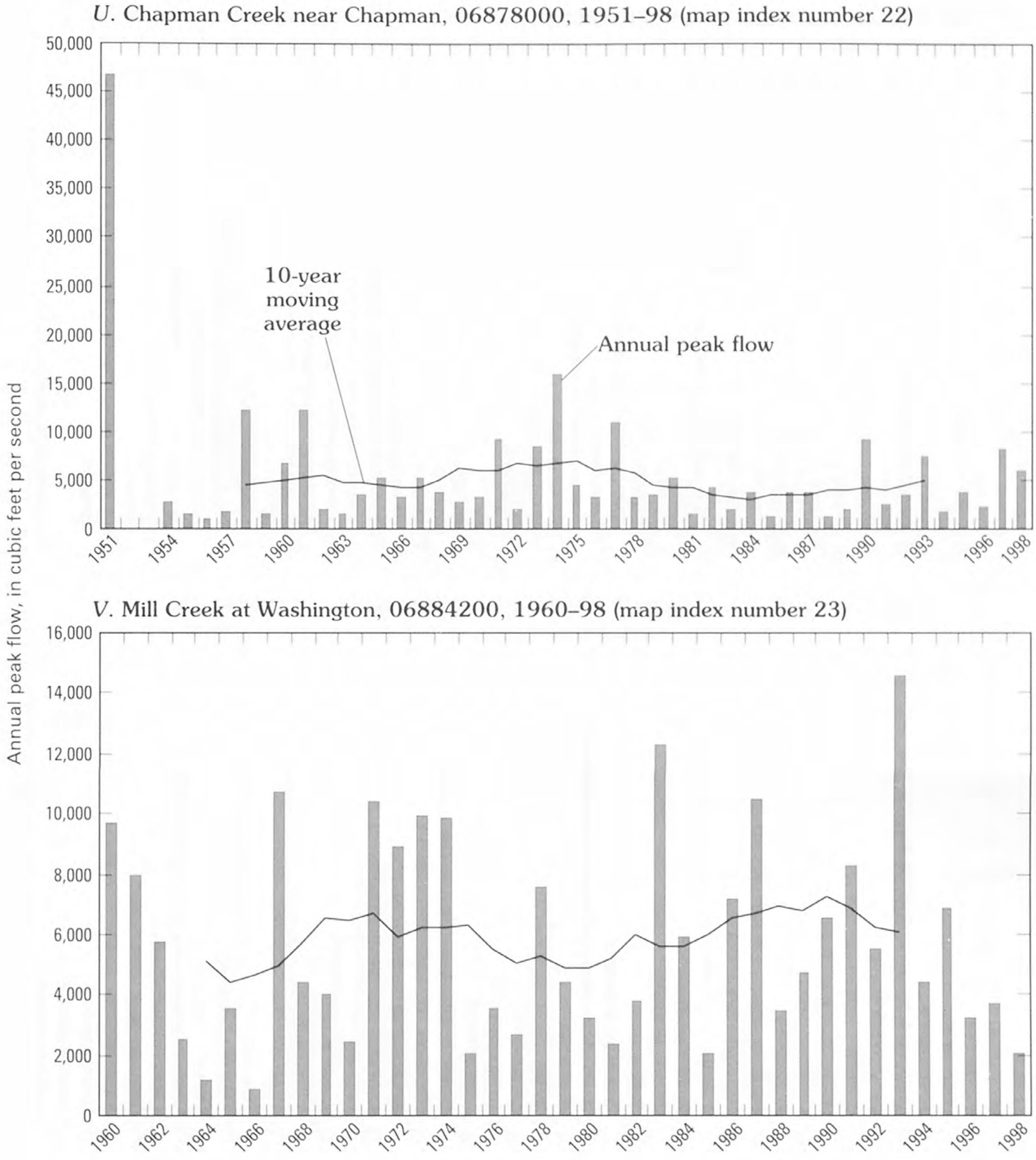


Figure 5 *(U–V)*. Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.

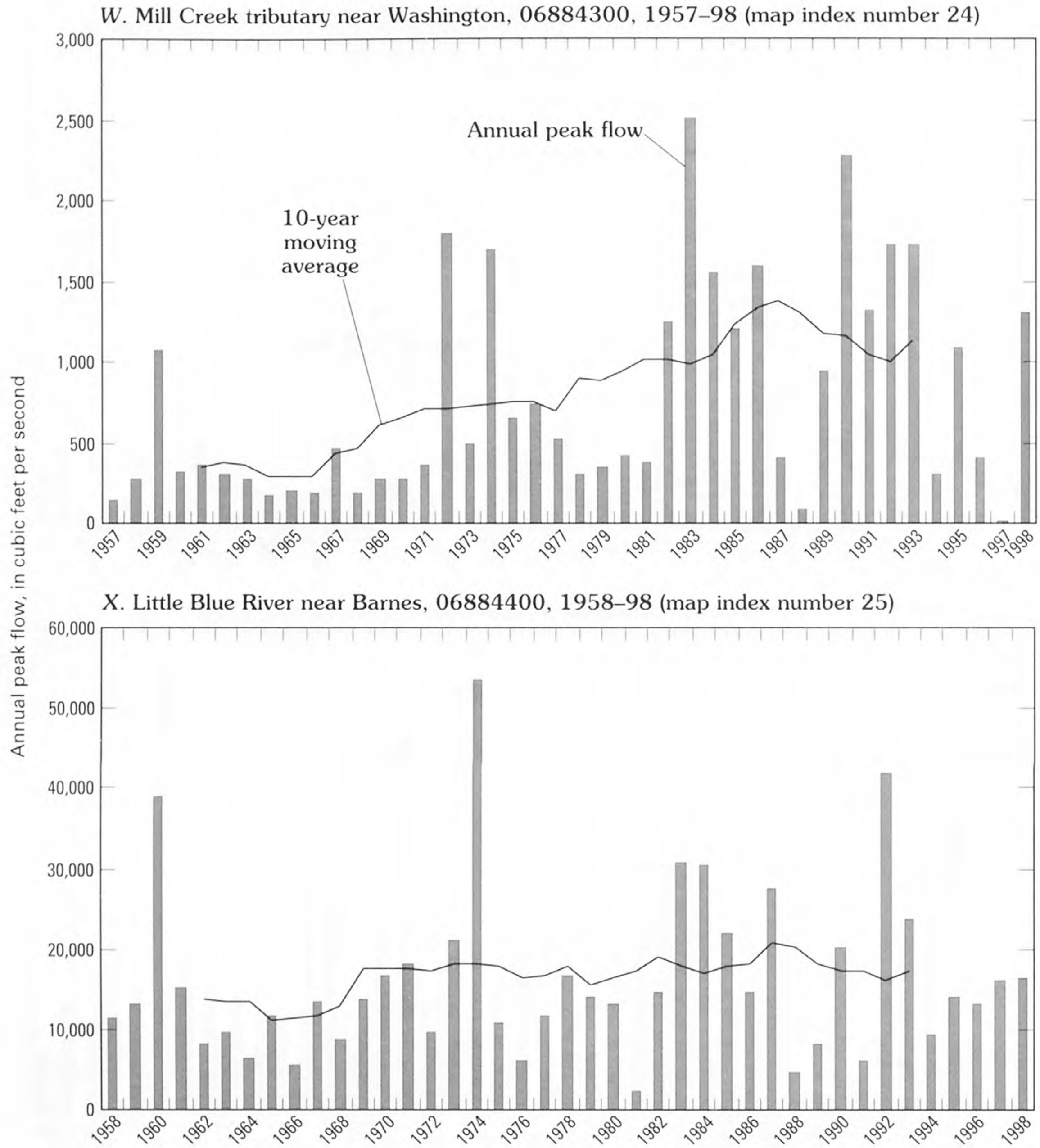


Figure 5 *(W–X)*. **Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.**

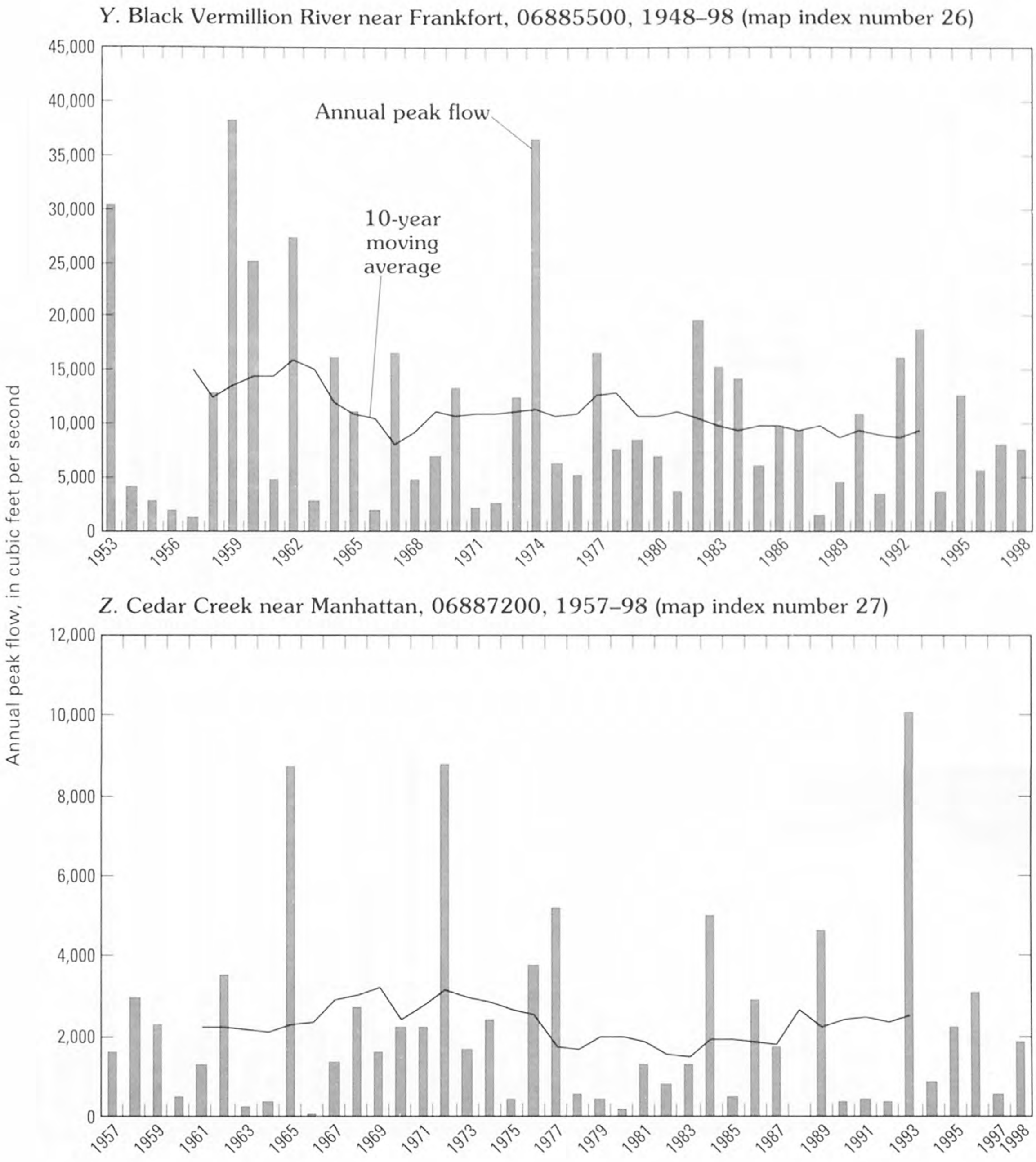


Figure 5 *(Y–Z)*. Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.

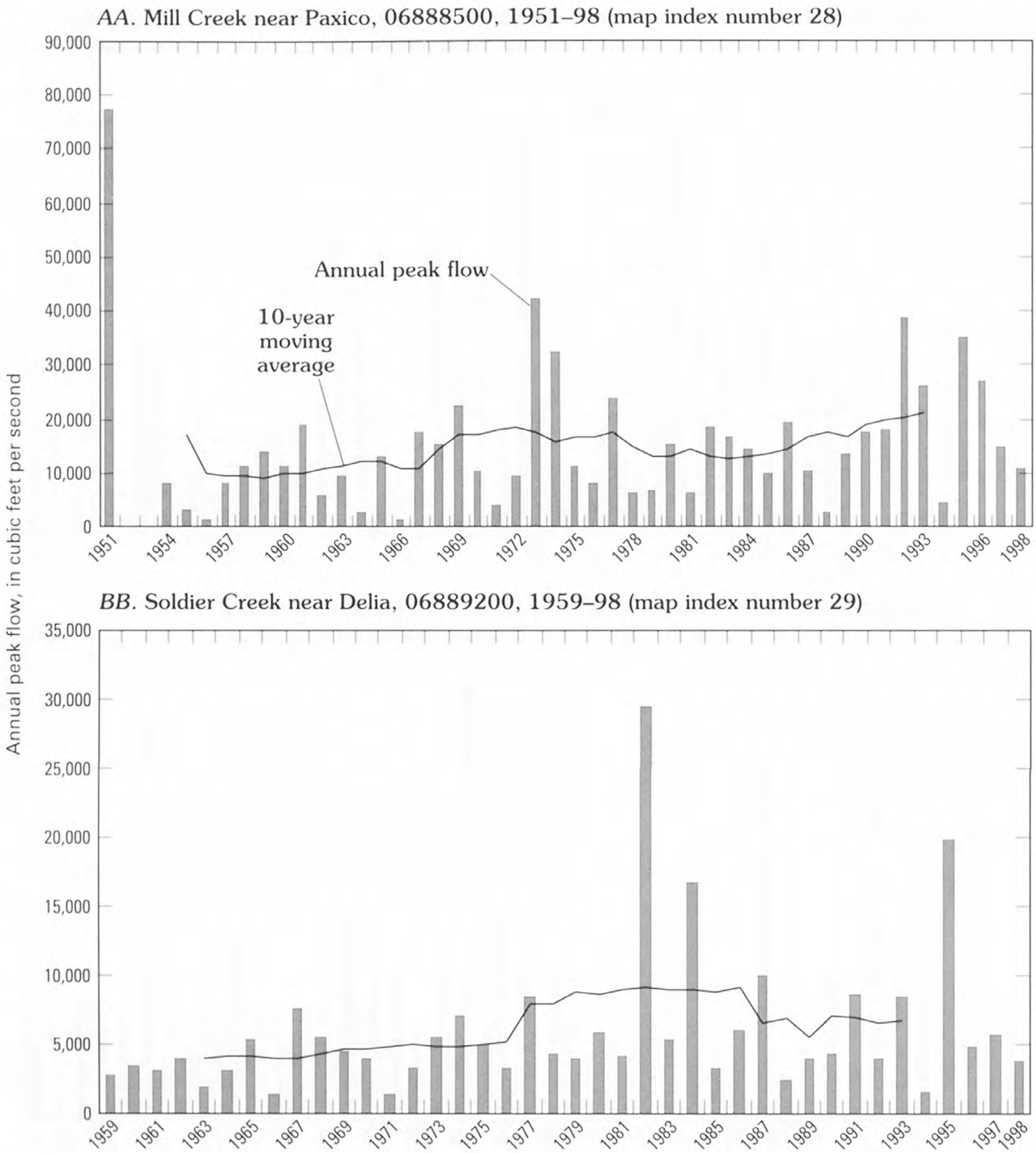


Figure 5 *(AA–BB)*. Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.

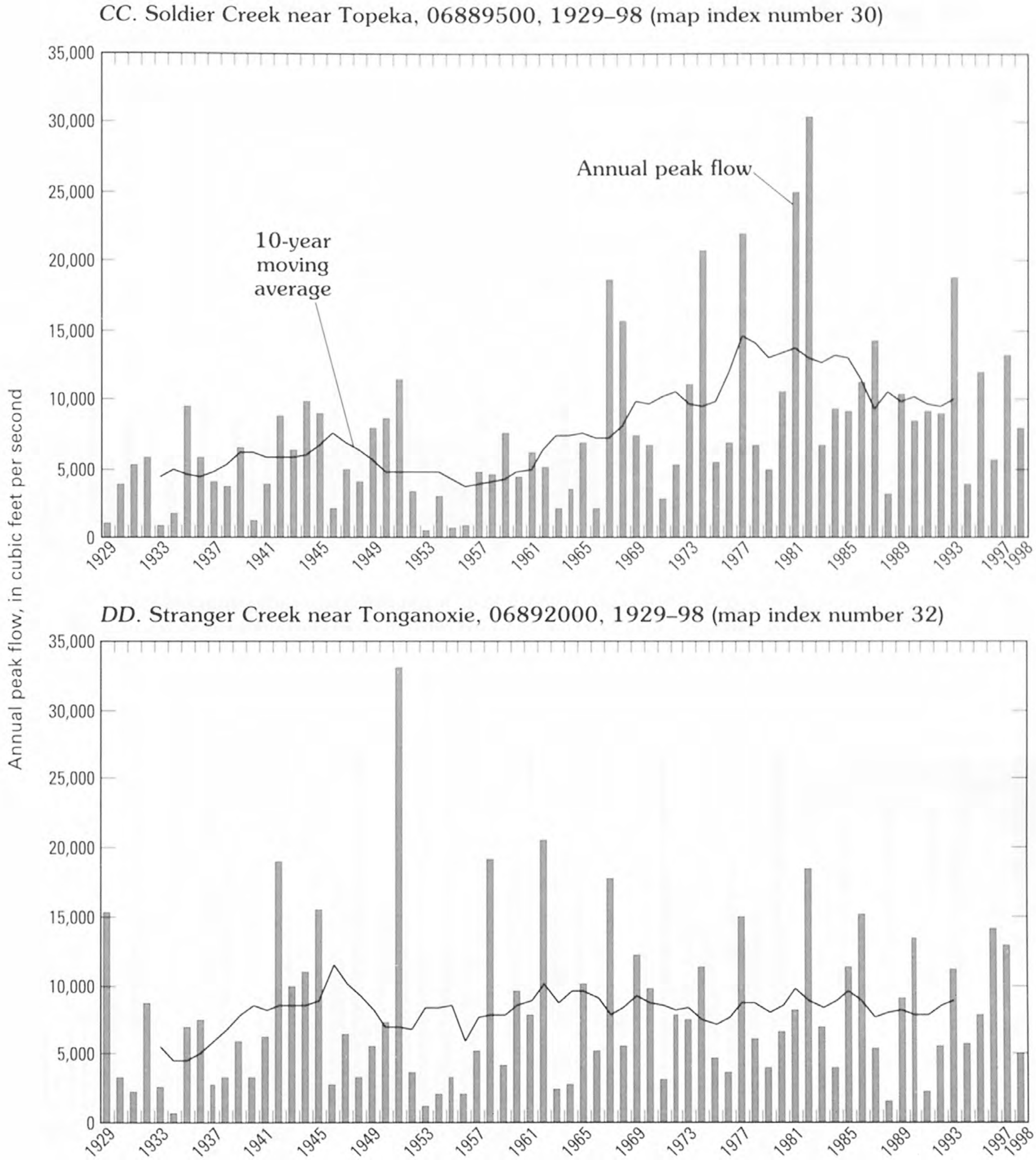


Figure 5 ***(CC–DD).*** **Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.**

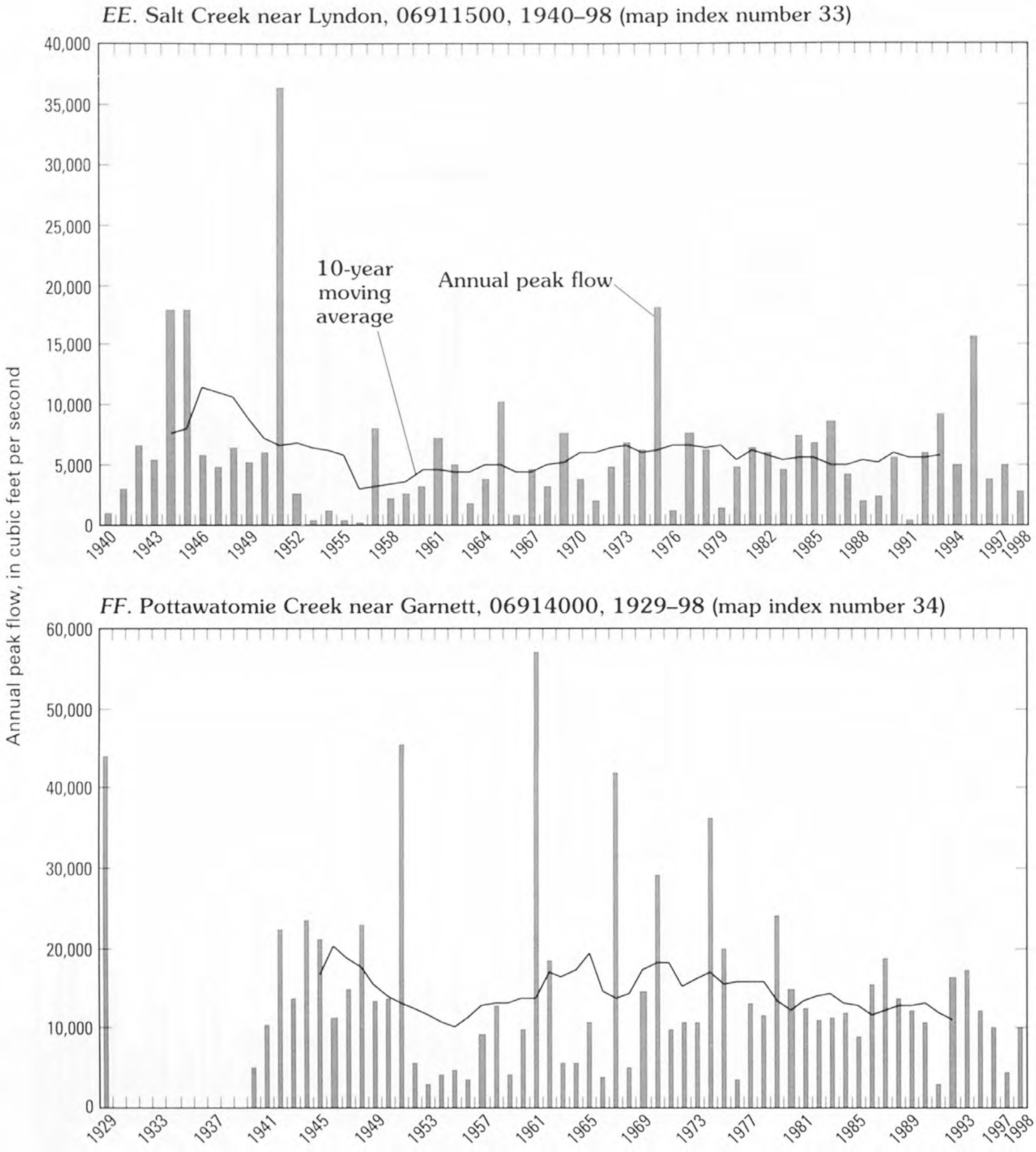
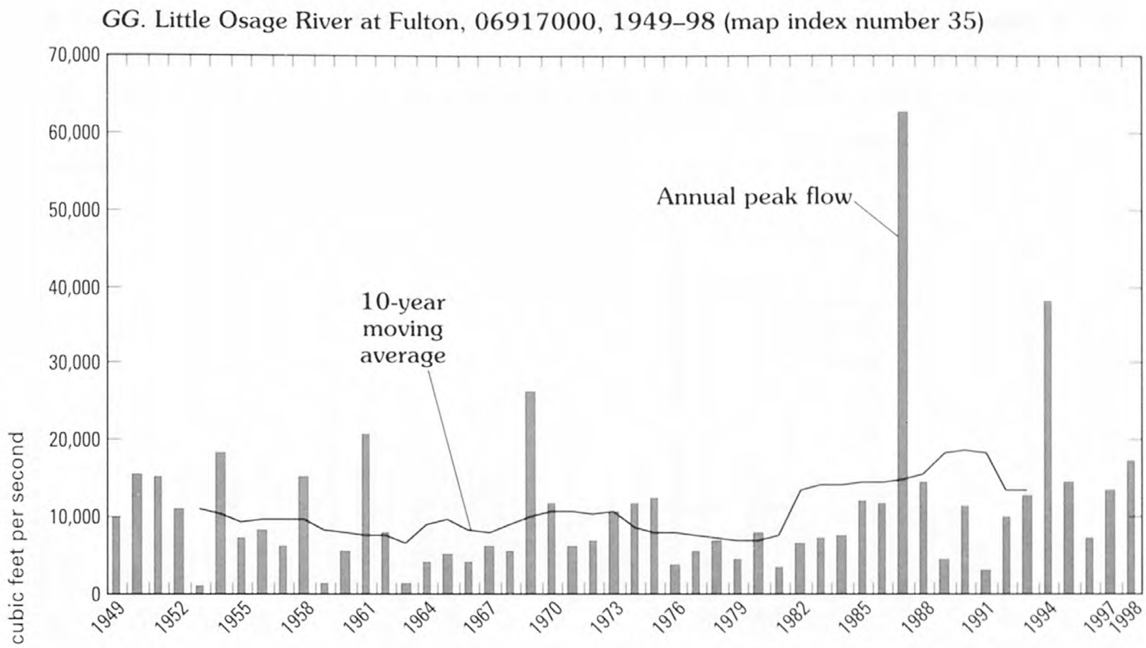


Figure 5 *(EE–FF).* Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.



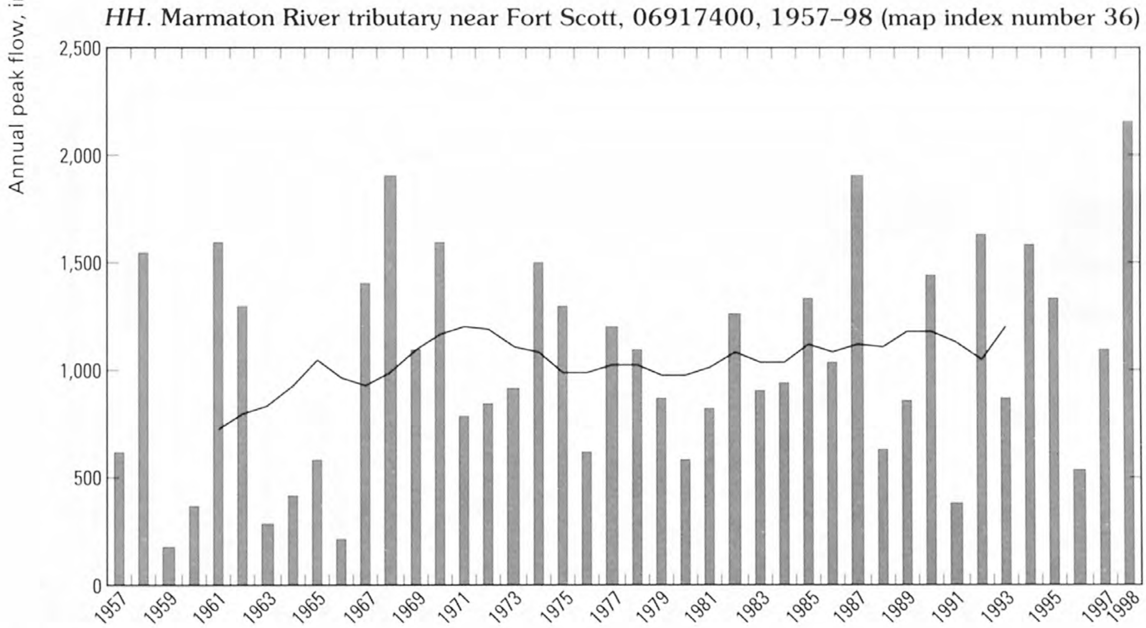


Figure 5 *(GG–HH)*. Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.

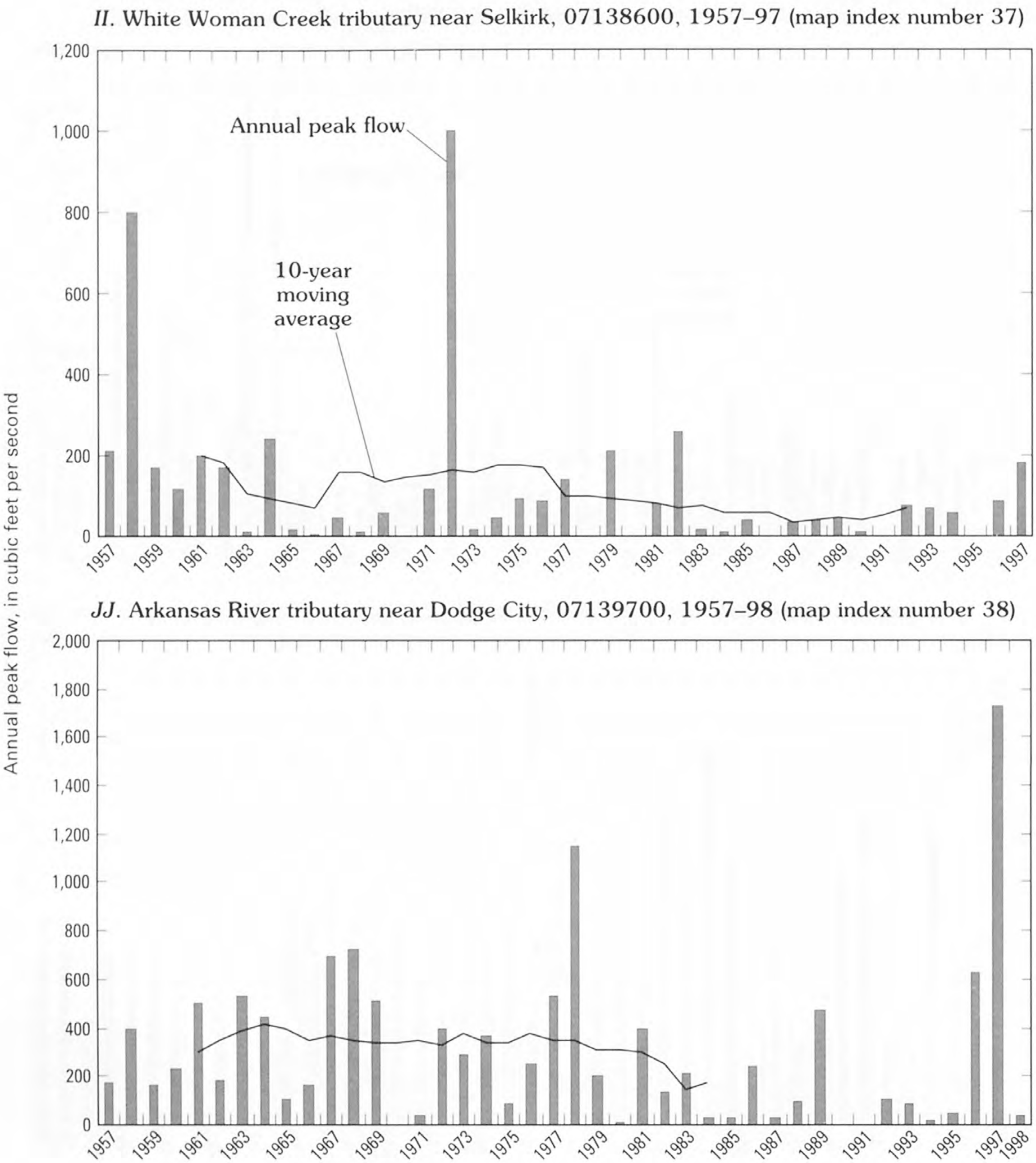


Figure 5 *(II–JJ)*. **Annual peak flows and 10-year moving averages using available periods of record–Continued. Location of stations shown in figure 3.**

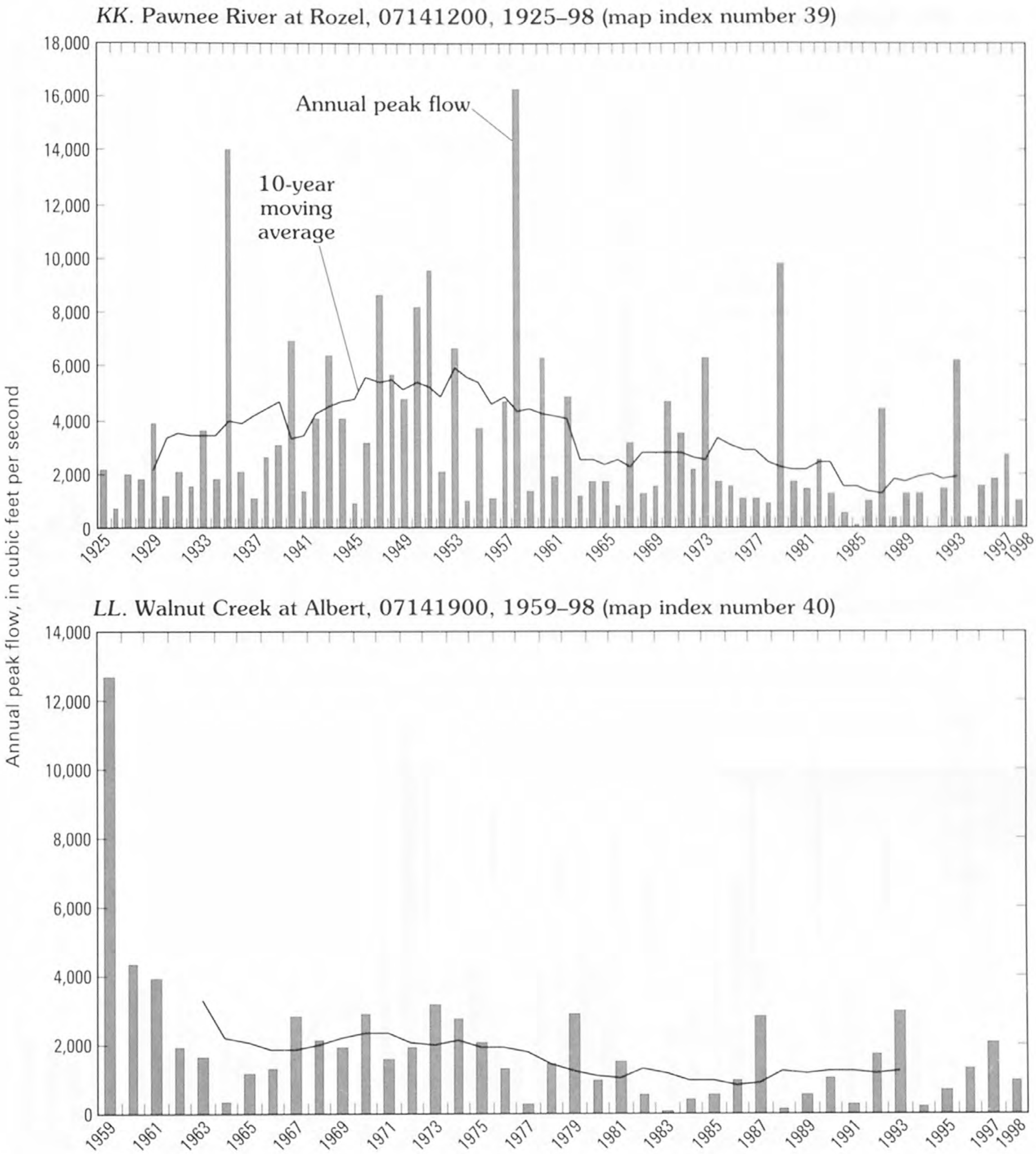


Figure 5 *(KK–LL)*. Annual peak flows and 10-year moving averages using available periods of record–Continued. Location of stations shown in figure 3.

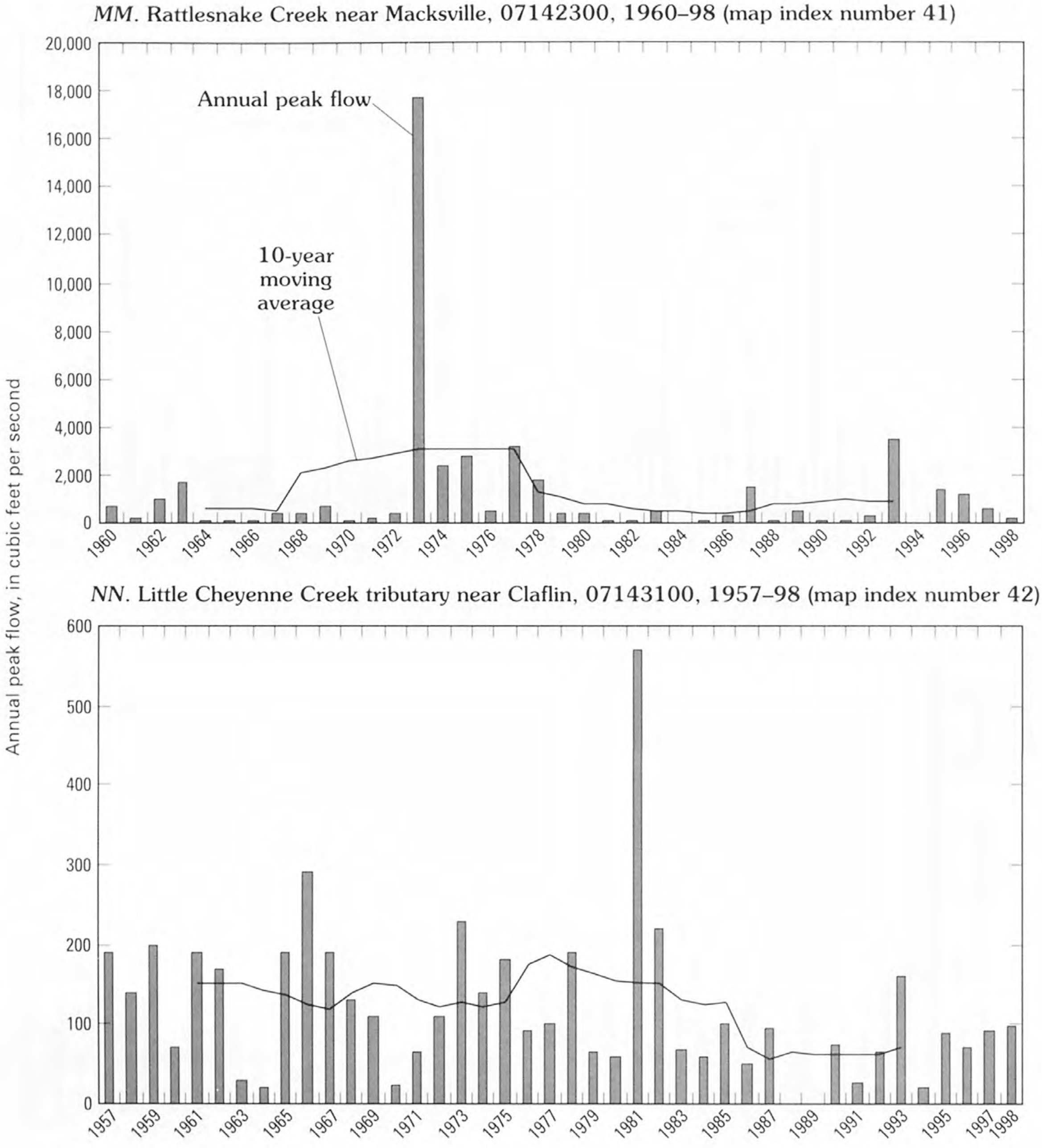
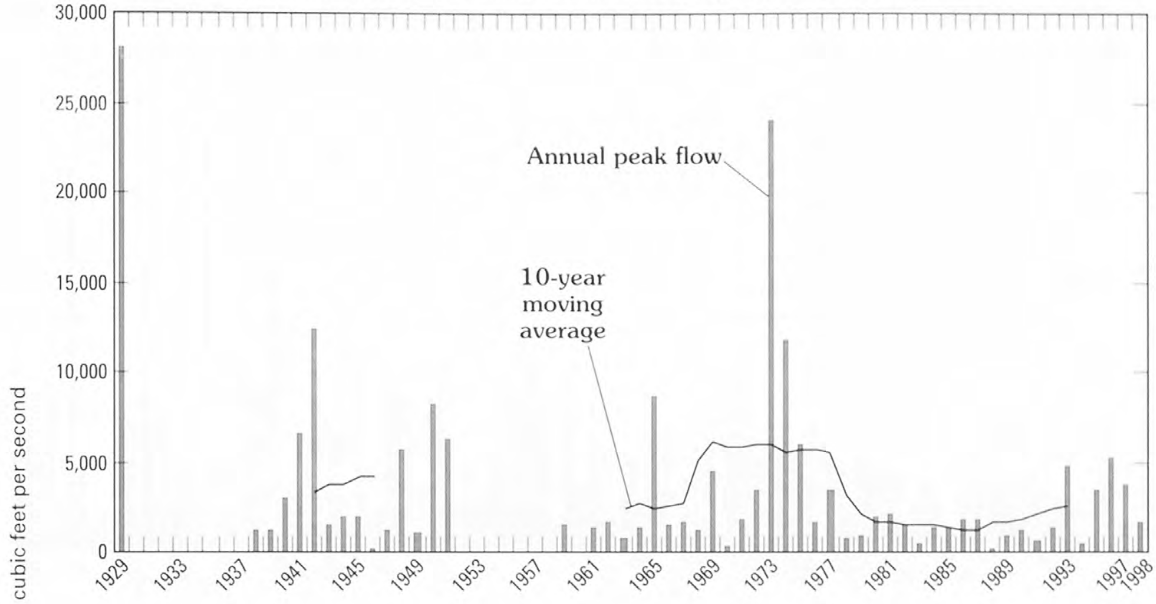


Figure 5 *(MM–NN)*. Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.

OO. Cow Creek near Lyons, 07143300, 1929–98 (map index number 43)



PP. Little Arkansas River at Valley Center, 07144200, 1916–98 (map index number 44)

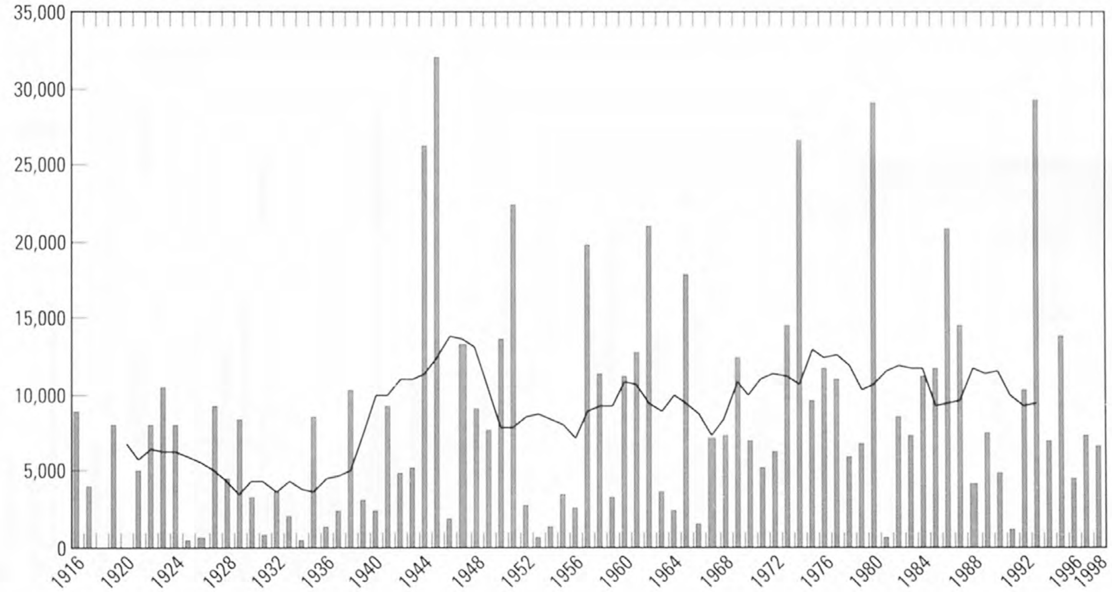


Figure 5 *(OO–PP)*. Annual peak flows and 10-year moving averages using available periods of record–Continued. Location of stations shown in figure 3.

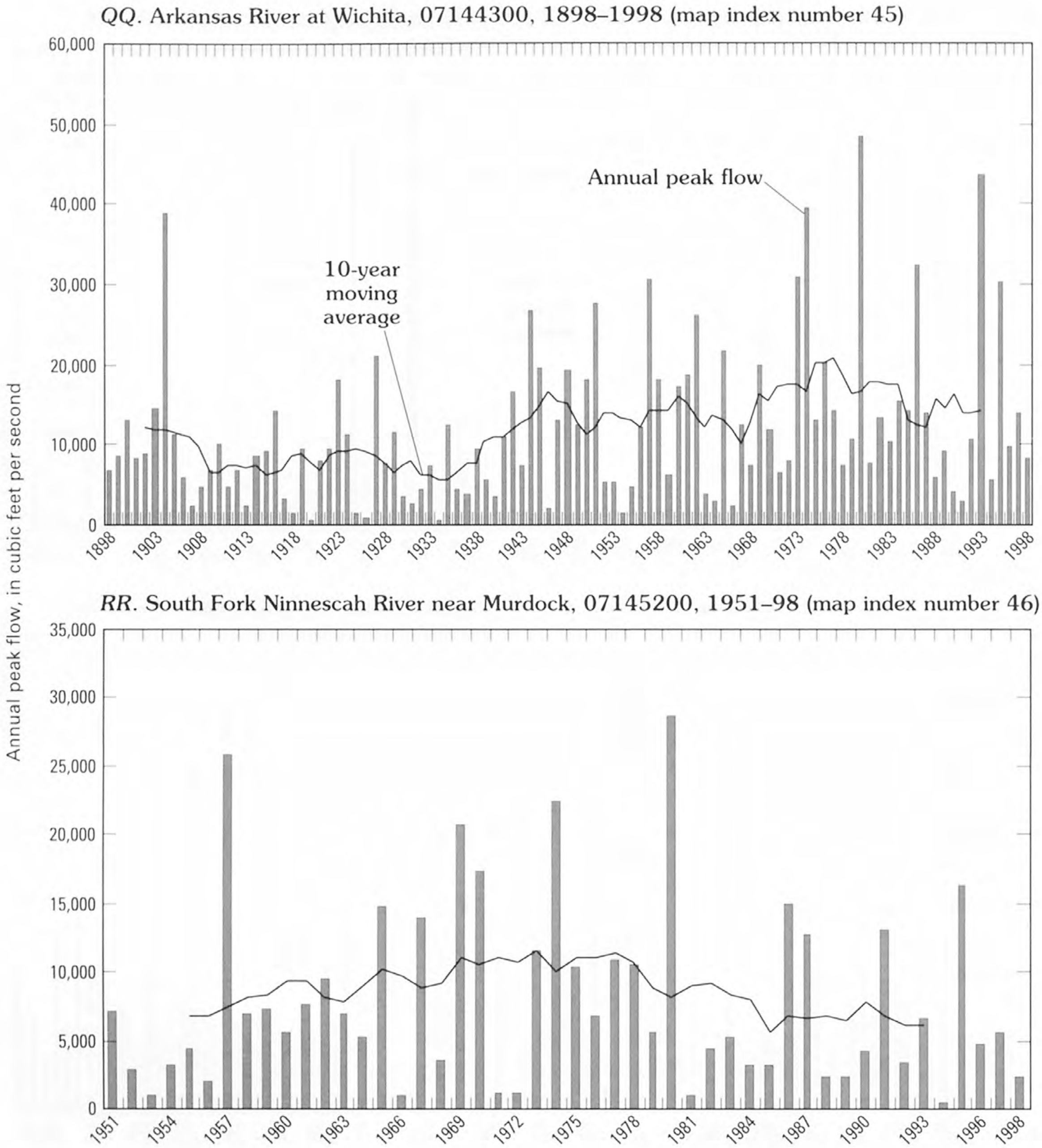
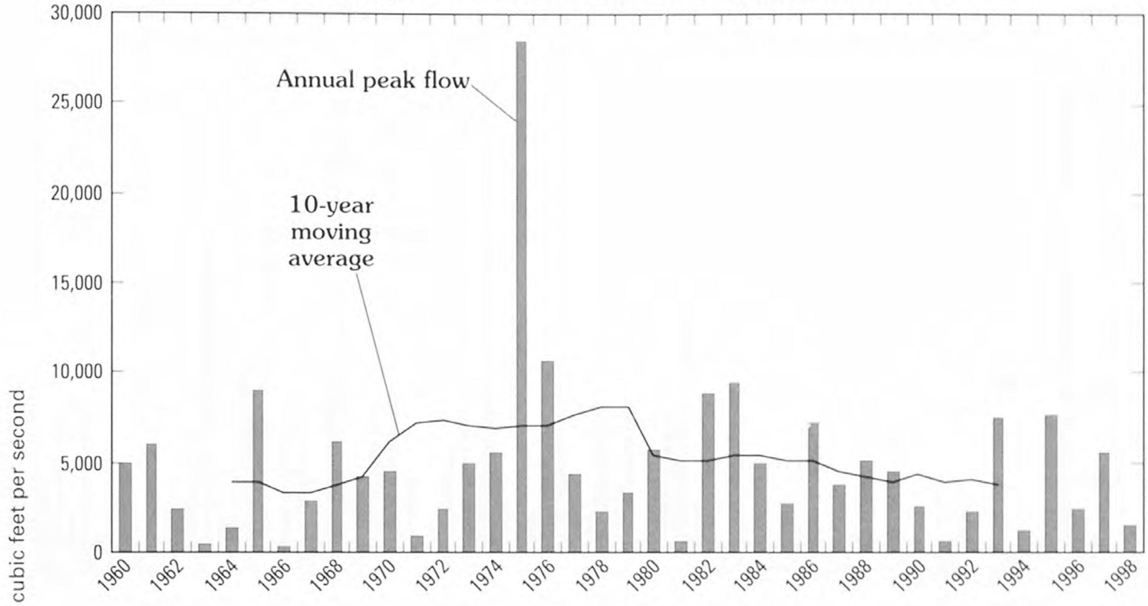


Figure 5 *(QQ–RR)*. Annual peak flows and 10-year moving averages using available periods of record–Continued. Location of stations shown in figure 3.

SS. Slate Creek at Wellington, 07145700, 1960–98 (map index number 47)



TT. Medicine Lodge River near Kiowa, 07149000, 1938–98 (map index number 48)

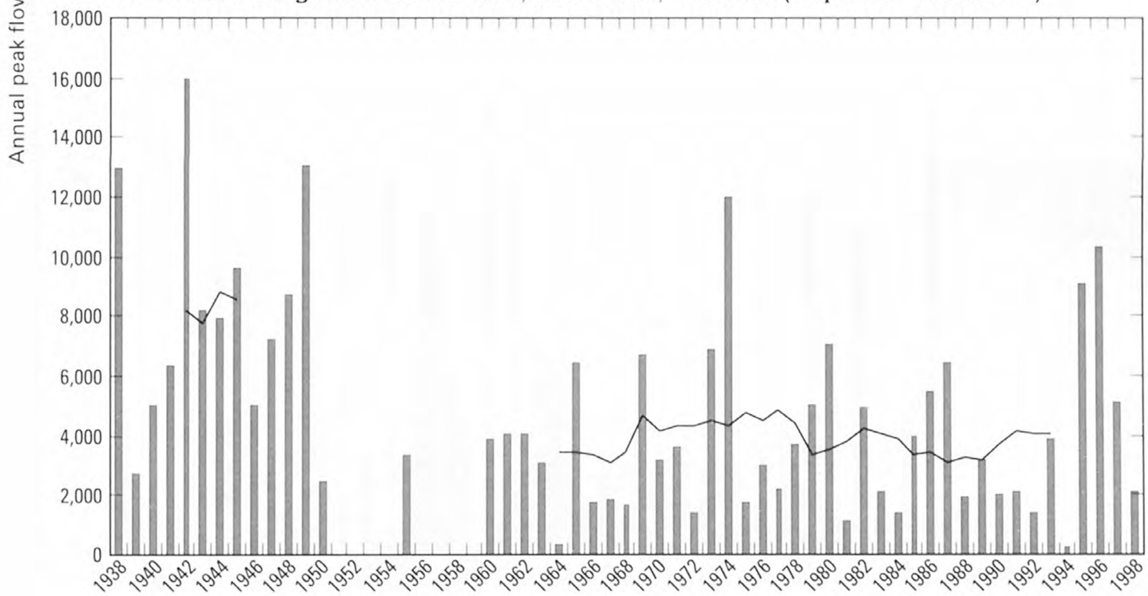


Figure 5 *(SS–TT)*. Annual peak flows and 10-year moving averages using available periods of record–Continued. Location of stations shown in figure 3.

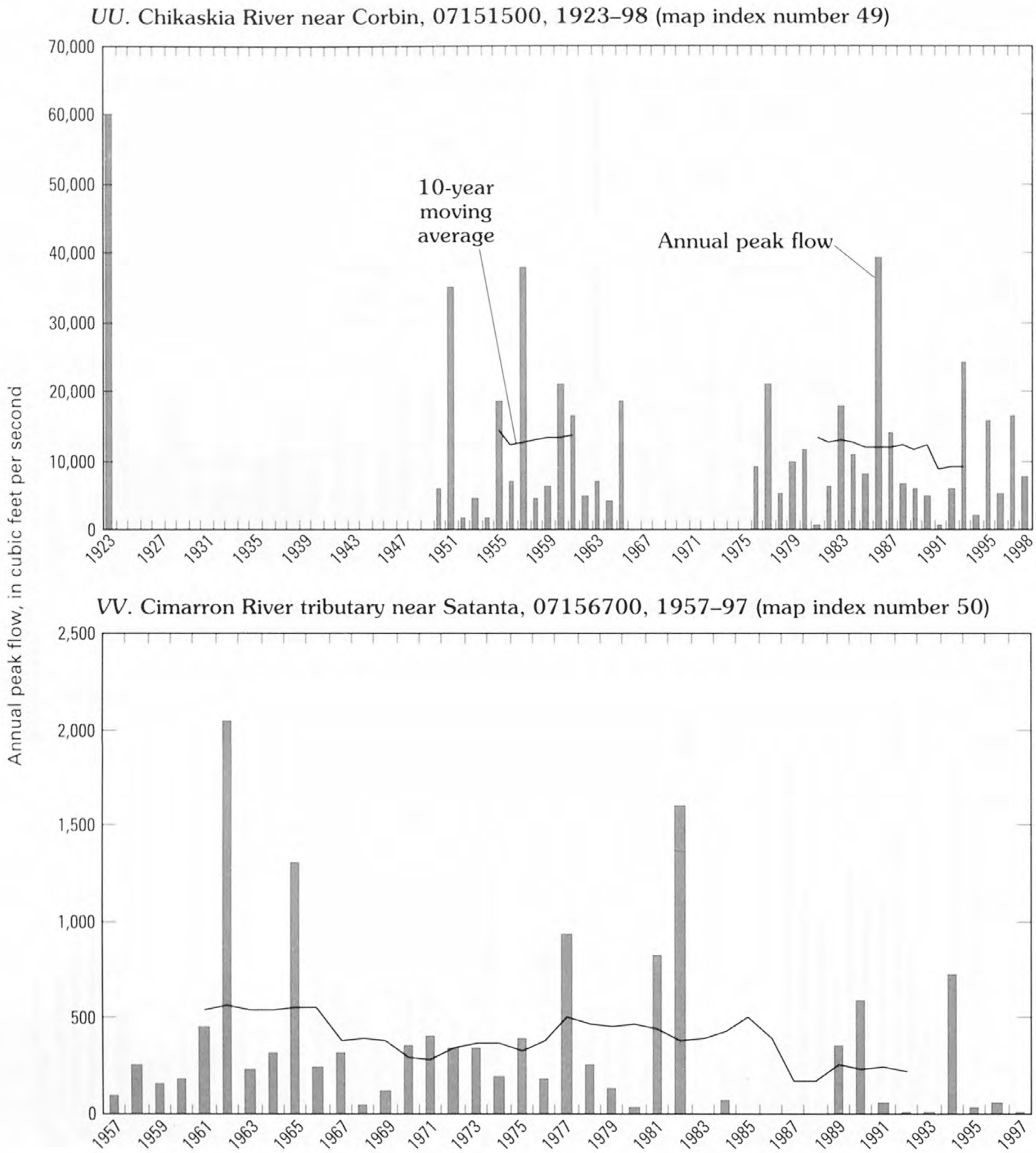


Figure 5 ***(UU–VV).*** **Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.**

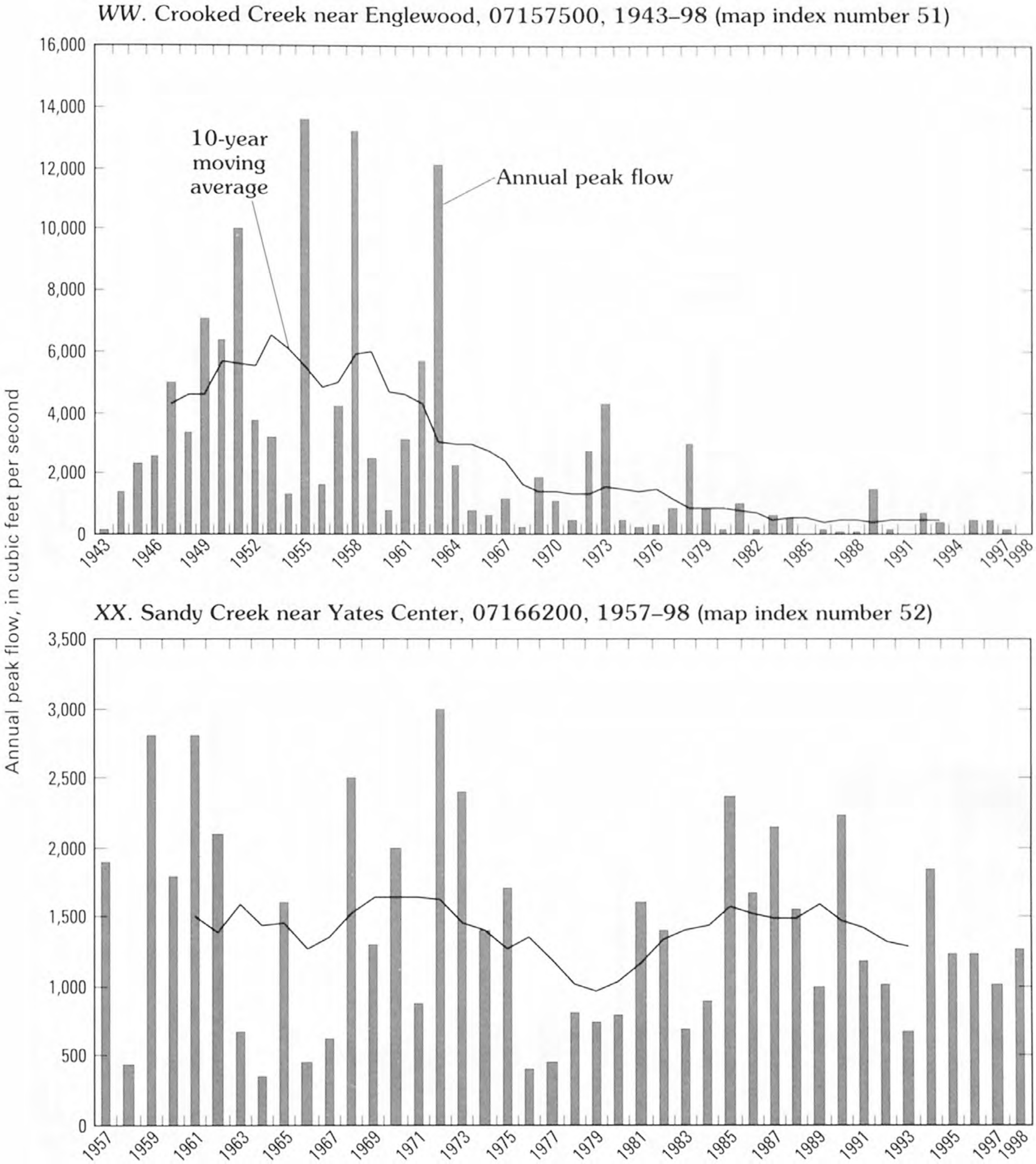


Figure 5 *(WW–XX)*. Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.

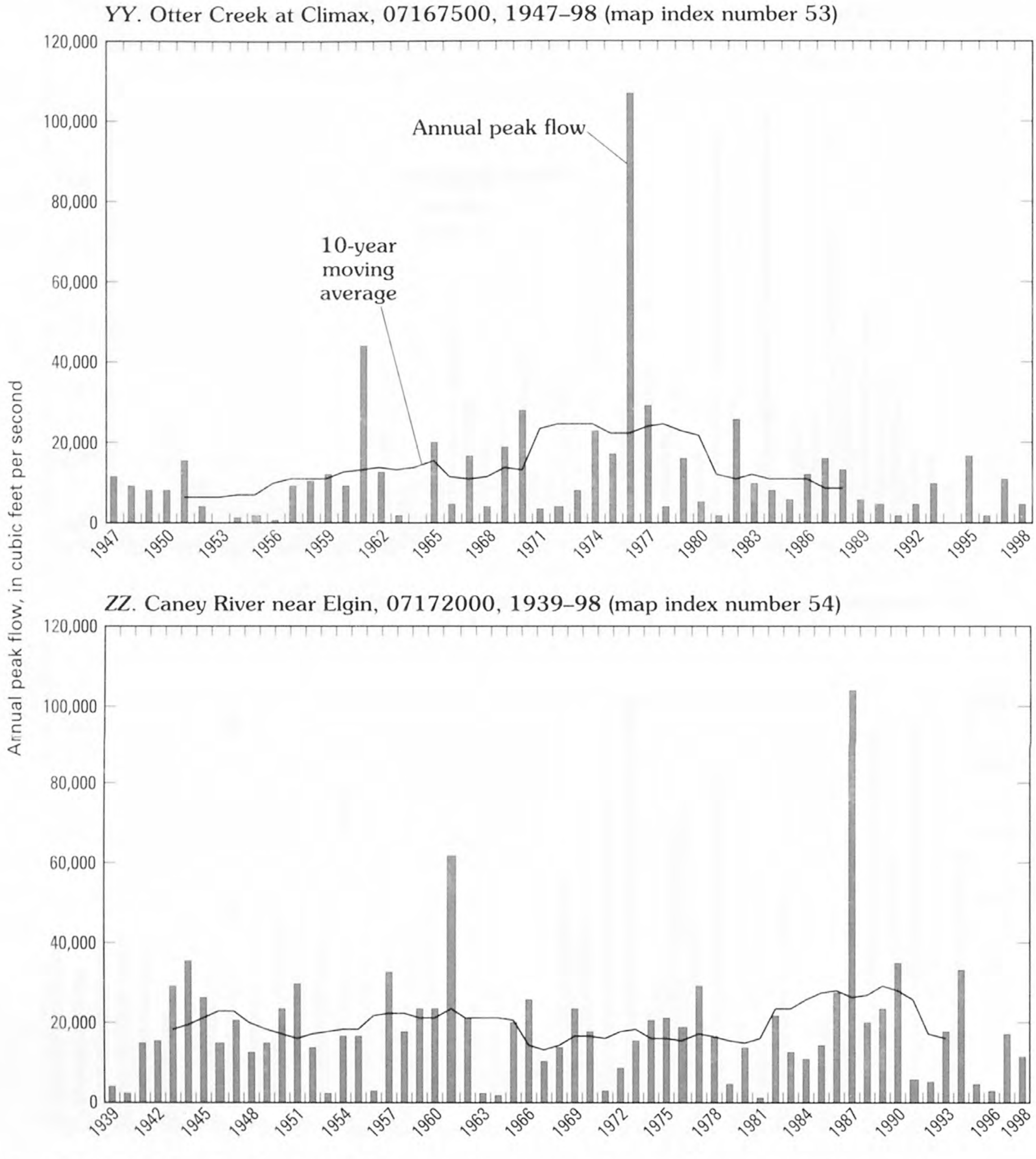


Figure 5 *(YY–ZZ)*. Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.

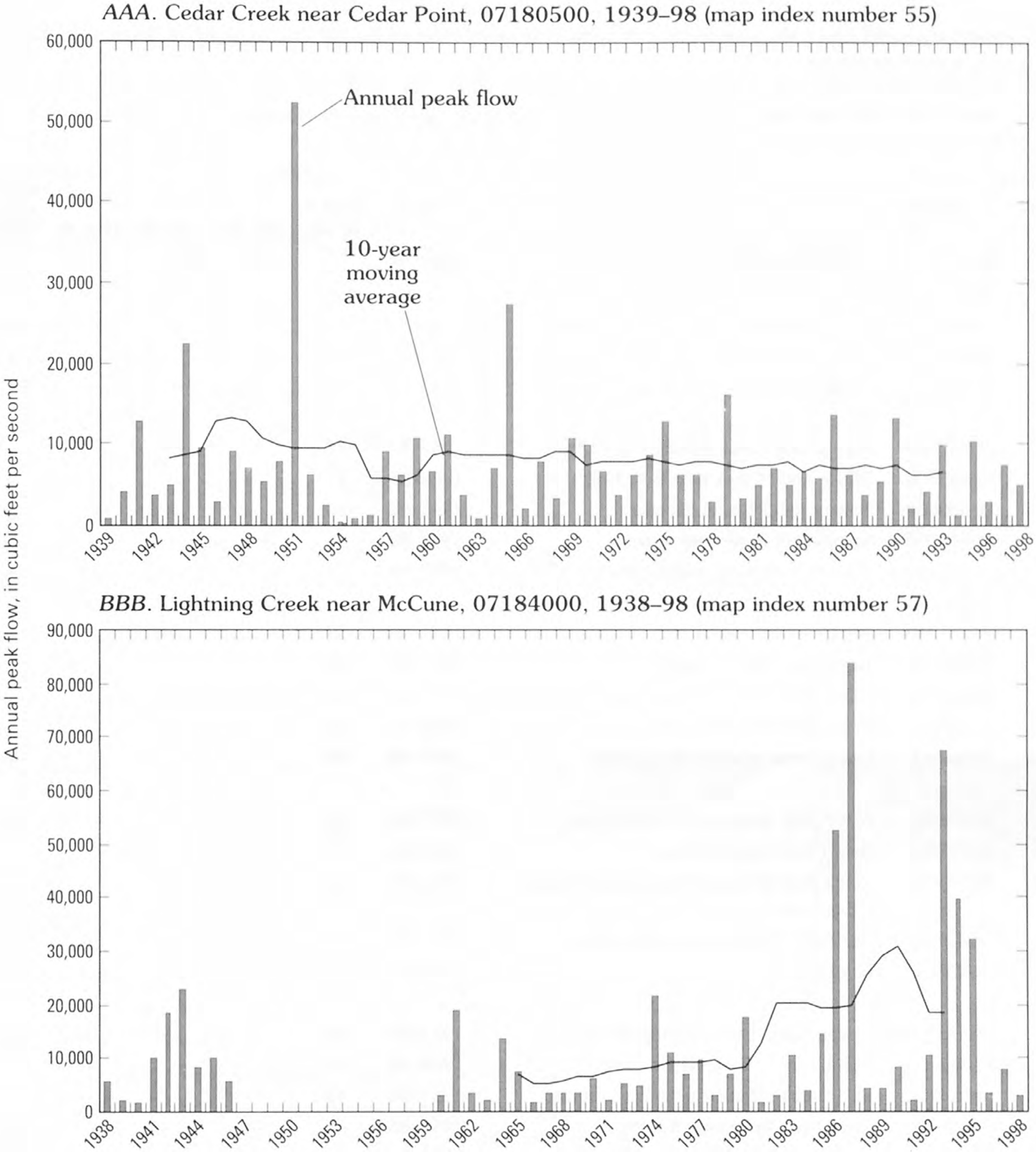


Figure 5 *(AAA–BBB)*. Annual peak flows and 10-year moving averages using available periods of record—Continued. Location of stations shown in figure 3.

Table 4. Results of Kendall's tau trend analysis for moving 30-year periods (except the last column, which is 28 years) for Kansas stream-gaging stations with more than 38 years of record

[Positive (+) indicates increasing trend, negative (-) indicates decreasing trend, zero (0) indicates no significant trend, and --- indicates record for this time period not available or incomplete]

Map index number (fig. 3)	Station number	Station name	Period of record	Years of record	1901–30	1906–35	1911–40	1916–45
1	06814000	Turkey Creek near Seneca	1949–98	50	---	---	---	---
2	06815700	Buttermilk Creek near Willis	1957–97	40	---	---	---	---
3	06844900	South Fork Sappa Creek near Achilles	1960–98	39	---	---	---	---
4	06845100	Long Branch Draw near Norcatur	1957–98	42	---	---	---	---
5	06846500	Beaver Creek at Cedar Bluffs	1946–98	54	---	---	---	---
6	06847600	Prairie Dog Creek tributary at Colby	1957–97	41	---	---	---	---
7	06853800	White Rock Creek near Burr Oak	1958–98	41	---	---	---	---
8	06860000	Smoky Hill River at Elkader	1938–98	60	---	---	---	---
9	06861000	Smoky Hill River near Arnold	1938–98	52	---	---	---	---
10	06863400	Big Creek tribuary near Ogallah	1957–98	42	---	---	---	---
11	06863500	Big Creek near Hays	1947–98	52	---	---	---	---
12	06863700	Big Creek tributary near Hays	1957–98	42	---	---	---	---
13	06864300	Smoky Hill River tributary at Dorrance	1957–98	42	---	---	---	---
14	06867000	Saline River near Russell	1946–98	52	---	---	---	---
15	06868300	Coon Creek tributary near Luray	1957–98	42	---	---	---	---
16	06871000	North Fork Solomon River at Glade	1953–98	46	---	---	---	---
17	06871500	Bow Creek near Stockton	1951–98	48	---	---	---	---
18	06873000	South Fork Solomon River above Webster Reservoir	1908–98	56	---	---	---	---
19	06873300	Ash Creek tributary near Stockton	1957–98	41	---	---	---	---
20	06876700	Salt Creek near Ada	1960–98	39	---	---	---	---
22	06878000	Chapman Creek near Chapman	1951–98	46	---	---	---	---
23	06884200	Mill Creek at Washington	1960–98	39	---	---	---	---
24	06884300	Mill Creek tributary near Washington	1957–98	42	---	---	---	---
25	06884400	Little Blue River near Barnes	1958–98	41	---	---	---	---
26	06885500	Black Vermillion River near Frankfort	1948–98	46	---	---	---	---
27	06887200	Cedar Creek near Manhattan	1957–98	42	---	---	---	---
28	06888500	Mill Creek near Paxico	1954–98	46	---	---	---	---
29	06889200	Soldier Creek near Delia	1959–98	40	---	---	---	---
30	06889500	Soldier Creek near Topeka	1929–98	70	---	---	---	---
32	06892000	Stranger Creek near Tonganoxie	1929–98	70	---	---	---	---
33	06911500	Salt Creek near Lyndon	1940–98	59	---	---	---	---
34	06914000	Pottawatomie Creek near Garnett	1929–98	60	---	---	---	---
35	06917000	Little Osage River at Fulton	1949–98	50	---	---	---	---
36	06917400	Marmaton River tributary near Fort Scott	1957–98	42	---	---	---	---
37	07138600	White Woman Creek tributary near Selkirk	1957–97	40	---	---	---	---

Map index number (fig. 3)	1921–50	1926–55	1931–60	1936–65	1941–70	1946–75	1951–80	1956–85	1961–90	1966–95	1971–98	Full record
1	---	---	---	---	---	---	---	0	(+)	(+)	0	(+)
2	---	---	---	---	---	---	---	---	(-)	0	---	(-)
3	---	---	---	---	---	---	---	---	0	0	0	0
4	---	---	---	---	---	---	---	---	(-)	0	0	(-)
5	---	---	---	---	---	0	0	(-)	(-)	0	0	---
6	---	---	---	---	---	---	---	---	0	0	---	0
7	---	---	---	---	---	---	---	---	0	0	0	0
8	---	---	---	---	0	0	0	(-)	(-)	0	0	(-)
9	---	---	---	---	---	---	(-)	(-)	(-)	(-)	0	(-)
10	---	---	---	---	---	---	---	---	0	0	0	0
11	---	---	---	---	---	---	(-)	(-)	(-)	0	0	(-)
12	---	---	---	---	---	---	---	---	0	0	0	0
13	---	---	---	---	---	---	---	---	0	0	0	0
14	---	---	---	---	---	---	0	(-)	(-)	0	0	(-)
15	---	---	---	---	---	---	---	---	0	0	0	0
16	---	---	---	---	---	---	---	(-)	(-)	0	0	(-)
17	---	---	---	---	---	---	---	0	0	0	0	(-)
18	---	---	---	---	---	(-)	0	(-)	(-)	0	0	(-)
19	---	---	---	---	---	---	---	---	0	0	(+)	0
20	---	---	---	---	---	---	---	---	0	0	0	0
22	---	---	---	---	---	---	---	0	0	0	0	0
23	---	---	---	---	---	---	---	---	0	0	0	0
24	---	---	---	---	---	---	---	---	(+)	(+)	0	(+)
25	---	---	---	---	---	---	---	---	0	0	0	0
26	---	---	---	---	---	---	0	0	0	0	0	0
27	---	---	---	---	---	---	---	---	0	0	0	0
28	---	---	---	---	---	---	---	0	0	0	0	(+)
29	---	---	---	---	---	---	---	---	0	0	0	(+)
30	---	---	0	0	0	0	(+)	(+)	(+)	0	0	(+)
32	---	---	0	0	0	0	0	0	0	0	0	0
33	---	---	---	---	0	0	0	(+)	0	0	0	0
34	---	---	---	---	0	0	(+)	0	0	0	0	0
35	---	---	---	---	---	---	0	0	0	(+)	(+)	0
36	---	---	---	---	---	---	---	---	0	0	0	0
37	---	---	---	---	---	---	---	---	0	0	---	0

Table 4. Results of Kendall's tau trend analysis for moving 30-year periods (except the last column, which is 28 years) for Kansas stream-gaging stations with more than 38 years of record—Continued

Map index number (fig. 3)	Station number	Station name	Period of record	Years of record	1901–30	1906–35	1911–40	1916–45
38	07139700	Arkansas River tributary near Dodge City	1957–98	40	---	---	---	---
39	07141200	Pawnee River at Rozel	1925–98	74	---	---	---	---
40	07141900	Walnut Creek at Albert	1959–98	40	---	---	---	---
41	07142300	Rattlesnake Creek near Macksville	1960–98	39	---	---	---	---
42	07143100	Little Cheyenne Creek tributary near Claflin	1957–98	42	---	---	---	---
43	07143300	Cow Creek near Lyons	1929–98	54	---	---	---	---
44	07144200	Little Arkansas River at Valley Center	1916–98	81	---	---	---	---
45	07144300	Arkansas River at Wichita	1898–1998	101	0	0	0	0
46	07145200	South Fork Ninnescah River near Murdock	1951–98	48	---	---	---	---
47	07145700	Slate Creek at Wellington	1960–98	39	---	---	---	---
48	07149000	Medicine Lodge River near Kiowa	1938–98	54	---	---	---	---
49	07151500	Chikaskia River near Corbin	1923–98	40	---	---	---	---
50	07156700	Cimarron River tributary near Satanta	1957–97	41	---	---	---	---
51	07157500	Crooked Creek near Englewood	1943–98	56	---	---	---	---
52	07166200	Sandy Creek near Yates Center	1957–98	42	---	---	---	---
53	07167500	Otter Creek at Climax	1947–98	51	---	---	---	---
54	07172000	Caney River near Elgin	1939–98	60	---	---	---	---
55	07180500	Cedar Creek near Cedar Point	1939–98	60	---	---	---	---
57	07184000	Lightning Creek near McCune	1938–98	48	---	---	---	---

Map index number (fig. 3)	1921–50	1926–55	1931–60	1936–65	1941–70	1946–75	1951–80	1956–85	1961–90	1966–95	1971–98	Full record
38	---	---	---	---	---	---	---	---	0	(-)	0	0
39	---	(+)	0	0	0	0	0	(-)	0	0	0	(-)
40	---	---	---	---	---	---	---	---	(-)	(-)	0	(-)
41	---	---	---	---	---	---	---	---	0	0	0	0
42	---	---	---	---	---	---	---	---	(-)	(-)	0	(-)
43	---	---	---	---	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	(+)
45	(+)	0	(+)	0	0	0	0	0	0	0	0	(+)
46	---	---	---	---	---	---	---	(+)	0	0	0	0
47	---	---	---	---	---	---	---	---	0	0	0	0
48	---	---	---	---	(-)	0	0	0	0	0	0	(-)
49	---	---	---	---	---	---	0	0	0	0	0	0
50	---	---	---	---	---	---	---	---	(-)	0	(-)	(-)
51	---	---	---	---	---	(-)	(-)	(-)	(-)	(-)	(-)	(-)
52	---	---	---	---	---	---	---	---	0	0	0	0
53	---	---	---	---	---	---	(+)	0	0	0	0	0
54	---	---	---	---	0	0	0	0	0	0	0	0
55	---	---	---	---	0	0	0	0	0	0	0	0
57	---	---	---	---	0	0	0	0	0	(+)	0	0

accounted for in total annual flow volume at the regulated stations. Analyzing the flow volumes for the larger drainage basins may provide more reliable indicators of flow trends because they are less susceptible to localized flooding and human-related factors. Larger drainages also have a larger ground-water component that can make them slower to respond to changes in precipitation. Again, the 29 flow-volume stream-gaging stations were distributed evenly and were representative of conditions across Kansas.

When the Kendall's tau test was applied to mean annual discharges in Kansas, a regional pattern similar to the peak-flow analysis resulted (fig. 6). Of the 29 stations studied, records from 6 (21 percent) showed a trend significant at the 95-percent confidence level (table 5). All six trends were negative and occurred in records from stream-gaging stations in the western one-half of Kansas, supporting the previous test results indicating a trend toward decreasing flows in that part of the State. Only one of the four regulated streams with larger drainage basins showed a significant trend. Records from 6 of the 29 stations exhibited a significant decreasing trend in both the annual peak-flow analysis (table 3) and the mean annual discharge analysis (table 5). No station showed a significant increasing trend in flow volume.

Decreasing streamflow volume in western Kansas, described by Jordan (1982) and Angelo (1994) and supported by the mean annual discharge trend analysis, is related to decreasing trends in peak flow. When rain falls on a dry streambed, more rain contributes to saturation of the streambed and less to actual streamflow. Therefore, peak flow would be expected to decrease over a period of time as mean annual discharge decreases.

EVALUATION OF TREND CAUSES

Factors Affecting Peak Flow

Establishing that a statistically significant trend in streamflow occurred over the past 40 years does not indicate that the trend will continue into the future. In

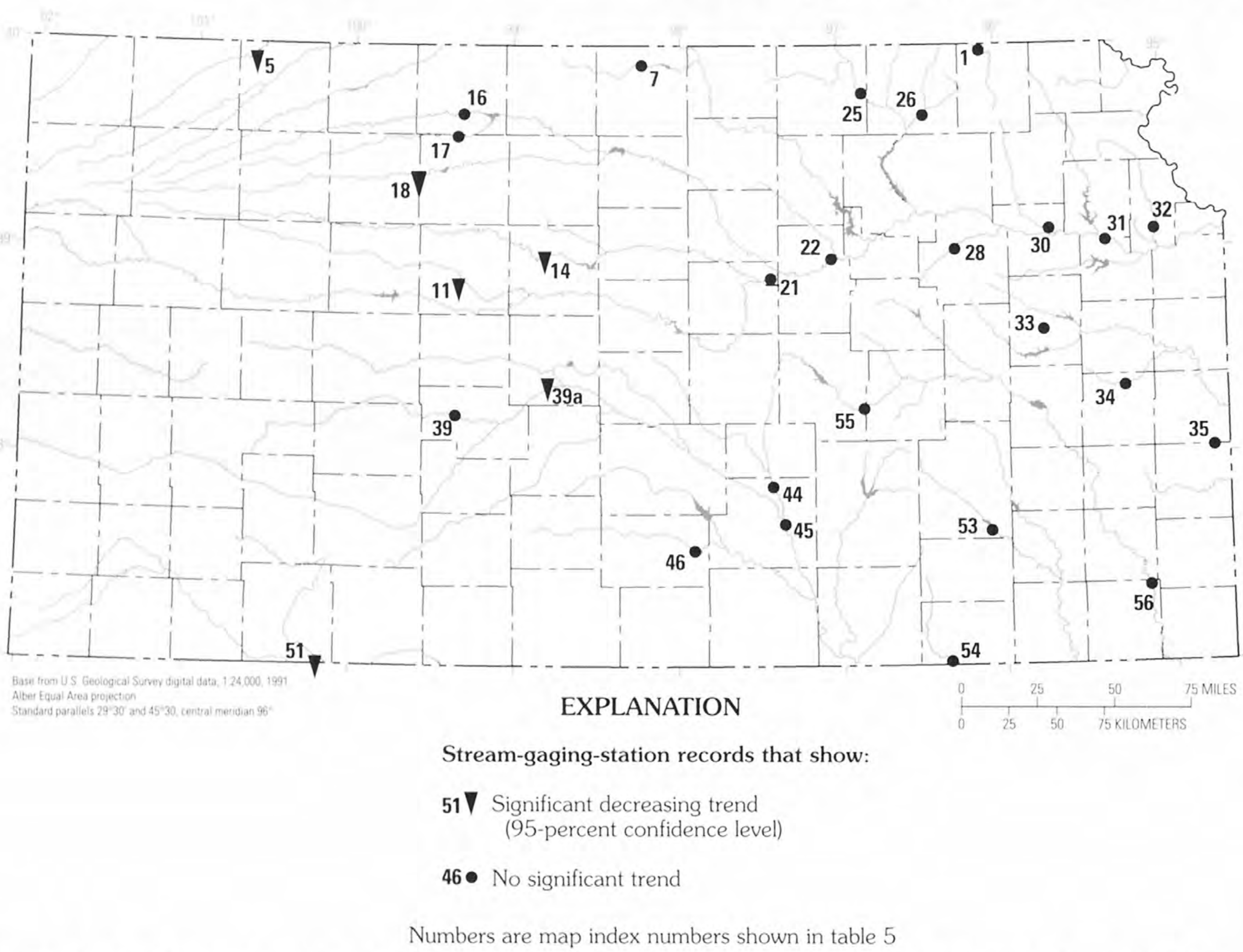


Figure 6. Results of Kendall's tau trend analysis for mean annual discharges at selected stream-gaging stations in Kansas, 1958–97.

Table 5. Results of Kendall's tau trend analysis for mean annual discharges at 29 stream-gaging stations in Kansas, 1958–97

[Shading indicates statistically significant at 95-percent confidence level (probability value less than or equal to 0.05). (ft^3/s)/yr, cubic feet per second per year; *, regulated stream-gaging station; <, less than]

Map index number (fig. 6)	Station number	Station name	Kendall's tau	Probability value	Slope [(ft^3/s)/yr]
1	06814000	Turkey Creek near Seneca	0.02	0.885	0.187
5	06846500	Beaver Creek at Cedar Bluffs	-.37	.001	-.262
7	06853800	White Rock Creek near Burr Oak	.10	.370	.259
11	06863500	Big Creek near Hays	-.24	.033	-.447
14	06867000	Saline River near Russell	-.22	.050	-1.250
16	06871000	North Fork Solomon River at Glade	-.14	.204	-.300
17	06871500	Bow Creek near Stockton	-.06	.625	-.045
18	06873000	South Fork Solomon River above Webster Reservoir	-.26	.021	-.632
21	*06876900	Solomon River at Niles	.05	.666	1.800
22	06878000	Chapman Creek near Chapman	.01	.954	.039
25	06884400	Little Blue River near Barnes	.05	.681	1.870
26	06885500	Black Vermillion River near Frankfort	.04	.718	.410
28	06888500	Mill Creek near Paxico	.39	.735	.504
30	06889500	Soldier Creek near Topeka	.08	.463	1.010
31	*06891000	Kansas River at Lecompton	.04	.735	19.300
32	06892000	Stranger Creek near Tonganoxie	.06	.568	1.040
33	06911500	Salt Creek near Lyndon	.07	.560	.338
34	06914000	Pottawatomie Creek near Garnett	.02	.843	.306
35	06917000	Little Osage River at Fulton	.20	.071	.413
39	07141200	Pawnee River at Rozel	-.21	.053	-.768
39a	*07141300	Arkansas River at Great Bend	-.34	.002	-5.190
44	07144200	Little Arkansas River at Valley Center	-.02	.898	-.684
45	07144300	Arkansas River at Wichita	-.17	.121	-9.550
46	07145200	South Fork Ninnescah River near Murdock	.10	.426	1.100
51	07157500	Crooked Creek near Englewood	-.45	<.001	-.362
53	07167500	Otter Creek at Climax	.03	.807	.131
54	07172000	Caney River near Elgin	.13	.258	3.040
55	07180500	Cedar Creek near Cedar Point	.01	.935	.067
56	*07183500	Neosho River near Parsons	.07	.522	14.500

evaluating whether the trend is likely to continue, the cause of the trend needs to be determined. Trends in peak streamflow can be caused by a variety of factors, many of which are difficult to relate statistically to the trend due to lack of appropriate data.

The most direct potential cause of an increasing trend in peak flow is an increase in either the frequency, intensity, or amount of rainfall. Increased rainfall frequency may support higher average streamflows, which then are supplemented during intense storms, resulting in higher peak flow.

Urbanization, particularly stream channelization and increasing paved surface areas, may result in higher downstream peak flows (Bedient and Huber, 1992). A substantial decrease in upstream water use, although not common, also could affect downstream peak flows.

Decreasing peak-flow trends also can be caused by changes in rainfall patterns, such as decreases in total rainfall or decreases in the intensity or frequency of rainfall. Construction of reservoirs, levees, and diversions may decrease peak flows. Increases in upstream water use are likely to contribute to decreasing streamflows. Ground-water depletion usually decreases streamflow, particularly over a long period of time, because it decreases base flow (ground-water contribution to streamflow). Average annual runoff in Kansas varies from 0.1 in. in the west to about 10 in. in the east (Sophocleous and Wilson, 2000). Terracing, particularly in western Kansas, could reduce available runoff, resulting in decreasing peak flows. In addition, changes in land use and farming practices can decrease streamflow. In the 1930s, the Federal government, primarily through the Soil Conservation Service, initiated a series of programs designed to reduce soil erosion. Land-management practices including contour farming, crop rotation, pasture improvement, highly erodible land repair, and construction of watershed dams all control soil erosion. These practices also reduce and delay surface runoff, which should result in a decrease in peak flows and flow volumes.

Precipitation Trend Analysis

Total precipitation in the United States has increased by 10 percent during the 20th century from 1910 to 1995 (Karl and Knight, 1998). The increase in precipitation has been attributed in part to increasing global temperatures. As the mean surface temperatures of the Earth increase, more evaporation occurs. Warmer temperatures also allow the atmosphere to hold more water that subsequently falls as precipitation. In their analysis of precipitation trends, Karl and Knight (1998) showed a statistically significant increase in the number of annual precipitation occurrences in each of the nine regions covering the entire contiguous United States. The same analysis also revealed an increase in the intensity of excessive rainfall in all nine regions, which has an even greater effect on total precipitation than does increased frequency.

An increasing trend in flood intensities would be expected from increased precipitation. Runoff occurs when rainfall intensity exceeds the infiltration capacity of the soil, which is affected primarily by the existing soil-moisture conditions. The increasing trend in rainfall frequency may not increase flood intensity if the time interval between rainfall allows adequate evapotranspiration to deplete the soil moisture. However, an increase in the intensity of rainfall does result in increased runoff and floods of greater magnitude. Lins and Slack (1999) found that across the United States annual minimum and mean streamflows were increasing significantly but that annual maximum flows were neither increasing nor decreasing nationwide.

The Kendall's tau test was applied to total annual precipitation values for each of the 26 meteorological divisions of the National Weather Service in Kansas, Oklahoma, and Nebraska for 1958–97, the same 40-year period used for the peak-flow analysis described earlier in this report. The precipitation data were from the National Climatic Data Center's database (National Oceanic and Atmospheric Administration, 1998).

When the Kendall's tau test was applied to annual precipitation, trends significant at the 95-percent confidence level (positive tau and slope) were detected for 3 of the 26 divisions (table 6). The three meteorological divisions showing significant increasing trends in annual precipitation were all located in south-central Oklahoma (fig. 7). One of three stream-gaging stations tested for trends in peak flow within those divisions showed a significant increasing trend in peak flow (station 07311500, map index number 68, table 2). The other two stations (07300500 and 07332500, map index numbers 67 and 69, table 2) showed no trend. Karl and Knight's (1998) study of regional precipitation trends in the United States also found no significant increasing trend in monthly median precipitation from 1910–96 in the regions containing Kansas, Oklahoma, and Nebraska. In addition, Karl and Knight (1998) found that the number of precipitation occurrences and the amount of rainfall during intense precipitation increased significantly during the same time period. They suggested that the amount of rainfall received during intense precipitation could result in an increase in peak flows without being reflected in the median precipitation data. Additional analysis of maximum rainfalls for various durations within the study area could determine more conclusively whether increasing streamflow trends in the eastern part of the

Table 6. Results of Kendall's tau trend analysis of mean annual precipitation in Kansas, Oklahoma, and Nebraska, 1958–97

[Shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05). $(ft^3/s)/yr$, cubic feet per second per year; NA, not available]

Meteorological division number (fig. 7)	Kendall's tau	Probability value	Slope $[(ft^3/s)/yr]$
	Kansas		
1401	0.181	0.108	0.085
1402	.054	.637	.038
1403	.051	.654	.063
1404	.074	.514	.033
1405	.014	.913	.008
1406	.053	.646	.049
1407	.066	.561	.038
1408	.055	.628	.034
1409	.104	.358	.098
	Nebraska		
2501	.418	.717	.015
2502	NA	NA	NA
2503	.190	.090	.106
2505	.130	.250	.066
2506	.023	.847	.018
2507	.140	.213	.048
2508	.062	.586	.030
2509	.009	.942	.002
	Oklahoma		
3401	.014	.913	.002
3402	.157	.164	.113
3403	.213	.058	.192
3404	.147	.191	.086
3405	.263	.019	.223
3406	.198	.077	.227
3407	.260	.020	.206
3408	.282	.012	.252
3409	.181	.108	.180

study area were caused by an increase in the amount of rainfall during intense precipitation.

The general lack of significant precipitation trends in all meteorological divisions in western Kansas and Nebraska indicated that the decreasing trends in peak flows apparent in those areas probably were due to factors other than total precipitation. Karl and Knight (1998) found no decrease in rainfall frequency or in rainfall intensity during excessive precipitation in the regions containing Kansas, Oklahoma, and Nebraska. Intensity of light rainfall may have changed; however, that would have little effect on peak flows.

Water-Table Trend Analysis

The Kendall's tau test was applied to winter water levels in 17 wells in Kansas for 1958–97. All the wells with water levels less than 50 ft below land surface for which annual data were available for the majority of the period were included. Wells with water levels less than 50 ft below land surface were used because they measure ground water that is likely to be more directly related to surface flow than water at greater depths. Water-level measurements used in the analysis were made during the winter months because less natural fluctuation normally occurs due to the fact that it is typically the driest season in Kansas. Also, water levels are more stable in winter because they have recovered from irrigation pumping during the previous summer. January measurements were used when available, and when unavailable, the closest February or December measurements were substituted. If no December, January, or February water level was available, the year was skipped. The water-level values used represented the altitude of the water table. A positive tau represented an increase in water-table altitude.

Of the 17 ground-water wells used in the water-table trend analysis, water levels in 13 showed significant trends (table 7). Water levels in 10 wells indicated that the water-table altitude at those locations was declining, whereas water levels in three wells showed that the water table at those locations was rising. The 10 wells with declining water-table altitudes were located in central and western Kansas (fig. 8). Of the two wells analyzed in eastern Kansas, the one located in northeastern Kansas (well W3, fig. 8) showed an increasing trend in water-table altitude, and the well located in southeastern Kansas (well W13, fig. 8) showed a decreasing trend.

Results of water-level trend analysis indicate that declining water levels may be a factor contributing to decreasing trends in peak flow. In general, if shallow ground-water levels are declining, perennial streams (continuous flow) become ephemeral (intermittent flow) with dry streambeds. Consequently, more rainfall is needed to create flow and to attain peak flows comparable to those under previous conditions. Angelo (1994) described areas in western Kansas where streambeds have changed from perennial to ephemeral because the water table declined below the streambed elevation. More detailed study of local ground-water/surface-water relations would be helpful

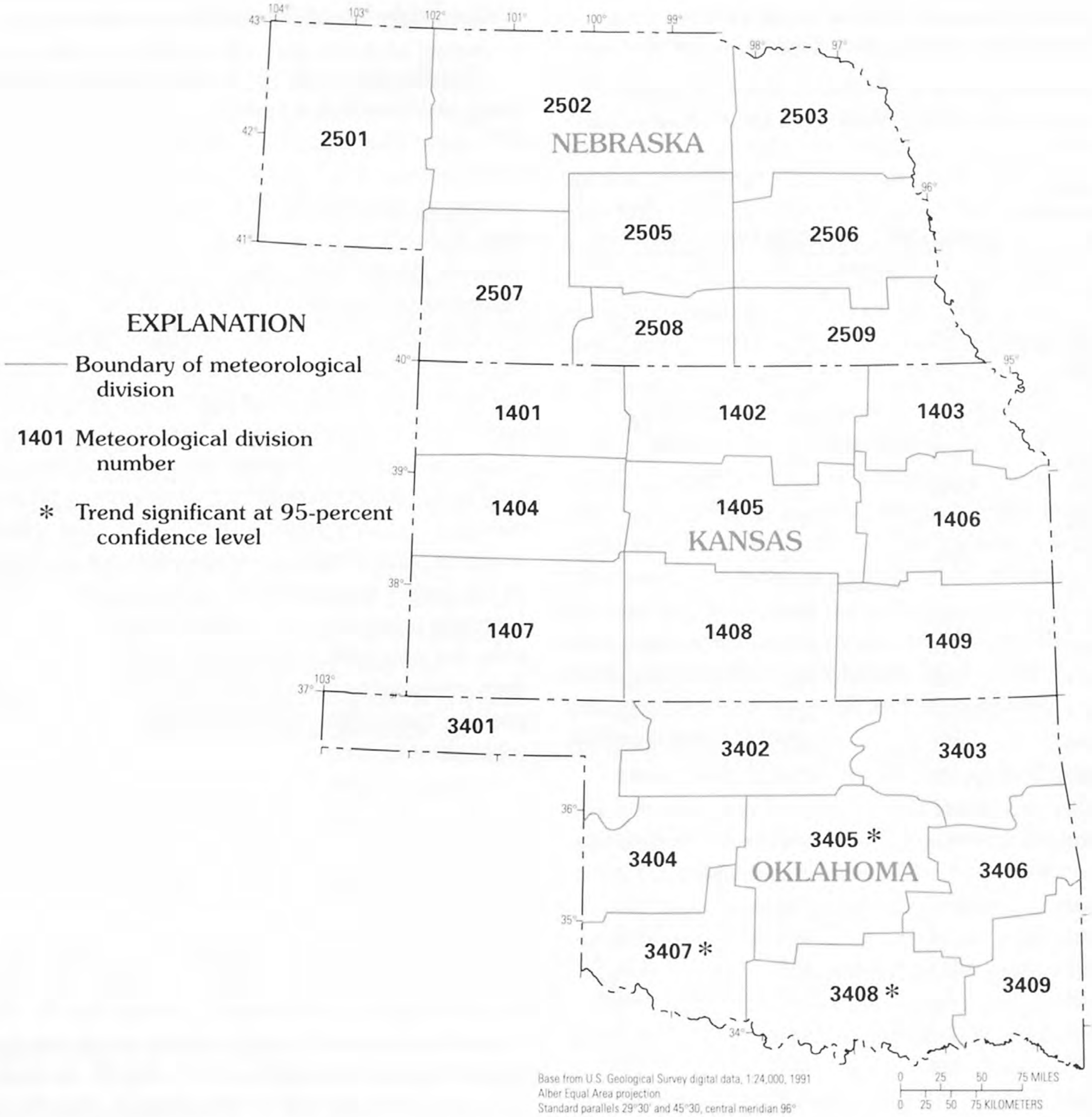


Figure 7. Location of 26 meteorological divisions of National Weather Service that were tested for trends in total annual precipitation. Significant trends (all of which were increasing) were found in three divisions in south-central Oklahoma.

in determining where declining water levels have affected peak flows.

Water Use

One important variable that could not be used in the analysis due to a lack of reliable historic records was water use. Estimates of total water withdrawals in Kansas from 1955 to 1995 are shown in table 8. The estimates were compiled from USGS Circulars, "*Estimated Use of Water in the United States*," which have been published every 5 years since 1950 (see "References Cited" at the end of this report). According to the estimates, water withdrawals increased by about 200 percent from 1955 through 1980 and then decreased slightly (by about 20 percent) from 1980 to 1995. Irrigation water use, which represents the State's largest category of water use, showed the same trend. Because the majority of irrigation withdrawals were from ground water, the same pattern of increasing withdrawals from 1955 through 1980 (by about 450 percent) and then decreasing withdrawals (by 37 percent) from 1980–95, was evident in the ground-water source category. Irrigation application rates vary

Table 7. Results of Kendall's tau trend analysis of winter (December, January, February) water levels in 17 shallow wells in Kansas, 1958–97

[Shading indicates statistically significant at the 95-percent confidence level (probability value less than or equal to 0.05). $(ft^3/s)/yr$, cubic feet per second per year; <, less than]

Map index number (fig. 8)	County and well number	Number of years with missing data	Kendall's tau[1]	Probability value	Slope $[(ft^3/s)/yr]$
W1	Cheyenne 1	2	-0.220	0.0297	-0.0204
W2	Cheyenne 2	4	-.442	.2970	.0309
W3	Douglas 1	0	+.043	<.0001	+.0150
W4	Gray 1	9	-.417	.6840	-.2000
W5	Hamilton 1	0	-.107	.0007	-.0171
W6	Hamilton 2	10	-.345	.0050	-.0642
W7	Harvey 1	4	-.246	.0038	-.0425
W8	Harvey 2	0	-.354	.0082	-.0278
W9	Kingman 1	14	+.025	.0001	+.0017
W10	Kiowa 1	5	-.142	.8820	-.0639
W11	Meade 1	5	+.606	<.0001	+.1900
W12	Meade 2	10	-.374	.0002	-.0299
W13	Neosho 1	0	-.460	<.0001	-.0926
W14	Reno 1	17	+.014	.9030	+.0017
W15	Reno 2	5	-.348	.0002	-.0512
W16	Sedgwick 1	0	-.297	.0046	-.0550
W17	Sedgwick 2	1	-.612	<.0001	-.0683

[1]Positive values for Kendall's tau and slope represent increasing water-table altitudes.

from year to year and depend on annual rainfall, surface-water availability, farm commodity prices, application technologies, and conservation practices (Solley and others, 1998).

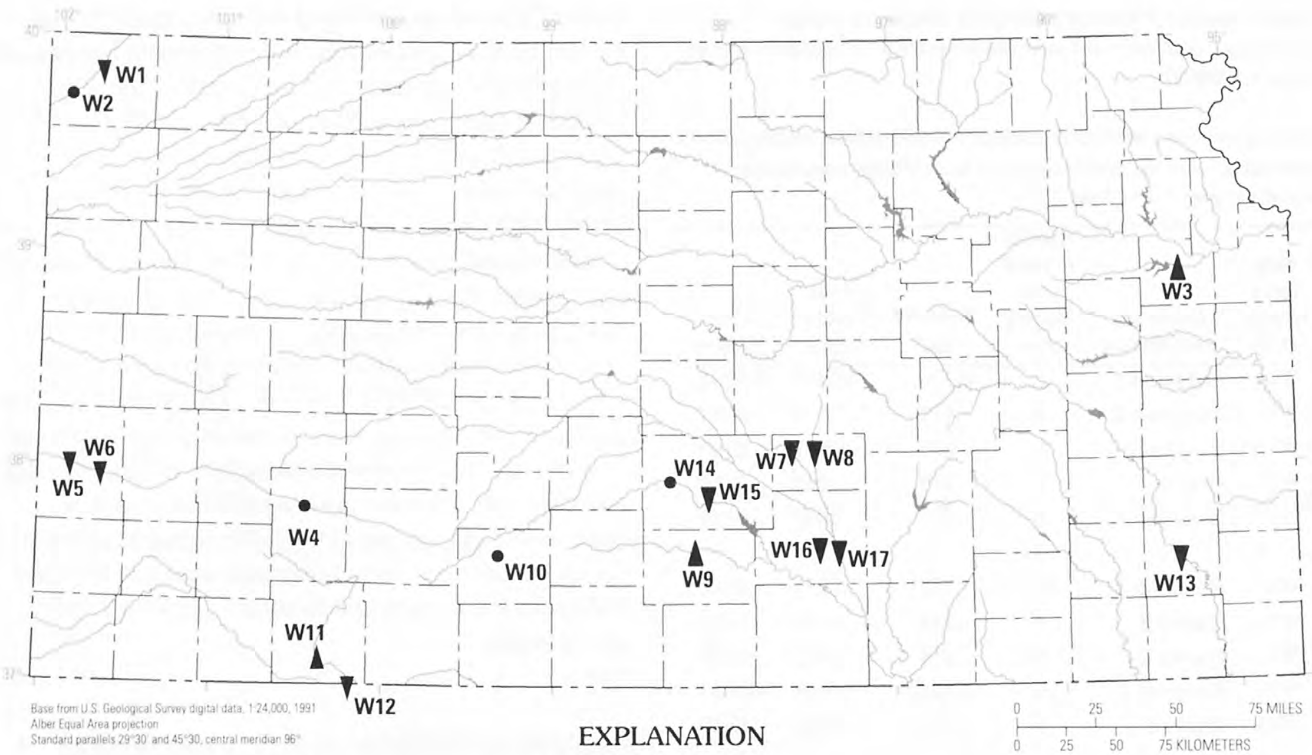
Irrigation water use and declines in ground-water levels in western Kansas and Nebraska probably have contributed to decreasing streamflows. The effect of ground-water depletion on surface-water flow is highly variable. Over the short term, irrigation drainage locally may increase both surface-water flow and the height of the water table. However, over the long term, excessive ground-water withdrawals will deplete surface-water supplies to some degree by lowering the water table (Sophocleous, 1998). Under base-flow conditions, the water level in a stream or lake intersects the ground-water level. Flow in some streams in western Kansas has changed from perennial to intermittent because ground-water development has caused the regional water table to decline below the streambed (Angelo, 1994; Sophocleous, 1998). Decreasing streamflows in western Oklahoma also have been attributed to depletion of ground water (Wahl and Wahl, 1988; Wahl and Tortorelli, 1996). In a study of rainfall-runoff relations for two river basins in central and western Kansas, Jordan (1982) found that the amount of runoff from 1967–75 was 50 percent less than the amount of runoff resulting from the same amount of rainfall from 1948–66. That study indicated that one-fourth to one-third of the decrease in streamflow could be attributed to a decrease in base flow that occurred concurrently with an increase in ground-water pumpage. Jordan (1982) attributed the remainder of the decrease to farming practices that increase soil-moisture storage and to construction of ponds and terraces.

EFFECTS OF TRENDS ON FLOOD-FREQUENCY ANALYSIS

Analysis of Flood-Frequency Estimates

Flood-frequency analysis uses annual peak flows to estimate the probabilities for certain flood magnitudes when designing bridges, highways, and other flood-plain structures. Frequency analysis assumes that the data series is stationary; that is, the statistical parameters, such as mean, variance, and skewness coefficient, do not change over time. If significant trends exist in the peak-flow series, the data are not stationary, violating the assumptions of frequency analysis and introducing error into the statistical analysis. Whether the error is large enough to invalidate the frequency analysis results becomes the issue.

The effects of significant trends on flood-frequency analysis were investigated by adding hypothetical trends to four nontrending stream-gaging-station records and comparing estimated flood magnitudes. Flood-frequency analysis was carried out according to procedures outlined in Bulletin 17B of the Interagency Advisory Committee on Water Data (1982). The guidelines presented in Bulletin 17B were established to provide consistency in flood-frequency analysis done by Federal agencies. It uses annual peak-flow series to compute flood-frequency curves by fitting a Pearson type-III distribution to the logarithms



EXPLANATION

Trends in water-table altitude

W11▲ Significant increasing trend (95-percent confidence level)

W16▼ Significant decreasing trend (95-percent confidence level)

W10● No significant trend

Numbers are map index numbers shown in table 7

Figure 8. Results of Kendall's tau analysis of winter (December, January, February) water levels in 17 shallow wells in Kansas, 1958–97.

of the peak flows. Special techniques are recommended for handling low outliers, zero-flow years, historic peaks, and other aspects of the procedure. As a general rule, frequency analysis is questioned when using a historical record less than 10 years in length and in estimating frequencies of floods greater than twice the length of record (Viessman and Lewis, 1996).

The four stream-gaging-station records used to examine the effects of trends on flood-frequency analysis were Caney River near Elgin (station 07172000, map index number 54), Stranger Creek near Tonganoxie (station 06892000, map index number 32), Pottawatomie Creek near Garnett (station 06914000, map index number 34), and Otter Creek at Climax (station 07167500, map index number 53). These stations were selected because each had a Kendall's tau value near zero and an associated large value for probablility (p), indicating no trend in the data (table 2). Trends were introduced to the records by adding a given hypothetical percentage increase or decrease incrementally to each year of the 40-year record. Increasing trends were added to the two station records that initially had positive tau values (map index numbers 54 and 32, table 2). The other two station records had negative tau values (map index numbers 34 and 53, table 2); therefore, decreasing trends were added to those records.

Tables 9–12 show how annual peak-flow values from 1958–97 were affected by the added trends. The first column after the year shows the annual peak flows with no change. The next flow column shows the peak with a slight trend added. The third flow column shows slightly more trend added. The final flow column shows the peak flows with just enough added trend to result in a Kendall's tau probability level of less than 0.05, indicating statistical significance. The bottoms of the tables show estimated floods that are based on each peak-flow series. The lower and upper ranges of the confidence limits are shown in parenthe-

Table 8. Estimated total water withdrawals in Kansas by water-use category, except hydroelectric, 1955–95

Water-use category	Estimated total water withdrawals (million gallons per day)[1]								
	1955	1960	1965	1970	1975	1980	1985	1990	1995
Total withdrawal	2,235	2,800	2,800	3,800	5,800	6,600	5,670	6,080	5,240
Public supply	205	200	280	250	290	290	316	373	370
Rural domestic and livestock	70	94	100	130	130	140	110	139	133
Irrigation	740	1,800	2,300	3,000	5,000	5,600	4,730	4,190	3,380
Industrial	1,220	700	100	360	390	530	510	1,385	1,352
Source of water									
Ground	1,006	1,200	2,300	3,100	5,000	5,600	4,800	4,360	3,510
Surface	1,229	1,600	550	640	810	980	866	1,720	1,720

[1]Estimates of total water withdrawals from MacKichan (1951, 1957), MacKichan and Kammerer (1961), Murray (1968), Murray and Reeves (1972, 1977), and Solley and others (1983, 1988, 1993, 1998).

ses for the original peak-flow series. It was determined that a 3-percent increasing trend was needed for the Caney River station (table 9) and the Stranger Creek (table 10) records to attain statistically significant trends. A 1.5-percent decreasing trend was needed for the Pottawatomie Creek station (table 11) and the Otter Creek station (table 12) records.

The comparison of flood magnitudes between a nontrending peak-flow series and the same series with an added 3-percent increasing trend revealed that flood estimates increased by as much as 70 percent. The 10-year flood estimate increased by 62 percent for Stranger Creek (table 10) and 63 percent for Caney River (table 9). The 50-year flood estimates increased by 66 percent (table 10) and 68 percent (table 9), respectively, and the 100-year flood estimates increased by 68 percent and 70 percent, respectively. In all cases for the Stranger Creek and Caney River station records, the flood estimate from the trending series was greater than the upper confidence limit established by the nontrending series, indicating the potential importance of accounting for trends.

Comparing flood magnitudes between the nontrending series and the same series with a 1.5-percent decreasing trend showed that the largest percentage change in flood estimates occurred for 5-year floods, which decreased by 28 percent for both the Pottawatomie Creek and Otter Creek station records. The 25-year flood estimate decreased by 20 percent and 23 percent, respectively. For both records, the flood estimates for the trending series were greater than the lower confidence limit established by the unaltered series for the 25-, 50-, and 100-year floods. The estimates were less than the lower limits, however, for the 5-year flood, again indicating the potential importance of accounting for trends.

The percentage differences derived by adding trends to the peak-flow records and then comparing flood magnitudes estimated using flood-frequency analysis are not intended to be used as "correction factors" for records with streamflow trends. The purpose of the comparison is to quantify the effect of peak-flow trends to consider their importance in flood-frequency analysis. Determining an appropriate method for applying flood-frequency analysis to streamflow records containing peak-flow trends was beyond the scope of this report.

Discussion

Flood risk changes over time. It appears that flood estimates for specific frequencies can change considerably on the basis of period of record used and on whether trends, either cyclic or monotonic, occur in the data. Flood-frequency analysis assumes that future peak-flow conditions will be similar to past conditions.

Determining the appropriate period of record to use when estimating flood recurrence intervals is perhaps a larger issue than previously thought. The traditional approach to flood-frequency estimation involves a tradeoff between bias and variance (National Research Council, 1999). Bias arises when long periods of record are used that include time periods when flood risk is different than during the current planning period. However, long periods of record result in better definition of the variance.

Climate variations may prove to be the most challenging aspect to estimating floods. Although human-related causes of peak-flow trends, such as changes in land and water use, can be projected into the future with reasonable accuracy, climate is much less predictable. As the National Research Council (1999,

Table 9. Results of Kendall's tau trend test and flood-frequency analysis of Caney River near Elgin (station 07172000, map index number 54) peak-flow record with increasing trend added

Year	Peak flow (cubic feet per second)						
	No change	2-percent increase[1]		2.5-percent increase[1]		3-percent increase[1]	
1958	17,900	1.00	17,900	1.000	17,900	1.00	17,900
1959	23,600	1.02	24,072	1.025	24,190	1.03	24,308
1960	23,600	1.04	24,544	1.050	24,780	1.06	25,016
1961	62,000	1.06	65,720	1.075	66,650	1.09	67,580
1962	21,100	1.08	22,788	1.100	23,210	1.12	23,632
1963	2,160	1.10	2,376	1.125	2,430	1.15	2,484
1964	1,930	1.12	2,162	1.150	2,220	1.18	2,277
1965	19,900	1.14	22,686	1.175	23,383	1.21	24,079
1966	25,800	1.16	29,928	1.200	30,960	1.24	31,992
1967	10,100	1.18	11,918	1.225	12,373	1.27	12,827
1968	13,800	1.20	16,560	1.250	17,250	1.30	17,940
1969	23,200	1.22	28,304	1.275	29,580	1.33	30,856
1970	17,800	1.24	22,072	1.300	23,140	1.36	24,208
1971	2,940	1.26	3,704	1.325	3,896	1.39	4,087
1972	8,650	1.28	11,072	1.350	11,678	1.42	12,283
1973	15,300	1.30	19,890	1.375	21,038	1.45	22,185
1974	20,600	1.32	27,192	1.400	28,840	1.48	30,488
1975	20,900	1.34	28,006	1.425	29,783	1.51	31,559
1976	19,100	1.36	25,976	1.450	27,695	1.54	29,414
1977	29,300	1.38	40,434	1.475	43,218	1.57	46,001
1978	16,700	1.40	23,380	1.500	25,050	1.60	26,720
1979	4,670	1.42	6,631	1.525	7,122	1.63	7,612
1980	13,600	1.44	19,584	1.550	21,080	1.66	22,576
1981	872	1.46	1,273	1.575	1,373	1.69	1,474
1982	22,000	1.48	32,560	1.600	35,200	1.72	37,840
1983	12,700	1.50	19,050	1.625	20,638	1.75	22,225
1984	10,600	1.52	16,112	1.650	17,490	1.78	18,868
1985	14,400	1.54	22,176	1.675	24,120	1.81	26,064
1986	27,600	1.56	43,056	1.700	46,920	1.84	50,784
1987	104,000	1.58	164,320	1.725	179,400	1.87	194,480
1988	19,900	1.60	31,840	1.750	34,825	1.90	37,810
1989	23,700	1.62	38,394	1.775	42,068	1.93	45,741
1990	34,600	1.64	56,744	1.800	62,280	1.96	67,816
1991	5,940	1.66	9,860	1.825	10,841	1.99	11,821
1992	5,110	1.68	8,585	1.850	9,454	2.02	10,322
1993	17,800	1.70	30,260	1.875	33,375	2.05	36,490
1994	32,900	1.72	56,588	1.900	62,510	2.08	68,432
1995	4,320	1.74	7,517	1.925	8,316	2.11	9,115
1996	3,020	1.76	5,315	1.950	5,889	2.14	6,463

Table 9. Results of Kendall's tau trend test and flood-frequency analysis of Caney River near Elgin (station 07172000, map index number 54) peak-flow record with increasing trend added—Continued

Year	Peak flow (cubic feet per second): No change	2-percent increase[1]		2.5-percent increase[1]		3-percent increase[1]	
1997	17,000	1.78	30,260	1.975	33,575	2.17	36,890
Mean	19,278		26,770		28,643		30,516
Median	17,800		22,737		23,751		24,258
Kendall's tau	.0115		.171		.179		.218
Probability level	.926		.124		.110		.049
Slope	9.62		329		437		524
100-year flood	84,900 [2](60,000, 136,000)		123,000		136,000		144,000
50-year flood	72,100 [2](51,900, 112,000)		104,000		114,000		121,000
25-year flood	59,500 [2](43,800, 89,300)		85,200		92,700		98,800
10-year flood	43,200 [2](32,900, 61,400)		61,200		65,900		70,400
5-year flood	31,300 [2](24,400, 42,300)		43,800		46,700		50,000

[1]First column is factor by which original peak flow is multiplied to impart trend.

[2]Values in parentheses indicate confidence limits.

Table 10. Results of Kendall's tau trend test and flood-frequency analysis of Stranger Creek near Tonganoxie (station 06892000, map index number 32) peak-flow record with increasing trend added

Year	Peak flow (cubic feet per second): No change	2-percent increase[1]		2.5-percent increase[1]		3-percent increase[1]	
1958	19,100	1.00	19,100	1.000	19,100	1.00	19,100
1959	4,120	1.02	4,202	1.025	4,223	1.03	4,244
1960	9,540	1.04	9,922	1.050	10,017	1.06	10,112
1961	7,820	1.06	8,289	1.075	8,407	1.09	8,524
1962	20,600	1.08	22,248	1.100	22,660	1.12	23,072
1963	2,410	1.10	2,651	1.125	2,711	1.15	2,772
1964	2,790	1.12	3,125	1.150	3,209	1.18	3,292
1965	10,100	1.14	11,514	1.175	11,868	1.21	12,221
1966	5,290	1.16	6,136	1.200	6,348	1.24	6,560
1967	17,800	1.18	21,004	1.225	21,805	1.27	22,606
1968	5,530	1.20	6,636	1.250	6,913	1.30	7,189
1969	12,200	1.22	14,884	1.275	15,555	1.33	16,226
1970	9,730	1.24	12,065	1.300	12,649	1.36	13,233
1971	3,220	1.26	4,057	1.325	4,267	1.39	4,476
1972	7,910	1.28	10,125	1.350	10,679	1.42	11,232
1973	7,560	1.30	9,828	1.375	10,395	1.45	10,962
1974	11,300	1.32	14,916	1.400	15,820	1.48	16,724
1975	4,710	1.34	6,311	1.425	6,712	1.51	7,112
1976	3,580	1.36	4,869	1.450	5,191	1.54	5,513
1977	14,900	1.38	20,562	1.475	21,978	1.57	23,393

Table 10. Results of Kendall's tau trend test and flood-frequency analysis of Stranger Creek near Tonganoxie (station 06892000, map index number 32) peak-flow record with increasing trend added—Continued

Year	Peak flow (cubic feet per second)						
	No change	2-percent increase[1]		2.5-percent increase[1]		3-percent increase[1]	
1978	6,130	1.40	8,582	1.500	9,195	1.60	9,808
1979	4,080	1.42	5,794	1.525	6,222	1.63	6,650
1980	6,620	1.44	9,533	1.550	10,261	1.66	10,989
1981	8,210	1.46	11,987	1.575	12,931	1.69	13,875
1982	18,400	1.48	27,232	1.600	29,440	1.72	31,648
1983	6,950	1.50	10,425	1.625	11,294	1.75	12,163
1984	4,070	1.52	6,186	1.650	6,716	1.78	7,245
1985	11,400	1.54	17,556	1.675	19,095	1.81	20,634
1986	15,100	1.56	23,556	1.700	25,670	1.84	27,784
1987	5,400	1.58	8,532	1.725	9,315	1.87	10,098
1988	1,490	1.60	2,384	1.750	2,608	1.90	2,831
1989	9,080	1.62	14,710	1.775	16,117	1.93	17,524
1990	13,400	1.64	21,976	1.800	24,120	1.96	26,264
1991	2,250	1.66	3,735	1.825	4,106	1.99	4,478
1992	5,580	1.68	9,374	1.850	10,323	2.02	11,272
1993	11,100	1.70	18,870	1.875	20,813	2.05	22,755
1994	5,700	1.72	9,804	1.900	10,830	2.08	11,856
1995	7,860	1.74	13,676	1.925	15,131	2.11	16,585
1996	14,100	1.76	24,816	1.950	27,495	2.14	30,174
1997	12,900	1.78	22,962	1.975	25,478	2.17	27,993
Mean	8,751		12,103		12,942		13,780
Median	7,840		10,023		10,754		11,564
Kendall's tau	.0231		.173		.208		.247
Probability level	.843		.118		.061		.025
Slope	16.8		165		200		243
100-year flood	29,600 [2](22,600, 42,700)		42,300		46,800		49,600
50-year flood	25,400 [2](19,800, 35,700)		36,200		39,900		42,200
25-year flood	21,,400 [2](17100, 29,100)		30,400		33,300		35,200
10-year flood	16,300 [2](13,400, 21,200)		23,000		25,000		26,400
5-year flood	12,600 [2](10,500, 15,700)		17,500		18,900		20,000

[1]First column is factor by which original peak flow is multiplied to impart trend.

[2]Values in parentheses indicate confidence limits.

Table 11. Results of Kendall's tau trend test and flood-frequency analysis of Pottawatomie Creek at Garnett (station 06914000, map index number 34) peak-flow record with decreasing trend added

Year	Peak flow (cubic feet per second)						
	No change	0.5-percent decrease[1]		1.0-percent decrease[1]		1.5-percent decrease[1]	
1958	12,900	1.000	12,900	1.00	12,900	1.000	12,900
1959	4,110	.995	4,089	.99	4,069	.985	4,048
1960	9,760	.990	9,662	.98	9,565	.970	9,467
1961	57,000	.985	56,145	.97	55,290	.955	54,435
1962	18,500	.980	18,130	.96	17,760	.940	17,390
1963	5,700	.975	5,558	.95	5,415	.925	5,273
1964	5,650	.970	5,481	.94	5,311	.910	5,142
1965	10,700	.965	10,326	.93	9,951	.895	9,577
1966	3,770	.960	3,619	.92	3,468	.880	3,318
1967	42,000	.955	40,110	.91	38,220	.865	36,330
1968	5,080	.950	4,826	.90	4,572	.850	4,318
1969	14,600	.945	13,797	.89	12,994	.835	12,191
1970	29,000	.940	27,260	.88	25,520	.820	23,780
1971	9,800	.935	9,163	.87	8,526	.805	7,889
1972	10,700	.930	9,951	.86	9,202	.790	8,453
1973	10,800	.925	9,990	.85	9,180	.775	8,370
1974	36,200	.920	33,304	.84	30,408	.760	27,512
1975	19,900	.915	18,209	.83	16,517	.745	14,826
1976	3,670	.910	3,340	.82	3,009	.730	2,679
1977	13,000	.905	11,765	.81	10,530	.715	9,295
1978	11,600	.900	10,440	.80	9,280	.700	8,120
1979	24,000	.895	21,480	.79	18,960	.685	16,440
1980	14,900	.890	13,261	.78	11,622	.670	9,983
1981	12,600	.885	11,151	.77	9,702	.655	8,253
1982	11,000	.880	9,680	.76	8,360	.640	7,040
1983	11,400	.875	9,975	.75	8,550	.625	7,125
1984	11,800	.870	10,266	.74	8,732	.610	7,198
1985	8,890	.865	7,690	.73	6,490	.595	5,290
1986	15,300	.860	13,158	.72	11,016	.580	8,874
1987	18,600	.855	15,903	.71	13,206	.565	10,509
1988	13,800	.850	11,730	.70	9,660	.550	7,590
1989	12,300	.845	10,394	.69	8,487	.535	6,581
1990	10,700	.840	8,988	.68	7,276	.520	5,564
1991	2,950	.835	2,463	.67	1,977	.505	1,490
1992	16,200	.830	13,446	.66	10,692	.490	7,938
1993	17,200	.825	14,190	.65	11,180	.475	8,170
1994	12,100	.820	9,922	.64	7,744	.460	5,566
1995	10,100	.815	8,232	.63	6,363	.445	4,495

Table 11. Results of Kendall's tau trend test and flood-frequency analysis of Pottawatomie Creek at Garnett (station 06914000, map index number 34) peak-flow record with decreasing trend added—Continued

Year	Peak flow (cubic feet per second)						
	No change	0.5-percent decrease[1]		1.0-percent decrease[1]		1.5-percent decrease[1]	
1996	4,510	0.810	3,653	0.62	2,796	0.430	1,939
1997	10,200	.805	8,211	.61	6,222	.415	4,233
Mean	14,325		13,046		11,768		10,490
Median	11,700		10,296		9,241		8,029
Kendall's tau	-.009		-.095		-.192		-.297
Probability level	.944		.395		.083		.007
Slope	-11.5		-53.5		-106		-162
100-year flood	52,100 [2](39,300, 77,000)		49,000		46,400		44,800
50-year flood	43,800 [2](33,700, 62,500)		40,800		38,200		36,100
25-year flood	36,100 [2](28,400, 49,600)		33,300		30,800		28,700
10-year flood	26,700 [2](21,700, 34,800)		24,300		22,100		20,100
5-year flood	20,100 [2](16,700, 25,100)		18,200		16,300		14,500

[1]First column is factor by which original peak flow is multiplied to impart trend.

[2]Values in parentheses indicate confidence limits.

Table 12. Results of Kendall's tau trend test and flood-frequency analysis of Otter Creek at Climax (station 07167500, map index number 53) peak-flow record with decreasing trend added

Year	Peak flow (cubic feet per second)						
	No change	0.5-percent decrease[1]		1.0-percent decrease[1]		1.5-percent decrease[1]	
1958	10,400	1.000	10,400	1.00	10,400	1.000	10,400
1959	11,900	.995	11,841	.99	11,781	.985	11,722
1960	9,110	.990	9,019	.98	8,928	.970	8,837
1961	44,000	.985	43,340	.97	42,680	.955	42,020
1962	12,400	.980	12,152	.96	11,904	.940	11,656
1963	1,750	.975	1,706	.95	1,663	.925	1,619
1964	254	.970	246	.94	239	.910	231
1965	19,800	.965	19,107	.93	18,414	.895	17,721
1966	4,640	.960	4,454	.92	4,269	.880	4,083
1967	16,600	.955	15,853	.91	15,106	.865	14,359
1968	3,980	.950	3,781	.90	3,582	.850	3,383
1969	18,600	.945	17,577	.89	16,554	.835	15,531
1970	27,800	.940	26,132	.88	24,464	.820	22,796
1971	3,560	.935	3,329	.87	3,097	.805	2,866
1972	3,870	.930	3,599	.86	3,328	.790	3,057
1973	7,860	.925	7,271	.85	6,681	.775	6,092
1974	22,800	.920	20,976	.84	19,152	.760	17,328
1975	17,200	.915	15,738	.83	14,276	.745	12,814
1976	107,000	.910	97,370	.82	87,740	.730	78,110

Table 12. Results of Kendall's tau trend test and flood-frequency analysis of Otter Creek at Climax (station 07167500, map index number 53) peak-flow record with decreasing trend added—Continued

Year	Peak flow (cubic feet per second)						
	No change	0.5-percent decrease[1]		1.0-percent decrease[1]		1.5-percent decrease[1]	
1977	29,000	0.905	26,245	0.81	23,490	0.715	20,735
1978	4,060	.900	3,654	.80	3,248	.700	2,842
1979	16,100	.895	14,410	.79	12,719	.685	11,029
1980	4,920	.890	4,379	.78	3,838	.670	3,296
1981	1,820	.885	1,611	.77	1,401	.655	1,192
1982	25,600	.880	22,528	.76	19,456	.640	16,384
1983	9,470	.875	8,286	.75	7,103	.625	5,919
1984	7,980	.870	6,943	.74	5,905	.610	4,868
1985	5,710	.865	4,939	.73	4,168	.595	3,397
1986	12,100	.860	10,406	.72	8,712	.580	7,018
1987	16,000	.855	13,680	.71	11,360	.565	9,040
1988	13,400	.850	11,390	.70	9,380	.550	7,370
1989	5,690	.845	4,808	.69	3,926	.535	3,044
1990	4,400	.840	3,696	.68	2,992	.520	2,288
1991	1,610	.835	1,344	.67	1,079	.505	813
1992	4,530	.830	3,760	.66	2,990	.490	2,220
1993	9,880	.825	8,151	.65	6,422	.475	4,693
1994	26,500	.820	21,730	.64	16,960	.460	12,190
1995	16,600	.815	13,529	.63	10,458	.445	7,387
1996	1,730	.810	1,401	.62	1,073	.430	744
1997	10,900	.805	8,775	.61	6,649	.415	4,523
Mean	14,288		12,989		11,690		10,390
Median	10,140		8,897		7,907		6,555
Kendall's tau	-.0526		-.100		-.162		-.218
Probability level	.641		.370		.145		.049
Slope	-50.2		-94		-134		-173
100-year flood	78,500 [2](52,200, 138,000)		72,500		67,100		62,700
50-year flood	61,800 [2](42,300, 103,500)		56,900		52,400		48,500
25-year flood	47,100 [2](33,300, 75,000)		43,300		39,600		36,300
10-year flood	30,800 [2](22,800, 45,500)		28,200		25,600		23,100
5-year flood	20,600 [2](15,700, 28,500)		18,700		16,800		14,900

[1]First column is factor by which original peak flow is multiplied to impart trend.

[2]Values in parentheses indicate confidence limits.

p. 67–68) explains in its recent study of the American River flood-frequency analysis:

> "Non-stationarities pose a serious challenge to flood frequency and risk analysis, and flood control design and practices. If cyclical or regime-like variations arise due to the natural dynamics of the climate system, a relatively short historical record may not be representative of the succeeding design period. Furthermore, by the time one recognizes that the project operation period has been different from the period of record used for design, the climate system may be ready to switch regimes again. Thus it is unclear whether the full record, the first half of the record, the last half of the record or some other suitably selected portion is most useful for future decisions… ."

A general conclusion, then, is that more uncertainty exists in flood-frequency estimates than that suggested by conventional statistical analysis. Although a large amount of uncertainty is built into the frequency analysis, it is rarely considered in flood-plain decision-making processes. The National Research Council (1999) recommends that the existing static flood-risk framework, in which a single flood-frequency distribution is estimated from all available data and applied to an indefinite future period, be replaced with a more dynamic framework. A more appropriate approach would be to consider the length of the record, climatic factors, the length of the planning period, risk and uncertainty, and then follow up with periodic flood-frequency updates.

SUMMARY

The magnitude of the annual peak flow for some streams in Kansas appears to be changing. The Kendall's tau trend test was used to identify and evaluate peak-flow trends in Kansas and in two adjoining States, Oklahoma and Nebraska. Initially, the same 40-year period of record, 1957–98, was used in the analysis. Thirteen (32 percent) of the 40 stream-gaging stations in Kansas that were analyzed showed a significant trend in peak flow. Of the 13 trending station records, 10 indicated decreasing trends occurring in the western one-half of the State. The three increasing-trend stations were located in eastern Kansas.

A similar pattern occurred when station records from Oklahoma and Nebraska were included in the peak-flow analysis. When the same 40-year period of record was analyzed for peak-flow trends at 88 stream-gaging stations in the three-State area, 22 (25 percent) of the station records showed significant trends. Four station records showed increasing trends, and 18 records showed decreasing trends. Nearly all the stations with decreasing trends were located in western Kansas and southwestern Nebraska, whereas most of the stations with increasing trends were scattered across the eastern one-half of the area.

As the period of record is adjusted, so is the trend test result. The Kendall's tau test also was used to identify trends over the entire available period of record for 54 stations in Kansas with a record length of more than 38 years. Of the 54 stations used in this part of the analysis, 23 station records (43 percent) showed significant trends over their entire record. Sixteen station records (30 percent) had decreasing trends, and seven records (13 percent) had increasing trends. The trend test then was applied to 30-year periods moving in 5-year increments through the available period of record to identify time periods within each station record when peak-flow trends were occurring.

In addition to the peak-flow analysis, flow volume in Kansas was analyzed for trends using mean annual discharge for 29 stream-gaging stations. A regional pattern similar to the peak-flow analysis was apparent. Records from six stations showed a significant trend. All six trends were decreasing and occurred in the western one-half of Kansas.

To help evaluate possible causes of the streamflow trends, the Kendall's tau trend analysis was applied to total annual precipitation in the three-State area and to ground-water levels in Kansas. A significant trend in annual precipitation was detected for 3 of the 26 meteorological divisions analyzed in the three-State area. All three trends in precipitation were increasing and occurred in meteorological divisions located in south-central Oklahoma. One of three stream-gaging stations tested for trends in peak flow within the three trending meteorological divisions showed a significant increasing trend in peak flow.

Although the increasing trends may be caused by changes in precipitation patterns, decreasing streamflow in western Kansas and Nebraska probably are caused by factors other than precipitation. The Kendall's tau test was applied to water levels in 17 ground-water wells in Kansas. Water levels in 13 wells showed significant trends. Water levels in 10 wells, all located in central and western Kansas, indicated that the water table was declining. As the water table declines below streambed elevation, more rainfall is necessary to create flow and to attain peak flows comparable to those under previous conditions. Therefore, declining water tables caused largely by ground-water withdrawals are contributing to decreasing trends in peak streamflow in western Kansas. Decreasing peak streamflow also may be related to other factors such as construction of ponds and terraces.

Peak-flow data are used to estimate probabilities for certain flood magnitudes. Nonstationary data, such as the peak-flow records containing trends, introduce statistical error into the flood-frequency analysis. To examine the effect of trends on flood-frequency analysis, hypothetical trends were systematically added to four nontrending station records. For each record, flood-frequency analysis was conducted on both the unchanged record and the corresponding record with the added trend. The resulting estimated flood magnitudes were compared. The magnitude of the 100-year flood changed by as much as 70 percent. In some cases, flood-frequency estimates calculated using trending peak-flow records fell outside the wide confidence limits established by flood-frequency analysis using the unaltered series, indicating the potential importance of accounting for trends in the analysis.

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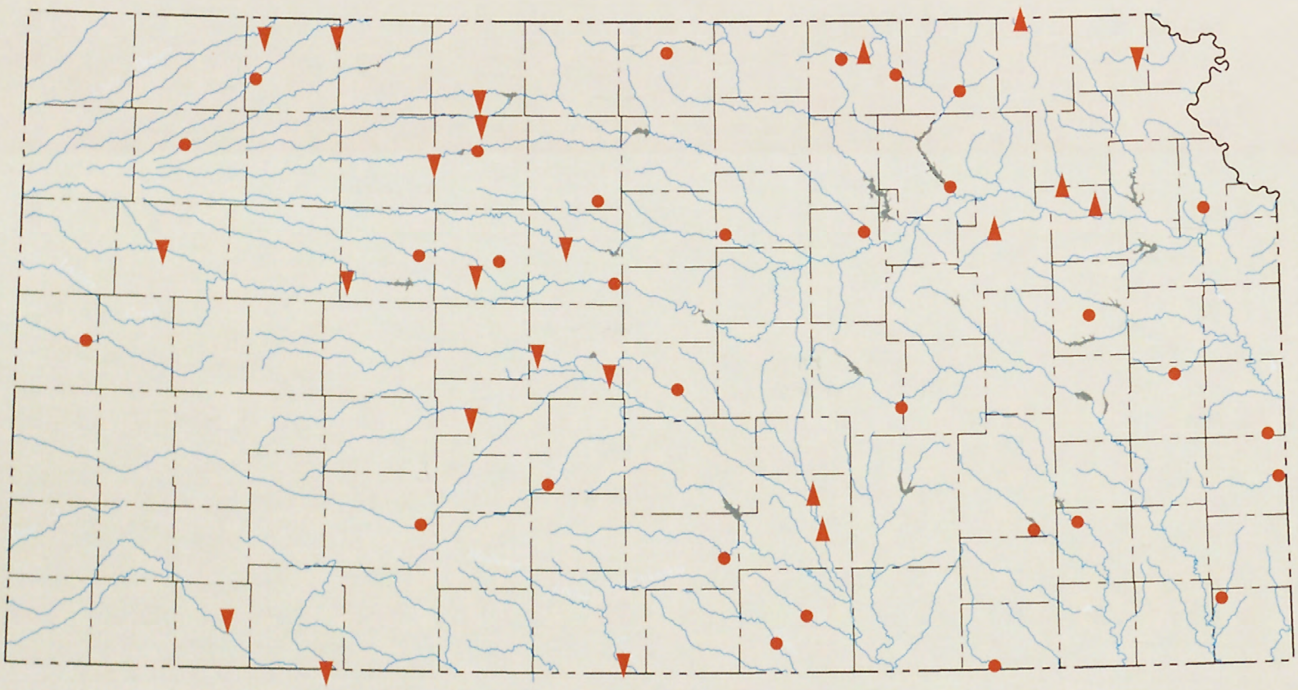

Stream-gaging-station records that show:

▲ Significant increasing trend (95-percent confidence level)
▼ Significant decreasing trend (95-percent confidence level)
● No significant trend

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