Tortorelli, R.L. and others—**Trends in Annual Peak Flows and Mean Annual Flows of Selected Streams Within and Near Oklahoma**—Scientific Investigations Report 2005–5192

Prepared in cooperation with the Oklahoma Department of Transportation

Trends in Annual Peak Flows and Mean Annual Flows of Selected Streams Within and Near Oklahoma

Fourche Maline 1927

Elm Fork North Fork of Red River 1995

Scientific Investigations Report 2005–5192

U.S. Department of the Interior
U.S. Geological Survey

Cover Photo Credit:

Top picture is flood of April 1927 Fourche Maline, automobile submerged for two days on mail highway between Talihina and Wister, one mile north of Summerfield, LeFlore County, Oklahoma; above present day Wister Lake. Photographer: H.D. Miser, U.S. Geological Survey.

Bottom picture is flood of June 3, 1995, Elm Fork of the North Fork Red River near Carl, Harmon County, Oklahoma, at State Highway 30 Bridge. Peak flow of record 62,3000 cubic feet per second. Photographer: Marty Phillips, U.S. Geological Survey.

Trends in Annual Peak Flows and Mean Annual Flows of Selected Streams Within and Near Oklahoma

By Robert L. Tortorelli, Teresa J. Rasmussen, and Charles A. Perry

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Scientific Investigations Report 2005–5192

U.S. Department of the Interior
U.S. Geological Survey

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

U.S. Geological Survey
P. Patrick Leahy, Acting Director

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Conversion Factors and Abbreviations

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

Trends in Annual Peak Flows and Mean Annual Flows of Selected Streams Within and Near Oklahoma

By Robert L. Tortorelli, Teresa J. Rasmussen, and Charles A. Perry

Abstract

Evidence that the magnitudes of the annual peak flow for some streams in Oklahoma are changing led to an investigation by the U.S. Geological Survey, in cooperation with the Oklahoma Department of Transportation, of trends in the magnitude of annual peak flows and mean annual flows in Oklahoma. Trends in peak flow are of particular interest to State and Federal highway agencies because trends might indicate changing levels of risk to highway structures in flood plains. The Kendall's tau test was used to identify trends and LOWESS trend lines were used as a graphical exploratory technique for trends. A peak-flow analysis used the entire period of record from 80 streamflow-gaging stations within and near Oklahoma that had a minimum of 36 years of record. Records from 3 streamflow-gaging stations indicated statistically significant upward trends in peak flows, while records from 12 stations indicated statistically significant downward trends. The records with upward trends were from streamflow-gaging stations scattered in the central and northeastern part of the study area, while the significant downward-trend stations were all located in the western part of the study area.

A peak-flow analysis used a recent 36-year period of record, 1968–2003, from 63 stations within and near Oklahoma. Seven station records had significant downward trends, and one station record had a significant upward trend. The significant downward-trend stations were located in the western part of the study area. The significant upward-trend station was located in the central part of the study area.

A peak-flow analysis used various 30-year periods separated by 5-year increments through the available periods of record from 63 stations within and near Oklahoma. From that analysis it is possible to identify time periods within each station record when peak-flow trends were occurring. Peak-flow trends generally were downward during 1956-85 and upward in 1966-95.

A mean annual-flow analysis used the entire period of record from 80 stations within and near Oklahoma that had more than 36 years of record. A regional pattern similar to the peak-flow analysis resulted, except more upward trends were significant. Twenty-eight records (35 percent) exhibited a trend; 22 streamflow-gaging stations indicated statistically significant upward trends in peak flows, while records from 6 stations indicated statistically significant downward trends. The significant downward-trend stations were located in the northwestern part of the study area. The LOWESS trend lines indicated an increase in streamflow at the end of the 20th century, around 1980-2000, for two-thirds of the stations analyzed.

A mean annual-flow analysis used a recent 36-year period of record, 1968–2003, from 63 stations within and near Oklahoma. Eighteen station records showed significant trends; 14 station records had upward trends, and 4 records had downward trends. The significant downward trend stations were located in the northwestern part of the study area.

Changes in precipitation patterns, long-term declines in ground-water levels in some stream basins, and increased water use may be contributing to peak-flow trends. To evaluate possible causes of the peak-flow trends, the Kendall's tau test was applied to total annual precipitation within and near Oklahoma, and to ground-water levels in Oklahoma. The lack of significant precipitation trends and presence of downward trends in ground-water levels in western Oklahoma indicated that declining water tables may be a factor contributing to downward trends in peak streamflow. Declining water tables maybe caused by ground-water withdrawals and other factors such as construction of ponds and terraces. Water use could not be used in the trend analyses due to a lack of reliable historic record. Estimates of total freshwater withdrawals in Oklahoma available on a 5-year basis from calendar year 1950 to 2000 were shown.

Peak-flow records containing trends may introduce statistical error into flood-frequency analysis. The effects of significant trends on flood-frequency analysis were investigated by adding hypothetical trends to four streamflow-gaging station records that had no significant trends. The added trends resulted in changes in the 100-year flood magnitudes of as much as 91 percent.

Introduction

There is evidence that the magnitudes of the annual peak flow for some streams in Oklahoma are changing. For example, annual peak-flow records for the Cimarron River near Waynoka in western Oklahoma (site 12, fig. 1, table 1) indicate that during the 18-year period, 1986–2003, the annual peak flow exceeded the 2-year flood discharge in only 2 years and never exceeded the 5-year flood discharge. During the previous 18-year period, 1968–85, the annual peak flow exceeded the 2-year flood discharge 8 times and exceeded the 5-year flood discharge 3 times. The recurrence intervals of annual peak flows for the Cimarron River near Waynoka 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 52 years of record from 1938–99 (Tortorelli, 2002). The peak flows of several sites along the Beaver-North Canadian River also have decreased over time (Wahl and Tortorelli, 1997). Conversely, annual peak-flow records (1964-2003) for the Washita River at Anadarko in south-central Oklahoma (site 72, fig. 1, table 1), which is regulated, indicate that during the 20-year period, 1984–2003, the annual peak flow exceeded the 2-year flood discharge 14 times and exceeded the 10-year flood discharge 4 times. During the previous 20-year period, 1964–83, the annual peak flow exceeded the 2-year flood discharge only 7 times and never exceeded the 10-year flood.

Recurrence interval is commonly used in hydrology to express the frequency of a random event. Recurrence interval is the reciprocal of the annual exceedance probability, and represents the ***average*** number of years between exceedances of the event magnitude. For instance, a flood discharge having an annual exceedance probability of 0.01 has a recurrence interval of 100 years. This does not imply that a 100-year flood peak will be exceeded each 100 years, but that it will be exceeded on the average of once every 100 years (Thomas and Corley, 1977). That peak might be exceeded in successive years, or more than once in the same year. The probability that a flood peak will be exceeded is associated with risk. Procedures for making flood risk estimates are given by the Interagency Advisory Committee on Water Data (IACWD) (1982).

Trends in peak streamflow are of particular interest to State and Federal highway agencies because trends might indicate changing levels of risk to highway structures in flood plains. Flood-frequency analysis of peak-flow records at streamflow-gaging stations, and regional frequency-analysis procedures used at ungaged sites, have been traditionally used to estimate flood-event magnitudes and assess flood risk. Frequency analysis is based on the assumption that annual flood discharges are independent and have an unchanging (stationary) distribution over time. A trend in annual peak flow could indicate that flood discharges are not independent, not stationary, or both, introducing an element of error into the flood-frequency analysis. This information will be useful for planning and operational purposes by developing the capability to identify changes in peak flows due to changes in land-use, climate, or engineering modifications and to revise estimates of flood frequency for these sites (Hirsch, 1999). The U.S. Geological Survey, in cooperation with the Oklahoma Department of Transportation, conducted an investigation to determine if trends in annual peak flow or mean annual flows are present in Oklahoma.

Purpose and Scope

The purposes of this report are to: (1) document whether significant trends exist in the magnitudes of annual peak flows and mean annual flows at selected streamflow-gaging stations within and near Oklahoma; (2) evaluate possible causes of the trends, including analyses of trends in precipitation, ground-water levels, and water use; and (3) document if trends in annual peak flows have a significant effect on flood magnitudes determined from flood-frequency analyses of data from selected streamflow sites. For the purpose of this report, a 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 annual peak-flow and mean-annual flow trends and the causes in Oklahoma. However, annual peak-flow and mean-annual flow records were analyzed from nearby streamflow-gaging stations in the adjoining States of Kansas, Missouri, Arkansas, and Texas to improve understanding of the regional pattern associated with trends in Oklahoma. Several different categories of analysis were used to identify trends in streamflow and any regional variation in trends. Peak flows from the entire available period of record through water year 2003 were investigated for selected streams within and near Oklahoma. Peak flows from the same 36-year period of record, water years 1968-2003, also were investigated for selected streams within and near Oklahoma. The complete periods of record were divided into moving 30-year blocks to recognize trending cycles in peak flow. Mean annual flows at selected streamflow-gaging stations within and near Oklahoma also were analyzed using mean annual flow values over the entire available period of record and the same 36-year period of record, water years 1968-2003.

The minimum length of record at any streamflow-gaging station used in the report was 36 years, from 1968-2003. The streamflow records are from unregulated streams with no substantial flow regulation or irrigation and from streamflows of which are substantially affected by regulation or irrigation. A stream is considered to be unregulated if runoff from the contributing drainage basin is unaffected by regulation, reservoirs, diversions, or other human-related activities. A stream is considered to be regulated if runoff from 20 percent or more of the contributing drainage basin is controlled by dams or other flow-regulation structures (Heimann and Tortorelli, 1988).

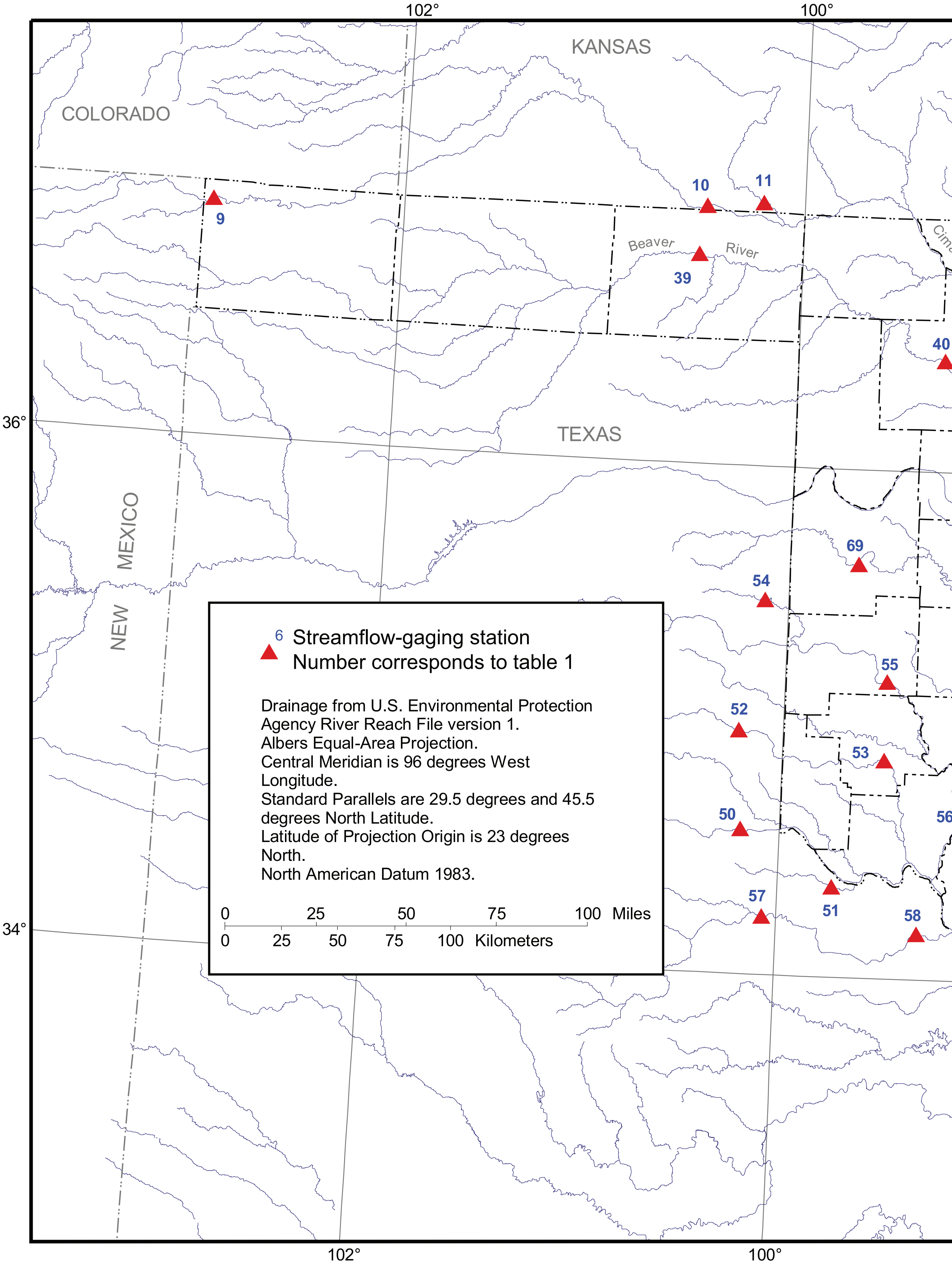

Figure 1. Locations of streamflow-gaging stations with a period of record of at least 36 years used in trend analyses.

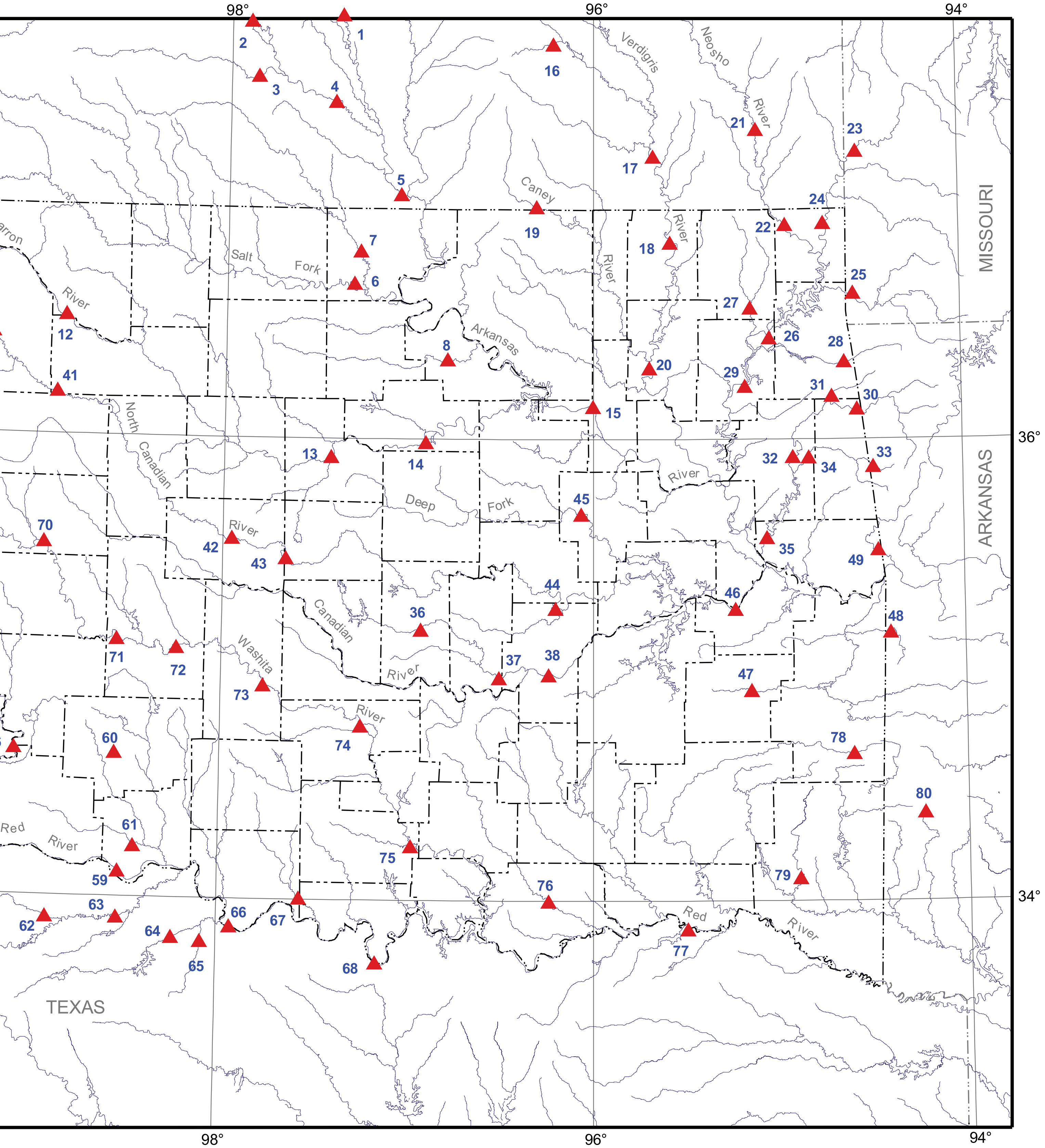
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Table 1. Summary of streamflow period of record for selected continuous-record streamflow-gaging stations used in study with at least 36 years of record from unregulated and regulated basins within and near Oklahoma

[I, irrigation; N, natural unregulated; R, regulated; mi^2, square miles; dms, degrees, minutes, seconds; Fk, Fork; R., River; abv, above; Res, Reservoir; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway; WY, water year]

Site number (fig. 1)	Station number	Station name	Type of record (I/N/R)	Continuous record period of record (complete water years)	Contributing drainage area (mi^2)	Latitude (dms)	Longitude (dms)
1	07144200	Little Arkansas River at Valley Center, Kans.	N	1923-2003	1,250	374956	0972316
2	07144780	North Fk Ninnescah R. abv Cheney Res, Kans.	N	1966-2003	476	375145	0980049
3	07145200	South Fk Ninnescah River near Murdock, Kans.	N	1951-59, 65-2003	543	373341	0975111
4	07145500	Ninnescah River near Peck, Kans.	N	1938-1963	1,785	372725	0972525
			R	1964-2003			
5	07146500	Arkansas River at Arkansas City, Kans.	N	1903-05, 22-42	36,106	370323	0970332
			R	1943-2003			
6	07151000	Salt Fork Arkansas R. at Tonkawa, Okla.[1]	N	1936-40	4,520	364019	0971833
			R	1942-2003			
7	07152000	Chikaskia R. near Blackwell, Okla.	N	1936-2003	1,859	364841	0971637
8	07153000	Black Bear Creek at Pawnee, Okla. [1]	N	1945-62	576	362037	0964757
			R	1968-2003			
9	07154500	Cimarron River near Kenton, Okla.	N	1951-2003	1,038	365536	1025731
10	07156900	Cimarron River near Forgan, Okla. [2]	N	1943-86, 88-2003	4,220	370040	1002929
11	07157500	Crooked Creek near Englewood, Kans.	N	1943-2003	813	370154	1001229
12	07158000	Cimarron River near Waynoka, Okla.	N	1938-2003	8,504	363102	0985245
13	07160000	Cimarron River near Guthrie, Okla.	N	1938-76, 84-2003	11,966	355514	0972532
14	07161450	Cimarron River near Ripley, Okla. [3]	N	1940-2003	13,053	355909	0965443
15	07164500	Arkansas River at Tulsa, Okla.	N	1926-64	62,074	360826	0960022
			R	1965-2003			
16	07167500	Otter Creek at Climax, Kans.	N	1947-2003	129	374229	0961324
17	07170500	Verdigris River at Independence, Kans. [1]	N	1896-1903, 1922-59	2,892	371325	0954039
			R	1967-2003			
18	07171000	Verdigris River near Lenapah, Okla. [1]	N	1939-59	3,639	365104	0953509
			R	1967-2003			
19	07172000	Caney River near Elgin, Kans.	N	1940-64	445	370014	0961859
			R	1965-2003			
20	07176000	Verdigris River near Claremore, Okla. [1]	N	1936-62	6,534	361826	0954152
			R	1964-2003			
21	07183500	Neosho River near Parsons, Kans. [1]	N	1922-62	4,905	372024	0950635
			R	1964-2003			

Table 1. Summary of streamflow period of record for selected continuous-record streamflow-gaging stations used in study with at least 36 years of record from unregulated and regulated basins within and near Oklahoma —Continued

[I, irrigation; N, natural unregulated; R, regulated; mi², square miles; dms, degrees, minutes, seconds; Fk, Fork; R., River; abv, above; Res, Reservoir; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway; WY, water year]

Site number (fig. 1)	Station number	Station name	Type of record (I/N/R)	Continuous record period of record (complete water years)	Contributing drainage area (mi²)	Latitude (dms)	Longitude (dms)
22	07185000	Neosho River near Commerce, Okla.[1]	N	1940-62	5,876	365543	0945726
			R	1964-2003			
23	07186000	Spring River near Waco, Mo.	N	1925-2003	1,164	371444	0943358
24	07188000	Spring River near Quapaw, Okla.	N	1940-2003	2,510	365604	0944446
25	07189000	Elk River near Tiff City, Mo.	N	1940-2003	872	363753	0943512
26	07190500	Neosho River near Langley, Okla.	R	1940-2003	10,335	362620	0950254
27	07191000	Big Cabin Creek near Big Cabin, Okla.	N	1948-2003	450	363406	0950907
28	07191220	Spavinaw Creek near Sycamore, Okla.	N	1962-2003	133	362007	0943827
29	07191500	Neosho River near Chouteau, Okla.[1]	N	1938-39	11,534	361346	0951057
			R	1965-2003			
30	07195500	Illinois River near Watts, Okla.	N	1956-2003	635	360748	0943419
31	07196000	Flint Creek near Kansas, Okla.	N	1956-76, 80-90, 93-2003	110	361111	0944224
32	07196500	Illinois River near Tahlequah, Okla.	N	1936-2003	959	355522	0945524
33	07196900	Baron Fork at Dutch Mills, Ark.	N	1959-2003	40.6	355248	0942911
34	07197000	Baron Fork at Eldon, Okla.	N	1949-2003	307	355516	0945018
35	07198000	Illinois River near Gore, Okla.[1]	N	1925, 40-51	1,626	353423	0950407
			R	1953-2003			
36	07230500	Little River near Tecumseh, Okla.[1]	N	1944-64	456	351021	0965554
			R	1966-2003			
37	07231000	Little River near Sasakwa, Okla.[1]	N	1943-61	884	345755	0963044
			R	1966-2003			
38	07231500	Canadian River at Calvin, Okla.	N	1906, 39-42, 45-64	23,151	345840	0961436
			R	1965-2003			
39	07234000	Beaver River at Beaver, Okla.[1, 4]	N	1938-71	3,685	364920	1003108
			IR	1979-2003			
40	07237500	North Canadian River at Woodward, Okla.[1, 4]	N	1939-71	6,777	362612	0991641
			IR	1979-2003			
41	07238000	North Canadian River near Seiling, Okla.[1, 4]	N	1947-71	7,414	361100	0985515
			IR	1979-2003			
42	07239500	North Canadian River near El Reno, Okla.[1]	N	1903-07, 38-47	8,143	353347	0975726
			R	1949-2003			
43	07241000	N. Canadian R. blw Lk Overholser nr OKC, Okla.	R	1953-68, 70-72, 74-87,89-2003	8,323	352843	0973947

Table 1. Summary of streamflow period of record for selected continuous-record streamflow-gaging stations used in study with at least 36 years of record from unregulated and regulated basins within and near Oklahoma —Continued

[I, irrigation; N, natural unregulated; R, regulated; mi², square miles; dms, degrees, minutes, seconds; Fk, Fork; R., River; abv, above; Res, Reservoir; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway; WY, water year]

Site number (fig. 1)	Station number	Station name	Type of record (I/N/R)	Continuous record period of record (complete water years)	Contributing drainage area (mi²)	Latitude (dms)	Longitude (dms)
44	07242000	North Canadian River near Wetumka, Okla.	R	1938-2003	9,391	351556	0961221
45	07243500	Deep Fork near Beggs, Okla.	N	1939-67	2,018	354026	0960406
			R	1968-2003			
46	07245000	Canadian River near Whitefield, Okla. [1]	N	1939-63	37,876	351550	0951421
			R	1965-2003			
47	07247500	Fourche Maline near Red Oak, Okla.	N	1939-63	122	345445	0950920
			R	1966-90, 92-2003			
48	07249400	James Fork near Hackett, Ark.	N	1959-2003	147	350945	0942425
49	07249985	Lee Creek near Short, Okla. [5]	N	1931-36, 51-91, 93-2003	420	353109	0942758
50	07299540	Prairie Dog Town Fork Red R. nr Childress, Tex.	N	1966-2003	2,958	343409	1001137
51	07299670	Groesbeck Creek at SH 6 near Quannah, Tex.	N	1963-2003	303	342116	0994424
52	07300000	Salt Fork Red River near Wellington, Tex. [1]	N	1953-66	1,013	345727	1001314
			R	1968-2003			
53	07300500	Salt Fork Red River at Mangum, Okla.	N	1938-2003	1,357	345130	0993030
54	07301410	Sweetwater Creek near Kelton, Tex.	N	1963-2003	267	352823	1000714
55	07301500	North Fork Red River near Carter, Okla. [6]	N	1938-62, 65-2003	1,938	351005	0993025
56	07305000	North Fork Red River near Headrick, Okla. [1]	N	1906-07, 38-43	3,845	343804	0990547
			R	1945-2003			
57	07307800	Pease River near Childress, Tex.	N	1961-62, 68-2003	2,195	341339	1000424
58	07308200	Pease River near Vernon, Tex.	N	1961-82, 93-2003	2,929	341047	0991923
59	07308500	Red River near Burkburnett, Tex.	N	1961-2003	14,634	340636	0983153
60	07311200	Blue Beaver Creek near Cache, Okla.	N	1965-2003	24.6	343724	0983348
61	07311500	Deep Red Creek near Randlett, Okla.	N	1950-2003	617	341315	0982710
62	07312200	Beaver Creek near Electra, Tex.	R	1961-2003	652	335421	0985417
63	07312500	Wichita River at Wichita Falls, Tex.	R	1939-2003	3,140	335434	0983200
64	07314900	Little Wichita River above Henrietta, Tex. [1]	R	1968-2003	1,037	334936	0981423
65	07315200	East Fork Little Wichita R. near Henrietta, Tex.	N	1964-2003	178	334846	0980505
66	07315500	Red River near Terral, Okla. [1]	N	1939-43	22,787	335243	0975603
			R	1945-2003			

Table 1. Summary of streamflow period of record for selected continuous-record streamflow-gaging stations used in study with at least 36 years of record from unregulated and regulated basins within and near Oklahoma —Continued

[I, irrigation; N, natural unregulated; R, regulated; mi², square miles; dms, degrees, minutes, seconds; Fk, Fork; R., River; abv, above; Res, Reservoir; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway; WY, water year]

Site number (fig. 1)	Station number	Station name	Type of record (I/N/R)	Continuous record period of record (complete water years)	Contributing drainage area (mi²)	Latitude (dms)	Longitude (dms)
67	07315700	Mud Creek near Courtney, Okla.	N	1961-2003	572	340015	0973400
68	07316000	Red River near Gainesville, Tex. [1]	N	1937-43	24,846	334340	0970935
			R	1945-2003			
69	07316500	Washita River near Cheyenne, Okla.	N	1938-60	794	353735	0994005
			R	1961-2003			
70	07325000	Washita River near Clinton, Okla. [1]	N	1936-60	1,977	353151	0985800
			R	1962-2003			
71	07325500	Washita River at Carnegie, Okla. [1]	N	1938-60	3,129	350702	0983349
			R	1962-2003			
72	07326500	Washita River at Anadarko, Okla. [1]	N	1903-08, 36-37	3,656	350503	0981435
			R	1964-2003			
73	07328100	Washita River at Alex, Okla.	R	1965-86, 89-2003	4,787	345533	0974625
74	07328500	Washita River near Pauls Valley, Okla. [1]	N	1938-60	5,330	344517	0971504
			R	1962-2003			
75	07331000	Washita River near Dickson, Okla. [1]	N	1929-60	7,202	341400	0965832
			R	1962-2003			
76	07332500	Blue River near Blue, Okla.	N	1937-2003	476	335949	0961427
77	07335500	Red River at Arthur City, Tex. [1]	N	1906-11, 37-43	38,595	335230	0953006
			R	1945-2003			
78	07335700	Kiamichi River near Big Cedar, Okla.	N	1966-2003	40.1	343818	0943645
79	07337900	Glover River near Glover, Okla.	N	1962-2003	315	340551	0945407
80	07340300	Cossatot River near Vandervoort, Ark.	N	1968-2003	89.6	342248	0941411

[1] Streamflow record period is omitted during transition between unregulated and regulated periods when reservoir (s) under construction.

[2] Includes streamflow record 1943-65 from nearby station 07157000, Cimarron River near Mocane, OK.

[3] Includes streamflow record 1940-89 from nearby station 07161000, Cimarron River at Perkins, OK.

[4] Pre- and post-irrigation development as defined in Wahl and Tortorelli (1997). Through WY 1971 is unregulated, WY 1972-78 are transition years to full irrigation development and regulated by reservoir.

[5] Was 07250000, Lee Creek near Van Buren, Ark., prior to WY 1993 and above Lee Creek Reservoir.

[6] Includes streamflow record 1938-44 from nearby station 07302000, North Fork Red River near Granite, OK.

An irrigation period of record is defined by those streamflow stations in the Beaver-North Canadian River above Canton Lake affected by irrigation well development in Wahl and Tortorelli (1997). Streamflow at some other stations likely has been affected by ground-water development, but it has not been documented. Records of annual peak flow may be longer than records of mean annual flow at some streamflow-gaging stations, because some annual peak flows may have been determined using indirect measurements of large floods that occurred outside of the period of continuous streamflow record (Tortorelli, 1997; Tortorelli and McCabe, 2001).

Changes in precipitation patterns, long-term declines in ground-water levels in some stream basins, and increased water use may be contributing to peak-flow trends. Total annual precipitation data within and near Oklahoma for the entire period of record, water years 1896-2003, and for a recent 36-year period of record, water years 1968-2003, also were investigated. Water level records were analyzed from wells in Oklahoma for the available periods of record. Estimates of total freshwater withdrawals in Oklahoma, available on a 5-year basis from calendar year 1950 to 2000, were shown and discussed.

Peak-flow records containing trends may introduce statistical error into flood-frequency analysis. The effects of significant trends on flood-frequency analysis were investigated by adding hypothetical trends to four streamflow-gaging station records that had no significant trends for a recent period of record, water years 1968-2003.

Acknowledgments

The following U.S. Geological Survey personnel provided assistance with this report: Jason Masoner produced the streamflow-gaging station site map and trend analyses results maps; and Lyn Osburn assisted in the design layout of the trend analysis graphs.

Methods

Kendall's Tau Test

Kendall's tau (Kendall and Gibbons, 1990), which served as the statistical basis for the trend analyses, is a non-parametric statistical test that can be used to indicate the likelihood of an upward or downward trend over time. A non-parametric test is one that is not based upon any particular probability distribution for the variables in question. A parametric test for trend, such as linear regression using time as a dependent variable, was not considered appropriate for streamflow because a parametric test is based on the normal distribution and streamflow characteristics may not be normally distributed. The Kendall's tau test is based on ranks of data values and does not depend specifically on the magnitudes of the data values. This test 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 annual 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 indicates that a trend does not exist. Therefore, the tau value is a measure of the correlation between the series and time. A trend was considered to be significant if the probability value (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 trend slope is a measure of the magnitude of the trend and was computed using Sen slope estimator (Sen, 1968; Helsel and Hirsch, 1992). The Kendall's tau test and Sen slope estimator were calculated with the *kensen* function in the statistical computer program S-Plus with the U.S. Geological Survey library (Insightful Corporation, 2002).

Results from past studies indicate that statistically significant trends in streamflow can be difficult to detect due to relatively short periods of record (Chiew and McMahon, 1993). 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, streamflow records 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, the sequences were minor and did not seem to substantially alter the overall results of the trend analysis.

LOWESS Trend Line

Smoothing is a graphical exploratory technique for depicting trends. The simplest smooths are moving averages or medians, whereby data are smoothed by calculating the mean or median for a portion of the total data within some window around a given time. Wahl and Tortorelli (1997) and Rasmussen and Perry (2001) used 10-year moving averages of annual peak flows and mean annual flows to graphically explore for trends.

LOWESS, or **LO**cally **WE**ighted **S**catterplot **S**moothing (Cleveland, 1979; Cleveland and Devlin, 1988) is a smoothing technique described in Helsel and Hirsch (1992) that is computationally intensive but reduces the influence of outliers and displays a smooth or trend line for the entire range of data. All graphs and LOWESS trend lines were produced in the statistical computer program S-Plus (Insightful Corporation, 2002). The primary parameter affecting the smoothness of the fit is the span, or window width, which controls the speed that the influence of points decreases with distance from a point of interest (Helsel and Hirsch, 1992; Insightful Corporation, 2002). All LOWESS trend lines were plotted with the computer program S-Plus using a span of 0.5 (Insightful Corporation, 2002).

Streamflow Trend Analyses

Peak Flow

All the streamflow stations used in the trend analyses are listed in table 1, and locations are shown in figure 1. The first part of the peak-flow analysis used the entire period of record from 80 currently (2003) operating streamflow-gaging stations within and near Oklahoma that had a minimum of 36 years of record (table 2, fig. 2). The second part of the peak-flow analysis used just a recent 36-year period of record, 1968–2003, from 63 stations within and near Oklahoma (table 3, fig. 3). The third part of the peak-flow analysis investigated trends for various 30-year periods separated by 5-year increments through the available periods of record from 63 stations within and near Oklahoma.

A trend analysis for streamflow in a large region requires both a large number of stations and a long period of record at each station. Many streamflow-gaging stations in Oklahoma began operation in the 1960s, so a minimum length of record of about 30-40 years might be optimal for trend analysis. Flow records for 20 long-term stations were examined to investigate which year in the 1960s might be the most advantageous beginning year for trend analysis for stations currently in operation. Graphs showing annual departure for median streamflow at the 20 stations (fig. 4-8, back of report) were plotted to determine the distribution of wet and dry years (Tortorelli and others, 1991). The graphs indicated that annual flow for 1968 was near the median value at most sites; whereas, annual flow for the several preceding dry years was less than the median value. The graphs also indicated that most stations had annual flows for the last available year of record (2003) that were closer to the median value than were the larger values for several proceeding wet years. On that basis, 36 years was selected as the minimum length of record for trend analysis for Oklahoma. The selected minimum record length of 36 years is more than one and a half times the length of the suspected drought cycle, which is estimated to be 22 years in the Great Plains (Mitchell and others, 1979).

Entire Period of Record

Peak-flow trends were analyzed by first applying the Kendall's tau test to the annual peak-flow values for the entire period of record from 80 streamflow-gaging stations within and near Oklahoma: 3 in Arkansas, 10 in Kansas, 2 in Missouri, 52 in Oklahoma, and 13 in Texas. Forty-one of the 80 stations had regulated streamflow. All the streamflow-gaging stations had at least a 36-year peak-flow record from 1968 through 2003. Some years were missing from the peak-flow series due to streamflow gages that were discontinued for a short period and no record was available for that period. However, a few missing values within the series has little effect on the test outcome (Helsel and Hirsch, 1992).

Twenty-seven of the 41 streamflow-gaging stations having regulated flow began collecting data in the 1960s. Because so many of Oklahoma streams are regulated, it was deemed important to include regulated streams in the analysis, but using just the regulated period of record. This eliminates the period before regulation as a possible cause for a trend at those sites. The only exceptions were 3 streamflow-gaging stations on the Beaver-North Canadian River (sites 39-41, table 1, fig. 1) for which the entire periods of record were analyzed as examples of the known effects of regulation and irrigation on streamflow trends. These sites were shown by Wahl and Tortorelli (1997) to have the effects of regulation and irrigation.

The 80 streamflow-gaging stations whose records were analyzed are distributed fairly well across Oklahoma and the neighboring states with a greater concentration in the east. Drainage areas of the associated basins vary in size from 24.6 to 62,074 mi^2 (table 1). Land-surface elevations within the study area generally slope gently downward from west to east. Relatively flat topography, shallow stream channels, and ephemeral (intermittent) flow generally characterize the western part of the study area while hilly topography, deep channels, and perennial (continuous) streamflow generally characterize the eastern part of the study area.

Mean annual precipitation ranges from 16 in. in western Oklahoma to 56 in. in southeastern Oklahoma (Tortorelli, 1997). Most of the precipitation is produced by late spring and early fall thunderstorms, and the quantity is variable, both spatially and temporally (Tortorelli 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 80 streamflow-gaging stations within and near Oklahoma indicated both upward and downward trends in peak flows across the study area (table 2, fig. 2). Some individual station records showed significant temporal trends, and slight patterns in the stations having trends in peak flows (fig. 2). Fifteen records (19 percent) of the 80 sets of records analyzed for trends in peak flow exhibited a significant trend (p-value of 0.05 or less; at the 95-percent confidence level). Records from 3 streamflow-gaging stations indicated statistically significant upward trends in peak flows, while records from 12 stations indicated statistically significant downward trends (table 2). The records with upward trends were from gaging stations scattered in the central and northeastern part of the study area, while the significant downward-trend stations were located in the western part of the study area (fig. 2). Figure 2 also shows peak-flow records with apparent upward and downward trends that are not statistically significant; and shows records that had no trend (p-value greater than 0.95; at less than the 5-percent confidence level). Graphs showing annual peak flows and LOWESS trend lines for each of the 80 peak-flow records are given in figures 9 through 28 (back of report).

Table 2. Results of Kendall's tau trend analyses of annual peak flows for entire period of record at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; N., north; Fk, Fork; R., River; abv, above; S., South; <, less than; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Number of years		Kendall's tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
					used	missing			((ft^3/s)/yr)	(percent of median)	
1	07144200	Little Arkansas River at Valley Center, Kans.	N	1916-2003	86	2	0.205	0.005	68.4	0.90	7,570
2	07144780	N. Fk Ninnescah R. abv Cheney Reservoir, Kans.	N	1966-2003	38	0	-0.027	0.821	-10.3	-0.31	3,285
3	07145200	S. Fk Ninnescah River near Murdock, Kans.	N	1951-2003	53	0	0.004	0.969	0.9	0.02	5,640
4	07145500	Ninnescah River near Peck, Kans.	R	1964-2003	40	0	0.065	0.560	79.6	0.66	12,100
5	07146500	Arkansas River at Arkansas City, Kans.	R	1943-2003	61	0	0.054	0.546	68.4	0.29	23,800
6	07151000	Salt Fork Arkansas R. at Tonkawa, Okla.	R	1942-2003	62	0	0.128	0.143	106.6	0.74	14,450
7	07152000	Chikaskia R. near Blackwell, Okla.	N	1923-2003	69	12	0.062	0.453	63.2	0.32	20,000
8	07153000	Black Bear Creek at Pawnee, Okla.	R	1968-2003	36	0	0.203	0.084	85.8	1.48	5,810
9	07154500	Cimarron River near Kenton, Okla.	N	1951-2003	53	0	-0.265	0.005	-102.7	-2.46	4,180
10	07156900	Cimarron River near Forgan, Okla. [2]	N	1943-2003	60	1	-0.482	<0.001	-86.1	-3.49	2,465
11	07157500	Crooked Creek near Englewood, Kans.	N	1943-2003	61	0	-0.491	<0.001	-50.6	-5.78	876
12	07158000	Cimarron River near Waynoka, Okla.	N	1938-2003	66	0	-0.423	<0.001	-388.0	-2.76	14,050
13	07160000	Cimarron River near Guthrie, Okla.	N	1935-2003	61	8	-0.045	0.610	-73.2	-0.22	34,000
14	07161450	Cimarron River near Ripley, Okla. [3]	N	1927-2003	76	1	0.096	0.222	155.2	0.43	35,750
15	07164500	Arkansas River at Tulsa, Okla.	R	1965-2003	39	0	0.225	0.045	783.1	1.72	45,400
16	07167500	Otter Creek at Climax, Kans.	N	1947-2003	56	1	0.105	0.255	60.2	0.65	9,205
17	07170500	Verdigris River at Independence, Kans.	R	1967-2003	37	0	0.012	0.927	7.9	0.04	21,700
18	07171000	Verdigris River near Lenapah, Okla.	R	1967-2003	37	0	0.036	0.764	69.7	0.22	31,600
19	07172000	Caney River near Elgin, Kans.	R	1965-2003	39	0	0.018	0.885	25.0	0.15	17,000

Table 2. Results of Kendall's tau trend analyses of annual peak flows for entire period of record at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma —Continued

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; N., north; Fk, Fork; R., River; abv, above; S., South; <, less than; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Number of years		Kendall's tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
					used	missing			((ft^3/s)/yr)	(percent of median)	
20	07176000	Verdigris River near Claremore, Okla.	R	1964-2003	40	0	0.104	0.351	67.9	0.26	26,600
21	07183500	Neosho River near Parsons, Kans.	R	1964-2003	40	0	0.140	0.208	189.1	0.67	28,250
22	07185000	Neosho River near Commerce, Okla.	R	1964-2003	40	0	0.092	0.408	197.6	0.58	34,200
23	07186000	Spring River near Waco, Mo.	N	1923-2003	81	0	0.087	0.250	68.9	0.37	18,400
24	07188000	Spring River near Quapaw, Okla.	N	1940-2003	64	0	0.013	0.880	21.7	0.06	35,800
25	07189000	Elk River near Tiff City, Mo.	N	1940-2003	64	0	0.010	0.912	12.3	0.05	23,050
26	07190500	Neosho River near Langley, Okla.	R	1940-2003	64	0	-0.035	0.685	-161.6	-0.27	59,800
27	07191000	Big Cabin Creek near Big Cabin, Okla.	N	1935-2003	64	5	-0.050	0.562	-35.4	-0.22	15,950
28	07191220	Spavinaw Creek near Sycamore, Okla.	N	1960-2003	44	0	0.030	0.785	6.4	0.15	4,275
29	07191500	Neosho River near Chouteau, Okla.	R	1965-2003	39	0	0.085	0.453	365.0	0.69	52,800
30	07195500	Illinois River near Watts, Okla.	N	1956-2003	48	0	0.043	0.676	48.2	0.24	20,500
31	07196000	Flint Creek near Kansas, Okla.	N	1956-2003	44	4	-0.025	0.816	-10.3	-0.29	3,555
32	07196500	Illinois River near Tahlequah, Okla.	N	1916-2003	71	17	-0.059	0.472	-76.1	-0.38	19,800
33	07196900	Baron Fork at Dutch Mills, Ark.	N	1958-2003	46	0	0.060	0.564	47.5	0.60	7,955
34	07197000	Baron Fork at Eldon, Okla.	N	1948-2003	56	0	0.027	0.777	27.7	0.18	15,750
35	07198000	Illinois River near Gore, Okla.	R	1953-2003	51	0	0.149	0.125	56.7	0.61	9,280
36	07230500	Little River near Tecumseh, Okla.	R	1966-2003	38	0	-0.138	0.227	-32.9	-0.65	5,070
37	07231000	Little River near Sasakwa, Okla.	R	1966-2003	38	0	0.023	0.850	16.4	0.22	7,475
38	07231500	Canadian River at Calvin, Okla.	R	1965-2003	39	0	0.103	0.364	536.8	1.07	50,200

Table 2. Results of Kendall's tau trend analyses of annual peak flows for entire period of record at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma —Continued

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[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Number of years		Kendall's tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
					used	missing			((ft^3/s)/yr)	(percent of median)	
39	07234000	Beaver River at Beaver, Okla. [4]	NIR	1938-2003	66	0	-0.636	<0.001	-167.6	-4.46	3,755
40	07237500	North Canadian River at Woodward, Okla.. [4]	NIR	1939-2003	65	0	-0.580	<0.001	-119.7	-6.49	1,845
41	07238000	North Canadian River near Seiling, Okla. [4]	NIR	1947-2003	57	0	-0.357	<0.001	-70.7	-2.39	2,960
42	07239500	North Canadian River near El Reno, Okla.	R	1949-2003	55	0	0.094	0.313	20.0	0.62	3,210
43	07241000	N. Canadian R. blw Lk Overholser nr OKC, Okla.	R	1953-2003	48	3	0.230	0.022	67.2	1.72	3,905
44	07242000	North Canadian River near Wetumka, Okla.	R	1938-2003	66	0	0.057	0.503	32.1	0.28	11,350
45	07243500	Deep Fork near Beggs, Okla.	R	1968-2003	36	0	0.052	0.663	54.8	0.65	8,460
46	07245000	Canadian River near Whitefield, Okla.	R	1965-2003	39	0	0.213	0.058	362.5	0.98	36,900
47	07247500	Fourche Maline near Red Oak, Okla.	R	1966-2003	38	0	-0.165	0.148	-48.8	-1.39	3,520
48	07249400	James Fork near Hackett, Ark.	N	1958-2003	46	0	0.046	0.656	27.1	0.41	6,660
49	07249985	Lee Creek near Short, Okla. [5]	N	1931-2003	62	11	-0.073	0.405	-87.1	-0.36	24,450
50	07299540	Prairie Dog Town Fork Red R. nr Childress, Tex.	N	1965-2003	39	0	-0.152	0.175	-215.0	-1.52	14,100
51	07299670	Groesbeck Creek at SH 6 near Quannah, Tex.	N	1962-2003	42	0	-0.024	0.828	-3.0	-0.15	1,945
52	07300000	Salt Fork Red River near Wellington, Tex.	R	1968-2003	36	0	-0.143	0.225	-94.1	-1.58	5,950
53	07300500	Salt Fork Red River at Mangum, Okla.	N	1938-2003	66	0	-0.326	<0.001	-200.9	-1.69	11,900
54	07301410	Sweetwater Creek near Kelton, Tex.	N	1962-2003	42	0	-0.326	0.002	-14.5	-2.65	548
55	07301500	North Fork Red River near Carter, Okla. [6]	N	1928-2003	71	5	-0.250	0.002	-87.5	-1.38	6,360
56	07305000	North Fork Red River near Headrick, Okla.	R	1945-2003	59	0	-0.052	0.565	-27.8	-0.24	11,400

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[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Number of years		Kendall's tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
					used	missing			((ft^3/s)/yr)	(percent of median)	
57	07307800	Pease River near Childress, Tex.	N	1960-2003	39	5	-0.320	0.004	-166.0	-2.94	5,640
58	07308200	Pease River near Vernon, Tex.	N	1960-2003	42	2	-0.142	0.190	-131.6	-1.21	10,900
59	07308500	Red River near Burkburnett, Tex.	N	1960-2003	44	0	0.002	0.991	12.5	0.05	27,700
60	07311200	Blue Beaver Creek near Cache, Okla.	N	1965-2003	39	0	0.099	0.384	16.4	0.91	1,800
61	07311500	Deep Red Creek near Randlett, Okla.	N	1950-2003	54	0	0.087	0.355	55.7	0.69	8,085
62	07312200	Beaver Creek near Electra, Tex.	R	1961-2003	43	0	-0.121	0.258	-21.2	-0.79	2,670
63	07312500	Wichita River at Wichita Falls, Tex.	R	1938-2003	66	0	-0.152	0.072	-31.8	-0.81	3,940
64	07314900	Little Wichita River above Henrietta, Tex.	R	1968-2003	35	1	-0.024	0.854	-2.6	-0.18	1,430
65	07315200	East Fork Little Wichita R. near Henrietta, Tex.	N	1964-2003	40	0	-0.044	0.701	-8.2	-0.71	1,160
66	07315500	Red River near Terral, Okla.	R	1945-2003	59	0	0.004	0.974	11.1	0.03	41,400
67	07315700	Mud Creek near Courtney, Okla.	N	1957-2003	44	3	0.131	0.213	90.1	1.62	5,555
68	07316000	Red River near Gainesville, Tex.	R	1945-2003	59	0	0.006	0.953	20.0	0.04	48,900
69	07316500	Washita River near Cheyenne, Okla.	R	1961-2003	43	0	-0.269	0.011	-25.4	-4.34	585
70	07325000	Washita River near Clinton, Okla.	R	1962-2003	42	0	0.034	0.762	7.1	0.33	2,180
71	07325500	Washita River at Carnegie, Okla.	R	1962-2003	42	0	0.121	0.264	53.4	1.00	5,355
72	07326500	Washita River at Anadarko, Okla.	R	1964-2003	40	0	0.215	0.052	74.1	1.58	4,680
73	07328100	Washita River at Alex, Okla.	R	1965-2003	37	2	0.219	0.058	161.5	2.02	8,000
74	07328500	Washita River near Pauls Valley, Okla.	R	1962-2003	42	0	0.152	0.159	118.8	1.00	11,900
75	07331000	Washita River near Dickson, Okla.	R	1962-2003	42	0	0.129	0.233	217.5	0.73	29,750

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[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Number of years		Kendall's tau[1]	Probability value	Trend slope[1]		Median (ft³/s)
					used	missing			((ft³/s)/yr)	(percent of median)	
76	07332500	Blue River near Blue, Okla.	N	1937-2003	67	0	0.062	0.462	30.0	0.34	8,770
77	07335500	Red River at Arthur City, Tex.	R	1945-2003	59	0	-0.129	0.150	-307.1	-0.54	56,500
78	07335700	Kiamichi River near Big Cedar, Okla.	N	1966-2003	38	0	0.046	0.697	36.4	0.39	9,250
79	07337900	Glover River near Glover, Okla.	N	1961-2003	43	0	0.075	0.483	160.0	0.55	29,300
80	07340300	Cossatot River near Vandervoort, Ark.	N	1961-2003	37	6	-0.218	0.060	-329.0	-2.02	16,300

[1] Positive value indicates upward trend and negative value indicates downward trend

[2] Includes peak flow record 1943-65 from nearby station 07157000, Cimarron River near Mocane, OK.

[3] Includes peak flow record 1927-89 from nearby station 07161000, Cimarron River at Perkins, OK.

[4] Pre- and post-irrigation development as defined in Wahl and Tortorelli (1997) Through WY 1971 is unregulated, WY 1972-78 are transition years to full irrigation development and regulated by reservoir.

[5] Was 07250000, Lee Creek near Van Buren, Ark., prior to WY 1993 and above Lee Creek Reservoir.

[6] Includes peak flow record 1938-44 from nearby station 07302000, North Fork Red River near Granite, OK.

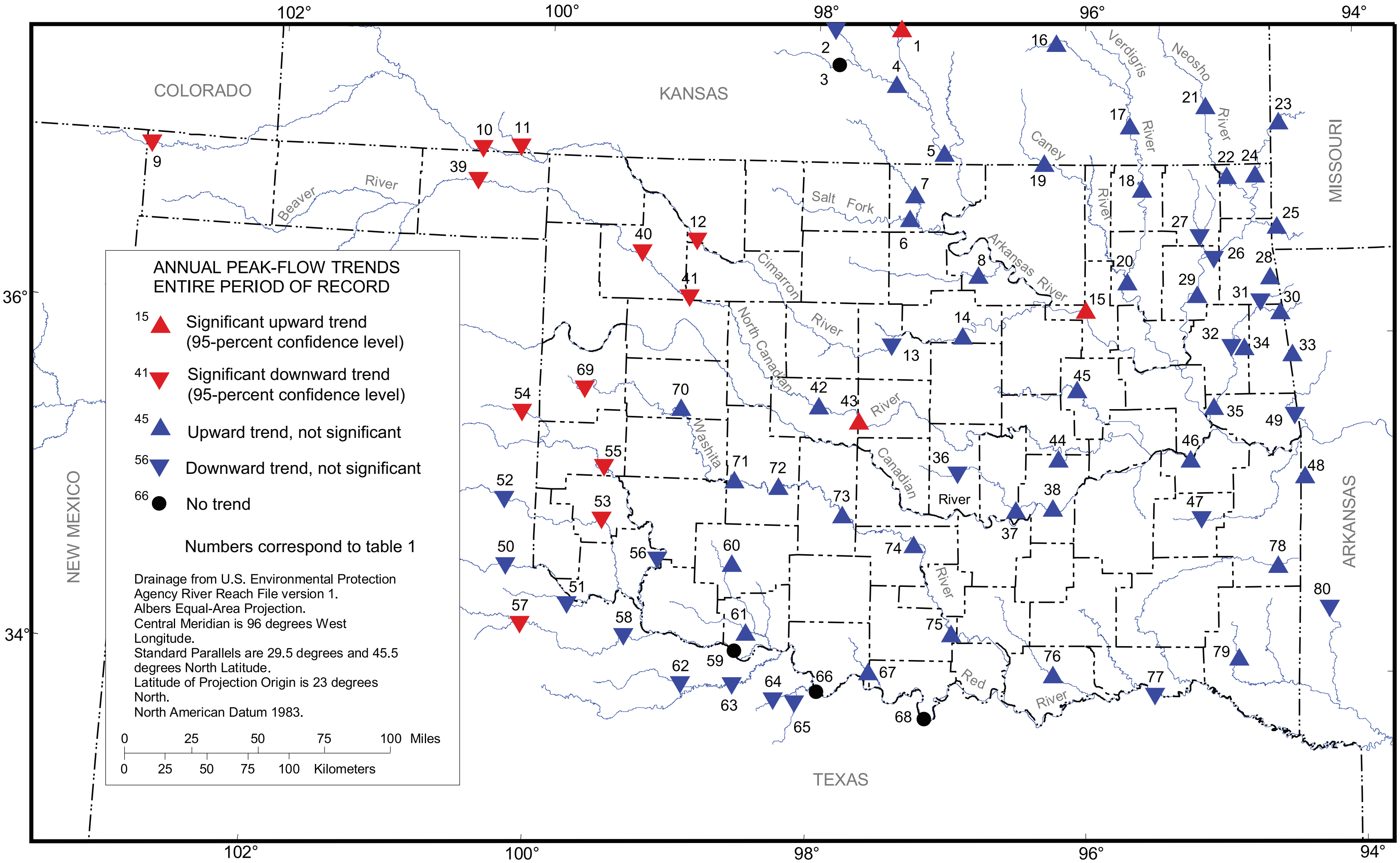

Figure 2. Results of Kendall's tau trend analyses of annual peak flows for entire period of record at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma.

Table 3. Results of Kendall’s tau trend analyses of annual peak flows for water years 1968-2003 at selected streamflow-gaging stations from unregulated and regulated basins within and near Oklahoma

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Number of years missing	Kendall’s tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
							((ft^3/s)/yr)	(percent of median)	
5	07146500	Arkansas River at Arkansas City, Kans.	R	0	0.038	0.754	62.9	0.24	25,900
6	07151000	Salt Fork Arkansas R. at Tonkawa, Okla.	R	0	0.205	0.081	285.9	1.83	15,650
7	07152000	Chikaskia R. near Blackwell, Okla.	N	0	0.095	0.422	219.8	0.93	23,600
8	07153000	Black Bear Creek at Pawnee, Okla.	R	0	0.203	0.084	85.8	1.48	5,810
9	07154500	Cimarron River near Kenton, Okla.	N	0	-0.151	0.200	-68.8	-1.80	3,815
10	07156900	Cimarron River near Forgan, Okla.	N	1	-0.254	0.033	-33.0	-3.41	968
11	07157500	Crooked Creek near Englewood, Kans.	N	0	-0.294	0.012	-15.5	-3.59	432
12	07158000	Cimarron River near Waynoka, Okla.	N	0	-0.240	0.041	-281.4	-2.72	10,350
13	07160000	Cimarron River near Guthrie, Okla.	N	6	0.163	0.212	406.7	1.48	27,550
14	07161450	Cimarron River near Ripley, Okla.[2]	N	0	0.154	0.191	544.3	1.56	34,800
15	07164500	Arkansas River at Tulsa, Okla.	R	0	0.210	0.074	696.1	1.52	45,800
18	07171000	Verdigris River near Lenapah, Okla.	R	0	0.010	0.946	13.9	0.04	31,650
19	07172000	Caney River near Elgin, Kans.	R	0	0.043	0.723	58.0	0.34	16,850
20	07176000	Verdigris River near Claremore, Okla.	R	0	0.005	0.978	4.6	0.02	27,650
22	07185000	Neosho River near Commerce, Okla.	R	0	0.035	0.775	57.1	0.17	34,200
24	07188000	Spring River near Quapaw, Okla.	N	0	0.044	0.713	141.4	0.40	35,500
25	07189000	Elk River near Tiff City, Mo.	N	0	0.024	0.849	51.7	0.20	25,550
26	07190500	Neosho River near Langley, Okla.	R	0	0.094	0.429	474.8	0.79	59,950
27	07191000	Big Cabin Creek near Big Cabin, Okla.	N	0	0.084	0.479	84.1	0.54	15,600
28	07191220	Spavinaw Creek near Sycamore, Okla.	N	0	-0.038	0.754	-15.0	-0.34	4,415
29	07191500	Neosho River near Chouteau, Okla.	R	0	0.052	0.663	264.5	0.49	53,900
30	07195500	Illinois River near Watts, Okla.	N	0	-0.044	0.713	-80.0	-0.38	21,000
31	07196000	Flint Creek near Kansas, Okla.	N	4	-0.077	0.549	-50.7	-1.19	4,245
32	07196500	Illinois River near Tahlequah, Okla.	N	0	0.041	0.733	56.2	0.28	20,050
34	07197000	Baron Fork at Eldon, Okla.	N	0	0.000	1.000	0.0	0.00	16,350
35	07198000	Illinois River near Gore, Okla.	R	0	0.071	0.549	39.4	0.38	10,400
36	07230500	Little River near Tecumseh, Okla.	R	0	-0.102	0.391	-30.0	-0.60	5,035
37	07231000	Little River near Sasakwa, Okla.	R	0	-0.002	1.000	-0.4	-0.00	7,475

Table 3. Results of Kendall's tau trend analyses of annual peak flows for water years 1968-2003 at selected streamflow-gaging stations from unregulated and regulated basins within and near Oklahoma —Continued

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Number of years missing	Kendall's tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
							((ft^3/s)/yr)	(percent of median)	
38	07231500	Canadian River at Calvin, Okla.	R	0	0.062	0.605	389.5	0.76	51,050
39	07234000	Beaver River at Beaver, Okla. [3]	NIR	0	-0.602	<0.001	-109.2	-11.53	947
40	07237500	North Canadian River at Woodward, Okla. [3]	NIR	0	-0.376	0.001	-43.6	-4.07	1,070
41	07238000	North Canadian River near Seiling, Okla. [3]	NIR	0	-0.229	0.051	-55.9	-2.13	2,625
42	07239500	North Canadian River near El Reno, Okla.	R	0	0.194	0.100	62.5	1.79	3,495
43	07241000	N. Canadian R. blw Lk Overholser nr OKC, Okla.	R	3	0.193	0.118	96.8	2.33	4,160
44	07242000	North Canadian River near Wetumka, Okla.	R	0	0.187	0.111	161.5	1.40	11,500
45	07243500	Deep Fork near Beggs, Okla.	R	0	0.052	0.663	54.8	0.65	8,460
46	07245000	Canadian River near Whitefield, Okla.	R	0	0.110	0.354	229.3	0.61	37,450
47	07247500	Fourche Maline near Red Oak, Okla.	R	0	-0.173	0.141	-49.1	-1.39	3,520
48	07249400	James Fork near Hackett, Ark.	N	0	-0.052	0.663	-45.6	-0.65	6,965
49	07249985	Lee Creek near Short, Okla. [4]	N	0	-0.078	0.513	-146.2	-0.58	25,150
50	07299540	Prairie Dog Town Fork Red R. nr Childress, Tex.	N	0	-0.124	0.294	-161.5	-1.17	13,850
52	07300000	Salt Fork Red River near Wellington, Tex.	R	0	-0.143	0.225	-94.1	-1.58	5,950
53	07300500	Salt Fork Red River at Mangum, Okla.	N	0	-0.341	0.004	-211.5	-3.45	6,135
54	07301410	Sweetwater Creek near Kelton, Tex.	N	0	-0.311	0.008	-16.2	-3.43	472
55	07301500	North Fork Red River near Carter, Okla.	N	0	-0.102	0.391	-47.5	-1.01	4,695
56	07305000	North Fork Red River near Headrick, Okla.	R	0	0.006	0.967	4.7	0.04	10,950
59	07308500	Red River near Burkburnett, Tex.	N	0	0.063	0.595	173.8	0.66	26,250
60	07311200	Blue Beaver Creek near Cache, Okla.	N	0	0.000	1.000	0.4	0.02	1,980
61	07311500	Deep Red Creek near Randlett, Okla.	N	0	0.000	1.000	-0.3	-0.00	8,555
66	07315500	Red River near Terral, Okla.	R	0	0.095	0.422	515.2	1.26	40,750
67	07315700	Mud Creek near Courtney, Okla.	N	0	0.035	0.775	43.7	0.65	6,720
68	07316000	Red River near Gainesville, Tex.	R	0	0.108	0.361	393.1	0.81	48,750

Table 3. Results of Kendall’s tau trend analyses of annual peak flows for water years 1968-2003 at selected streamflow-gaging stations from unregulated and regulated basins within and near Oklahoma —Continued

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Number of years missing	Kendall’s tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
							((ft^3/s)/yr)	(percent of median)	
69	07316500	Washita River near Cheyenne, Okla.	R	0	-0.210	0.074	-16.9	-3.05	554
70	07325000	Washita River near Clinton, Okla.	R	0	0.079	0.505	12.5	0.54	2,295
71	07325500	Washita River at Carnegie, Okla.	R	0	0.133	0.258	71.6	1.34	5,355
72	07326500	Washita River at Anadarko, Okla.	R	0	0.267	0.023	95.5	2.04	4,680
73	07328100	Washita River at Alex, Okla.	R	2	0.201	0.097	182.5	2.25	8,095
74	07328500	Washita River near Pauls Valley, Okla.	R	0	0.095	0.421	73.6	0.60	12,200
75	07331000	Washita River near Dickson, Okla.	R	0	-0.056	0.643	-101.5	-0.32	31,900
76	07332500	Blue River near Blue, Okla.	N	0	-0.062	0.605	-83.2	-0.76	10,950
77	07335500	Red River at Arthur City, Tex.	R	0	-0.114	0.333	-477.3	-0.85	55,950
78	07335700	Kiamichi River near Big Cedar, Okla.	N	0	0.014	0.913	16.6	0.18	9,400
79	07337900	Glover River near Glover, Okla.	N	0	-0.037	0.764	-95.0	-0.31	30,800

[1] Positive value indicates upward trend and negative value indicates downward trend

[2] Includes peak flow record 1968-89 from nearby station 07161000, Cimarron River at Perkins, OK.

[3] Pre- and post-irrigation development as defined in Wahl and Tortorelli (1997). Through WY 1971 is unregulated, WY 1972-78 are transition years to full irrigation development and regulated by reservoir.

[4] Was 07250000, Lee Creek near Van Buren, Ark., prior to WY 1993 and above Lee Creek Reservoir.

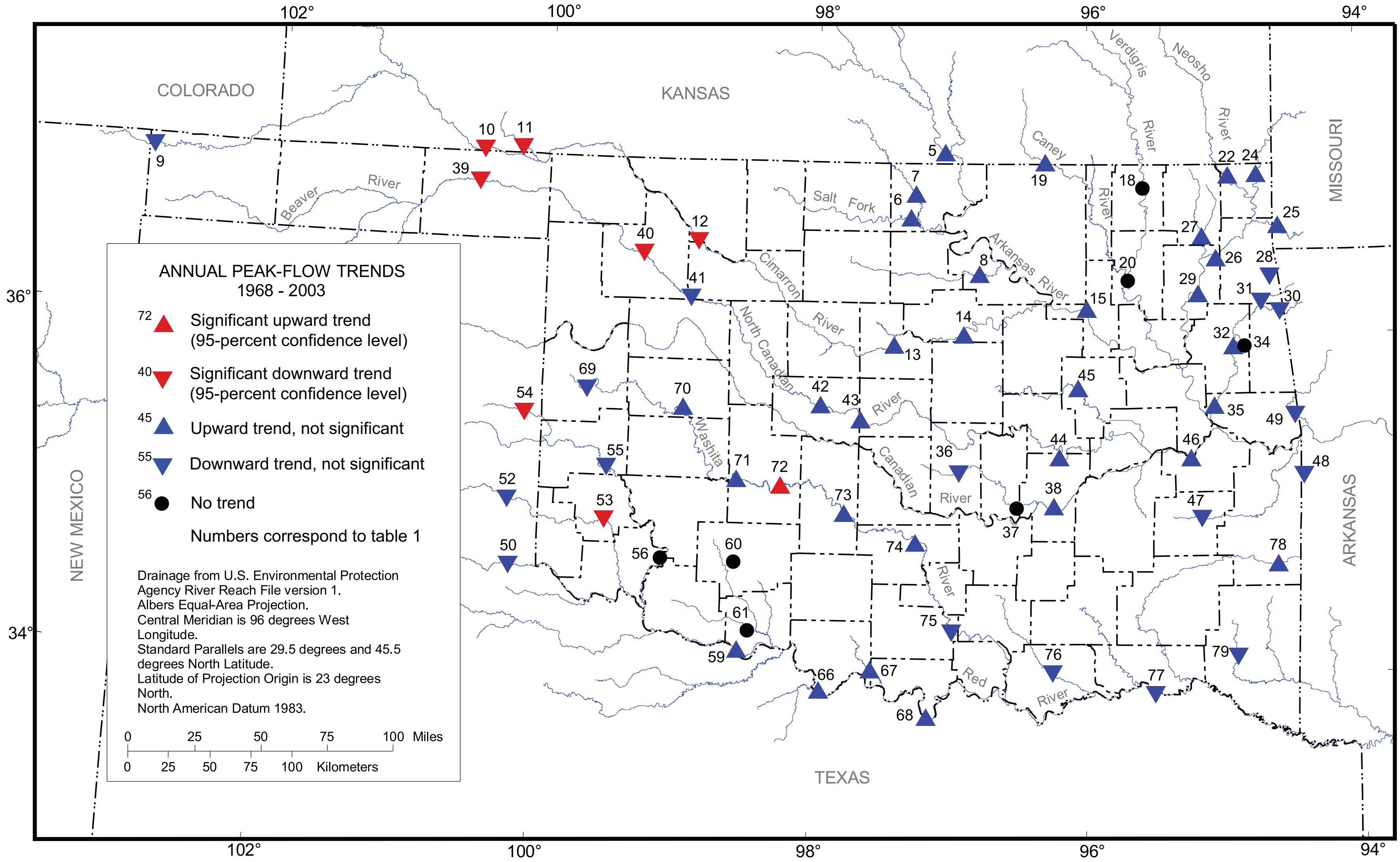

Figure 3. Results of Kendall's tau trend analyses of annual peak flows for water years 1968-2003 at selected streamflow-gaging stations from unregulated and regulated basins within and near Oklahoma.

Recent Period, 1968-2003

The trend test result may change as the period of record changes. To see if there are peak-flow trends during a recent 36-year period, the Kendall's tau test also was used to identify trends over the 1968–2003 period (table 3, fig. 3) from 63 streamflow-gaging stations within and near Oklahoma; 1 in Arkansas, 3 in Kansas, 1 in Missouri, 52 in Oklahoma, and 6 in Texas; of which 35 stations had regulated streamflow. This analysis has the advantage of providing trend information for the same period for all sites. The analysis was restricted to streamflow-gaging stations within Oklahoma and stations in other states near the Oklahoma border.

Eight of the 63 station records showed significant trends. Seven station records had significant downward trends, and one station record had a significant upward trend (fig. 3). Again the significant downward-trend stations were all located in the western part of the study area. The significant upward-trend station was located in the central part of the study area. Sixteen stations (sites 7,12-14, 24-27, 32, 39-40, 44, 49, 53, 55, 76) had peak-flow data dating back to at least 1940. Four of these 15 records showed significant downward trends (sites 12, 39-40, 53) when tested over the recent 36-year period (table 3). Trends for the same four stations were significant over the entire periods of record as well (table 2). Figure 3 also shows stations with records that had apparent trends that are not statistically significant and records with no trend.

30-Year Periods

Table 4 shows results of a trend test on records from each of 63 streamflow-gaging stations within and near Oklahoma using different 30-year periods. The 30-year periods were varied by 5-year increments through the available periods of record. For example, the first 30-year period used for any station was 1931-60. The second 30-year period, 1936-65, began 5-years after the first. The last period used was 28 years rather than 30 years, 1976-2003, because the last available year of data for this study was 2003.

From table 4, it is possible to identify time periods within each station record when peak-flow trends were occurring. For example, the Cimarron River near Forgan and near Waynoka, and the Beaver River at Beaver (sites 10, 12, 39; table 4) showed a downward trend throughout the period of record. The North Canadian River near Wetumka (site 44, table 4) showed a variable pattern with a non-significant downward trend from 1941–70, changing to an upward trend from 1961–90, and changing to a non-significant upward trend from 1976-2003 and for the overall period. Two stations on highly-regulated streams, Arkansas River at Tulsa and the North Canadian River below Lake Overholser near Oklahoma City, showed an upward trend through most of the period of record (sites 15, 43; table 4). Table 4 also shows time periods when trends were more geographically widespread, such as 1956–85 when station records showed significant trends that were generally downward and 1966-95 when station records showed significant trends that were generally upward.

Mean Annual Flow

Mean annual flow also was analyzed for trends. Mean annual flow is the average of the individual daily mean discharge values. The first part of the mean annual-flow analysis used the entire period of record from 80 stations within and near Oklahoma that had a minimum of 36 years of record (table 5, fig. 29). The second part of the mean annual-flow analysis used just a recent 36-year period of record, 1968–2003, from 63 stations within and near Oklahoma (table 6, fig. 30). Regulated streams were used in the mean annual-flow analysis. Losses from lake evaporation and diversions were not accounted for in mean annual flow data at the regulated stations. Rasmussen and Perry (2001) noted that analyzing the mean annual flow for the larger drainage basins may provide more reliable indicators of flow trends, because annual flows from large basins are less susceptible to localized flooding and human-related factors. Larger drainages also have a slower response to changes in precipitation. However, all stations were analyzed in order to make the mean-annual flow analysis comparable with the annual peak-flow analysis.

Downward trends in peak flow may be related to downward trends in mean annual flow. Decreasing streamflow volume in western Kansas, described by Jordan (1982) and Angelo (1994) and supported by the mean annual flow trend analysis (Rasmussen and Perry, 2001), is related to downward trends in peak flow. Wahl and Tortorelli (1997) also found downward trends in both mean annual flow and peak flow when studying the Beaver-North Canadian River in western Oklahoma. When rain falls on a dry streambed, more rain contributes to saturation of the streambed and less to actual streamflow. Therefore, annual peak flows might be expected to decrease over a period of time if mean annual discharge decreases.

Entire Period of Record

When the Kendall's tau test was applied to mean annual flows for the entire period of record from 80 streamflow-gaging stations within and near Oklahoma, a regional pattern of trends similar to that for the peak-flow analysis resulted (fig. 29). More significant upward trends were found for the mean-annual flow analysis than for the peak-flow analysis. Twenty-eight sets (35 percent) of the 80 sets of records analyzed for trends in mean annual flow showed a significant trend at the 95-percent confidence level. Records from 22 streamflow-gaging stations indicated statistically significant upward trends in mean annual flows, while records from 6 stations indicated statistically significant downward trends (table 5). The records with upward trends were from gaging stations scattered in a band through the central, southwest, and north-central parts of the study area; while the significant downward-trend stations

Table 4. Results of Kendall's tau trend analyses of annual peak flows for moving 30-year periods (except the last column which is 28 years) at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway; (+) indicates upward trend, (-) indicates downward trend, significant at 95-percent confidence level (probability value less than or equal to 0.05); + indicates upward trend, not significant; - indicates downward trend, not significant; 0 indicates no trend (probability value greater than or equal to 0.95)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Years of record	1931-60	1936-65	1941-70	1946-75	1951-80	1956-85	1961-90	1966-95	1971-2000	1976-2003	Full record
5	07146500	Arkansas River at Arkansas City, Kans.	R	1943-2003	61				+	+	-	+	+	+	+	+
6	07151000	Salt Fork Arkansas R. at Tonkawa, Okla.	R	1942-2003	62				+	+	-	+	+	(+)	(+)	+
7	07152000	Chikaskia R. near Blackwell, Okla.	N	1923-2003	69		+	-	+	-	-	-	+	+	(+)	+
8	07153000	Black Bear Creek near Pawnee, Okla.	R	1968-2003	36									(+)	+	+
9	07154500	Cimarron River near Kenton, Okla.	N	1951-2003	53					0	-	-	-	-	-	(-)
10	07156900	Cimarron River near Forgan, Okla. [1]	N	1943-2003	60				(-)	(-)	(-)	(-)	(-)	(-)	-	(-)
11	07157500	Crooked Creek near Englewood, Kans.	N	1943-2003	61				(-)	(-)	(-)	(-)	(-)	(-)	-	(-)
12	07158000	Cimarron River near Waynoka, Okla.	N	1938-2003	66			(-)	-	-	-	-	-	-	(-)	(-)
13	07160000	Cimarron River near Guthrie, Okla.	N	1935-2003	61			-	-	-	-	+	(+)	+	0	-
14	07161450	Cimarron River near Ripley, Okla. [2]	N	1927-2003	76	(+)	+	-	-	0	-	+	(+)	+	+	+
15	07164500	Arkansas River at Tulsa, Okla.	R	1965-2003	39								(+)	+	(+)	(+)
18	07171000	Verdigris River near Lenapah, Okla.	R	1967-2003	37									+	-	+
19	07172000	Caney River near Elgin, Kans.	R	1965-2003	39								+	+	0	+
20	07176000	Verdigris River near Claremore, Okla.	R	1964-2003	40								+	+	+	+
22	07185000	Neosho River near Commerce, Okla.	R	1964-2003	40								(+)	+	-	+

Table 4. Results of Kendall's tau trend analyses of annual peak flows for moving 30-year periods (except the last column which is 28 years) at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma —Continued

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway; (+) indicates upward trend, (-) indicates downward trend, significant at 95-percent confidence level (probability value less than or equal to 0.05); + indicates upward trend, not significant; - indicates downward trend, not significant; 0 indicates no trend (probability value greater than or equal to 0.95)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Years of record	1931-60	1936-65	1941-70	1946-75	1951-80	1956-85	1961-90	1966-95	1971-2000	1976-2003	Full record
24	07188000	Spring River near Quapaw, Okla.	N	1940-2003	64			(-)	+	+	+	+	(+)	+	-	+
25	07189000	Elk River near Tiff City, Mo.	N	1940-2003	64			-	+	+	+	+	+	+	+	+
26	07190500	Neosho River near Langley, Okla.	R	1940-2003	64			(-)	-	+	0	+	(+)	+	+	-
27	07191000	Big Cabin Creek near Big Cabin, Okla.	N	1935-2003	64			-	+	+	+	+	+	+	+	-
28	07191220	Spavinaw Creek near Sycamore, Okla.	N	1960-2003	44							+	+	+	+	+
29	07191500	Neosho River near Chouteau, Okla.	R	1965-2003	39								+	+	+	+
30	07195500	Illinois River near Watts, Okla.	N	1956-2003	48						0	+	0	+	+	+
31	07196000	Flint Creek near Kansas, Okla.	N	1956-2003	44						-	-	0	+	+	-
32	07196500	Illinois River near Tahlequah, Okla.	N	1916-2003	71		-	(-)	-	+	-	+	+	+	+	-
34	07197000	Baron Fork at Eldon, Okla.	N	1948-2003	56					0	-	+	-	+		+
35	07198000	Illinois River near Gore, Okla.	R	1953-2003	51						-	(+)	+	+	+	+
36	07230500	Little River near Tecumseh, Okla.	R	1966-2003	38								-	+	+	-
37	07231000	Little River near Sasakwa, Okla.	R	1966-2003	38								+	+	+	+
38	07231500	Canadian River at Calvin, Okla.	R	1965-2003	39								+	+	+	+
39	07234000	Beaver River at Beaver, Okla.[3]	NIR	1938-2003	66			-	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

Table 4. Results of Kendall's tau trend analyses of annual peak flows for moving 30-year periods (except the last column which is 28 years) at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma —Continued

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Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Years of record	1931-60	1936-65	1941-70	1946-75	1951-80	1956-85	1961-90	1966-95	1971-2000	1976-2003	Full record
40	07237500	North Canadian River at Woodward, Okla. [3]	NIR	1939-2003	65			(-)	(-)	-	(-)	(-)	(-)	(-)	-	(-)
41	07238000	North Canadian River near Seiling, Okla. [3]	NIR	1947-2003	57					-	-	(-)	(-)	-	-	(-)
42	07239500	North Canadian River near El Reno, Okla.	R	1949-2003	55					0	+	(+)	(+)	+	-	+
43	07241000	N. Canadian R. blw Lk Overholser nr OKC, Okla.	R	1953-2003	48						+	(+)	(+)	(+)	+	(+)
44	07242000	North Canadian River near Wetumka, Okla.	R	1938-2003	66			-	-	-	+	(+)	(+)	(+)	+	+
45	07243500	Deep Fork near Beggs, Okla.	R	1968-2003	36									+	+	+
46	07245000	Canadian River near Whitefield, Okla.	R	1965-2003	39								(+)	(+)	+	+
47	07247500	Fourche Maline near Red Oak, Okla.	R	1966-2003	38								-	-	-	-
48	07249400	James Fork near Hackett, Ark.	N	1958-2003	46							+	+	+	+	+
49	07249985	Lee Creek near Short, Okla. [4]	N	1931-2003	62					+	-	+	-	-	+	-
50	07299540	Prairie Dog Town Fork Red R. nr Childress, Tex.	N	1965-2003	39								-	0	-	-
52	07300000	Salt Fork Red River near Wellington, Tex.	R	1968-2003	36									-	-	-
53	07300500	Salt Fork Red River at Mangum, Okla.	N	1938-2003	66			-	-	-	(-)	-	-	(-)	(-)	(-)
54	07301410	Sweetwater Creek near Kelton, Tex.	N	1962-2003	42								(-)	-	-	(-)
55	07301500	North Fork Red River near Carter, Okla. [5]	N	1928-2003	71	+	-	-	-	-	(-)	+	-	-	-	(-)

Table 4. Results of Kendall's tau trend analyses of annual peak flows for moving 30-year periods (except the last column which is 28 years) at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma —Continued

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway; (+) indicates upward trend, (-) indicates downward trend, significant at 95-percent confidence level (probability value less than or equal to 0.05); + indicates upward trend, not significant; - indicates downward trend, not significant; 0 indicates no trend (probability value greater than or equal to 0.95)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Years of record	1931-60	1936-65	1941-70	1946-75	1951-80	1956-85	1961-90	1966-95	1971-2000	1976-2003	Full record
56	07305000	North Fork Red River near Headrick, Okla.	R	1945-2003	59				-	-	-	+	+	+	-	-
59	07308500	Red River near Burkburnett, Tex.	N	1960-2003	44							+	+	+	-	0
60	07311200	Blue Beaver Creek near Cache, Okla.	N	1965-2003	39								+	+	-	+
61	07311500	Deep Red Creek near Randlett, Okla.	N	1950-2003	54					-	+	(+)	(+)	+	-	+
66	07315500	Red River near Terral, Okla.	R	1945-2003	59				-	-	-	+	(+)	+	0	0
67	07315700	Mud Creek near Courtney, Okla.	N	1957-2003	44							(+)	(+)	+	0	+
68	07316000	Red River near Gainesville, Tex.	R	1945-2003	59				-	-	0	(+)	(+)	+	-	0
69	07316500	Washita River near Cheyenne, Okla.	R	1961-2003	43							(-)	(-)	-	0	(-)
70	07325000	Washita River near Clinton, Okla.	R	1962-2003	42								+	+	+	+
71	07325500	Washita River at Carnegie, Okla.	R	1962-2003	42								+	+	0	+
72	07326500	Washita River at Anadarko, Okla.	R	1964-2003	40								(+)	(+)	+	+
73	07328100	Washita River at Alex, Okla.	R	1965-2003	37								(+)	(+)	+	+
74	07328500	Washita River near Pauls Valley, Okla.	R	1962-2003	42								(+)	+	+	+
75	07331000	Washita River near Dickson, Okla.	R	1962-2003	42								+	-	-	+
76	07332500	Blue River near Blue, Okla.	N	1937-2003	67			-	+	+	+	+	+	-	+	+
77	07335500	Red River at Arthur City, Tex.	R	1945-2003	59				-	-	0	+	-	-	+	-

Table 4. Results of Kendall's tau trend analyses of annual peak flows for moving 30-year periods (except the last column which is 28 years) at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma —Continued

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway; (+) indicates upward trend, (-) indicates downward trend, significant at 95-percent confidence level (probability value less than or equal to 0.05); + indicates upward trend, not significant; - indicates downward trend, not significant; 0 indicates no trend (probability value greater than or equal to 0.95)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Years of record	1931-60	1936-65	1941-70	1946-75	1951-80	1956-85	1961-90	1966-95	1971-2000	1976-2003	Full record
78	07335700	Kiamichi River near Big Cedar, Okla.	N	1966-2003	38								+	+	+	+
79	07337900	Glover River near Glover, Okla.	N	1961-2003	43							+	+	-	+	+

[1] Includes peak flow record 1943-65 from nearby station 07157000, Cimarron River near Mocane, OK.

[2] Includes peak flow record 1927-89 from nearby station 07161000, Cimarron River at Perkins, OK.

[3] Pre- and post-irrigation development as defined in Wahl and Tortorelli (1997) Through WY 1971 is unregulated, WY 1972-78 are transition years to full irrigation development and regulated by reservoir.

[4] Was 07250000, Lee Creek near Van Buren, Ark., prior to WY 1993 and above Lee Creek Reservoir.

[5] Includes peak flow record 1938-44 from nearby station 07302000, North Fork Red River near Granite, OK.

Table 5. Results of Kendall's tau trend analyses of mean annual flows for entire period of record at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma —Contin

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; Fk, Fork; Res, Reservoir; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Number of years		Kendall's tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
					used	missing			((ft^3/s)/yr)	(percent of median)	
1	07144200	Little Arkansas River at Valley Center, Kans.	N	1923-2003	81	0	0.220	0.004	2.72	1.08	251.9
2	07144780	North Fk Ninnescah R. abv Cheney Res, Kans.	N	1966-2003	38	0	0.065	0.571	0.39	0.30	129.2
3	07145200	South Fk Ninnescah River near Murdock, Kans.	N	1951-2003	48	5	0.167	0.097	1.22	0.62	197.8
4	07145500	Ninnescah River near Peck, Kans.	R	1964-2003	40	0	0.156	0.159	4.78	0.94	506.8
5	07146500	Arkansas River at Arkansas City, Kans.	R	1943-2003	61	0	-0.028	0.751	-2.59	-0.14	1,907.0
6	07151000	Salt Fork Arkansas R. at Tonkawa, Okla.	R	1942-2003	62	0	0.201	0.021	9.21	1.17	784.8
7	07152000	Chikaskia R. near Blackwell, Okla.	N	1936-2003	68	0	0.231	0.005	6.16	1.34	458.2
8	07153000	Black Bear Creek near Pawnee, Okla.	R	1968-2003	36	0	0.184	0.117	4.98	2.65	188.0
9	07154500	Cimarron River near Kenton, Okla.	N	1951-2003	53	0	-0.361	<0.001	-0.33	-3.38	9.8
10	07156900	Cimarron River near Forgan, Okla. [2]	N	1943-2003	60	1	-0.568	<0.001	-1.11	-1.79	62.0
11	07157500	Crooked Creek near Englewood, Kans.	N	1943-2003	61	0	-0.430	<0.001	-0.33	-2.12	15.6
12	07158000	Cimarron River near Waynoka, Okla.	N	1938-2003	66	0	-0.180	0.033	-2.41	-1.04	231.4
13	07160000	Cimarron River near Guthrie, Okla.	N	1938-2003	59	7	0.207	0.021	10.11	1.08	939.7
14	07161450	Cimarron River near Ripley, Okla. [3]	N	1940-2003	64	0	0.212	0.013	14.89	1.12	1,331.0
15	07164500	Arkansas River at Tulsa, Okla.	R	1965-2003	39	0	0.193	0.086	119.13	1.52	7,861.0
16	07167500	Otter Creek at Climax, Kans.	N	1947-2003	57	0	0.118	0.196	0.61	0.77	79.5
17	07170500	Verdigris River at Independence, Kans.	R	1967-2003	37	0	-0.006	0.969	-0.40	-0.02	1,912.0
18	07171000	Verdigris River near Lenapah, Okla.	R	1967-2003	37	0	0.030	0.804	4.93	0.20	2,489.0
19	07172000	Caney River near Elgin, Kans.	R	1965-2003	39	0	0.104	0.358	2.91	1.06	273.7
20	07176000	Verdigris River near Claremore, Okla.	R	1964-2003	40	0	0.144	0.196	53.61	1.31	4,086.5

Table 5. Results of Kendall's tau trend analyses of mean annual flows for entire period of record at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma —Continued

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; Fk, Fork; Res, Reservoir; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Number of years		Kendall's tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
					used	missing			((ft^3/s)/yr)	(percent of median)	
21	07183500	Neosho River near Parsons, Kans.	R	1964-2003	40	0	0.015	0.898	4.11	0.16	2,568.5
22	07185000	Neosho River near Commerce, Okla.	R	1964-2003	40	0	0.073	0.514	16.51	0.49	3,357.0
23	07186000	Spring River near Waco, Mo.	N	1925-2003	79	0	0.115	0.134	4.12	0.48	850.0
24	07188000	Spring River near Quapaw, Okla.	N	1940-2003	64	0	0.100	0.247	8.82	0.44	1,990.5
25	07189000	Elk River near Tiff City, Mo.	N	1940-2003	64	0	0.163	0.853	0.66	0.08	789.5
26	07190500	Neosho River near Langley, Okla.	R	1940-2003	64	0	0.061	0.483	22.53	0.31	7,193.5
27	07191000	Big Cabin Creek near Big Cabin, Okla.	N	1948-2003	56	0	0.106	0.249	1.76	0.54	327.1
28	07191220	Spavinaw Creek near Sycamore, Okla.	N	1962-2003	42	0	0.145	0.179	0.92	0.94	97.5
29	07191500	Neosho River near Chouteau, Okla.	R	1965-2003	39	0	0.074	0.514	38.12	0.46	8,339.0
30	07195500	Illinois River near Watts, Okla.	N	1956-2003	48	0	0.144	0.152	3.82	0.63	610.9
31	07196000	Flint Creek near Kansas, Okla.	N	1956-2003	43	5	0.070	0.516	0.41	0.39	103.8
32	07196500	Illinois River near Tahlequah, Okla.	N	1936-2003	68	0	0.104	0.214	3.09	0.33	925.5
33	07196900	Baron Fork at Dutch Mills, Ark.	N	1959-2003	45	0	0.183	0.078	0.43	0.96	44.9
34	07197000	Baron Fork at Eldon, Okla.	N	1949-2003	55	0	0.164	0.079	2.48	0.76	327.8
35	07198000	Illinois River near Gore, Okla.	R	1953-2003	51	0	0.195	0.044	16.02	1.07	1,500.0
36	07230500	Little River near Tecumseh, Okla.	R	1966-2003	38	0	0.329	0.004	3.99	3.72	107.2
37	07231000	Little River near Sasakwa, Okla.	R	1966-2003	38	0	0.189	0.097	5.39	1.73	311.6
38	07231500	Canadian River at Calvin, Okla.	R	1965-2003	39	0	0.306	0.006	39.04	2.97	1,314.0
39	07234000	Beaver River at Beaver, Okla. [4]	NIR	1938-2003	66	0	-0.573	<0.001	-1.48	-4.40	33.6

Table 5. Results of Kendall's tau trend analyses of mean annual flows for entire period of record at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma —Continued

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; Fk, Fork; Res, Reservoir; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Number of years		Kendall's tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
					used	missing			((ft^3/s)/yr)	(percent of median)	
40	07237500	North Canadian River at Woodward, Okla. [4]	NIR	1939-2003	65	0	-0.182	0.033	-1.28	-1.15	111.2
41	07238000	North Canadian River near Seiling, Okla. [4]	NIR	1947-2003	57	0	-0.023	0.810	-0.22	-0.15	151.0
42	07239500	North Canadian River near El Reno, Okla.	R	1949-2003	55	0	0.176	0.059	2.05	1.27	161.6
43	07241000	N. Canadian R. blw Lk Overholser nr OKC, Okla.	R	1953-2003	48	3	0.326	0.001	4.02	3.31	121.4
44	07242000	North Canadian River near Wetumka, Okla.	R	1938-2003	66	0	0.173	0.041	6.60	0.95	692.0
45	07243500	Deep Fork near Beggs, Okla.	R	1968-2003	36	0	0.133	0.258	11.92	1.47	808.4
46	07245000	Canadian River near Whitefield, Okla.	R	1965-2003	39	0	0.233	0.037	109.07	2.06	5,304.0
47	07247500	Fourche Maline near Red Oak, Okla.	R	1966-2003	37	1	0.081	0.488	1.04	0.65	161.0
48	07249400	James Fork near Hackett, Ark.	N	1959-2003	45	0	0.157	0.125	1.29	0.87	147.7
49	07249985	Lee Creek near Short, Okla. [5]	N	1951-2003	52	1	0.204	0.034	4.20	0.88	479.5
50	07299540	Prairie Dog Town Fork Red R. nr Childress, Tex.	N	1966-2003	38	0	0.138	0.227	1.08	0.93	116.3
51	07299670	Groesbeck Creek at SH 6 near Quannah, Tex.	N	1963-2003	41	0	0.429	<0.001	0.61	3.18	19.2
52	07300000	Salt Fork Red River near Wellington, Tex.	R	1968-2003	36	0	0.075	0.531	0.24	0.49	49.2
53	07300500	Salt Fork Red River at Mangum, Okla.	N	1938-2003	66	0	-0.034	0.690	-0.13	-0.18	73.0
54	07301410	Sweetwater Creek near Kelton, Tex.	N	1963-2003	41	0	-0.028	0.805	-0.02	-0.15	13.1
55	07301500	North Fork Red River near Carter, Okla.[6]	N	1938-2003	64	2	0.017	0.844	0.09	0.08	115.6
56	07305000	North Fork Red River near Headrick, Okla.	R	1945-2003	59	0	-0.002	0.990	-0.02	-0.03	72.7
57	07307800	Pease River near Childress, Tex.	N	1961-2003	38	5	-0.137	0.232	-0.49	-1.08	45.3
58	07308200	Pease River near Vernon, Tex.	N	1961-2003	33	10	-0.223	0.070	-1.44	-1.75	82.3

Table 5. Results of Kendall's tau trend analyses of mean annual flows for entire period of record at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma —Continued

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; Fk, Fork; Res, Reservoir; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Number of years		Kendall's tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
					used	missing			((ft^3/s)/yr)	(percent of median)	
59	07308500	Red River near Burkburnett, Tex.	N	1961-2003	43	0	0.249	0.019	17.89	1.80	991.4
60	07311200	Blue Beaver Creek near Cache, Okla.	N	1965-2003	39	0	0.223	0.047	0.26	2.08	12.5
61	07311500	Deep Red Creek near Randlett, Okla.	N	1950-2003	54	0	0.138	0.144	1.41	1.26	111.6
62	07312200	Beaver Creek near Electra, Tex.	R	1961-2003	43	0	0.019	0.867	0.13	0.25	52.3
63	07312500	Wichita River at Wichita Falls, Tex.	R	1939-2003	65	0	-0.117	0.171	-1.05	-0.57	185.5
64	07314900	Little Wichita River above Henrietta, Tex.	R	1968-2003	36	0	-0.065	0.586	-0.12	-0.64	18.7
65	07315200	East Fork Little Wichita R. near Henrietta, Tex.	N	1965-2003	39	0	-0.053	0.646	-0.10	-0.56	17.9
66	07315500	Red River near Terral, Okla.	R	1945-2003	59	0	0.059	0.513	7.06	0.36	1,963.0
67	07315700	Mud Creek near Courtney, Okla.	N	1961-2003	43	0	0.194	0.069	3.14	2.53	124.1
68	07316000	Red River near Gainesville, Tex.	R	1945-2003	59	0	0.105	0.244	13.70	0.53	2,562.0
69	07316500	Washita River near Cheyenne, Okla.	R	1961-2003	43	0	0.275	0.010	0.42	2.76	15.2
70	07325000	Washita River near Clinton, Okla.	R	1962-2003	42	0	0.389	<0.001	3.71	5.23	71.0
71	07325500	Washita River at Carnegie, Okla.	R	1962-2003	42	0	0.331	0.002	9.30	3.13	296.8
72	07326500	Washita River at Anadarko, Okla.	R	1964-2003	40	0	0.359	0.001	13.23	3.63	364.0
73	07328100	Washita River at Alex, Okla.	R	1965-2003	37	2	0.426	<0.001	20.03	3.80	527.5
74	07328500	Washita River near Pauls Valley, Okla.	R	1962-2003	42	0	0.409	<0.001	25.37	3.65	694.9
75	07331000	Washita River near Dickson, Okla.	R	1962-2003	42	0	0.380	<0.001	45.99	3.29	1,400.0
76	07332500	Blue River near Blue, Okla.	N	1937-2003	67	0	0.090	0.284	1.36	0.53	254.5
77	07335500	Red River at Arthur City, Tex.	R	1945-2003	59	0	0.114	0.205	45.67	0.61	7,537.0

Table 5. Results of Kendall's tau trend analyses of mean annual flows for entire period of record at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma —Continued

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; Fk, Fork; Res, Reservoir; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Start-end WY	Number of years		Kendall's tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
					used	missing			((ft^3/s)/yr)	(percent of median)	
78	07335700	Kiamichi River near Big Cedar, Okla.	N	1966-2003	38	0	0.158	0.167	0.78	0.86	90.4
79	07337900	Glover River near Glover, Okla.	N	1962-2003	42	0	0.194	0.072	5.87	1.21	486.0
80	07340300	Cossatot River near Vandervoort, Ark.	N	1968-2003	36	0	-0.060	0.614	-0.89	-0.48	186.7

[1] Positive value indicates upward trend and negative value indicates downward trend

[2] Includes streamflow record 1943-65 from nearby station 07157000, Cimarron River near Mocane, OK.

[3] Includes streamflow record 1927-89 from nearby station 07161000, Cimarron River at Perkins, OK.

[4] Pre- and post-irrigation development as defined in Wahl and Tortorelli (1997) Through WY 1971 is unregulated, WY 1972-78 are transition years to full irrigation development and regulated by reservoir.

[5] Was 07250000, Lee Creek near Van Buren, Ark., prior to WY 1993 and above Lee Creek Reservoir.

[6] Includes streamflow record 1938-44 from nearby station 07302000, North Fork Red River near Granite, OK.

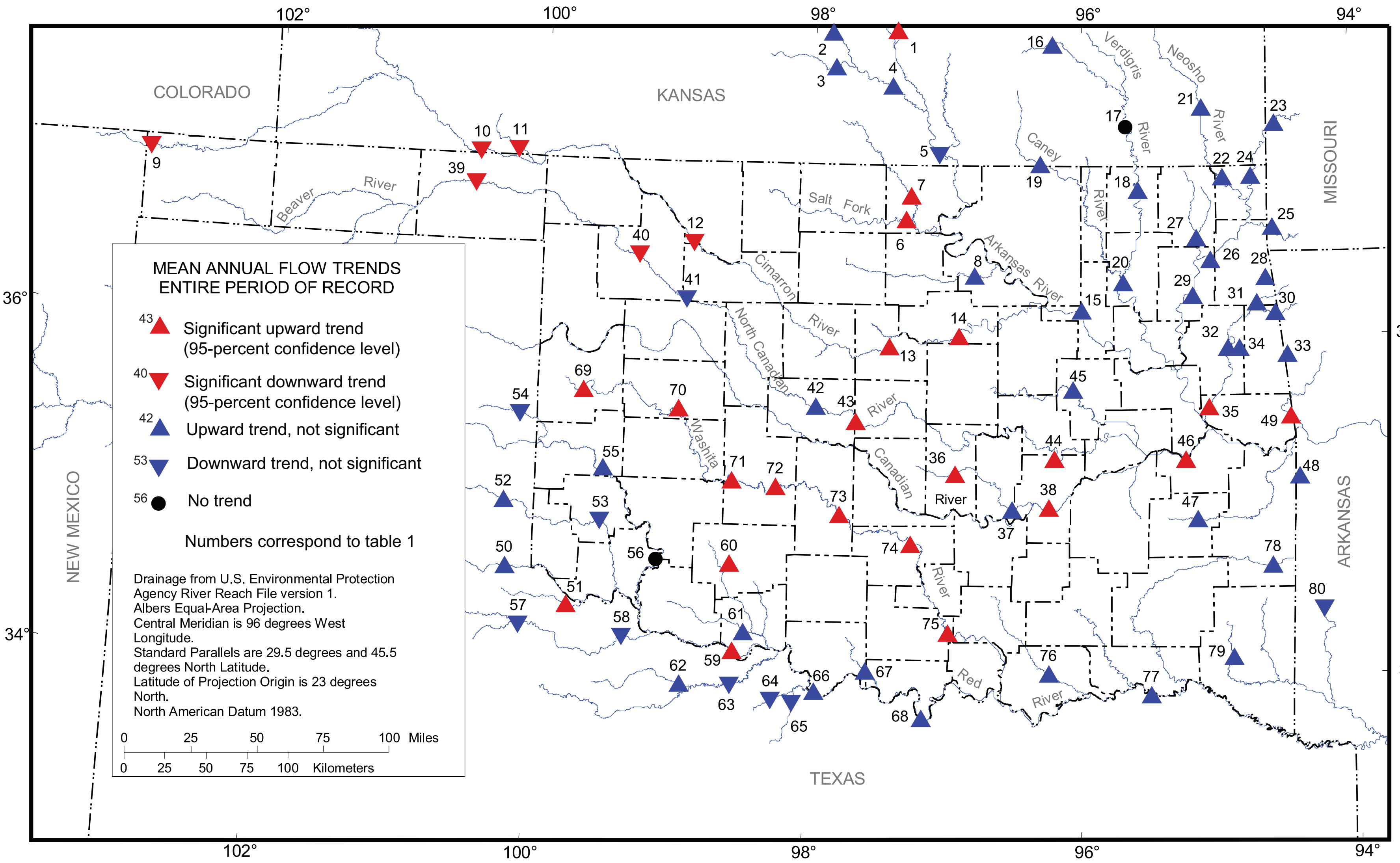

Figure 29. Results of Kendall's tau trend analyses of mean annual flows for entire period of record at selected streamflow-gaging stations with a period of record of at least 36 years from unregulated and regulated basins within and near Oklahoma.

Table 6. Results of Kendall's tau trend analyses of mean annual flows for water years 1968-2003 at selected streamflow-gaging stations from unregulated and regulated basins within and near Oklahoma

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Number of years missing	Kendall's tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
							((ft^3/s)/yr)	(percent of median)	
5	07146500	Arkansas River at Arkansas City, Kans.	R	0	0.070	0.558	9.16	0.50	1,814.5
6	07151000	Salt Fork Arkansas R. at Tonkawa, Okla.	R	0	0.270	0.021	23.41	2.69	869.1
7	07152000	Chikaskia R. near Blackwell, Okla.	N	0	0.210	0.074	12.63	2.10	602.2
8	07153000	Black Bear Creek at Pawnee, Okla.	R	0	0.184	0.117	4.98	2.65	188.0
9	07154500	Cimarron River near Kenton, Okla.	N	0	-0.243	0.038	-0.23	-2.95	7.9
10	07156900	Cimarron River near Forgan, Okla.	N	1	-0.639	<0.001	-1.20	-2.90	41.5
11	07157500	Crooked Creek near Englewood, Kans.	N	0	-0.419	<0.001	-0.36	-2.83	12.7
12	07158000	Cimarron River near Waynoka, Okla.	N	0	0.035	0.775	0.49	0.23	212.2
13	07160000	Cimarron River near Guthrie, Okla.	N	7	0.273	0.390	27.19	2.52	1,078.0
14	07161450	Cimarron River near Ripley, Okla. [2]	N	0	0.283	0.016	42.06	2.72	1,544.5
15	07164500	Arkansas River at Tulsa, Okla.	R	0	0.143	0.225	104.77	1.33	7,877.0
18	07171000	Verdigris River near Lenapah, Okla.	R	0	-0.016	0.902	-5.40	-0.22	2,509.0
19	07172000	Caney River near Elgin, Kans.	R	0	0.035	0.775	1.08	0.39	277.4
20	07176000	Verdigris River near Claremore, Okla.	R	0	0.025	0.838	6.13	0.14	4,315.0
22	07185000	Neosho River near Commerce, Okla.	R	0	-0.052	0.663	-21.48	-0.60	3,553.5
24	07188000	Spring River near Quapaw, Okla.	N	0	0.014	0.913	1.78	0.09	2,072.0
25	07189000	Elk River near Tiff City, Mo.	N	0	-0.063	0.595	-2.90	-0.34	853.4
26	07190500	Neosho River near Langley, Okla.	R	0	-0.016	0.902	-11.18	-0.15	7,484.0
27	07191000	Big Cabin Creek near Big Cabin, Okla.	N	0	0.022	0.859	0.54	0.15	350.4
28	07191220	Spavinaw Creek near Sycamore, Okla.	N	0	-0.038	0.754	-0.42	-0.40	104.2
29	07191500	Neosho River near Chouteau, Okla.	R	0	-0.032	0.796	-25.55	-0.31	8,374.5
30	07195500	Illinois River near Watts, Okla.	N	0	0.013	0.924	0.16	0.02	656.6
31	07196000	Flint Creek near Kansas, Okla.	N	5	-0.140	0.277	-1.32	-1.11	119.1
32	07196500	Illinois River near Tahlequah, Okla.	N	0	-0.003	0.989	-0.28	-0.03	1,018.0
34	07197000	Baron Fork at Eldon, Okla.	N	0	0.006	0.967	0.36	0.10	354.6
35	07198000	Illinois River near Gore, Okla.	R	0	-0.027	0.827	-4.78	-0.29	1,669.5
36	07230500	Little River near Tecumseh, Okla.	R	0	0.267	0.023	3.52	2.91	120.9
37	07231000	Little River near Sasakwa, Okla.	R	0	0.102	0.391	3.21	0.95	339.1
38	07231500	Canadian River at Calvin, Okla.	R	0	0.206	0.079	27.31	1.85	1,480.0
39	07234000	Beaver River at Beaver, Okla. [3]	NIR	0	-0.475	<0.001	-0.99	-7.04	14.1

Table 6. Results of Kendall's tau trend analyses of mean annual flows for water years 1968-2003 at selected streamflow-gaging stations from unregulated and regulated basins within and near Oklahoma —Continued

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Number of years missing	Kendall's tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
							((ft^3/s)/yr)	(percent of median)	
40	07237500	North Canadian River at Woodward, Okla.[3]	NIR	0	0.049	0.683	0.39	0.41	94.5
41	07238000	North Canadian River near Seiling, Okla.. [3]	NIR	0	0.127	0.282	1.77	1.16	152.4
42	07239500	North Canadian River near El Reno, Okla.	R	0	0.292	0.013	6.00	3.16	190.0
43	07241000	N. Canadian R. blw Lk Overholser nr OKC, Okla.	R	3	0.367	0.003	7.44	4.76	156.3
44	07242000	North Canadian River near Wetumka, Okla.	R	0	0.254	0.030	18.79	2.38	788.0
45	07243500	Deep Fork near Beggs, Okla.	R	0	0.133	0.258	11.92	1.47	808.4
46	07245000	Canadian River near Whitefield, Okla.	R	0	0.117	0.320	50.89	0.78	6,531.0
47	07247500	Fourche Maline near Red Oak, Okla.	R	1	0.012	0.932	0.29	0.18	163.7
48	07249400	James Fork near Hackett, Ark.	N	0	0.045	0.704	0.54	0.34	160.0
49	07249985	Lee Creek near Short, Okla. [4]	N	1	-0.002	1.000	-0.08	-0.01	606.5
50	07299540	Prairie Dog Town Fork Red R. nr Childress, Tex.	N	0	0.390	<0.001	0.64	3.14	20.4
52	07300000	Salt Fork Red River near Wellington, Tex.	R	0	0.075	0.531	0.24	0.49	49.2
53	07300500	Salt Fork Red River at Mangum, Okla.	N	0	0.010	0.946	0.08	0.11	72.2
54	07301410	Sweetwater Creek near Kelton, Tex.	N	0	0.010	0.946	0.02	0.14	13.2
55	07301500	North Fork Red River near Carter, Okla.	N	0	0.179	0.127	1.90	1.64	116.1
56	07305000	North Fork Red River near Headrick, Okla.	R	0	0.010	0.946	0.08	0.11	72.2
59	07308500	Red River near Burkburnett, Tex.	N	0	0.206	0.079	19.18	1.89	1,012.5
60	07311200	Blue Beaver Creek near Cache, Okla.	N	0	0.133	0.258	0.15	1.07	13.8
61	07311500	Deep Red Creek near Randlett, Okla.	N	0	0.111	0.347	1.60	1.12	142.6
66	07315500	Red River near Terral, Okla.	R	0	0.146	0.215	30.75	1.56	1,974.0
67	07315700	Mud Creek near Courtney, Okla.	N	0	0.082	0.487	0.91	0.57	157.9
68	07316000	Red River near Gainesville, Tex.	R	0	0.168	0.153	49.49	1.81	2,734.0
69	07316500	Washita River near Cheyenne, Okla.	R	0	0.335	0.004	0.60	4.02	15.0
70	07325000	Washita River near Clinton, Okla.	R	0	0.356	0.002	4.92	6.56	75.0
71	07325500	Washita River at Carnegie, Okla.	R	0	0.308	0.009	10.83	3.55	304.9

Table 6. Results of Kendall’s tau trend analyses of mean annual flows for water years 1968-2003 at selected streamflow-gaging stations from unregulated and regulated basins within and near Oklahoma —Continued

[no., number; I, irrigation; N, natural unregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; yr, year; R., River; abv, above; <, less than; N., North; blw, below; Lk, Lake; nr, near; OKC, Oklahoma City; SH state highway]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Site no. (fig. 1)	Station number	Station name	Type of record (I/N/R)	Number of years missing	Kendall’s tau[1]	Probability value	Trend slope[1]		Median (ft^3/s)
							((ft^3/s)/yr)	(percent of median)	
72	07326500	Washita River at Anadarko, Okla.	R	0	0.327	0.005	14.25	3.75	380.4
73	07328100	Washita River at Alex, Okla.	R	2	0.398	<0.001	21.22	3.54	600.2
74	07328500	Washita River near Pauls Valley, Okla.	R	0	0.354	0.002	27.84	3.32	838.9
75	07331000	Washita River near Dickson, Okla.	R	0	0.267	0.023	44.59	2.73	1,631.0
76	07332500	Blue River near Blue, Okla.	N	0	0.003	0.989	0.48	0.15	308.6
77	07335500	Red River at Arthur City, Tex.	R	0	0.111	0.347	84.35	0.92	9,197.0
78	07335700	Kiamichi River near Big Cedar, Okla.	N	0	0.095	0.422	0.41	0.44	91.7
79	07337900	Glover River near Glover, Okla.	N	0	0.032	0.796	1.05	0.19	557.1

[1] Positive value indicates upward trend and negative value indicates downward trend

[2] Includes streamflow record 1968-89 from nearby station 07161000, Cimarron River at Perkins, OK

[3] Pre- and post-irrigation development as defined in Wahl and Tortorelli (1997). Through WY 1971 is unregulated, WY 1972-78 are transition years to full irrigation development and regulated by reservoir.

[4] Was 07250000, Lee Creek near Van Buren, Ark., prior to WY 1993 and above Lee Creek Reservoir.

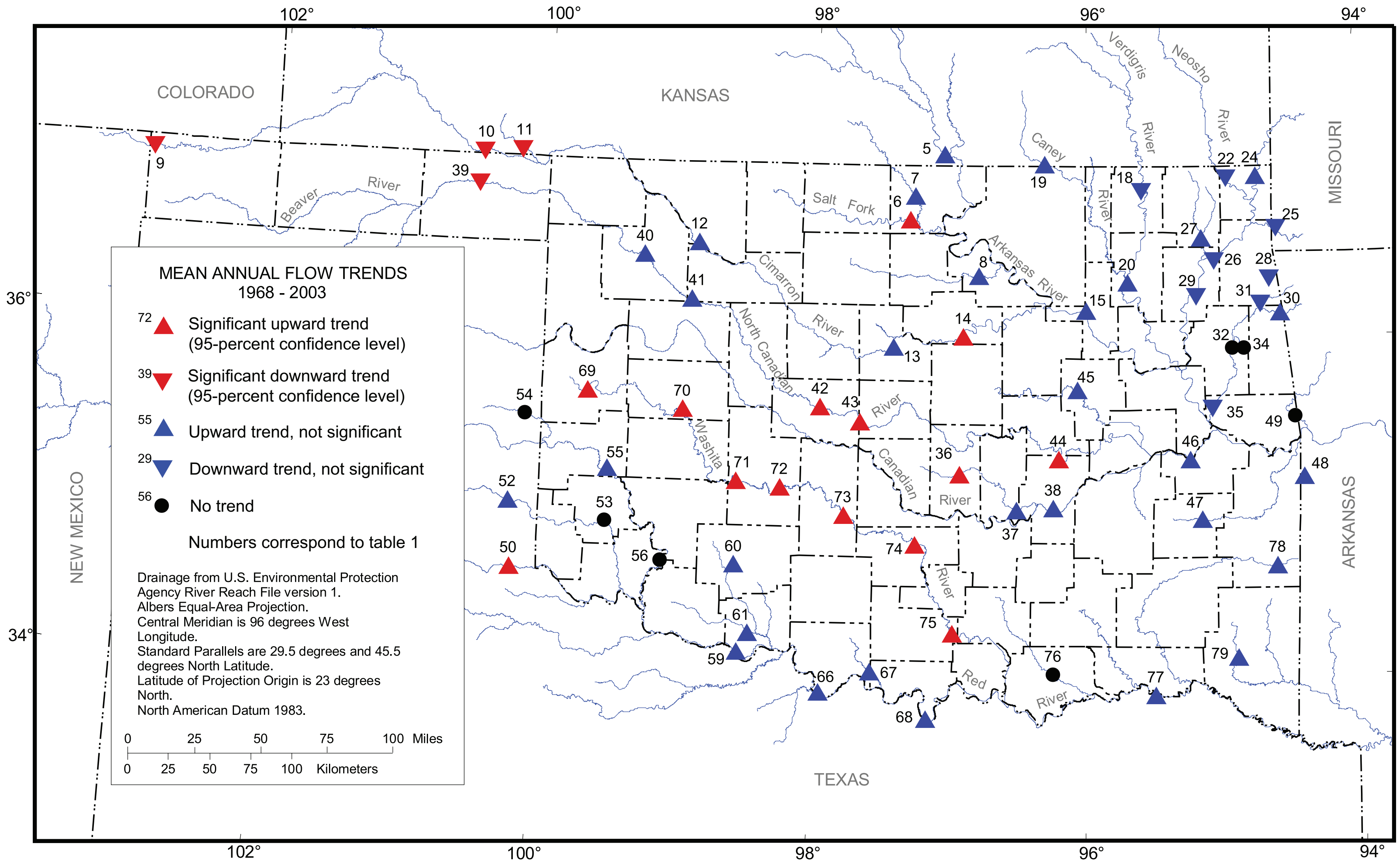

Figure 30. Results of Kendall's tau trend analyses of mean annual flows for water years 1968-2003 at selected streamflow-gaging stations from unregulated and regulated basins within and near Oklahoma.

were located in the northwestern part of the study area (fig. 29). Figure 29 also shows apparent upward and downward trends that are not statistically significant and shows records with no trend.

Graphs showing mean annual flows and LOWESS trend lines for each of the 80 peak-flow records are given in figures 31 through 50 (back of report). The LOWESS trend lines indicated an increase in streamflow at the end of the 20th century, around 1980-2000, for about three-quarters of the stations analyzed, 59 stations (sites 6-8, 13-14, 17-20, 23-38, 41-51, 54-55, 57, 59-62, 65-80; figs. 32, 34-50). This same trend was reported by Garbrecht and others (2004) in 10 long-term streamflow stations in the Great Plains.

Recent Period, 1968-2003

The trend test result may change as the period of record changes. To see if there are mean annual flow trends during a recent 36-year period, the Kendall's tau test also was used to identify trends over the 36-year period, 1968–2003 (table 6, fig. 30) from 63 streamflow-gaging stations within and near Oklahoma. This analysis has the advantage of providing trend information for the same period for all sites. The analysis again was restricted to streamflow-gaging stations within Oklahoma and stations in other states near the Oklahoma border. Of the 63 stations used, 18 station records showed significant trends. Records from 14 streamflow-gaging stations indicated upward trends in mean annual flows, while records from 4 stations indicated downward trends (fig. 30). Again the significant downward-trend stations were located in the northwestern part of the study area.

Fourteen stations (sites 7,12-14, 24-26, 32, 39-40, 44, 53, 55, 76) had mean-annual flow data dating back to at least 1940. One of these 14 stations (site 39, table 6) had record with a significant downward trend in mean annual flow when tested over the recent 36-year period, while one station had record with a significant upward trend in mean annual flow (site 44, table 6). Trends for the same two stations proved significant over the longer period of record as well (table 5). Figure 30 also shows stations with records that had apparent trends that are not statistically significant and records with no trend.

Evaluation of Trend Causes

Factors Affecting Peak Flow

Establishing that a statistically significant trend in streamflow occurred over the past 36 years does not indicate that the trend will continue into the future. In 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 upward 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.

Downward 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. Ground-water depletion usually decreases streamflow, particularly over a long period of time, because it decreases base flow (ground-water contribution to streamflow). Increases in upstream water use are likely to contribute to decreasing streamflows. Terracing, particularly in the western part of the study area, could reduce available runoff, resulting in downward peak flows (Jordan, 1982; Wahl and Tortorelli, 1997; Rasmussen and Perry, 2001). In addition, changes in land use and farming practices can decrease streamflow. The Federal government in the 1930s, 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 may result in a decrease in peak flows.

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. 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 rainfall in all nine regions, which may have an even greater effect on total precipitation than does increased number of storms.

An upward 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 upward trend in number of storms may not increase flood intensity if the time interval between storms allows adequate evapotranspiration to deplete the soil moisture. However, an increase in rainfall intensity does result in increased runoff and floods of greater magnitude.

The Kendall's tau test was applied to total annual precipitation values for each of the 20 climate divisions of the National Weather Service within and near Oklahoma (fig. 51) for the entire period of record, water years 1896-2003 (table 7). The precipitation data were retrieved from the National Climatic Data Center database (National Oceanic and Atmospheric Administration, 2004).

When the Kendall's tau test was applied to annual precipitation for the entire period of record, significant upward trends were detected for 2 of the 20 climate divisions (table 7). The two climate divisions showing significant upward trends in annual precipitation were located in north-central and west-central Oklahoma (fig. 51). No streamflow-gaging stations tested for trends in peak flow within those divisions showed a significant upward trend in peak flow (table 2, fig. 2). Four climate divisions showing close to significant upward trends in annual precipitation were located in central, southwest, and southeast Oklahoma, and southwest Arkansas (fig. 51). Only one streamflow-gaging station tested for trends in peak flow within those divisions showed a significant upward trend in peak flow (site 43, table 2, fig. 2). No climate divisions showed significant downward trends in annual precipitation (table 7). Graphs showing annual precipitation and LOWESS trend lines for each of the 20 climate division records are given in figures 52 through 56 (back of report). The LOWESS trend lines indicated an increase in annual precipitation at the end of the 20th century, around 1980-2000, at most of the stations analyzed, except Texas Climate Division One, High Plains (fig. 51-56). This same trend was reported by Garbrecht and others (2004) at 10 long-term stations in the Great Plains.

Karl and Knight's (1998) study of regional precipitation trends in the United States also found no significant upward 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 storms 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 upward streamflow trends in the eastern part of the study area were caused by an increase in the amount of rainfall during intense precipitation.

The Kendall's tau test also was applied to total annual precipitation values for each of the 20 climate divisions of the National Weather Service within and near Oklahoma (fig. 51) for 1968–2003 (table 8), the same 36-year period used for the annual peak-flow and mean annual flow analyses. No climate divisions showed significant upward or downward trends in annual precipitation (table 8). Rasmussen and Perry (2001) found significant upward trends for the central, southwest, and south-central climate divisions of Oklahoma for the period 1958-97. This change in trends may be due to some dry years since 1997.

The general lack of significant precipitation trends in all climate divisions in western Kansas, Oklahoma, and Texas indicates that the downward trends in peak flows apparent in those areas probably are 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 probably would have little effect on peak flows.

Water-Table Trend Analysis

The Kendall's tau test was applied to records of winter water levels in 26 wells in Oklahoma (table 9, fig. 57). Data from all but well site 19 were from the Oklahoma Water Resources Board annual mass measurements (Oklahoma Water Resources board, 2005). Because only 12 well sites (well sites 2-3, 7-8, 11-13, 18-19, 22-24) had periods of record from 1968 or earlier, only the entire period of record through 2003 was analyzed.

Most of the well records were from shallow wells in major aquifers (water levels less than 100 feet below land surface). Records from several deep wells (water levels greater than 100 feet below land surface) such as in the High Plains aquifer (well sites 2-3, 7-8, and 22-23) also were analyzed (table 9, fig. 57). All well data were considered to be from ground-water sources that would likely have an influence on the surface-water flow. Winter-time water-level measurements were used for the trend analysis because those measurements are not affected by transpiration from vegetation and irrigation pumping. January measurements were used when available, and when unavailable, the closest February or March measurements were substituted. The water-level values used represented the depth below ground surface of the water table. Therefore, a negative Kendall's tau value represents an increase in water-level (less distance below ground surface).

Water levels in 24 of the 26 ground-water wells used in the water-table trend analysis showed significant trends (table 9, fig. 57). Water levels in 7 wells indicated that the water levels at those locations were declining, while water levels in 17 wells showed that the water levels at those locations were rising. The 7 wells with declining water levels were located in western, central, and south-central Oklahoma (fig. 57), and five of the 7 wells were in the panhandle in the High Plains aquifer (well sites 2, 7-8, and 22-23). The 17 wells with rising water levels reflected the increase in streamflow and precipitation about 1980-2000 as reported by Garbrecht and others (2004) at 10 long-term stations in the Great Plains. Caution must be taken to interpret these results, however, because 12 of the 17 wells have relatively short periods of record. Figure 57 also shows apparent trends that are not statistically significant. Graphs showing well-water levels and LOWESS trend lines

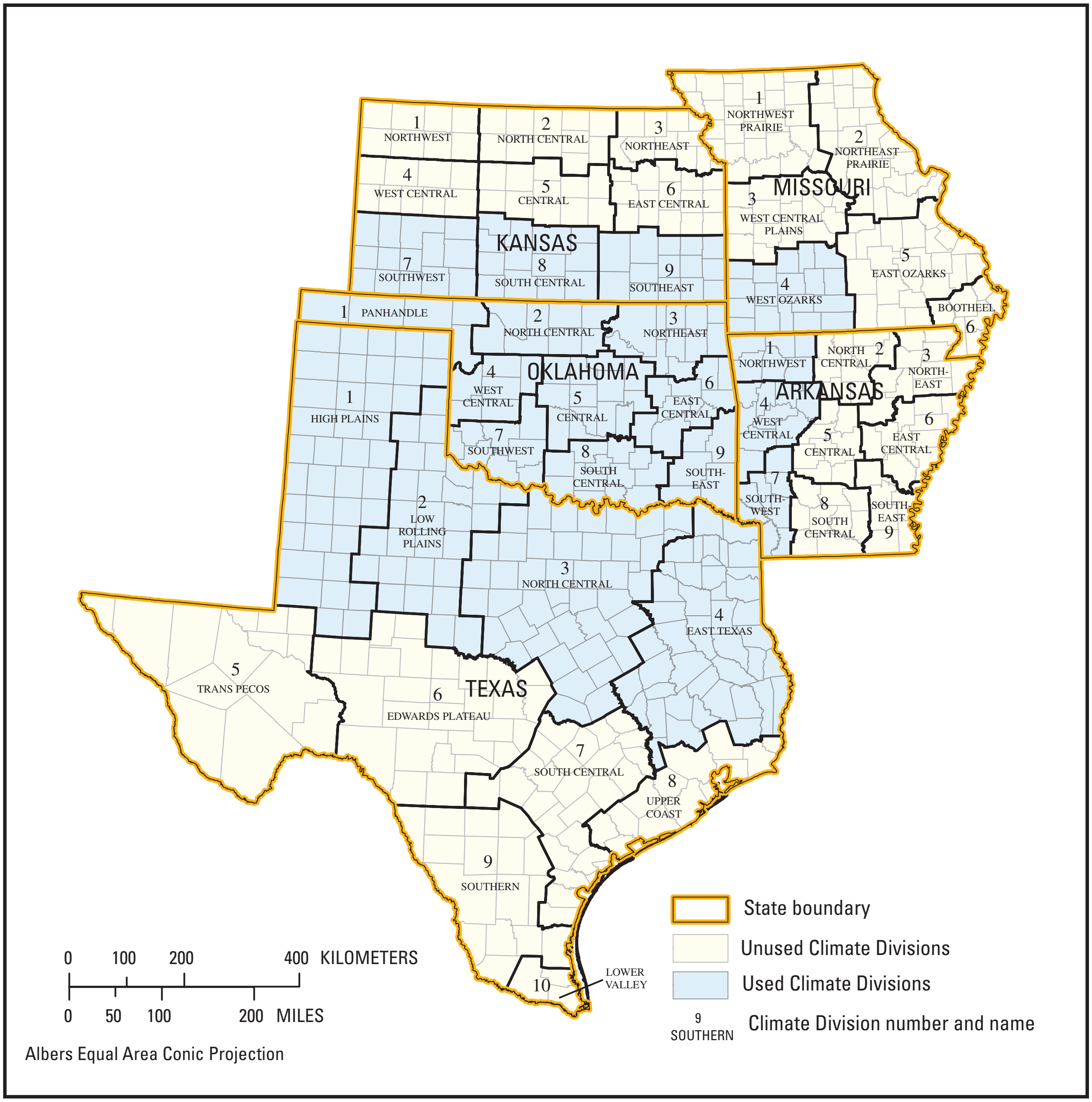

Figure 51. National Weather Service Climate Divisions used in annual precipitation trend analyses.

Table 7. Results of Kendall’s tau trend analyses of total annual precipitation within and near Oklahoma, water years 1896-2003

[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Climate division number - region descriptor[1] (fig. 51)	Kendall’s tau [2]	Probability value	Trend slope [2]		Median (inch)
			(inch/year)	(percent of median)	
		Arkansas			
1 - Northwest	0.032	0.621	0.011	0.025	44.475
4 - West Central	0.035	0.590	0.013	0.027	47.905
7 - Southwest	0.120	0.067	0.053	0.105	50.485
		Kansas			
7 - Southwest	0.082	0.211	0.017	0.091	18.705
8 - South Central	0.086	0.187	0.027	0.101	26.680
9 - Southeast	0.098	0.133	0.033	0.087	37.720
		Missouri			
4 - West Ozarks	-0.008	0.905	-0.002	-0.005	43.345
		Oklahoma			
1 - Panhandle	0.089	0.175	0.020	0.102	19.540
2 - North Central	0.138	0.034	0.040	0.139	28.685
3 - Northeast	0.056	0.396	0.018	0.046	38.950
4 - West Central	0.137	0.036	0.038	0.146	26.115
5 - Central	0.127	0.052	0.045	0.135	33.420
6 - East Central	0.102	0.119	0.039	0.091	42.865
7 - Southwest	0.117	0.074	0.035	0.127	27.560
8 - South Central	0.087	0.181	0.033	0.089	36.935
9 - Southeast	0.125	0.056	0.053	0.109	48.505
		Texas			
1 - High Plains	0.035	0.597	0.006	0.033	18.055
2 - Low Rolling Plains	0.046	0.480	0.014	0.061	23.025
3 - North Central	0.032	0.621	0.014	0.041	34.095
4 - East Texas	0.062	0.342	0.027	0.057	47.110

[1] from http://www.cdc.noaa.gov/USclimate/map.html

[2] Positive value indicates upward trend and negative value indicates downward trend

Table 8. Results of Kendall's tau trend analyses of total annual precipitation within and near Oklahoma, water years 1968-2003

[no statistically significant changes at 95-percent confidence level (probability value less than or equal to 0.05)]

Climate division number-region descriptor[1] (fig. 51)	Kendall's tau [2]	Probability value	Trend slope [2] (inch/year)	Trend slope [2] (percent of median)	Median (inch)
		Arkansas			
1 - Northwest	-0.032	0.796	-0.031	-0.069	45.350
4 - West Central	0.032	0.796	0.039	0.079	49.635
7 - Southwest	0.041	0.733	0.047	0.085	54.470
		Kansas			
7 - Southwest	0.140	0.236	0.090	0.464	19.315
8 - South Central	0.108	0.361	0.114	0.418	27.280
9 - Southeast	0.044	0.713	0.057	0.146	38.995
		Missouri			
4 - West Ozarks	0.003	0.989	0.009	0.021	43.640
		Oklahoma			
1 - Panhandle	0.094	0.429	0.067	0.321	20.880
2 - North Central	0.162	0.169	0.144	0.484	29.765
3 - Northeast	0.086	0.470	0.095	0.242	39.135
4 - West Central	0.143	0.225	0.130	0.483	26.820
5 - Central	0.162	0.169	0.159	0.470	33.840
6 - East Central	0.073	0.540	0.118	0.259	45.570
7 - Southwest	0.114	0.334	0.130	0.455	28.570
8 - South Central	0.060	0.614	0.083	0.217	38.370
9 - Southeast	0.048	0.693	0.073	0.143	51.140
		Texas			
1 - High Plains	-0.014	0.913	-0.009	-0.049	18.490
2 - Low Rolling Plains	-0.013	0.924	-0.007	-0.028	23.390
3 - North Central	0.064	0.595	0.057	0.163	35.235
4 - East Texas	0.081	0.496	0.108	0.226	47.720

[1] from http://www.cdc.noaa.gov/USclimate/map.html

[2] Positive value indicates upward trend and negative value indicates downward trend

Table 9. Results of Kendall’s tau trend analyses of annual winter water levels for entire period of record in 26 selected ground-water wells in Oklahoma

[no., number; OWRB, Oklahoma Water Resources Board; WY, water year; feet/yr, feet per year; A&T, Alluvial and Terrace Deposits; R., River]
[shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05)]

Well Site no. (fig. 57)	OWRB well number [1]	County [1]	Aquifer [1]	Use [1]	Start-end WY [1]	Number of years		Kendall’s tau[2]	Probability value	Trend slope[2] (feet/yr)
						used	missing			
1	9006	Alfalfa	A&T Salt Fork Arkansas R.	Irrigation	1975-2003	26	3	-0.495	<0.001	-0.24
2	572	Beaver	High Plains	Irrigation	1968-2003	36	0	0.775	<0.001	0.63
3	9031	Beaver	High Plains	Irrigation	1968-2003	34	2	-0.512	<0.001	-0.65
4	9131	Bryan	Edwards-Trinity	Domestic	1977-2003	27	0	-0.803	<0.001	-1.33
5	4039	Caddo	Rush Springs	Irrigation	1977-2003	26	1	-0.520	<0.001	-0.63
6	9173	Cherokee	Ozark Plateaus	Domestic	1981-2003	23	0	-0.429	0.006	-0.39
7	2074	Cimarron	High Plains	Irrigation	1967-2003	37	0	0.231	<0.001	1.01
8	2300	Cimarron	High Plains	Irrigation	1967-2003	36	1	0.740	<0.001	1.40
9	9262	Cleveland	Central Oklahoma	Domestic	1983-2003	20	1	0.357	0.030	0.40
10	9419	Garfield	A&T Enid Isolated	Domestic	1975-2003	28	1	-0.804	<0.001	-0.95
11	9436	Greer	Blaine	Irrigation	1952-2003	45	7	-0.477	<0.001	-0.49
12	9470	Harmon	Blaine	Irrigation	1952-2003	43	9	-0.395	<0.001	-0.68
13	9497	Jackson	Blaine	Irrigation	1954-2003	44	6	-0.354	<0.001	-0.24
14	9558	Lincoln	Vanoss	Irrigation	1980-2003	22	2	-0.758	<0.001	-0.59
15	9595	McCurtain	Edwards-Trinity	Observation	1977-2003	27	0	-0.379	0.006	-0.17
16	9587	Major	A&T Cimarron River	Observation	1976-2003	27	1	-0.322	0.020	-0.08
17	9588	Marshall	Edwards-Trinity	Domestic	1978-2003	26	0	0.902	<0.001	1.30
18	9608	Oklahoma	Central Oklahoma	Public Supply	1967-2003	26	2	-0.206	0.146	-1.17
19	USGS[3]	Pontotoc	Arbuckle-Simpson	Observation	1959-2003	45	0	-0.210	<0.001	-0.21
20	9626	Osage		Domestic	1979-2003	25	0	-0.143	0.327	-0.29
21	9647	Roger Mills	High Plains	Domestic	1980-2003	24	0	-0.576	<0.001	-0.17
22	1362	Texas	High Plains	Irrigation	1966-2003	38	0	0.991	<0.001	2.79
23	9695	Texas	High Plains	Irrigation	1966-2003	38	0	0.994	<0.001	1.49
24	9818	Tillman	A&T North Fork Red River	Irrigation	1945-2003	55	4	-0.393	<0.001	-0.21
25	9842	Washita	Rush Springs	Irrigation	1979-2003	24	1	-0.964	<0.001	-1.45
26	9898	Woodward	A&T Beaver-North Canadian R.	Observation	1978-2003	25	1	-0.667	<0.001	-0.50

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[1] Data from OWRB web site, except Site 19. Water Well Search with Water Levels; http://www.owrb.state.ok.us/wd/search/search.php?type=wl

[2] Negative value indicates increasing water level and positive value indicates decreasing water level.

[3] USGS well number 343457096404501, Fittstown Well; Yearly data taken from measurement nearest to January 1.

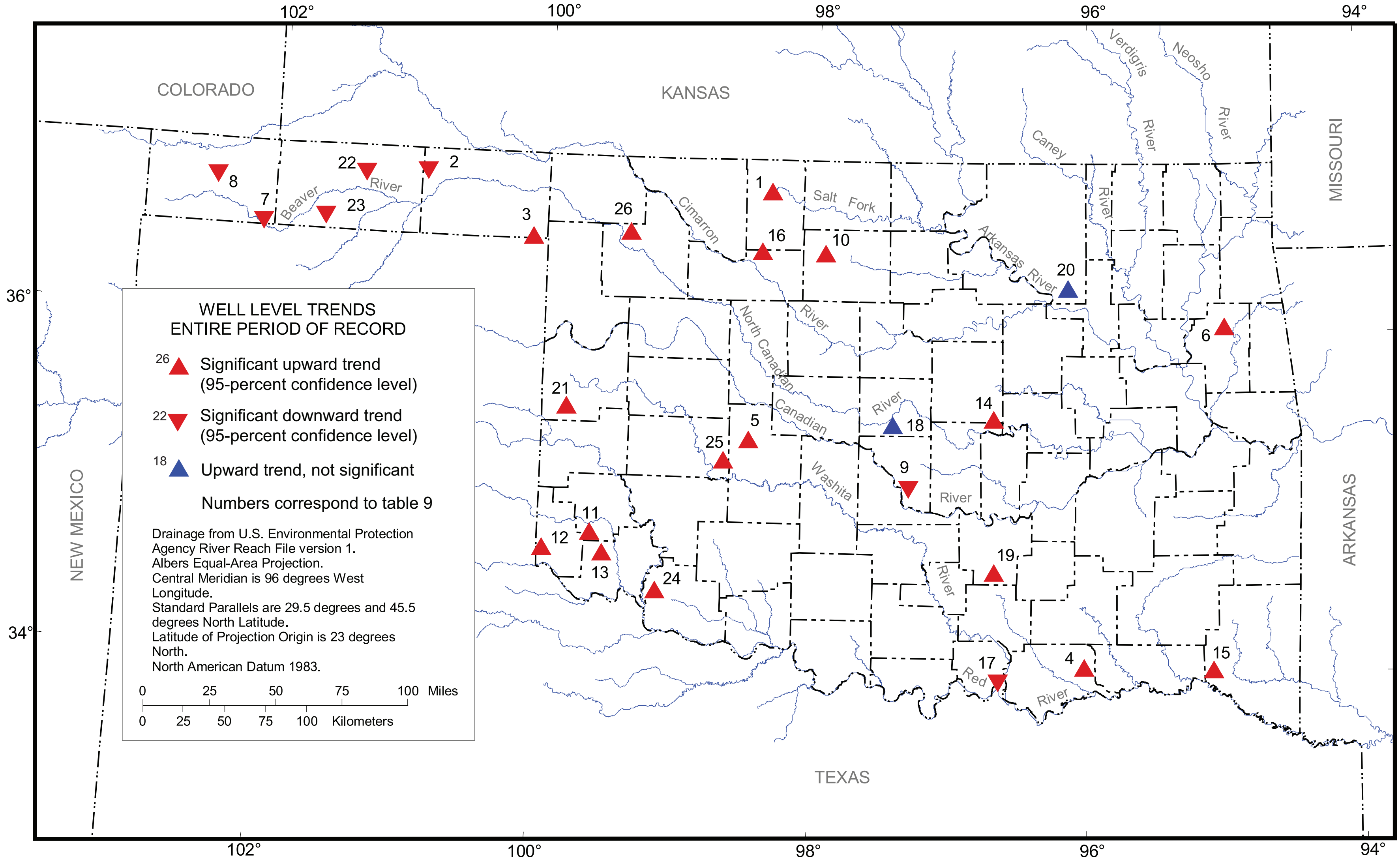

Figure 57. Locations of ground-water wells used in trend analyses and results of Kendall's tau trend analyses of annual winter water levels for entire period of record in 26 selected ground-water wells in Oklahoma.

for each of the 26 water-level records are given in figures 58 through 64 (back of report).

Results of water-level trend analysis indicate that declining water levels may be a factor contributing to downward trends in peak flow in the western part of Oklahoma. In general, if shallow ground-water levels are declining, perennial streams (continuous flow) may tend to become ephemeral (intermittent flow) with dry streambeds. Under those conditions, more rainfall probably is needed to attain peak flows comparable to those under previous conditions. Wahl and Tortorelli (1997) suggested declining ground-water levels as one of the possible causes of lower peak flows in the Beaver-North Canadian River. 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 interaction would be helpful 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 Oklahoma available on a 5-year basis from calendar year 1950 to 2000 are shown in table 10. As shown in table 10, estimated water withdrawals increased by about 400 percent from 1950 through 1975 and then decreased slightly (by about 15 percent) from 1975 to 2000. Withdrawals for irrigation water use, the largest category of water use in Oklahoma, increased by about 500 percent from 1950 through 1975 and then decreased by about 35 percent from 1975 to 2000. Since the majority of irrigation withdrawals were from ground water (see references cited in table 10), the same pattern was evident in the ground-water source category: withdrawals increased from 1950 through 1975 by about 650 percent and then decreased by about 35 percent from 1975-2000. Irrigation application rates vary from year to year and depend on annual rainfall, surface-water availability, farm commodity prices, pump fuel costs, application technologies, and conservation practices (Solley and others, 1998).

Irrigation water use and declines in ground-water levels in western Oklahoma and Kansas probably have contributed to decreasing streamflows. 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, 1997). In a study of rainfall-runoff relations for two river basins in central and western Kansas, Jordan (1982) found that the amount of

Table 10. Estimated total freshwater withdrawals in Oklahoma by water-use category, 1950-2000

Water-use category	Estimated total freshwater withdrawals (million gallons per day)[1]										
	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000
Total Withdrawal	422	890	778	1,225	1,473	2,108	1,719	1,268	1,418	1,775	1,769
Public supply	140	185	206	224	262	340	306	520	515	567	675
Rural domestic and livestock	70	50	59	72	81	99	93	31	171	176	193
Irrigation	180	225	274	364	819	1,160	870	445	601	864	717
Industrial, Commercial [2]	32	430	239	565	311	509	450	272	131	168	184
Source of water											
Ground	165	280	299	380	859	1,234	954	561	659	954	771
Surface	257	610	479	845	614	874	765	707	760	821	997

[1] Estimates of total fresh-water withdrawals from MacKichan (1951, 1957); MacKichan and Kammerer (1961); Murray (1968); Murray and Reeves (1972, 1977); Solley and others (1983, 1988, 1993, 1998); Hutson and others (2004) Partial values may not add to totals because of independent rounding

[2] Includes thermoelectric power except 1950

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

Flood-frequency analysis uses annual peak flow data to estimate the probabilities for certain flood magnitudes when designing bridges, highways, and other flood-plain structures. Frequency analysis assumes that the peak-flow data series represent a stationary data series; 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 data series, the data are not stationary, and the flood-frequency analysis may have substantial errors that invalidate the results.

The effects of significant trends on flood-frequency analysis were investigated by adding hypothetical trends to four streamflow-gaging station records that had no significant trends and comparing estimated flood magnitudes on the unchanged record and the corresponding records with the added trends. Flood-frequency analysis was conducted using procedures outlined in Bulletin 17B of the Interagency Advisory Committee on Water Data (1982). Flood-frequency curves were developed by fitting a Pearson type-III distribution to the logarithms of the annual peak flows.

The four streamflow-gaging-station records used to examine the effects of trends on flood-frequency analysis for water years 1968-2003 were Illinois River near Tahlequah (site 32), Deep Fork near Beggs (site 45), Little River near Sasakwa (site 37), and Washita River near Dickson (site 75). These stations were selected because each had a Kendall’s tau value near zero and an associated large p-value, indicating no trend in the data (table 3). Trends were introduced to the records by adding a given hypothetical percentage increase or decrease incrementally to each year of the 36-year record. Upward trends were added to the two station records that initially had positive Kendall’s tau values (sites 32 and 45, table 3). Downward trends were added to the two station records that initially had negative Kendall’s tau values (sites 37 and 75, table 3).

Tables 11–14 show how annual peak-flow values from 1968–2003 were affected by the added trends. The first column after the water 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 parentheses for the original peak-flow series. It was determined that a 3-percent upward trend was needed for the Illinois River near Tahlequah (site 32, table 11) and a 4-percent upward trend was needed for the Deep Fork near Beggs (site 45, table 12) records to attain statistically significant trends. A 2-percent downward trend was needed for the Little River near Sasakwa (site 37, table 13) and a 1-percent downward trend was needed for the Washita River near Dickson (site 75, table 14) records to attain statistically significant trends.

The comparison of flood magnitudes between a non-trending peak-flow series and the same series with an added 4-percent upward trend revealed that flood estimates increased by as much as 91 percent. The 10- year flood estimate increased by 76 percent for Illinois River (table 11) and 80 percent for Deep Fork (table 12). The 50-year flood estimates increased by 82 percent (table 11) and 88 percent (table 12), respectively, and the 100-year flood estimates increased by 84 percent (table 11) and 91 percent (table 12), respectively. In all cases for the Illinois River near Tahlequah and Deep Fork near Beggs station records, the flood estimates from the 3-percent and the 4-percent upward trend series were greater than the upper confidence limit established by the non-trending series, indicating the potential importance of accounting for trends.

The comparison of flood magnitudes between a non-trending peak-flow series and the same series with an added 2-percent downward trend revealed that flood estimates decreased by as much as 34 percent. The 10-year flood estimate decreased by 29 percent for Little River (table 13) and 33 percent for Washita River (table 14). The 25-, 50-year, and 100-year flood estimates decreased by about 28 percent (table 13) and about 33 percent (table 14), respectively. In all cases for the Little River near Sasakwa and Washita River near Dickson station records, the flood estimates from the 1.5-percent and the 2-percent downward trend series were less than the lower confidence limit established by the non-trending series, 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 the 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.

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

Table 11. Results of Kendall’s tau trend test and flood-frequency analysis of Illinois River near Tahlequah, Oklahoma, (Site 32) peak-flow record with upward trend added to period of record, water years 1968-2003

[ft^3/s, cubic feet per second; yr, year; %, percent]

Water Year	Peak flow (cubic feet per second)						
	No change	2-percent increase[1]		3-percent increase[1]		4-percent increase[1]	
1968	17,300	1.00	17,300	1.00	17,300	1.00	17,300
1969	31,900	1.02	32,538	1.03	32,857	1.04	33,176
1970	14,400	1.04	14,976	1.06	15,264	1.08	15,552
1971	20,300	1.06	21,518	1.09	22,127	1.12	22,736
1972	9,190	1.08	9,925	1.12	10,293	1.16	10,660
1973	18,200	1.10	20,020	1.15	20,930	1.20	21,840
1974	66,400	1.12	74,368	1.18	78,352	1.24	82,336
1975	31,700	1.14	36,138	1.21	38,357	1.28	40,576
1976	33,000	1.16	38,280	1.24	40,920	1.32	43,560
1977	10,400	1.18	12,272	1.27	13,208	1.36	14,144
1978	22,200	1.20	26,640	1.30	28,860	1.40	31,080
1979	17,100	1.22	20,862	1.33	22,743	1.44	24,624
1980	2,700	1.24	3,348	1.36	3,672	1.48	3,996
1981	4,550	1.26	5,733	1.39	6,325	1.52	6,916
1982	25,300	1.28	32,384	1.42	35,926	1.56	39,468
1983	15,800	1.30	20,540	1.45	22,910	1.60	25,280
1984	9,710	1.32	12,817	1.48	14,371	1.64	15,924
1985	45,700	1.34	61,238	1.51	69,007	1.68	76,776
1986	32,500	1.36	44,200	1.54	50,050	1.72	55,900
1987	56,800	1.38	78,384	1.57	89,176	1.76	99,968
1988	28,300	1.40	39,620	1.60	45,280	1.80	50,940
1989	10,800	1.42	15,336	1.63	17,604	1.84	19,872
1990	54,900	1.44	79,056	1.66	91,134	1.88	103,212
1991	11,200	1.46	16,352	1.69	18,928	1.92	21,504
1992	12,600	1.48	18,648	1.72	21,672	1.96	24,696
1993	28,500	1.50	42,750	1.75	49,875	2.00	57,000
1994	16,300	1.52	24,776	1.78	29,014	2.04	33,252
1995	20,500	1.54	31,570	1.81	37,105	2.08	42,640
1996	19,200	1.56	29,952	1.84	35,328	2.12	40,704
1997	21,100	1.58	33,338	1.87	39,457	2.16	45,576
1998	25,700	1.60	41,120	1.90	48,830	2.20	56,540
1999	19,600	1.62	31,752	1.93	37,828	2.24	43,904
2000	35,100	1.64	57,564	1.96	68,796	2.28	80,028

Table 11. Results of Kendall's tau trend test and flood-frequency analysis of Illinois River near Tahlequah, Oklahoma, (Site 32) peak-flow record with upward trend added to period of record, water years 1968-2003 —Continued

[ft^3/s, cubic feet per second; yr, year; %, percent]

Water Year	Peak flow (cubic feet per second)						
	No change	2-percent increase[1]		3-percent increase[1]		4-percent increase[1]	
2001	25,400	1.66	42,164	1.99	50,546	2.32	58,928
2002	19,800	1.68	33,264	2.02	39,996	2.36	46,728
2003	5,570	1.70	9,469	2.05	11,418	2.40	13,368
Mean	23,326		31,395		35,429		39,464
Median	20,050		30,761		34,092		36,360
Kendall's tau	0.041		0.190		0.251		0.295
Probability level	0.733		0.105		0.032		0.012
Trend slope (ft^3)/yr	56.2		451.5		653.2		858.2
% median	0.28		1.47		1.92		2.36
100-year flood	72,900 (55,900; 106,000)[2]		101,000		117,000		134,000
50-year flood	63,800 (49,700; 89,800)[2]		87,900		102,000		116,000
25-year flood	54,600 (43,400; 74,600)[2]		75,100		86,300		97,900
10-year flood	42,600 (34,800; 55,600)[2]		58,200		66,400		74,800
5-year flood	33,400 (27,800; 41,800)[2]		45,300		51,400		57,500

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

[2] Computations based on 1968-2003 peak flows only; values in parenthesis indicate 95-percent confidence limits

Table 12. Results of Kendall's tau trend test and flood-frequency analysis of Deep Fork near Beggs, Oklahoma, (Site 45) peak-flow record with upward trend added to period of record, water years 1968-2003

[ft^3/s, cubic feet per second; yr, year; %, percent]

Water Year	Peak flow (cubic feet per second)						
	No change	2-percent increase[1]		3-percent increase[1]		4-percent increase[1]	
1968	6,250	1.00	6,250	1.00	6,250	1.00	6,250
1969	4,440	1.02	4,529	1.03	4,573	1.04	4,618
1970	5,540	1.04	5,762	1.06	5,872	1.08	5,983
1971	5,620	1.06	5,957	1.09	6,126	1.12	6,294
1972	8,350	1.08	9,018	1.12	9,352	1.16	9,686
1973	11,600	1.10	12,760	1.15	13,340	1.20	13,920
1974	30,900	1.12	34,608	1.18	36,462	1.24	38,316
1975	29,800	1.14	33,972	1.21	36,058	1.28	38,144
1976	8,320	1.16	9,651	1.24	10,317	1.32	10,982
1977	2,780	1.18	3,280	1.27	3,531	1.36	3,781
1978	3,340	1.20	4,008	1.30	4,342	1.40	4,676
1979	8,570	1.22	10,455	1.33	11,398	1.44	12,341
1980	5,210	1.24	6,460	1.36	7,086	1.48	7,711
1981	3,290	1.26	4,145	1.39	4,573	1.52	5,001
1982	12,200	1.28	15,616	1.42	17,324	1.56	19,032
1983	9,740	1.30	12,662	1.45	14,123	1.60	15,584
1984	21,800	1.32	28,776	1.48	32,264	1.64	35,752
1985	27,700	1.34	37,118	1.51	41,827	1.68	46,536
1986	15,800	1.36	21,488	1.54	24,332	1.72	27,176
1987	14,800	1.38	20,424	1.57	23,236	1.76	26,048
1988	20,900	1.40	29,260	1.60	33,440	1.80	37,620
1989	8,330	1.42	11,829	1.63	13,578	1.84	15,327
1990	37,000	1.44	53,280	1.66	61,420	1.88	69,560
1991	5,070	1.46	7,402	1.69	8,568	1.92	9,734
1992	12,500	1.48	18,500	1.72	21,500	1.96	24,500
1993	30,700	1.50	46,050	1.75	53,725	2.00	61,400
1994	7,760	1.52	11,795	1.78	13,813	2.04	15,830
1995	21,800	1.54	33,572	1.81	39,458	2.08	45,344
1996	2,620	1.56	4,087	1.84	4,821	2.12	5,554
1997	6,930	1.58	10,949	1.87	12,959	2.16	14,969
1998	18,900	1.60	30,240	1.90	35,910	2.20	41,580
1999	19,600	1.62	31,752	1.93	37,828	2.24	43,904
2000	6,390	1.64	10,480	1.96	12,524	2.28	14,569

Table 12. Results of Kendall's tau trend test and flood-frequency analysis of Deep Fork near Beggs, Oklahoma, (Site 45) peak-flow record with upward trend added to period of record, water years 1968-2003 —Continued

[ft^3/s, cubic feet per second; yr, year; %, percent]

Water Year	Peak flow (cubic feet per second)						
	No change	2-percent increase[1]		3-percent increase[1]		4-percent increase[1]	
2001	10,200	1.66	16,932	1.99	20,298	2.32	23,664
2002	5,340	1.68	8,971	2.02	10,787	2.36	12,602
2003	2,550	1.70	4,335	2.05	5,228	2.40	6,120
Mean	12,573		17,122		19,396		21,670
Median	8,460		11,812		13,459		15,148
Kendall's tau	0.052		0.178		0.221		0.254
Probability level	0.663		0.131		0.060		0.030
Trend slope							
(ft^3)/yr	54.8		227.9		312.3		412.4
% median	0.65		1.93		2.32		2.72
100-year flood	58,200 (40,800; 96,000)[2]		84,000		97,400		111,000
50-year flood	46,900 (33,900; 73,900)[2]		67,000		77,500		88,100
25-year flood	37,000 (27,500; 55,400)[2]		52,200		60,200		68,200
10-year flood	25,600 (19,800; 35,700)[2]		35,600		40,700		46,000
5-year flood	18,200 (14,500; 24,000)[2]		24,900		28,300		31,800

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

[2] Computations based on 1968-2003 peak flows only; values in parenthesis indicate 95-percent confidence limits.

Table 13. Results of Kendall's tau trend test and flood-frequency analysis of Little River near Sasakwa, Oklahoma, (Site 37) peak-flow record with downward trend added to period of record, water years 1968-2003

[ft^3/s, cubic feet per second; yr, year; %, percent]

Water Year	Peak flow (cubic feet per second)						
	No change	1.0-percent decrease[1]		1.5-percent decrease[1]		2.0-percent decrease[1]	
1968	15,800	1.00	15,800	1.000	15,800	1.000	15,800
1969	3,940	0.99	3,901	0.985	3,881	0.980	3,861
1970	7,950	0.98	7,791	0.970	7,712	0.960	7,632
1971	15,600	0.97	15,132	0.955	14,898	0.940	14,664
1972	3,910	0.96	3,754	0.940	3,675	0.920	3,597
1973	9,150	0.95	8,693	0.925	8,464	0.900	8,235
1974	10,900	0.94	10,246	0.910	9,919	0.880	9,592
1975	7,480	0.93	6,956	0.895	6,695	0.860	6,433
1976	4,200	0.92	3,864	0.880	3,696	0.840	3,528
1977	4,720	0.91	4,295	0.865	4,083	0.820	3,870
1978	5,680	0.90	5,112	0.850	4,828	0.800	4,544
1979	11,100	0.89	9,879	0.835	9,269	0.780	8,658
1980	3,130	0.88	2,754	0.820	2,567	0.760	2,379
1981	859	0.87	747	0.805	691	0.740	636
1982	6,650	0.86	5,719	0.790	5,254	0.720	4,788
1983	6,280	0.85	5,338	0.775	4,867	0.700	4,396
1984	8,880	0.84	7,459	0.760	6,749	0.680	6,038
1985	18,500	0.83	15,355	0.745	13,783	0.660	12,210
1986	6,400	0.82	5,248	0.730	4,672	0.640	4,096
1987	7,720	0.81	6,253	0.715	5,520	0.620	4,786
1988	7,760	0.80	6,208	0.700	5,432	0.600	4,656
1989	7,470	0.79	5,901	0.685	5,117	0.580	4,333
1990	16,400	0.78	12,792	0.670	10,988	0.560	9,184
1991	4,950	0.77	3,812	0.655	3,242	0.540	2,673
1992	8,780	0.76	6,673	0.640	5,619	0.520	4,566
1993	15,400	0.75	11,550	0.625	9,625	0.500	7,700
1994	4,910	0.74	3,633	0.610	2,995	0.480	2,357
1995	8,200	0.73	5,986	0.595	4,879	0.460	3,772
1996	6,460	0.72	4,651	0.580	3,747	0.440	2,842
1997	8,850	0.71	6,284	0.565	5,000	0.420	3,717
1998	12,700	0.70	8,890	0.550	6,985	0.400	5,080
1999	15,600	0.69	10,764	0.535	8,346	0.380	5,928
2000	5,750	0.68	3,910	0.520	2,990	0.360	2,070

Table 13. Results of Kendall’s tau trend test and flood-frequency analysis of Little River near Sasakwa, Oklahoma, (Site 37) peak-flow record with downward trend added to period of record, water years 1968-2003 —Continued

[ft^3/s, cubic feet per second; yr, year; %, percent]

Water Year	Peak flow (cubic feet per second)						
	No change	1.0-percent decrease[1]		1.5-percent decrease[1]		2.0-percent decrease[1]	
2001	6,580	0.67	4,409	0.505	3,323	0.340	2,237
2002	5,630	0.66	3,716	0.490	2,759	0.320	1,802
2003	2,560	0.65	1,664	0.475	1,216	0.300	768
Mean	8,246		6,809		6,091		5,373
Median	7,475		5,944		5,058		4,470
Kendall’s tau	-0.002		-0.140		-0.229		-0.346
Probability level	1.000		0.236		0.051		0.003
Trend slope (ft^3)/yr	-0.4		-70.6		-110.3		-138.1
% median	0.00		-1.19		-2.18		-3.09
100-year flood	23,600 (18,800; 32,600)[2]		20,000		18,400		16,900
50-year flood	20,600 (16,700; 27,600)[2]		17,400		16,100		14,800
25-year flood	17,700 (14,600; 23,000)[2]		15,000		13,800		12,700
10-year flood	14,000 (11,900; 17,400)[2]		11,800		10,800		9,900
5-year flood	11,300 (9,720; 13,500)[2]		9,380		8,510		7,730

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

[2] Computations based on 1968-2003 peak flows only; values in parenthesis indicate 95-percent confidence limits.

Table 14. Results of Kendall's tau trend test and flood-frequency analysis of Washita River near Dickson, Oklahoma, (Site 75) peak-flow record with downward trend added to period of record, water years 1968-2003

[ft^3/s, cubic feet per second; yr, year; %, percent]

Water Year	Peak flow (cubic feet per second)						
	No change	1.0-percent decrease[1]		1.5-percent decrease[1]		2.0-percent decrease[1]	
1968	34,100	1.00	34,100	1.000	34,100	1.000	34,100
1969	25,700	0.99	25,443	0.985	25,315	0.980	25,186
1970	23,100	0.98	22,638	0.970	22,407	0.960	22,176
1971	43,600	0.97	42,292	0.955	41,638	0.940	40,984
1972	8,950	0.96	8,592	0.940	8,413	0.920	8,234
1973	35,700	0.95	33,915	0.925	33,023	0.900	32,130
1974	42,300	0.94	39,762	0.910	38,493	0.880	37,224
1975	39,000	0.93	36,270	0.895	34,905	0.860	33,540
1976	16,800	0.92	15,456	0.880	14,784	0.840	14,112
1977	35,200	0.91	32,032	0.865	30,448	0.820	28,864
1978	27,800	0.90	25,020	0.850	23,630	0.800	22,240
1979	32,400	0.89	28,836	0.835	27,054	0.780	25,272
1980	35,200	0.88	30,976	0.820	28,864	0.760	26,752
1981	8,120	0.87	7,064	0.805	6,537	0.740	6,009
1982	41,800	0.86	35,948	0.790	33,022	0.720	30,096
1983	29,500	0.85	25,075	0.775	22,863	0.700	20,650
1984	23,000	0.84	19,320	0.760	17,480	0.680	15,640
1985	34,500	0.83	28,635	0.745	25,703	0.660	22,770
1986	25,700	0.82	21,074	0.730	18,761	0.640	16,448
1987	105,000	0.81	85,050	0.715	75,075	0.620	65,100
1988	34,100	0.80	27,280	0.700	23,870	0.600	20,460
1989	31,400	0.79	24,806	0.685	21,509	0.580	18,212
1990	118,000	0.78	92,040	0.670	79,060	0.560	66,080
1991	27,300	0.77	21,021	0.655	17,882	0.540	14,742
1992	47,900	0.76	36,404	0.640	30,656	0.520	24,908
1993	56,500	0.75	42,375	0.625	35,313	0.500	28,250
1994	32,900	0.74	24,346	0.610	20,069	0.480	15,792
1995	52,100	0.73	38,033	0.595	31,000	0.460	23,966
1996	11,400	0.72	8,208	0.580	6,612	0.440	5,016
1997	30,000	0.71	21,300	0.565	16,950	0.420	12,600
1998	38,000	0.70	26,600	0.550	20,900	0.400	15,200
1999	27,900	0.69	19,251	0.535	14,927	0.380	10,602
2000	10,500	0.68	7,140	0.520	5,460	0.360	3,780

Table 14. Results of Kendall's tau trend test and flood-frequency analysis of Washita River near Dickson, Oklahoma, (Site 75) peak-flow record with downward trend added to period of record, water years 1968-2003 —Continued

[ft^3/s, cubic feet per second; yr, year; %, percent]

Water Year	Peak flow (cubic feet per second)						
	No change	1.0-percent decrease[1]		1.5-percent decrease[1]		2.0-percent decrease[1]	
2001	30,700	0.67	20,569	0.505	15,504	0.340	10,438
2002	28,700	0.66	18,942	0.490	14,063	0.320	9,184
2003	8,330	0.65	5,415	0.475	3,957	0.300	2,499
Mean	34,811		28,645		25,562		22,479
Median	31,900		25,259		23,246		21,413
Kendall's tau	-0.056		-0.248		-0.333		-0.429
Probability level	0.643		0.035		0.004		<0.001
Trend slope							
(ft^3)/yr	-101.5		-409.1		-547.1		-683.7
% median	-0.32		-1.62		-2.35		-3.19
100-year flood	100,000 (77,900; 142,000)[2]		79,100		70,400		66,500
50-year flood	88,900 (70,200; 123,000)[2]		71,200		68,300		59,400
25-year flood	77,300 (62,100; 104,000)[2]		62,900		56,700		52,000
10-year flood	61,600 (50,700; 79,400)[2]		50,900		46,200		41,500
5-year flood	49,100 (41,200; 61,000)[2]		41,000		37,200		32,900

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

[2] Computations based on 1968-2003 peak flows only; values in parenthesis indicate 95-percent confidence limits.

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, 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, is that more uncertainty exists in flood-frequency estimates than 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 Oklahoma appears to be changing. The U.S. Geological Survey, in cooperation with the Oklahoma Department of Transportation, conducted a study to determine if trends in annual peak streamflow or mean annual flows are present in Oklahoma. The Kendall’s tau trend test was used to identify and evaluate annual peak-flow trends in Oklahoma and nearby streamflow-gaging stations in the adjoining States of Kansas, Missouri, Arkansas, and Texas. LOWESS trend lines were used as a graphical exploratory technique for trends. The first part of the peak-flow analysis used the entire period of record from 80 currently operating streamflow-gaging stations within and near Oklahoma that had a minimum of 36 years of record. Records from 3 streamflow-gaging stations indicated statistically significant upward trends in peak flows, while records from 12 stations indicated statistically significant downward trends. The records with upward trends were from gaging stations scattered in the central and northeastern part of the study area, while the significant downward-trend stations were located in the western part of the study area.

The trend test result may change as the period of record changes. The second part of the peak-flow analysis used a recent 36-year period of record, 1968–2003, from 63 stations within and near Oklahoma. Seven station records had significant downward trends, and one record had a significant upward trend. Again the significant downward-trend stations were located in the western part of the study area. The significant upward-trend station was located in the central part of the study area.

The third part of the peak-flow analysis investigated trends for various 30-year periods separated by 5-year increments through the available periods of record from 63 stations within and near Oklahoma. From that analysis it is possible to identify time periods within each station record when peak-flow trends were occurring. Streamflow trends generally were downward during 1956-85 and upward in 1966-95.

Mean annual flow also was analyzed for trends. Mean annual flow is the average of the individual daily mean discharge values. The first part of the mean annual-flow analysis used the entire period of record from 80 stations within and near Oklahoma that had a minimum of 36 years of record. A regional pattern similar to the peak-flow analysis resulted, except more significant upward trends were found. Twenty-eight records (35 percent) exhibited a trend; 22 streamflow-gaging stations indicated statistically significant upward trends in mean annual flows, while records from 6 stations indicated statistically significant downward trends. The records with upward trends were from gaging stations scattered in a band through the central, and southwest and north-central parts of the study area; while the significant downward-trend stations were located in the northwestern part of the study area. The LOWESS trend lines indicated an increase in streamflow at the end of the 20th century, around 1980-2000, for two-thirds of the stations analyzed.

The second part of the mean annual-flow analysis used just a recent 36-year period of record, 1968– 2003, from 63 stations within and near Oklahoma. Eighteen station records showed significant trends; 14 station records had upward trends, and 4 records had an downward trend. Again the significant downward-trend stations were located in the northwestern part of the study area.

The most direct potential cause of an upward trend in peak flow is an increase in either the frequency, intensity, or amount of rainfall. Downward 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. The Kendall's tau test was applied to total annual precipitation values for each of the 20 climate divisions of the National Weather Service within and near Oklahoma, for the entire period of record, water year 1896-2003. Two climate divisions showing significant upward trends in annual precipitation were located in west-central and north-central Oklahoma. Four climate divisions showing close to significant upward trends in annual precipitation were located in southwest, central and southeast Oklahoma, and southwest Arkansas. No climate divisions showed significant downward trends in annual precipitation. The LOWESS trend lines indicated an increase in annual precipitation at the end of the 20th century, around 1980-2000, at all of the stations analyzed, except Texas Climate Division One, High Plains.

The Kendall's tau test was applied to total annual precipitation values for each of the 20 climate divisions for 1968–2003, the same 36-year period used for the annual peak-flow and mean annual flow analyses. No climate divisions showed either significant upward or downward trends in annual precipitation.

Downward trends in peak flows apparent in western Kansas, Oklahoma, and Texas probably are due to factors other than total precipitation. The Kendall's tau test was applied to records of winter water levels in 26 wells in Oklahoma for the entire period of record. Water levels in 7 wells indicated that the water levels at those locations was declining, while water levels in 17 wells showed that the water table at those locations was rising. The 7 wells with declining water levels were located in western, central and south-central Oklahoma with five wells in the panhandle in the High Plains aquifer. The 17 wells with rising water levels reflected the increase in streamflow and precipitation about 1980-2000. Caution must be taken to interpret these results, however, because 12 of the 17 wells have relatively short periods of record. Results of water-level trend analysis indicate that declining water levels may be a factor contributing to downward trends in peak flow in the western part of Oklahoma.

Water use could not be used in the trend analyses due to a lack of reliable historic record. Estimates of total water withdrawals in Oklahoma available on a 5-year basis from calendar year 1950 to 2000 were shown. Irrigation water use and declines in ground-water levels in western Oklahoma and Kansas probably have contributed to decreasing streamflows. 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 may be a factor contributing to downward trends in peak streamflow in western Oklahoma and Kansas. Decreasing peak streamflow also may be related to other factors such as construction of ponds and terraces.

Flood-frequency analysis uses annual peak flow data to estimate the probabilities for certain flood magnitudes. If significant trends exist in the peak-flow data series, the data are not stationary, and the flood- frequency analysis may have substantial errors that invalidate the statistical results. The effects of significant trends on flood-frequency analysis were investigated by adding hypothetical trends to four stream flow-gaging station records that had no significant trends and comparing estimated flood magnitudes on the unchanged record and the corresponding records with the added trends. The magnitude of the 100-year flood changed by as much as 91 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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Figures

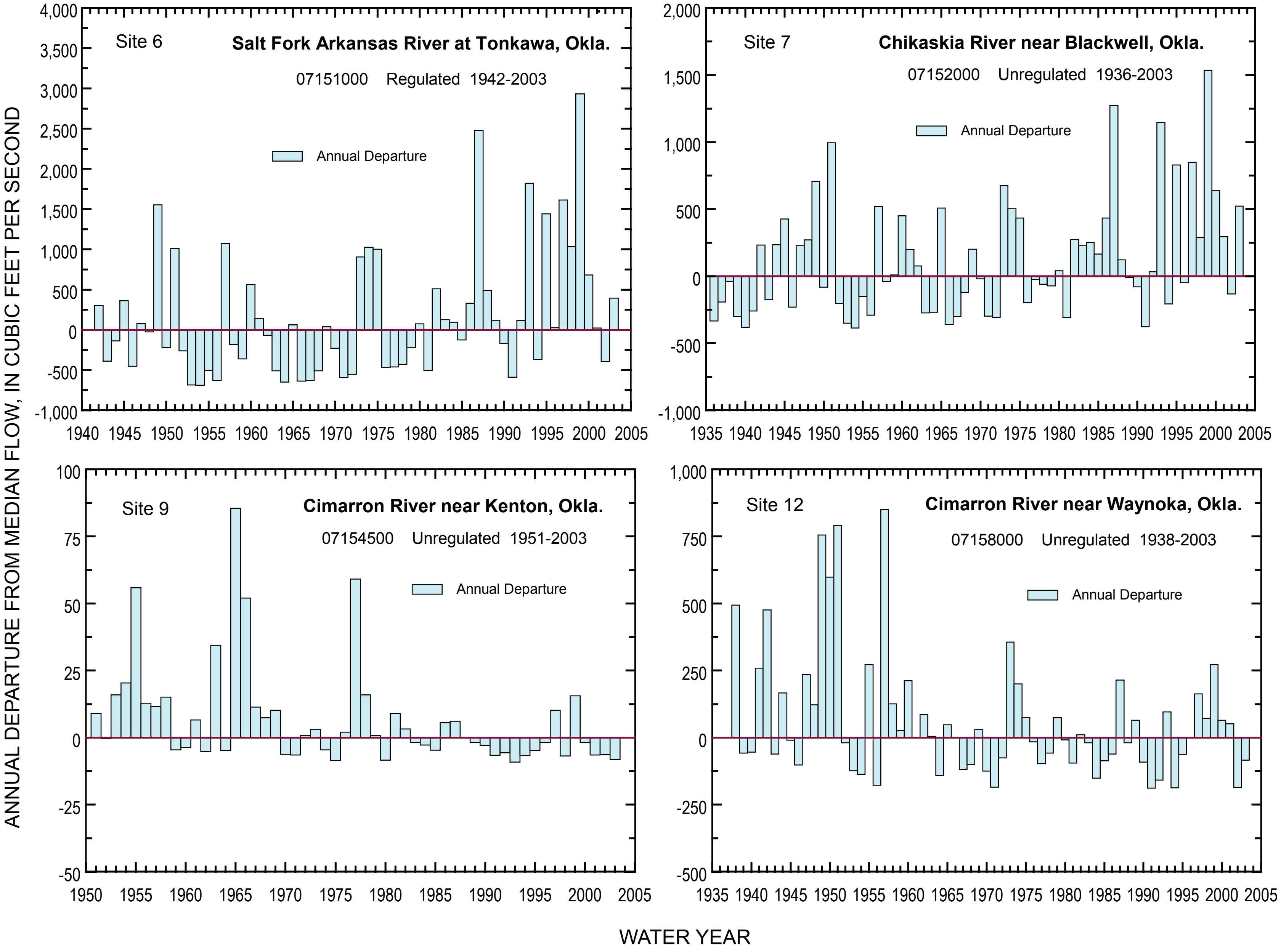

Figure 4. Annual departure from median flows using available periods of record for sites 6, 7, 9, and 12.

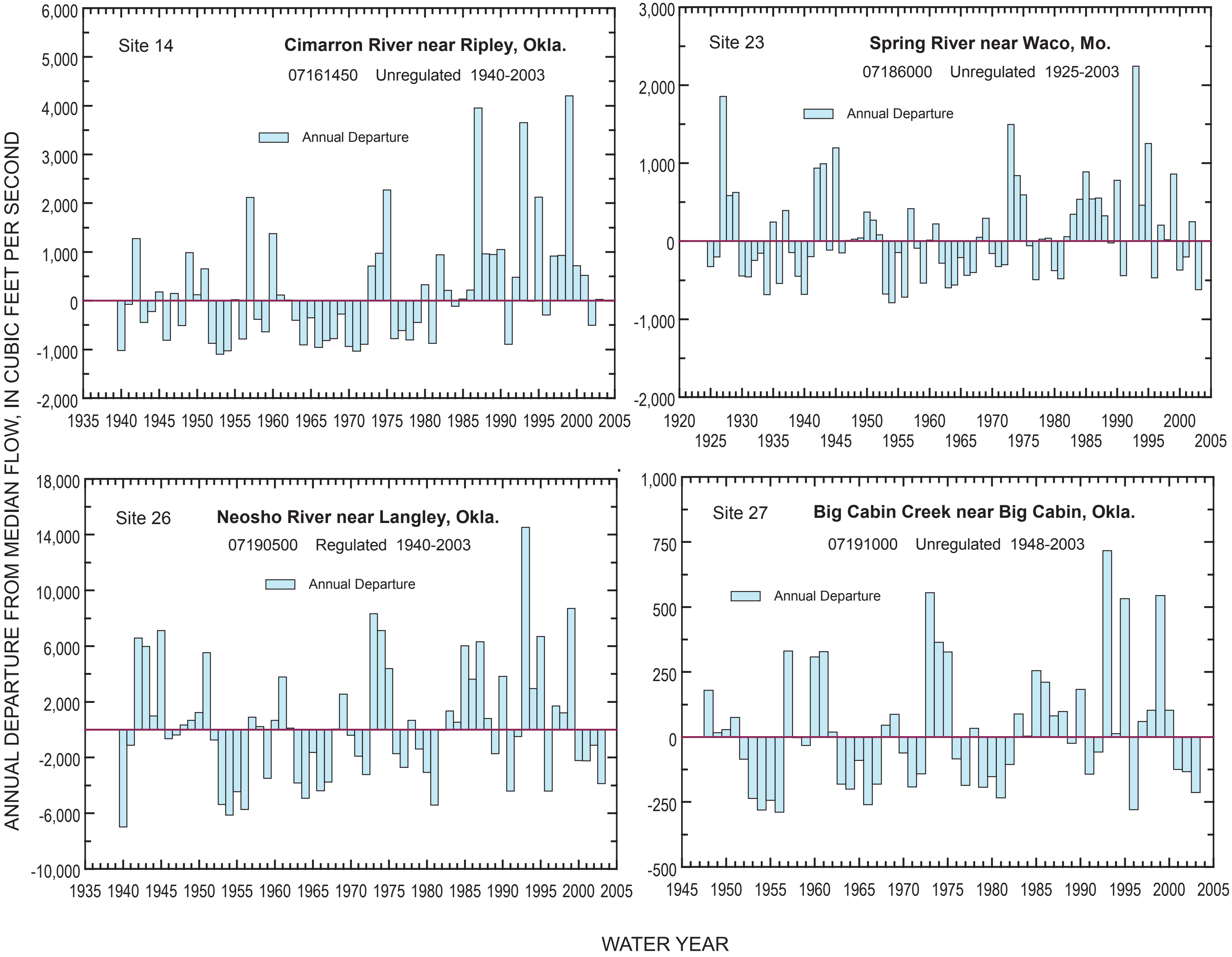

Figure 5. Annual departure from median flows using available periods of record for sites 14, 23, 26, and 27.

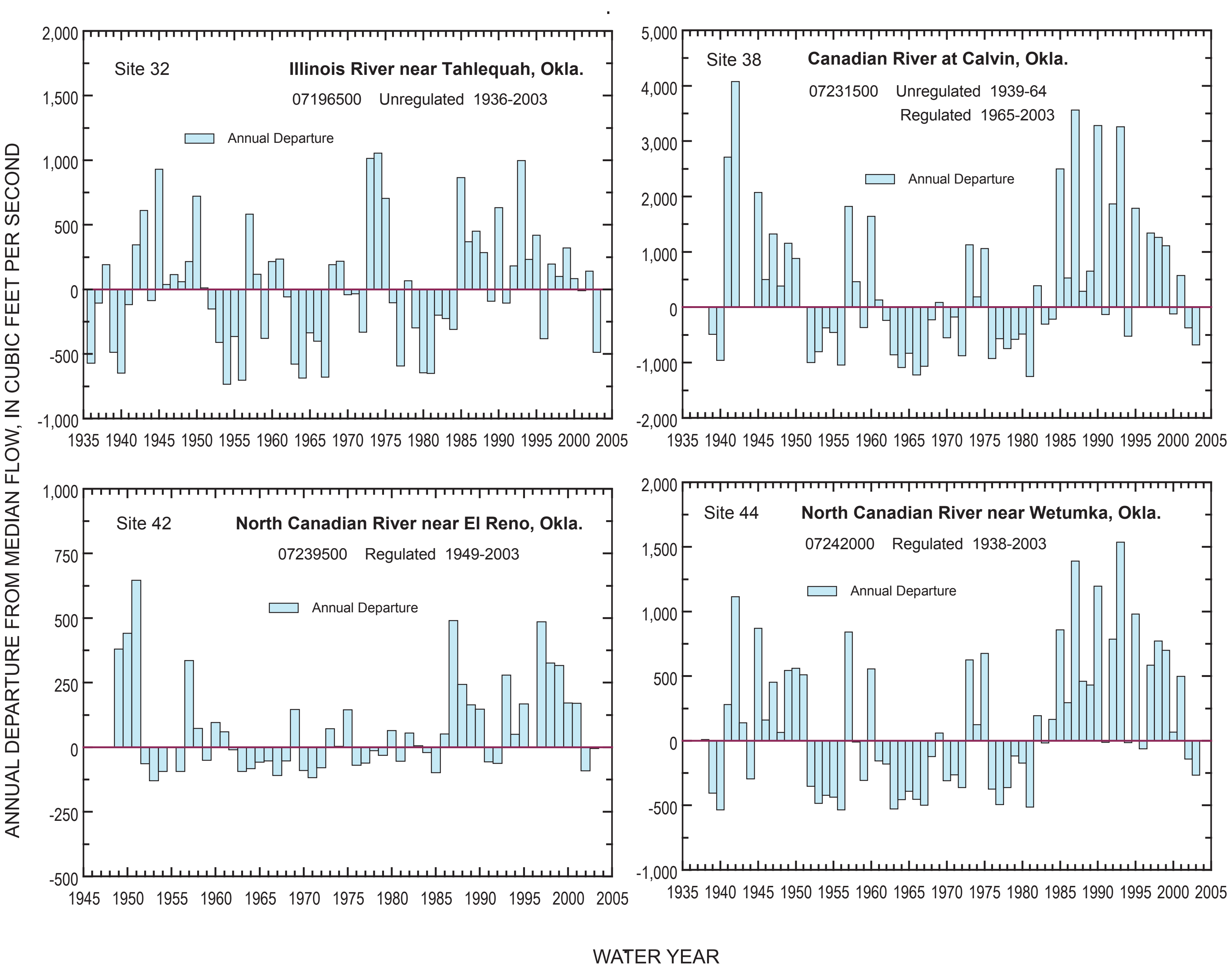

Figure 6. Annual departure from median flows using available periods of record for sites 32, 38, 42, and 44.

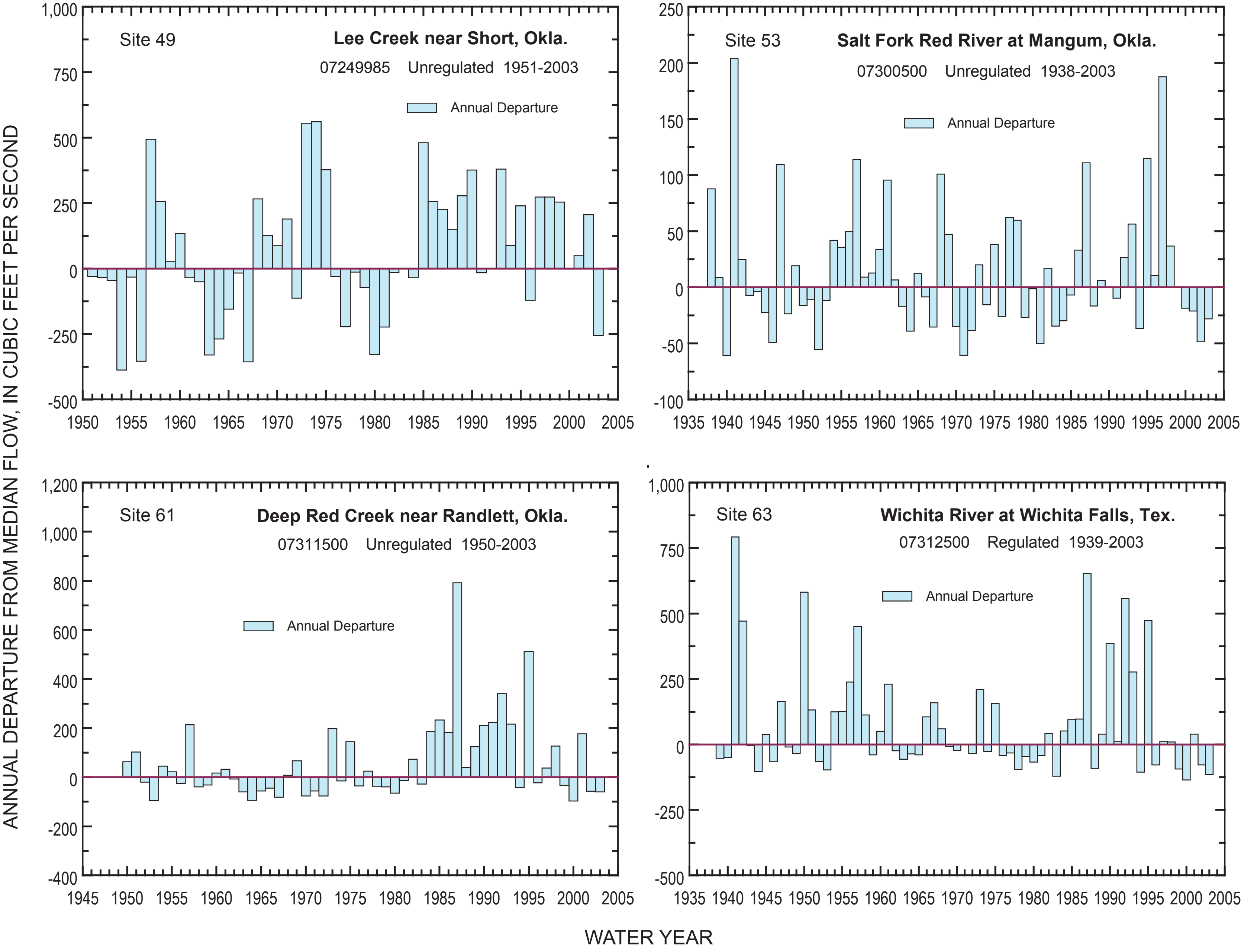

Figure 7. Annual departure from median flows using available periods of record for sites 49, 53, 61, and 63.

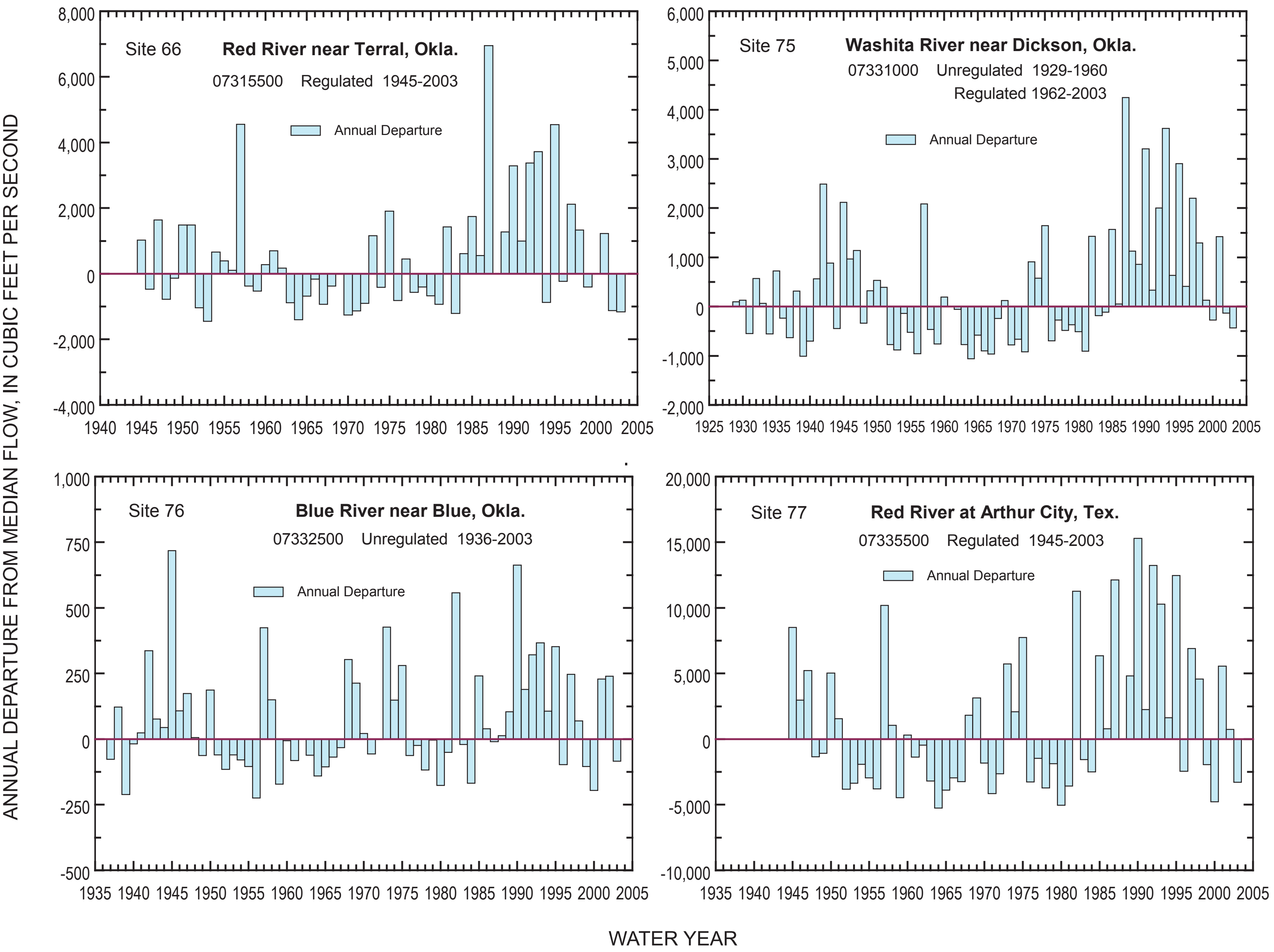

Figure 8. Annual departure from median flows using available periods of record for sites 66, 75, 76, and 77.

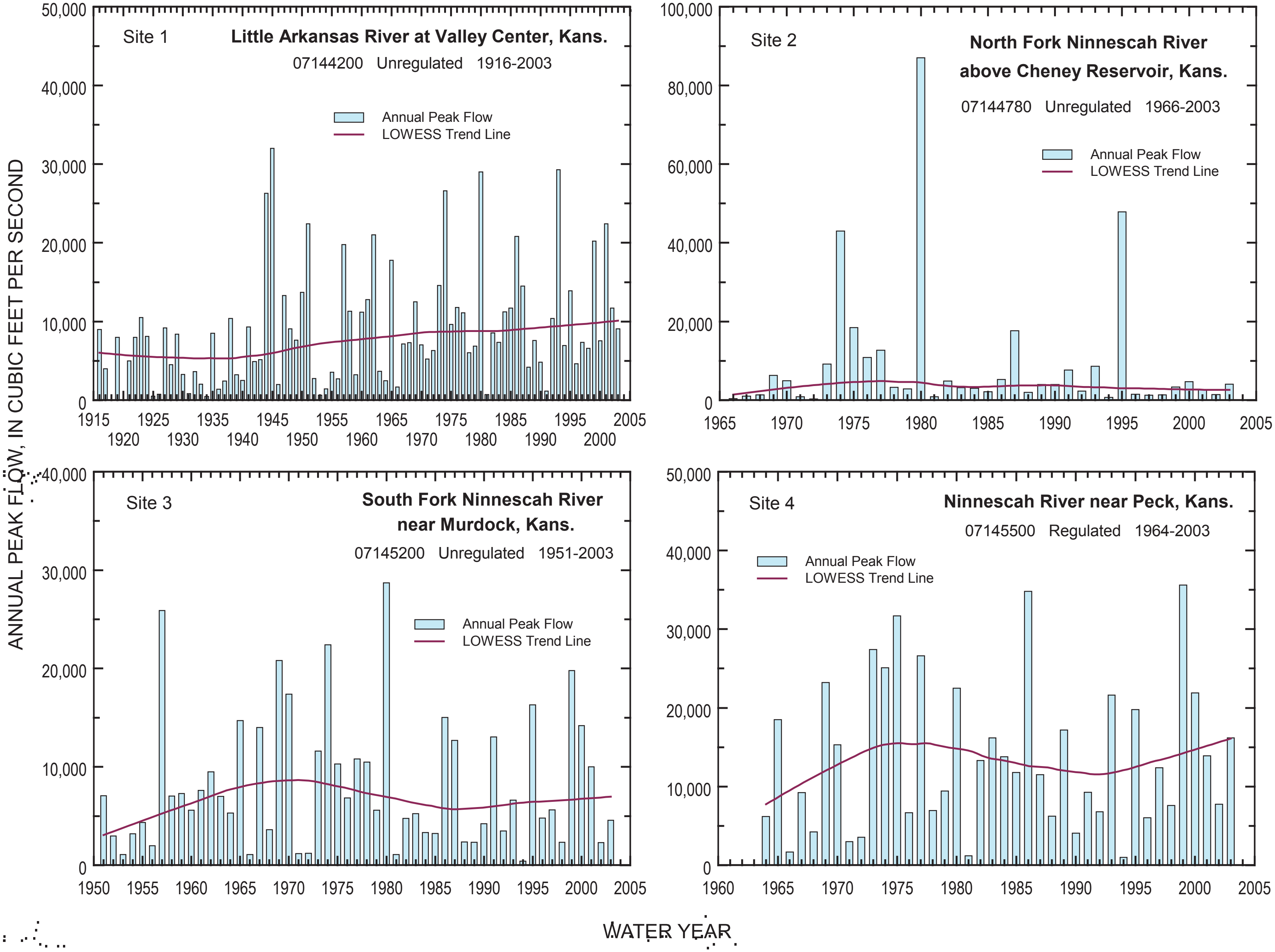

Figure 9. Annual peak flows and LOWESS trend lines using available periods of record for sites 1-4.

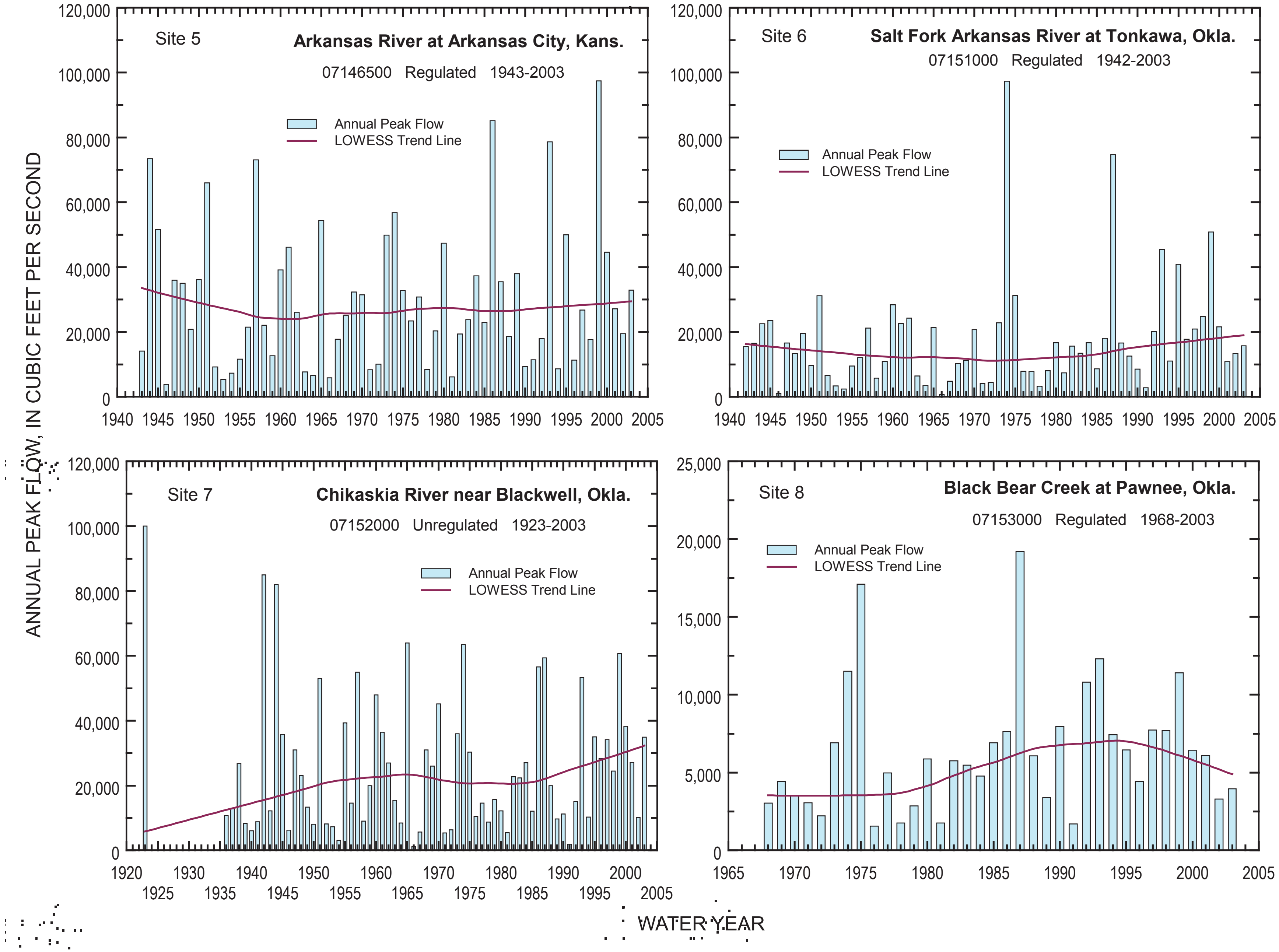

Figure 10. Annual peak flows and LOWESS trend lines using available periods of record for sites 5-8.

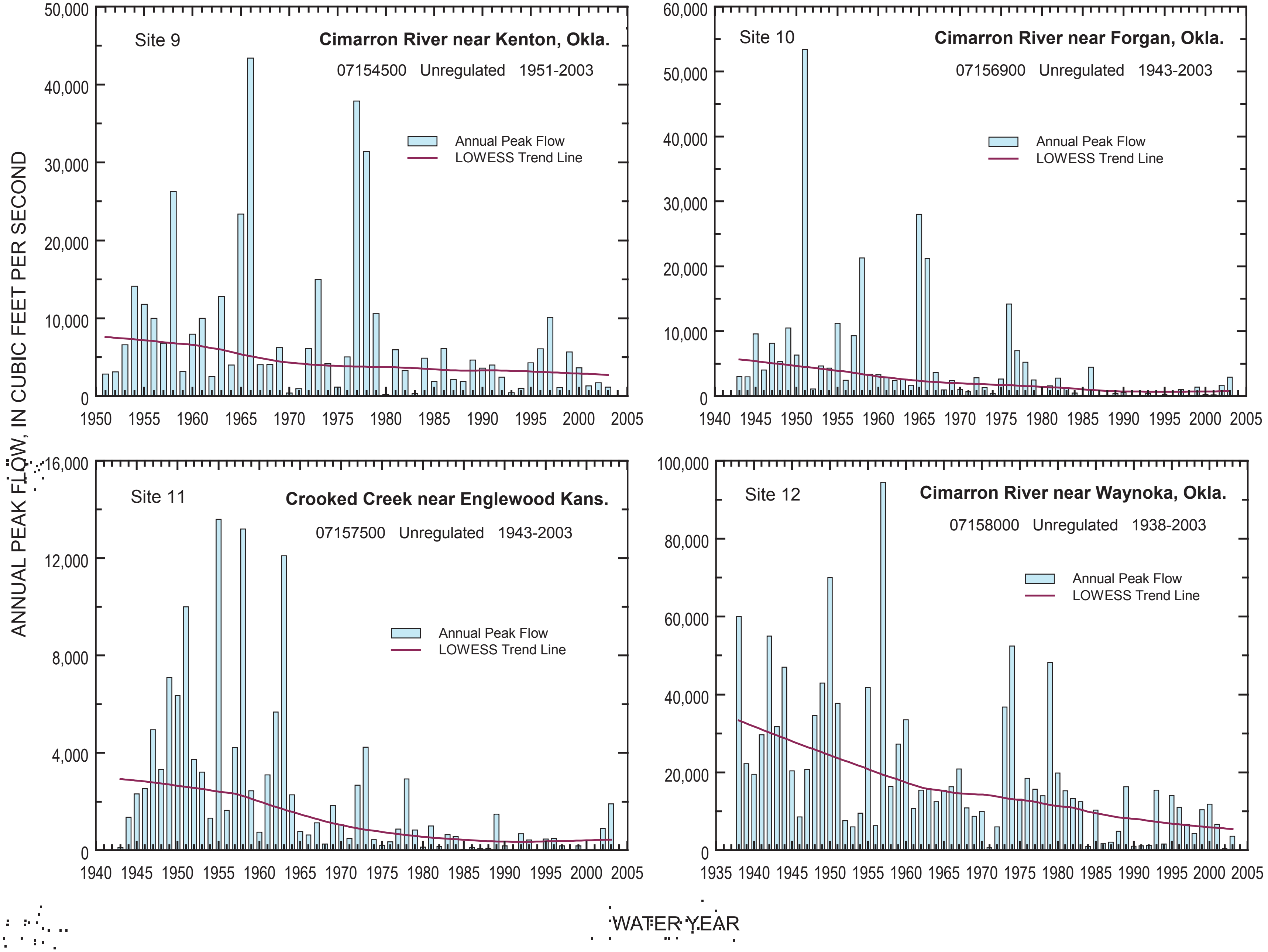

Figure 11. Annual peak flows and LOWESS trend lines using available periods of record for sites 9-12.

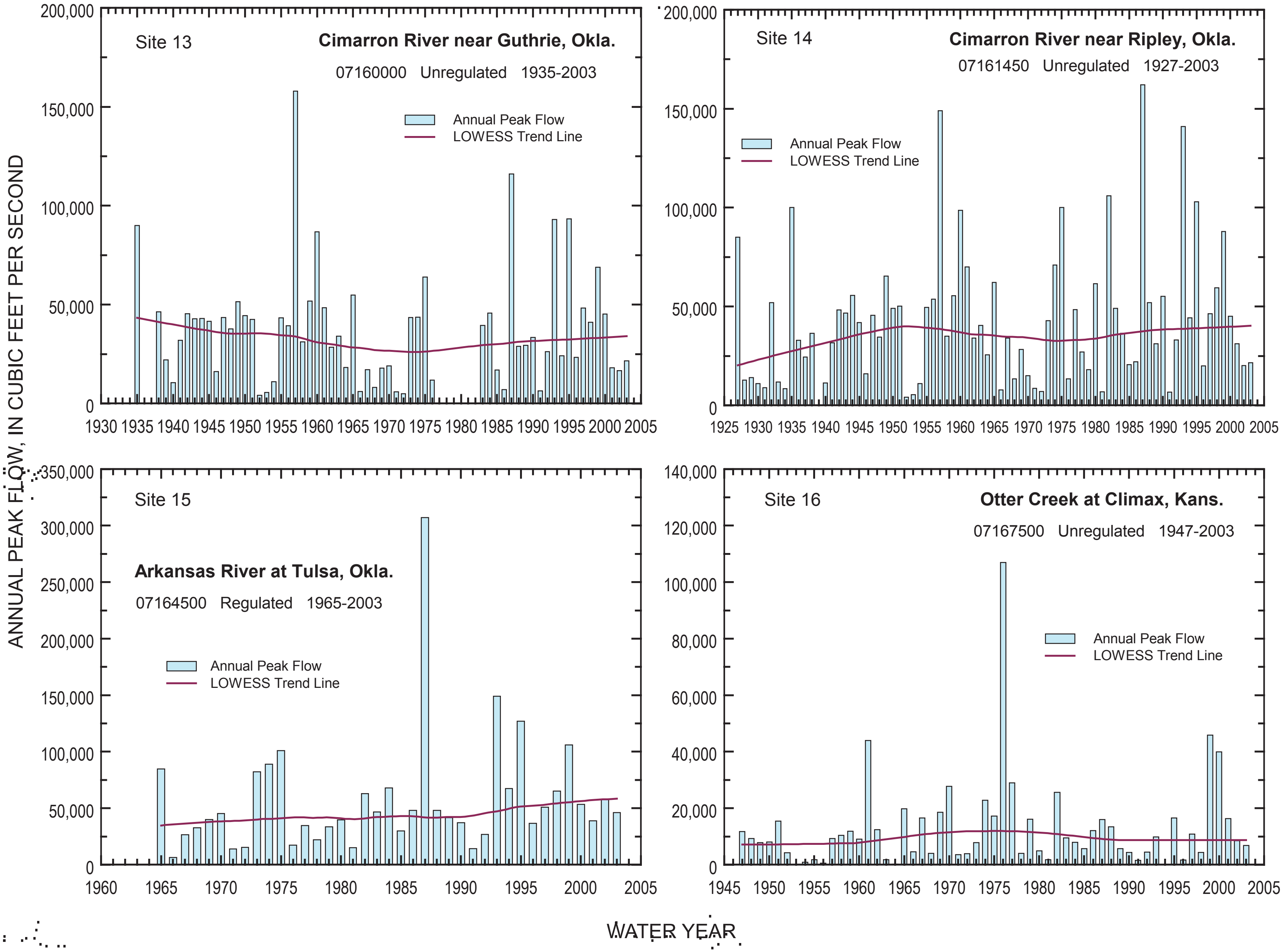

Figure 12. Annual peak flows and LOWESS trend lines using available periods of record for sites 13-16.

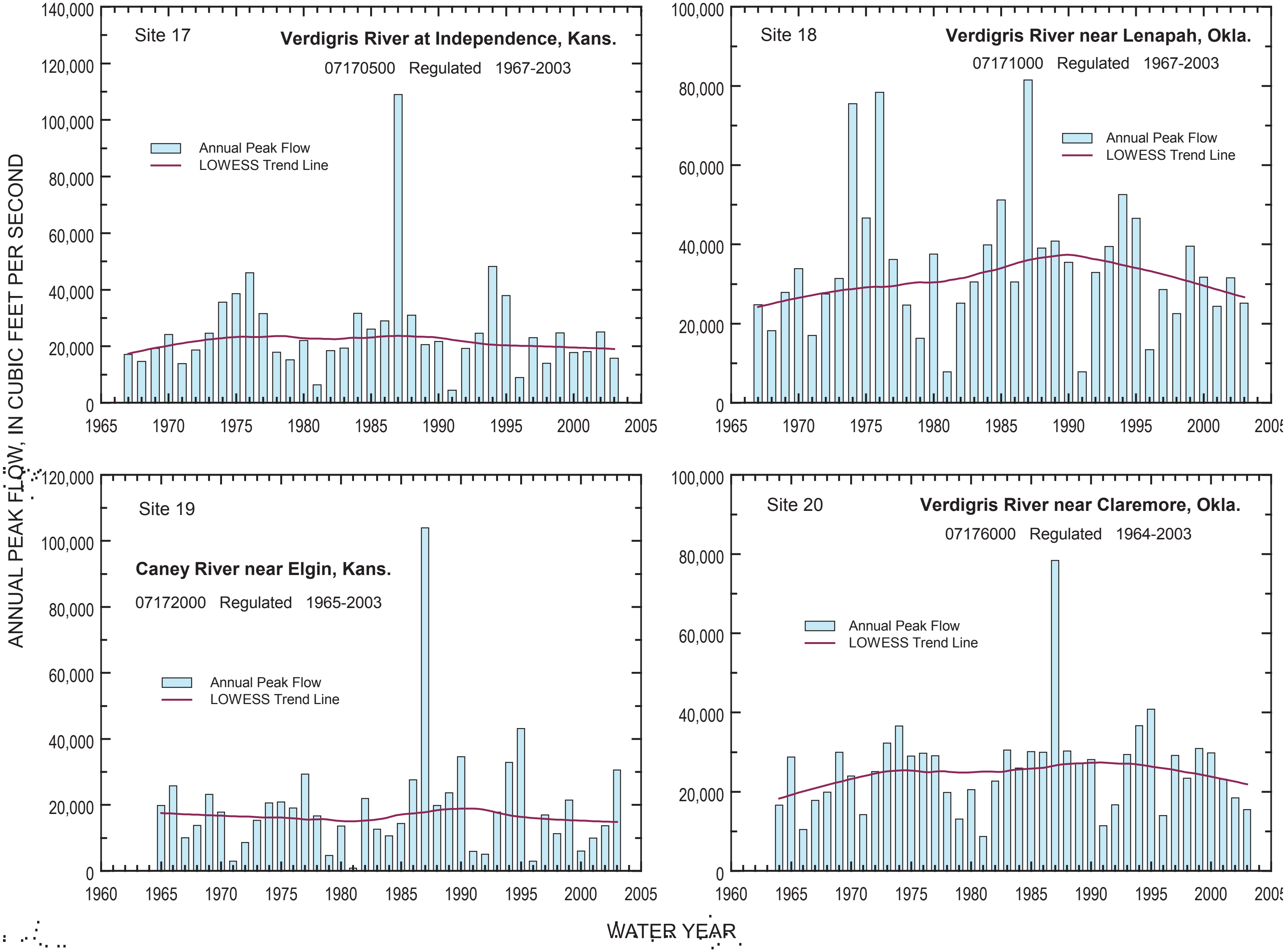

Figure 13. Annual peak flows and LOWESS trend lines using available periods of record for sites 17-20.

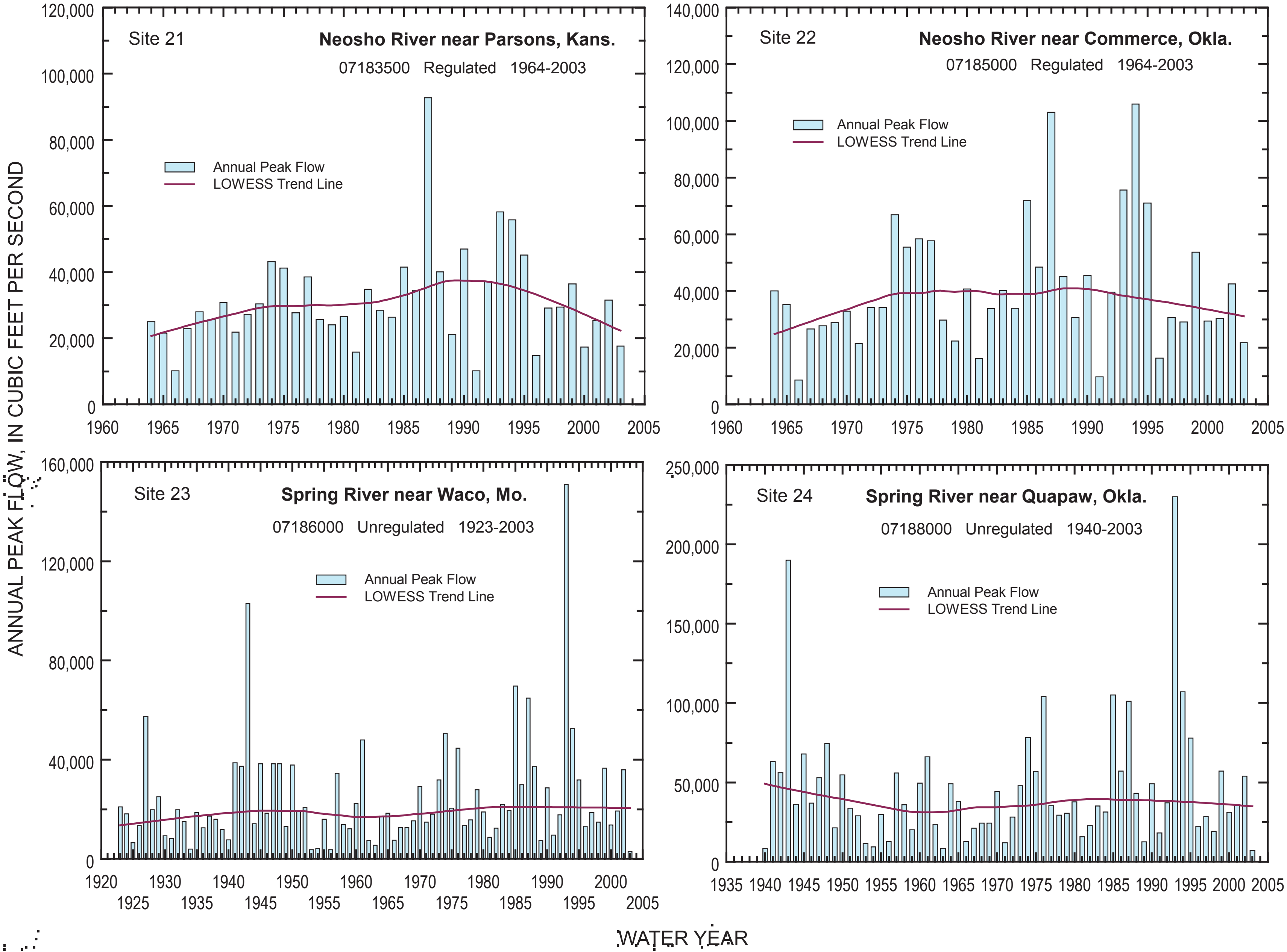

Figure 14. Annual peak flows and LOWESS trend lines using available periods of record for sites 21-24.

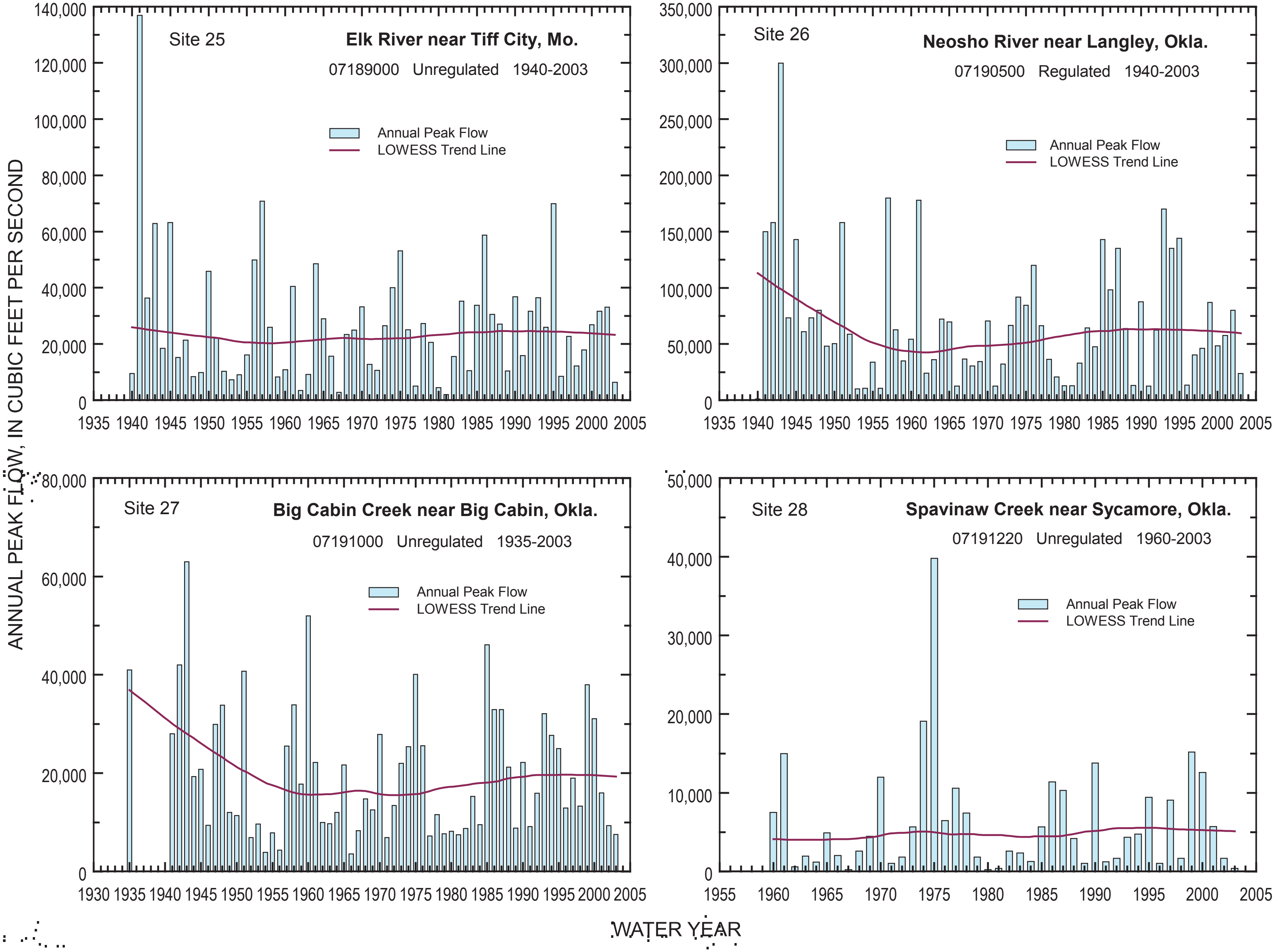

Figure 15. Annual peak flows and LOWESS trend lines using available periods of record for sites 25-28.

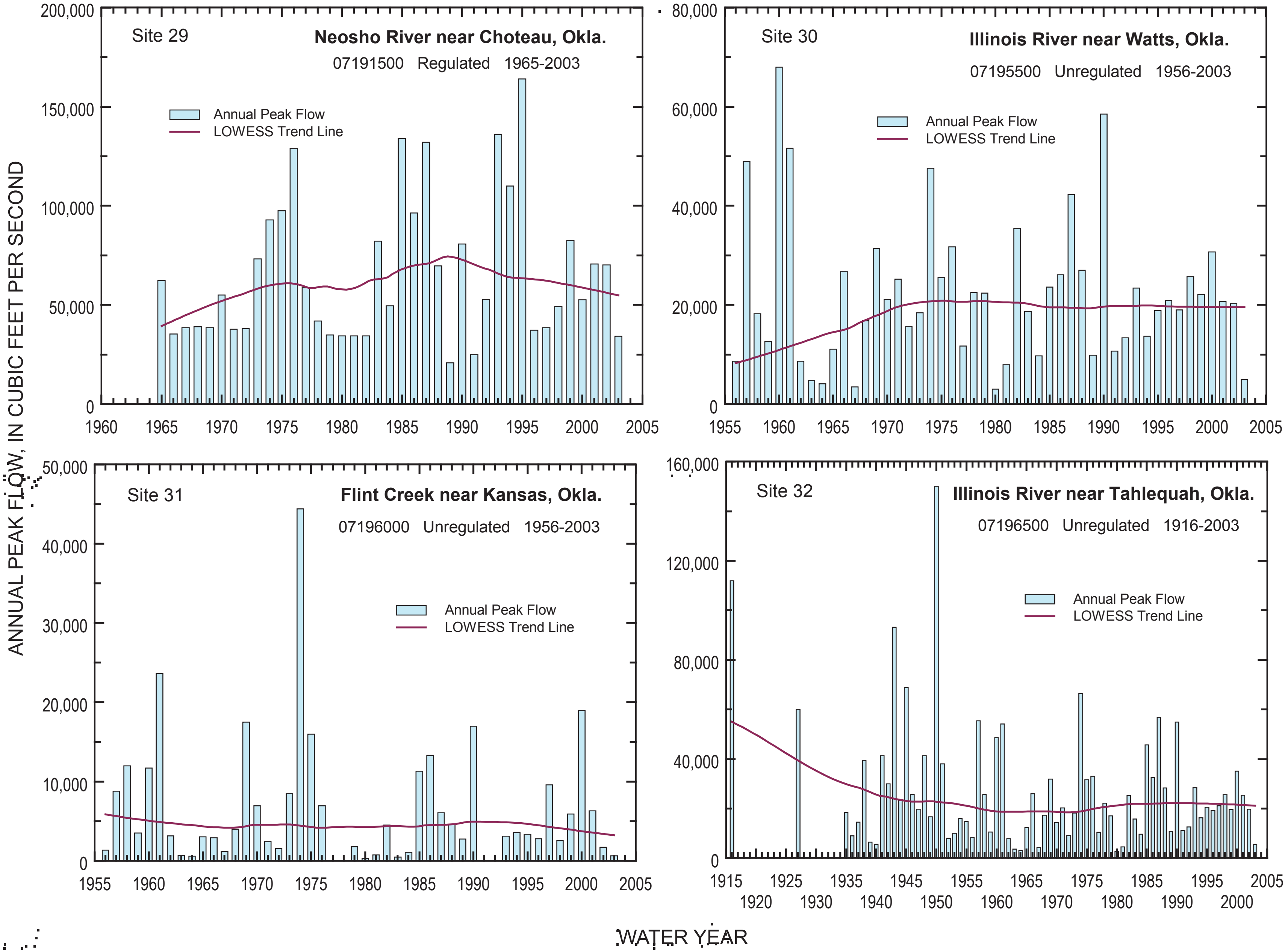

Figure 16. Annual peak flows and LOWESS trend lines using available periods of record for sites 29-32.

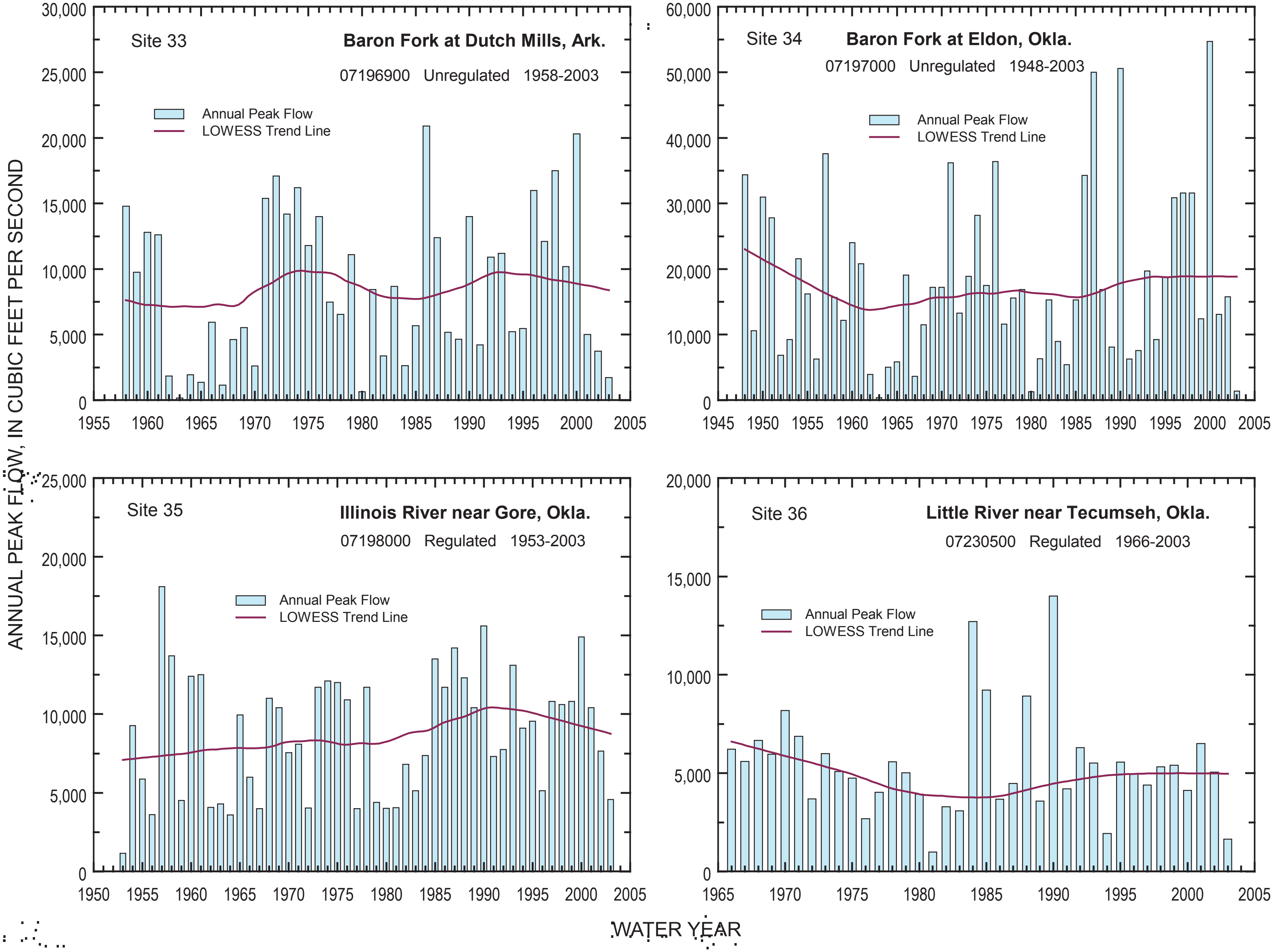

Figure 17. Annual peak flows and LOWESS trend lines using available periods of record for sites 33-36.

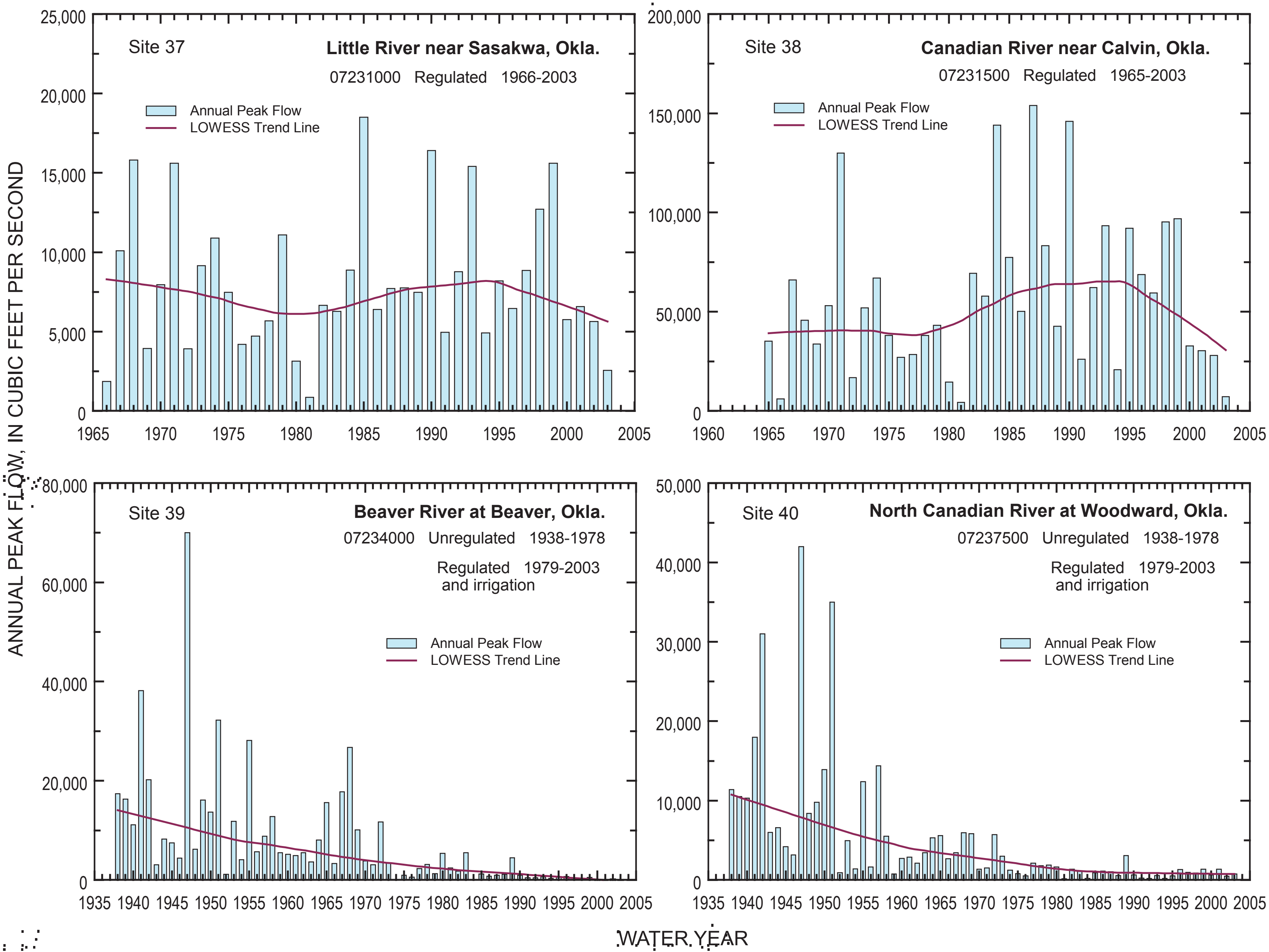

Figure 18. Annual peak flows and LOWESS trend lines using available periods of record for sites 37-40.

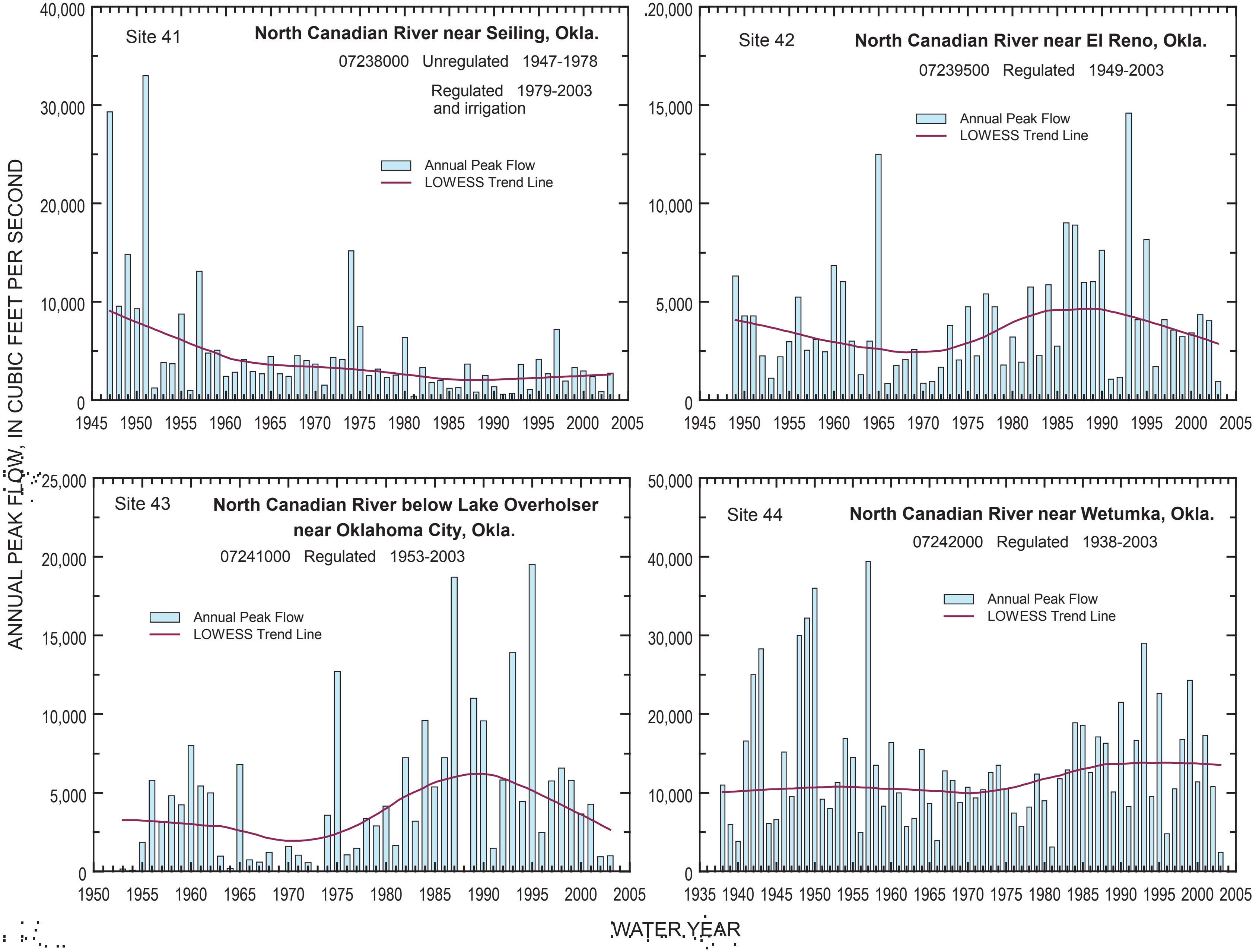

Figure 19. Annual peak flows and LOWESS trend lines using available periods of record for sites 41-44.

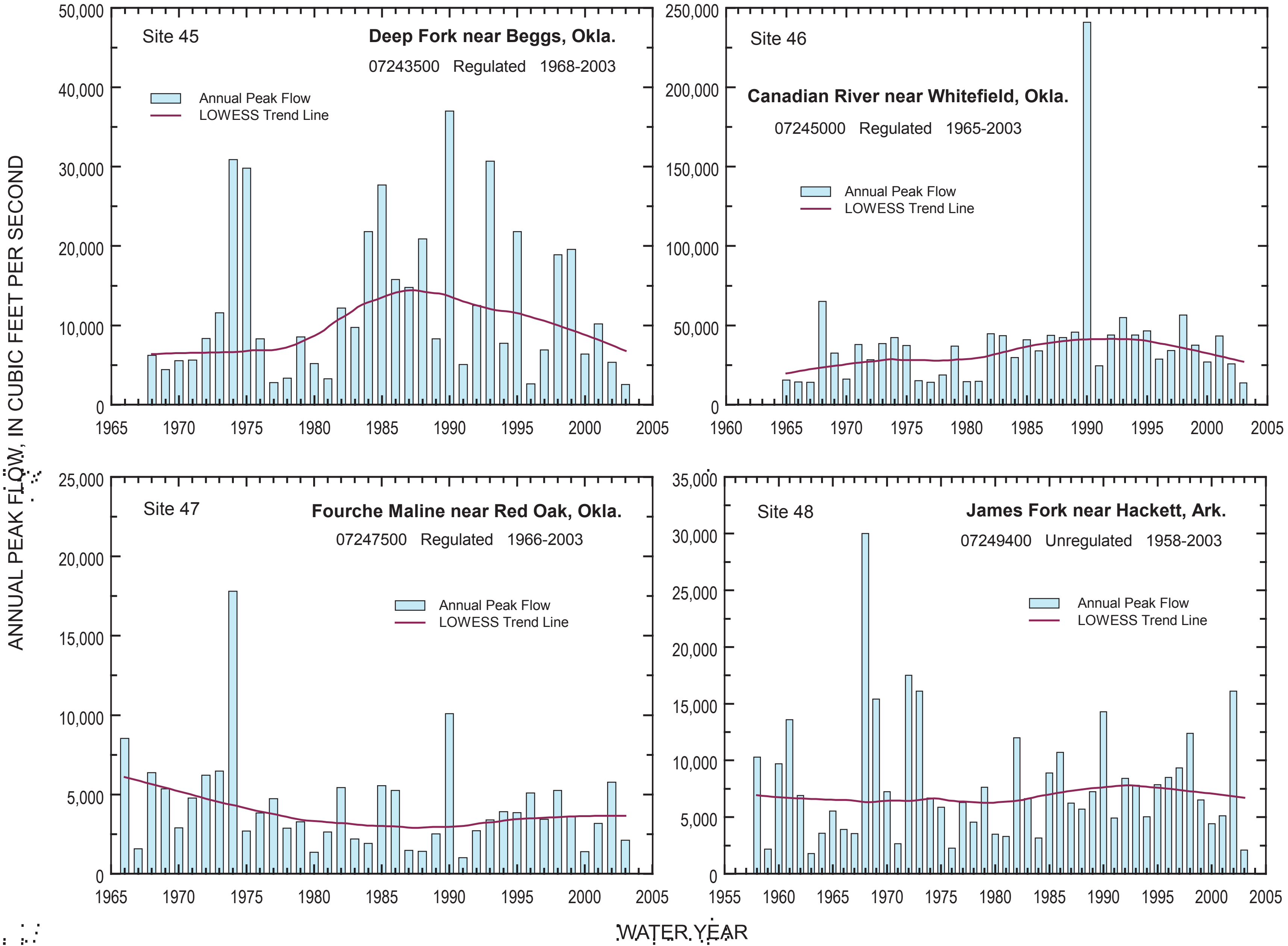

Figure 20. Annual peak flows and LOWESS trend lines using available periods of record for sites 45-48.

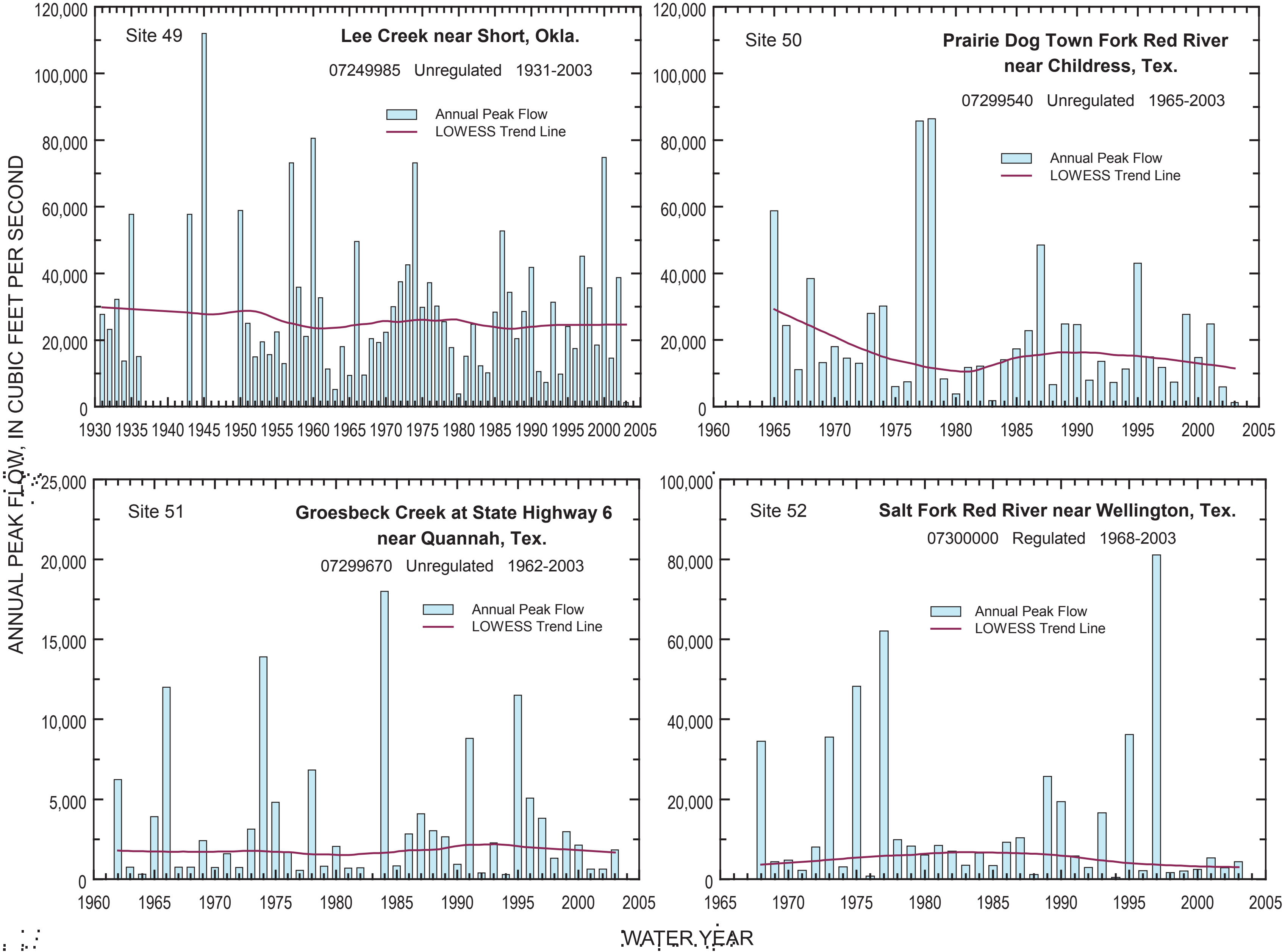

Figure 21. Annual peak flows and LOWESS trend lines using available periods of record for sites 49-52.

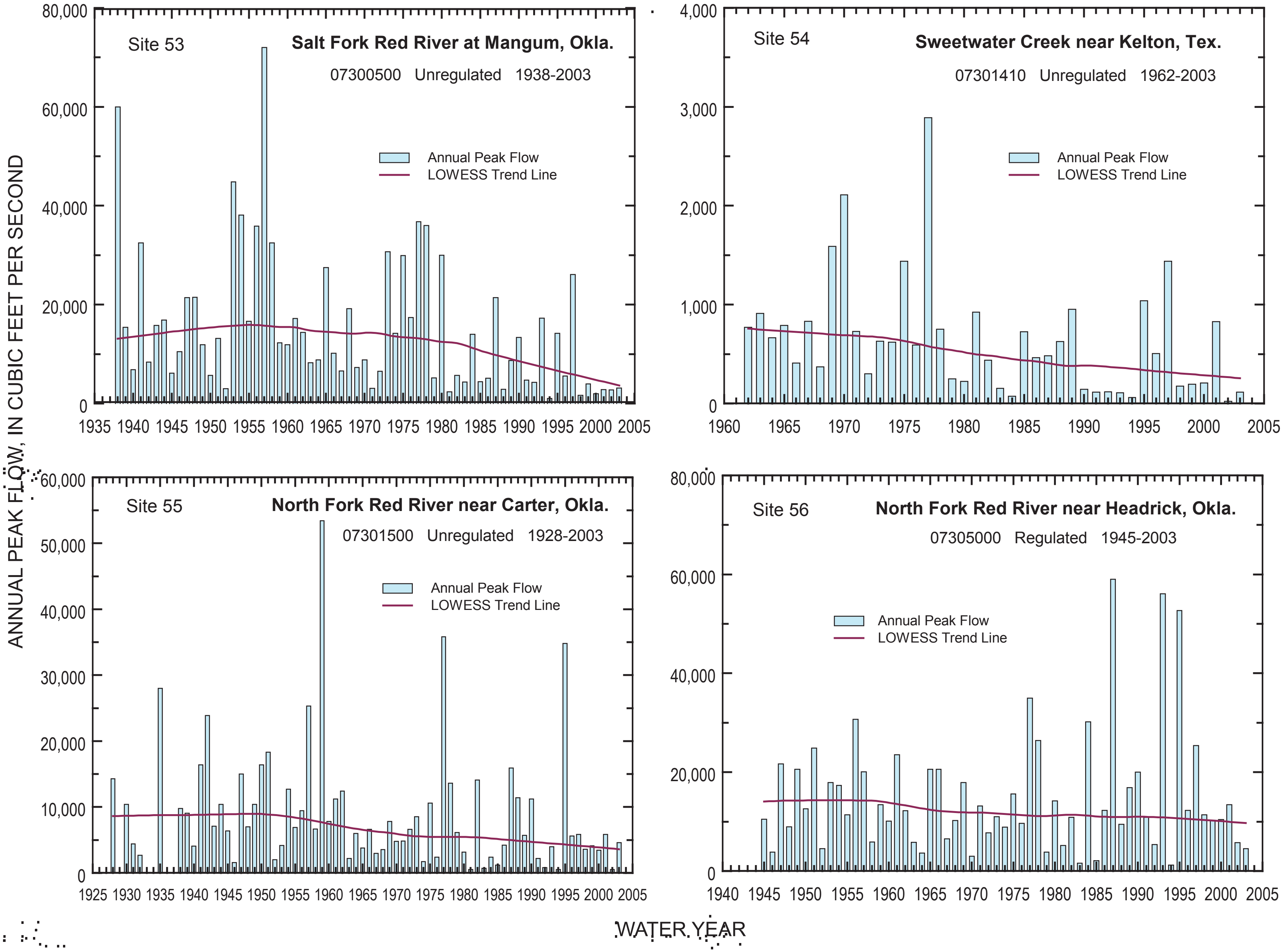

Figure 22. Annual peak flows and LOWESS trend lines using available periods of record for sites 53-56.

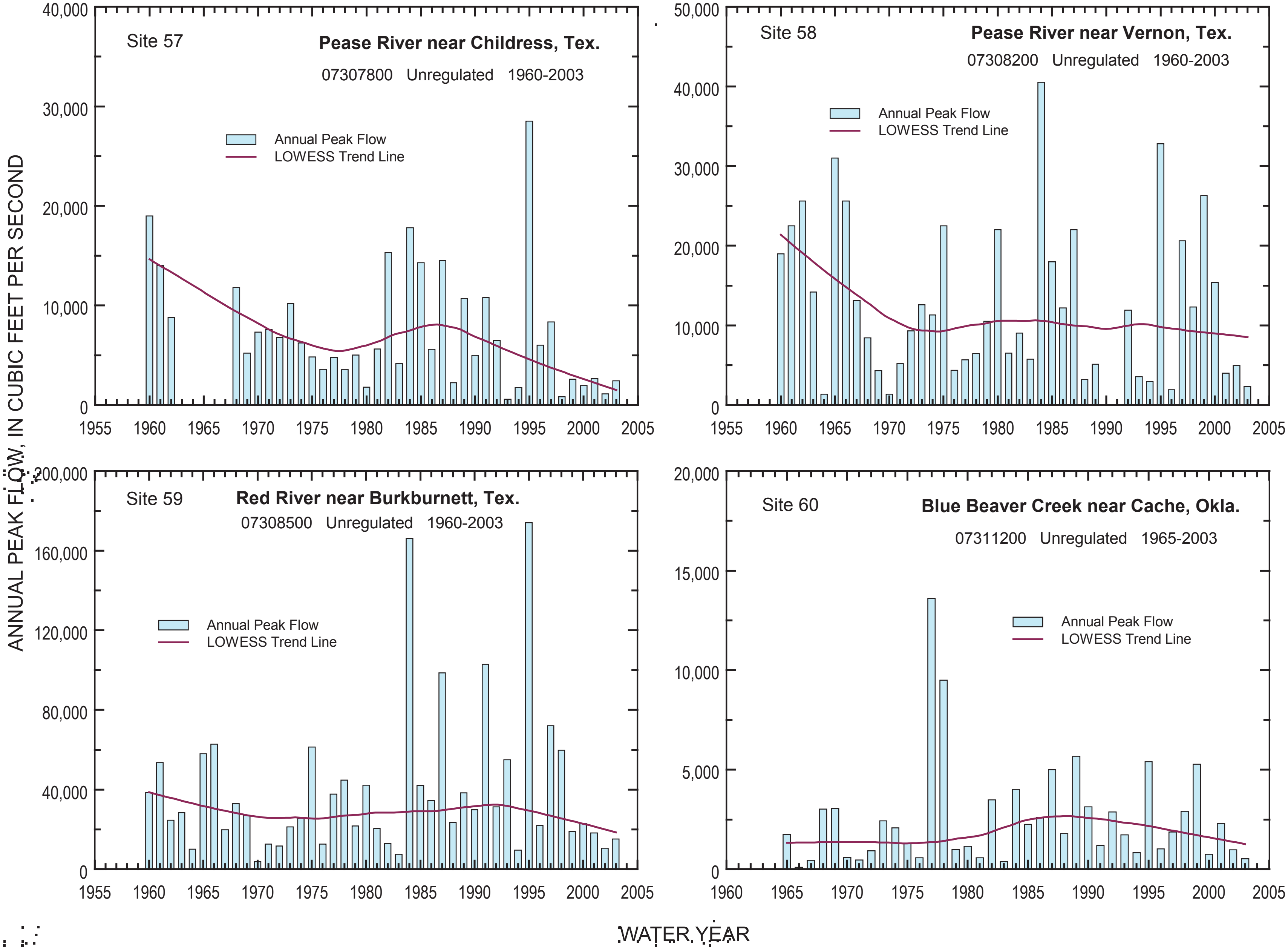

Figure 23. Annual peak flows and LOWESS trend lines using available periods of record for sites 57-60.

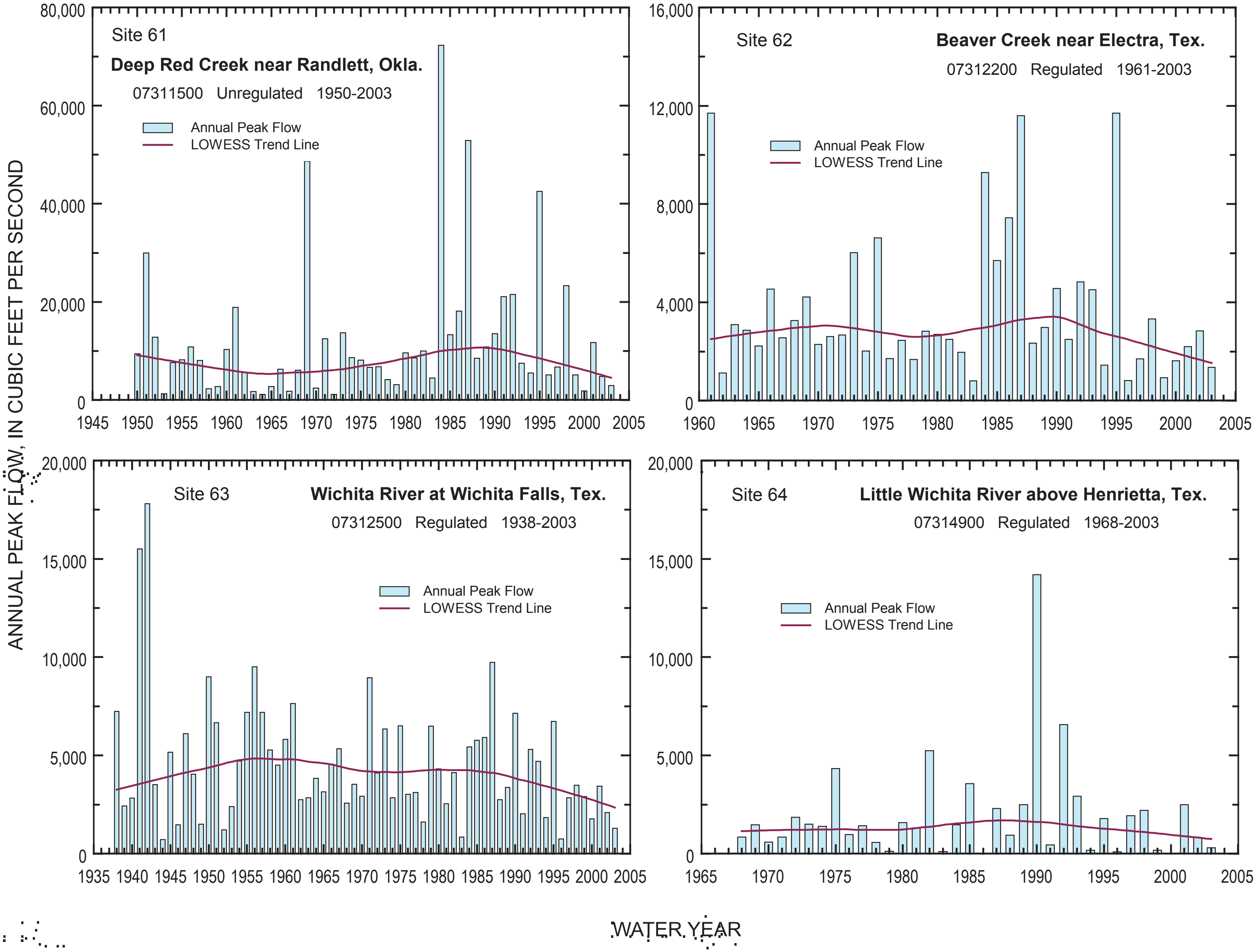

Figure 24. Annual peak flows and LOWESS trend lines using available periods of record for sites 61-64

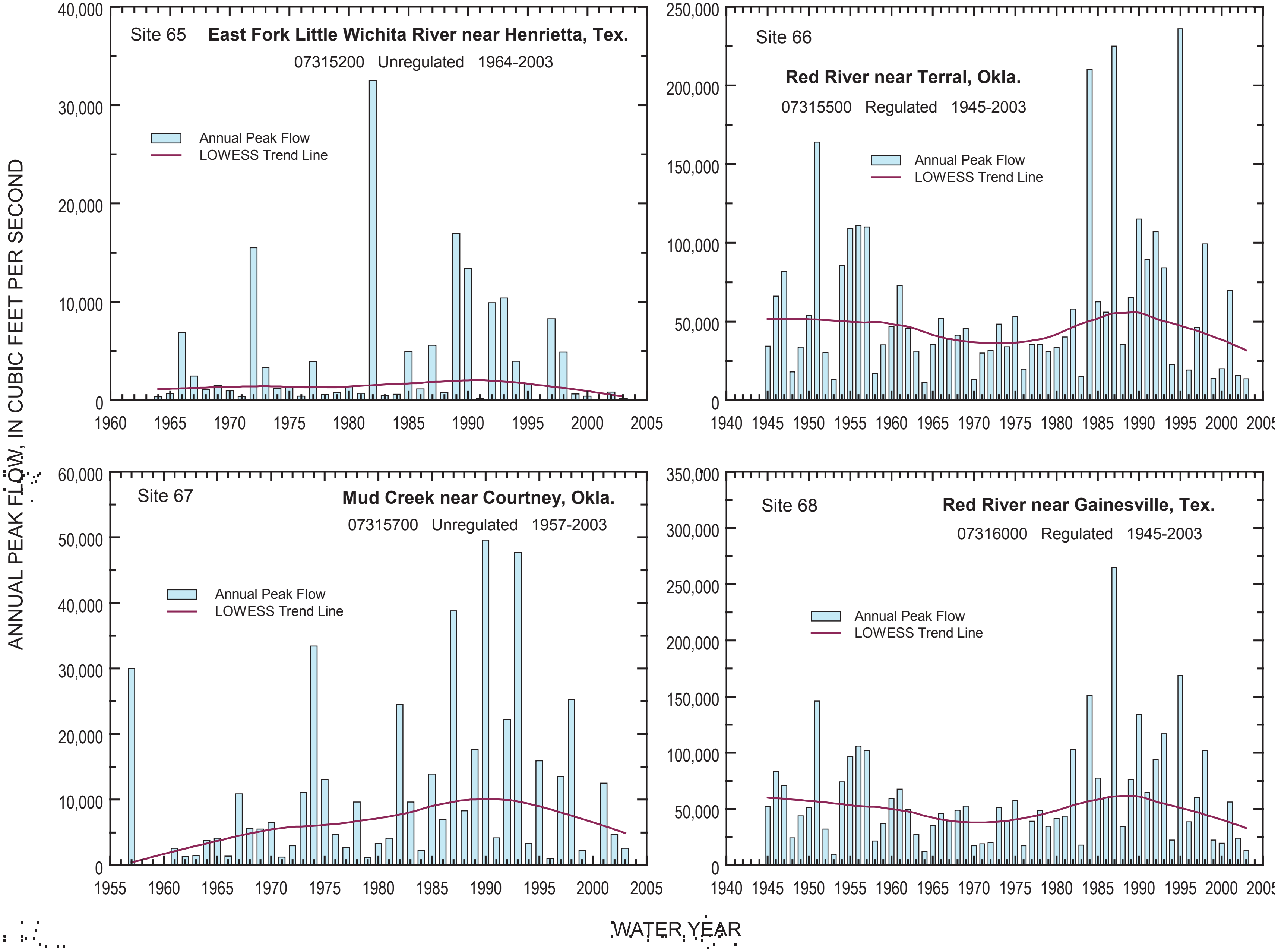

Figure 25. Annual peak flows and LOWESS trend lines using available periods of record for sites 65-68.

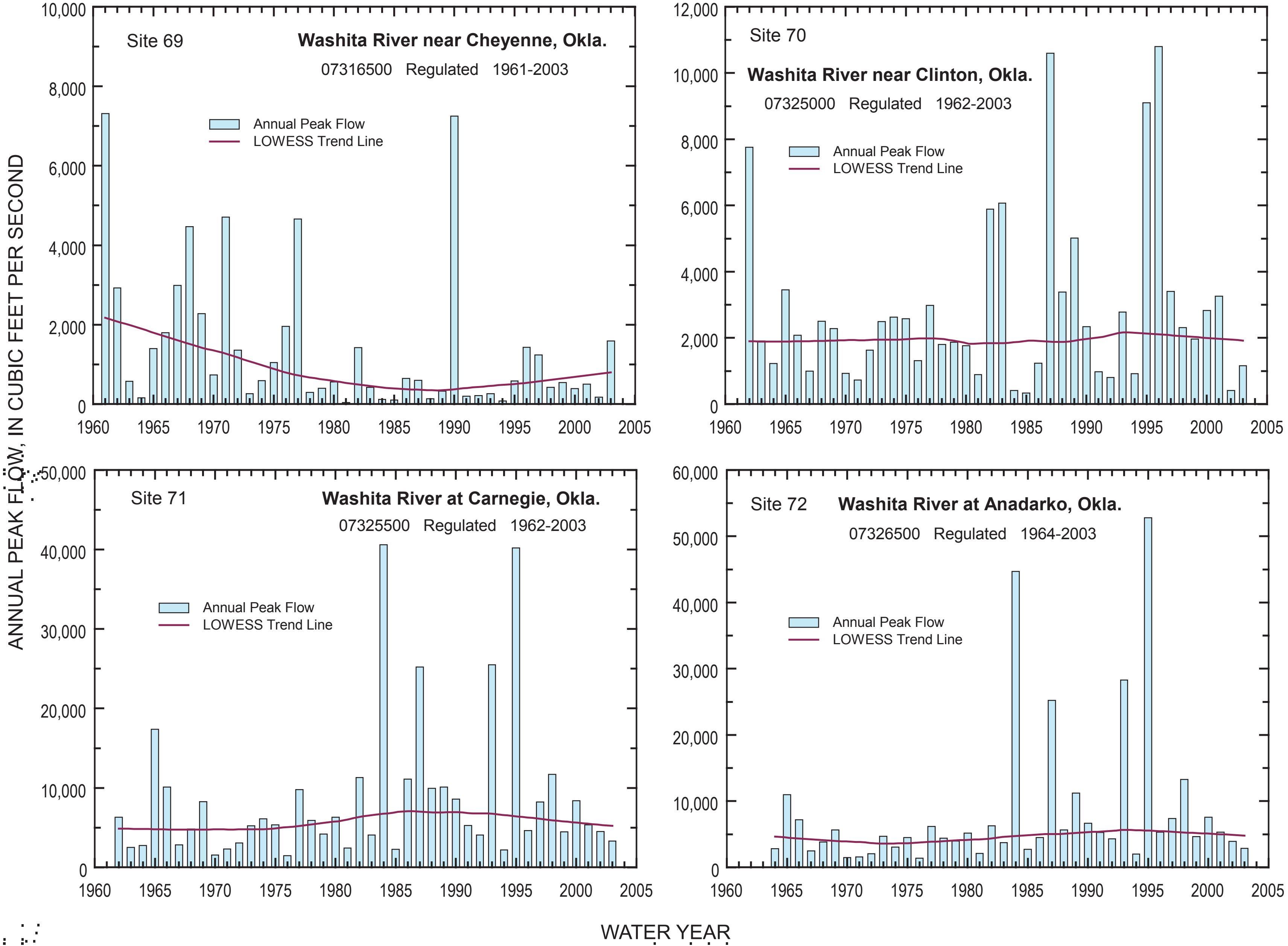

Figure 26. Annual peak flows and LOWESS trend lines using available periods of record for sites 69-72.

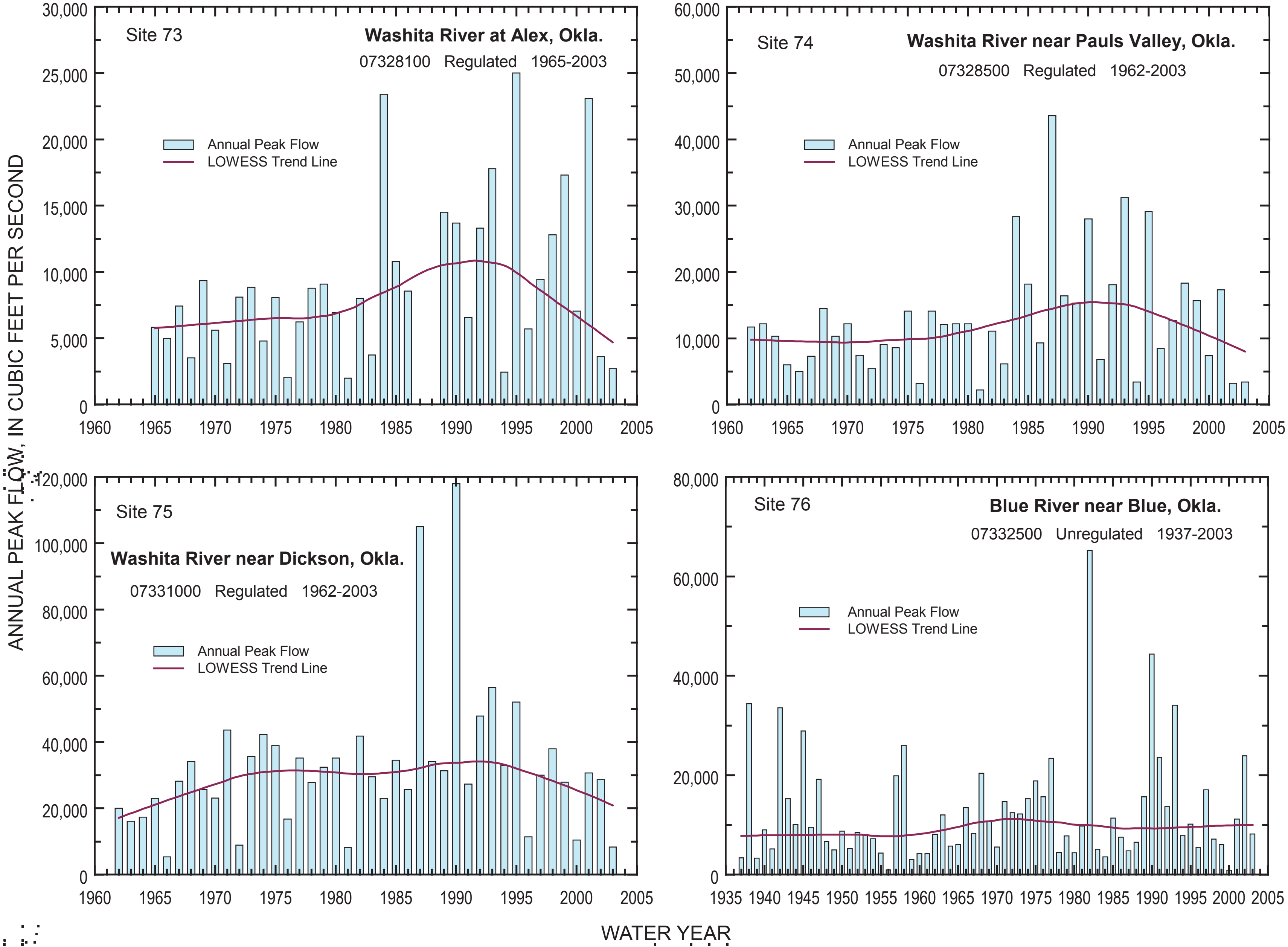

Figure 27. Annual peak flows and LOWESS trend lines using available periods of record for sites 73-76.

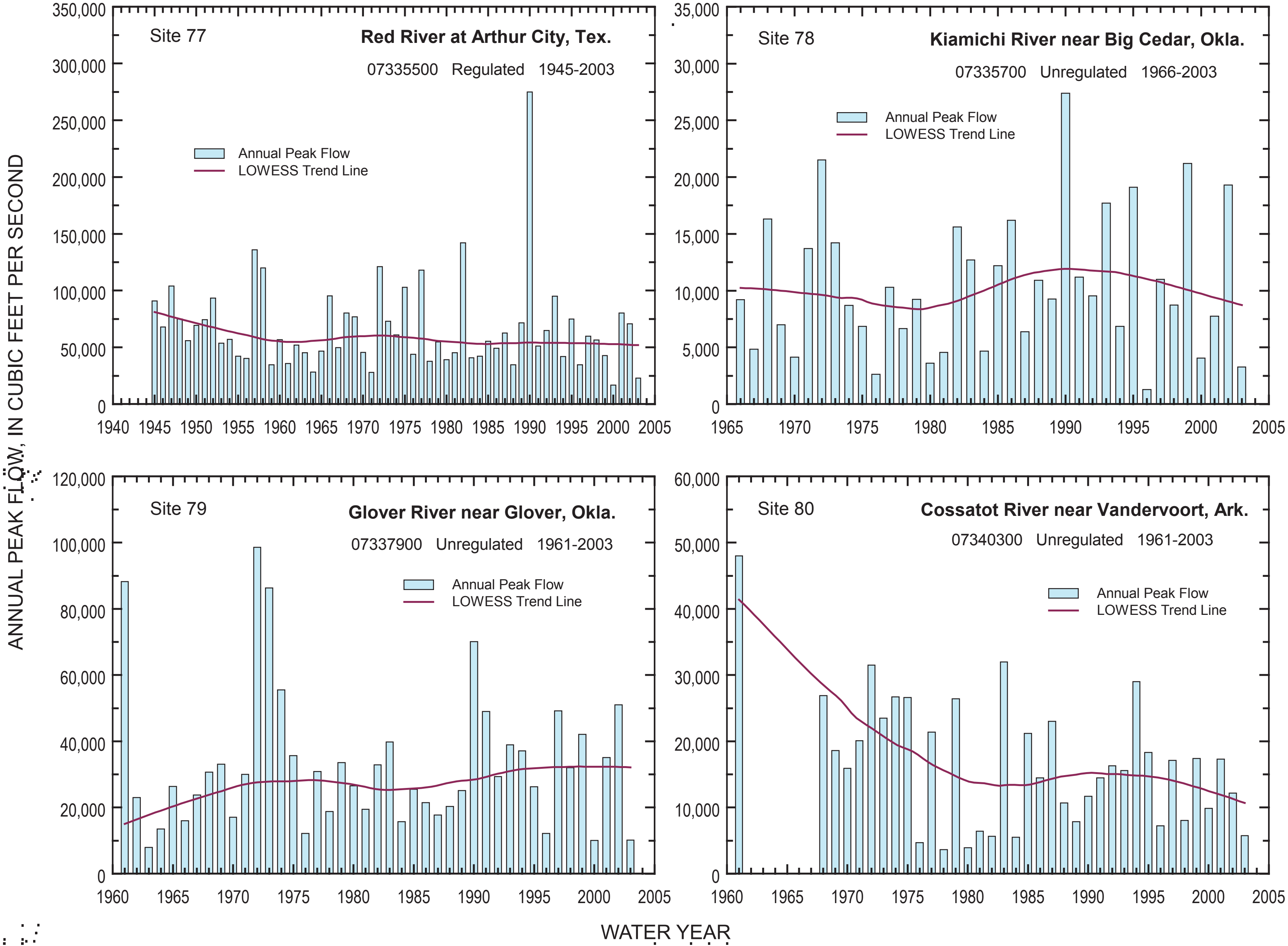

Figure 28. Annual peak flows and LOWESS trend lines using available periods of record for sites 77-80.

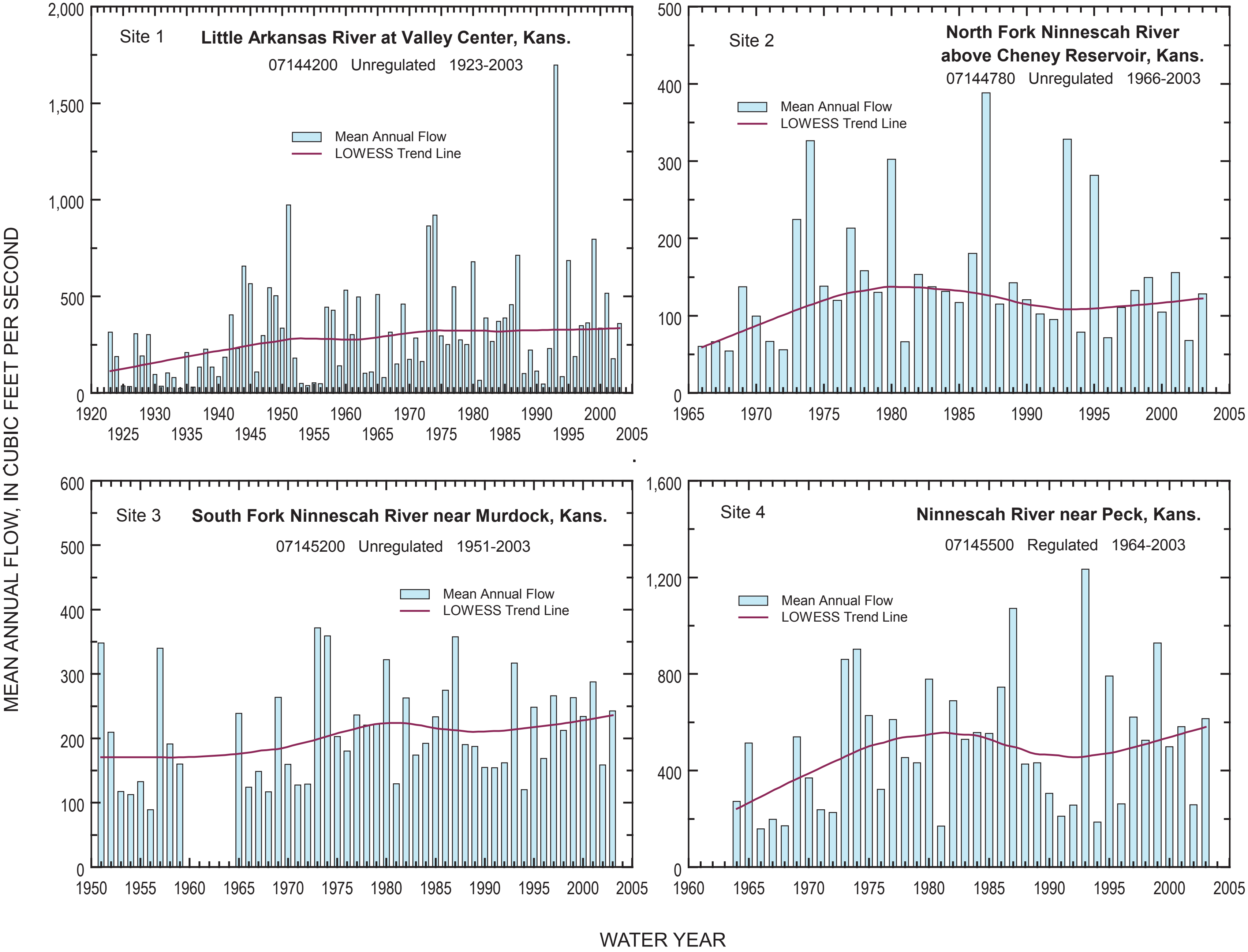

Figure 31. Mean annual flows and LOWESS trend lines using available periods of record for sites 1-4.

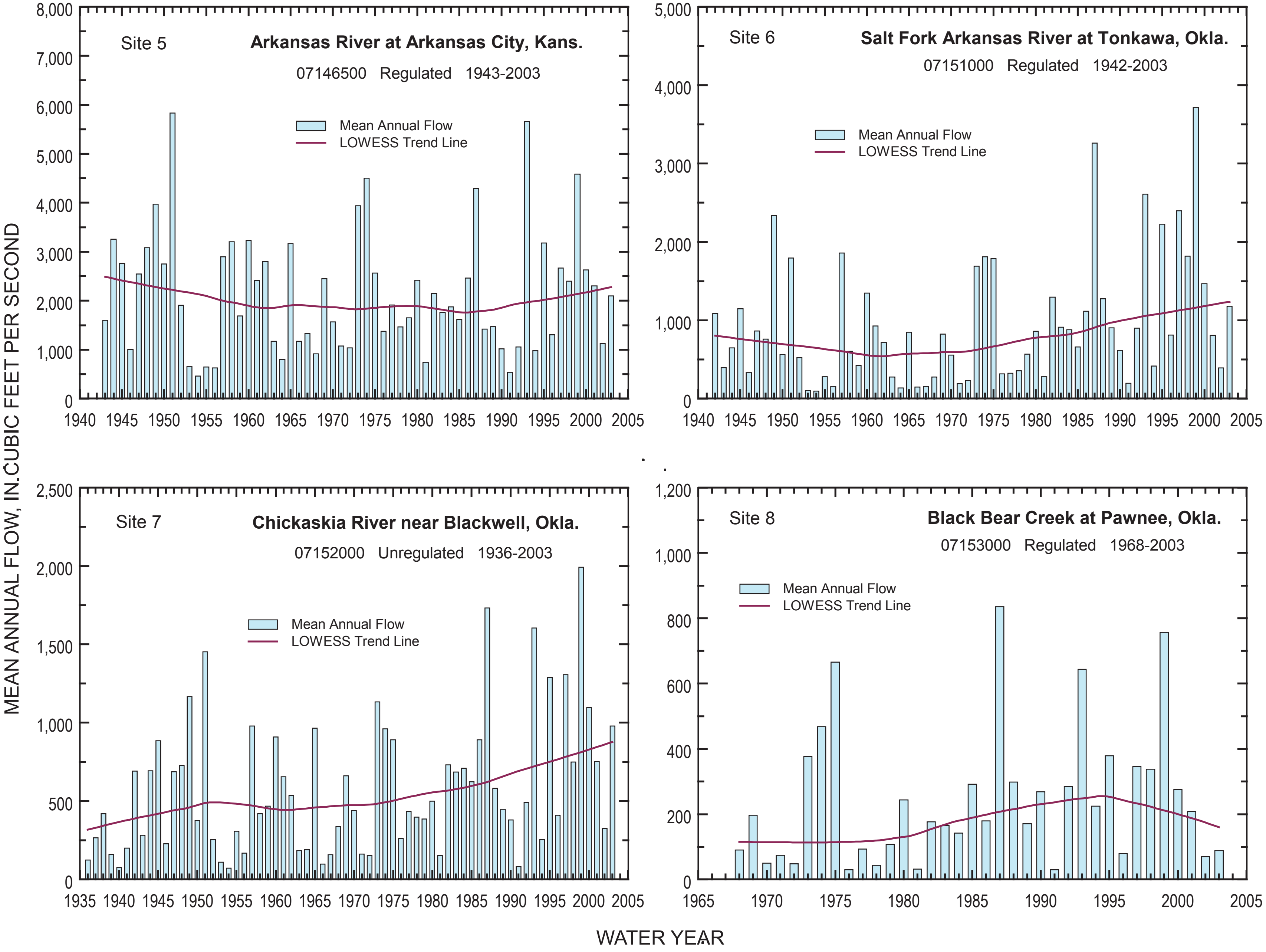

Figure 32. Mean annual flows and LOWESS trend lines using available periods of record for sites 5-8.

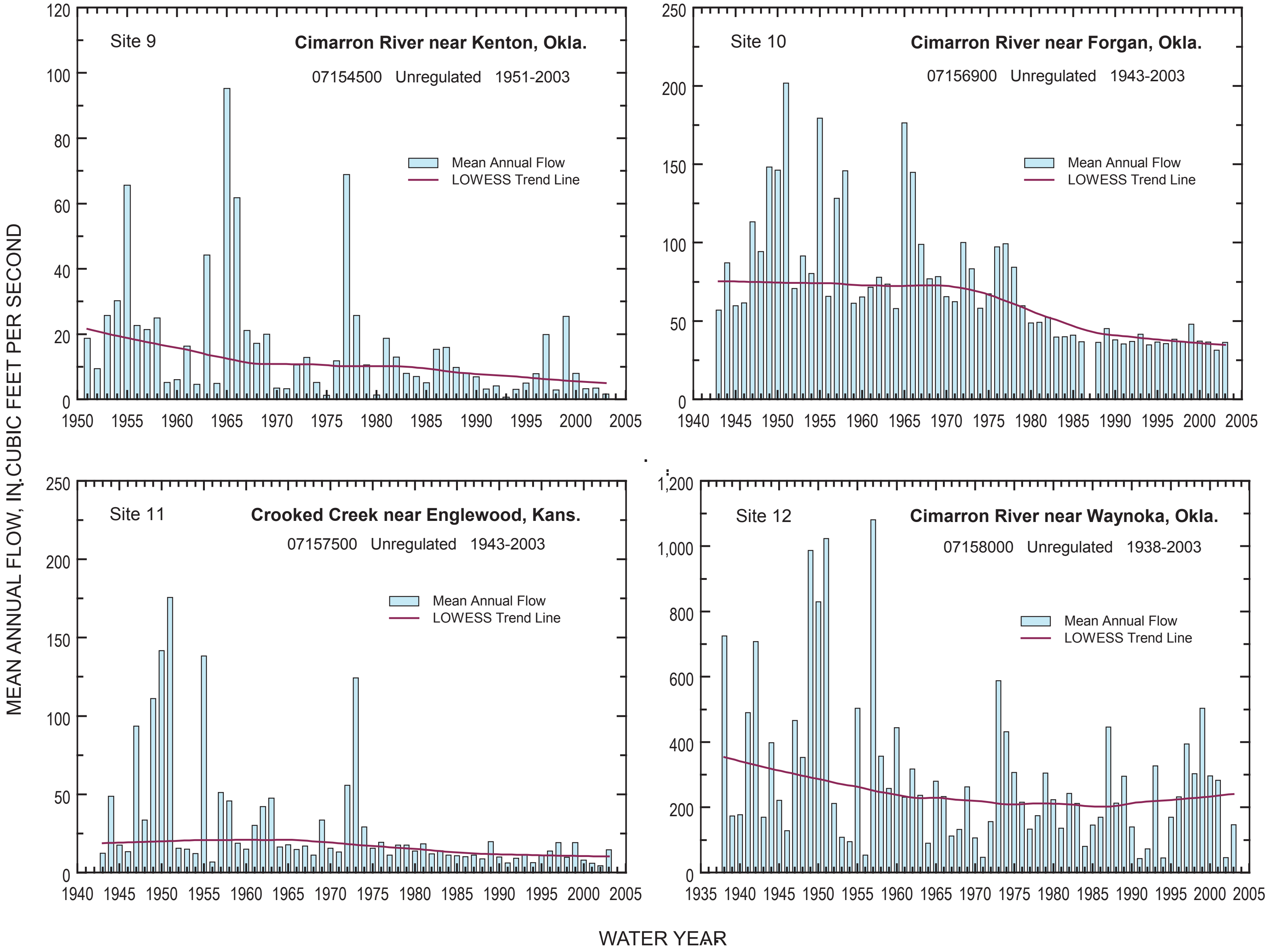

Figure 33. Mean annual flows and LOWESS trend lines using available periods of record for sites 9-12.

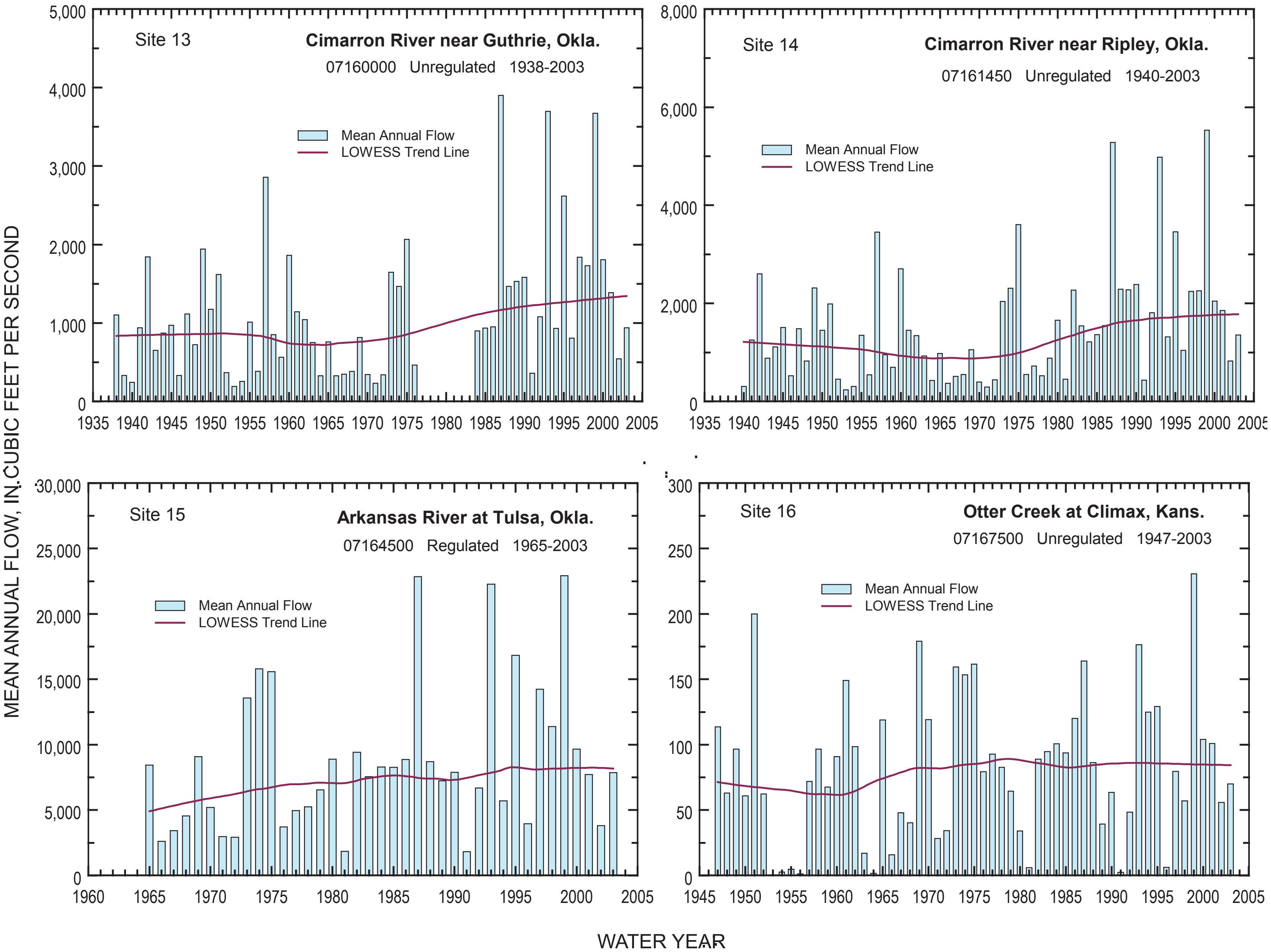

Figure 34. Mean annual flows and LOWESS trend lines using available periods of record for sites 13-16.

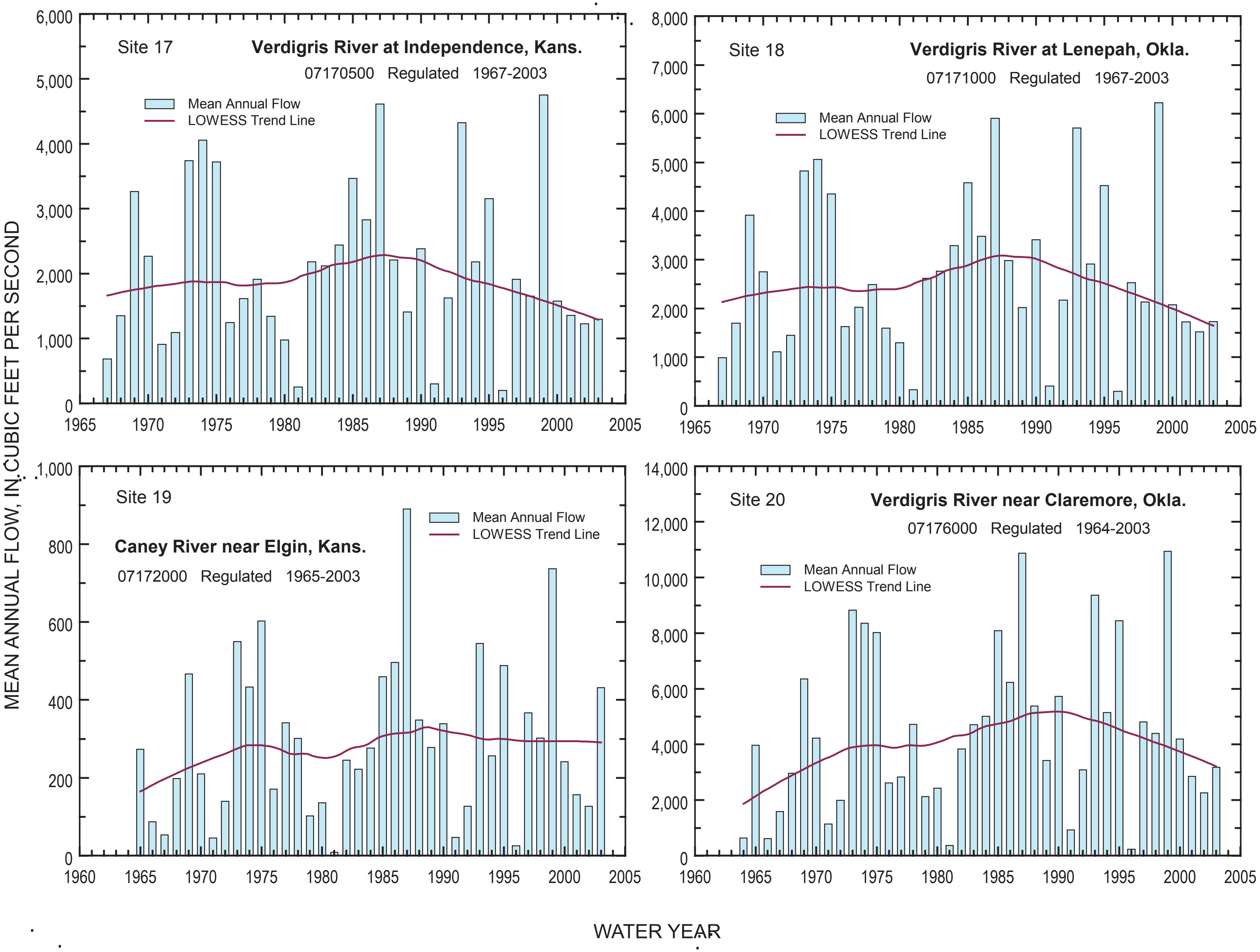

Figure 35. Mean annual flows and LOWESS trend lines using available periods of record for sites 17-20.

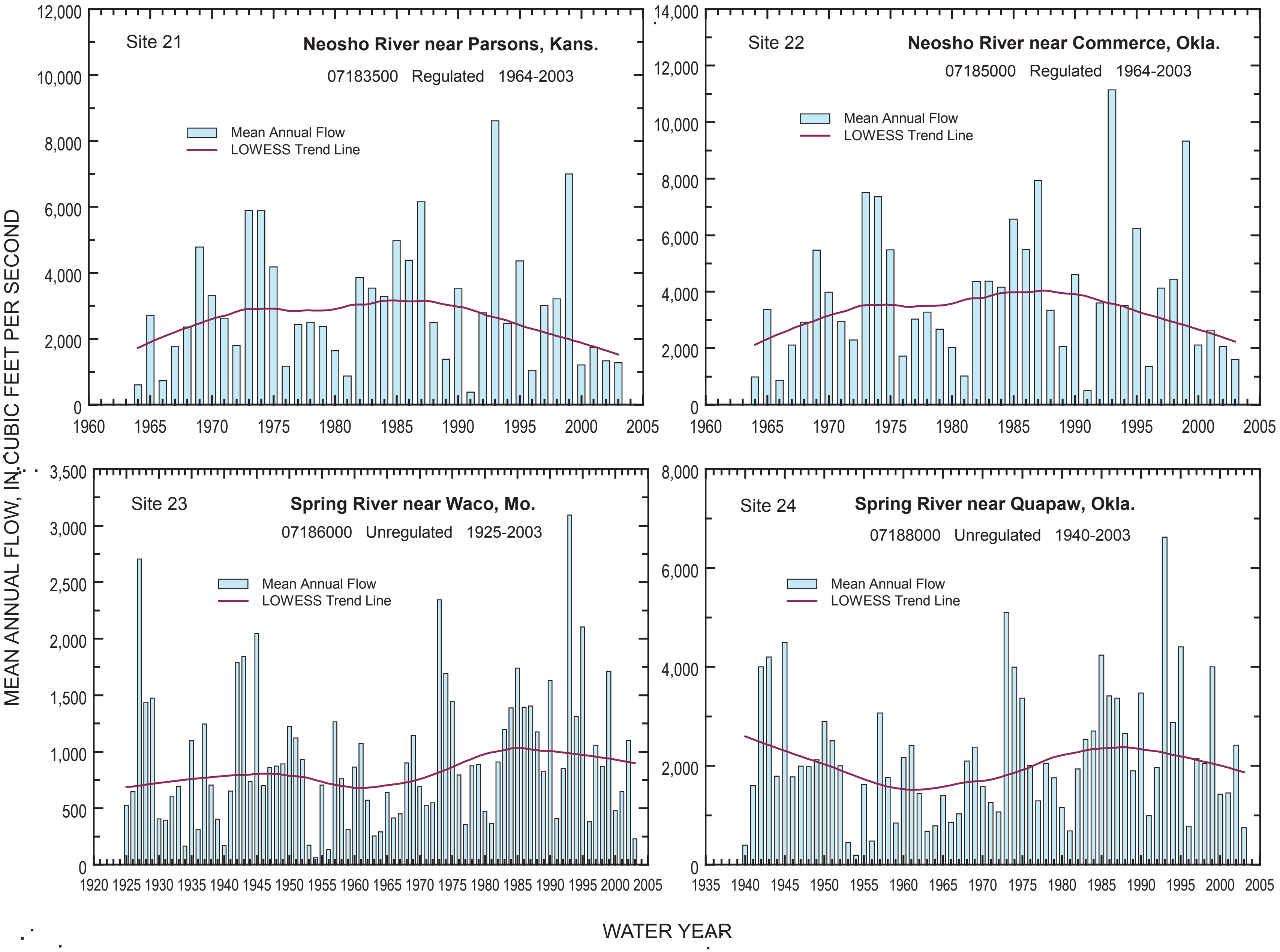

Figure 36. Mean annual flows and LOWESS trend lines using available periods of record for sites 21-24.

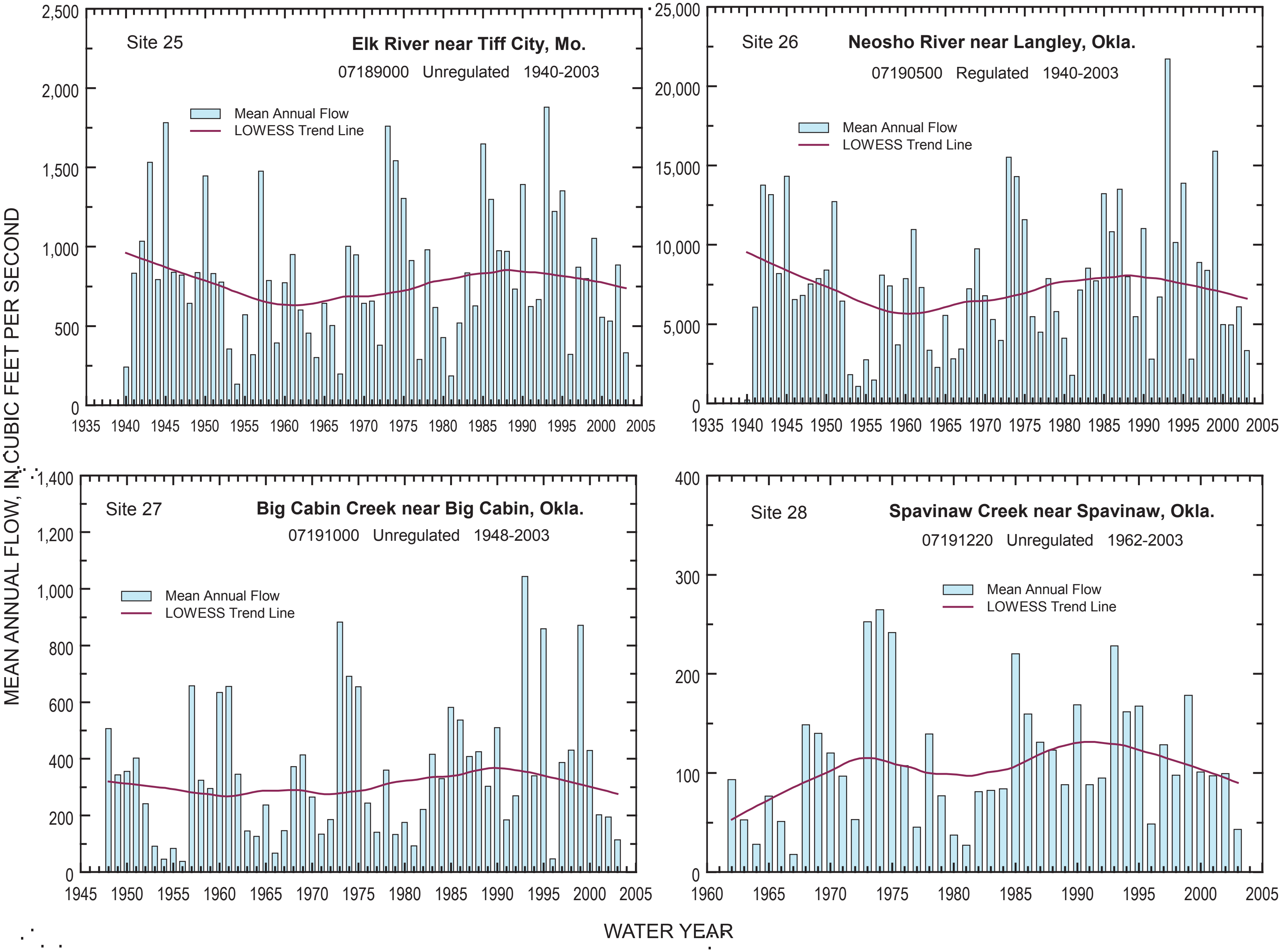

Figure 37. Mean annual flows and LOWESS trend lines using available periods of record for sites 25-28.

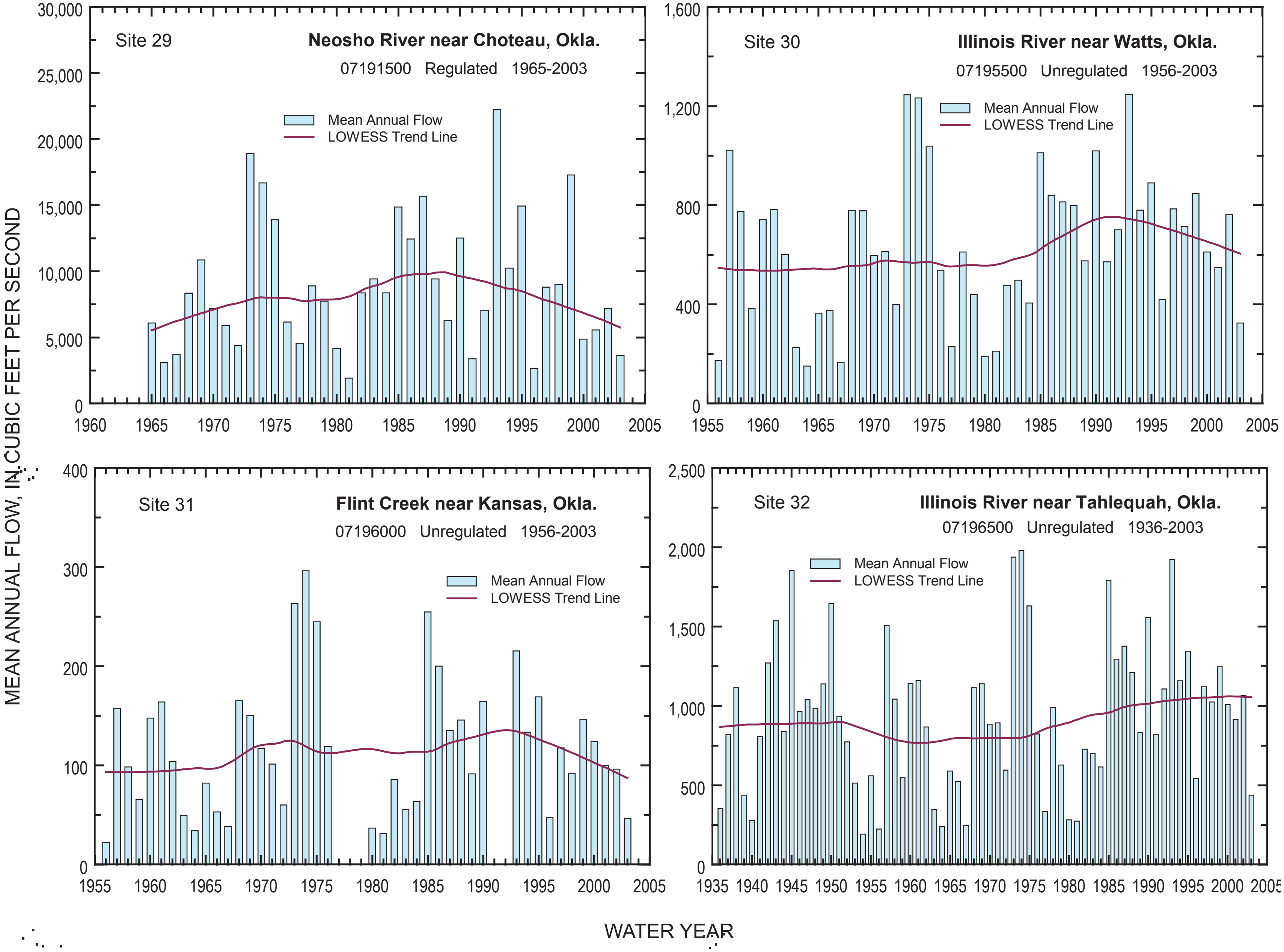

Figure 38. Mean annual flows and LOWESS trend lines using available periods of record for sites 29-32.

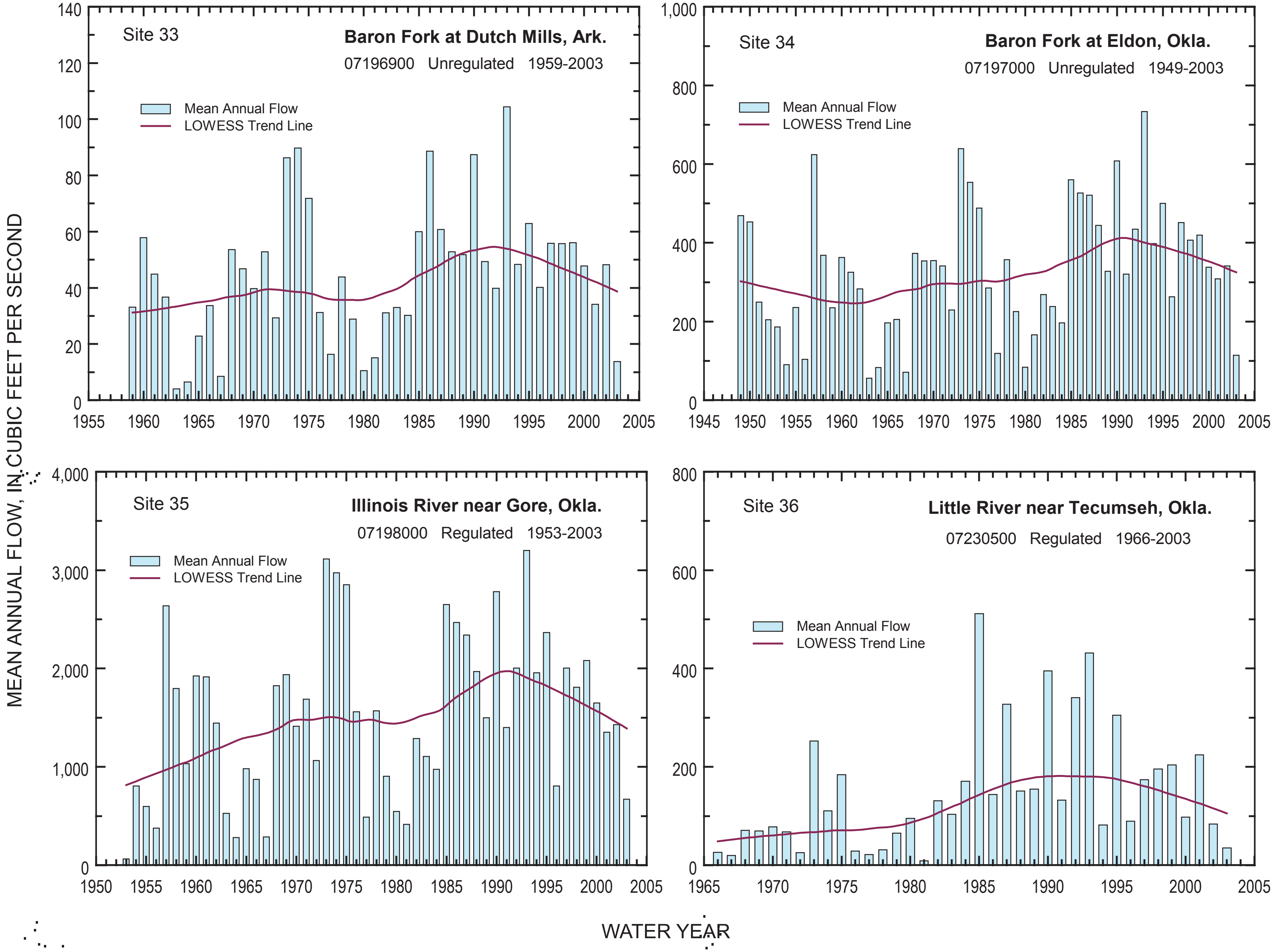

Figure 39. Mean annual flows and LOWESS trend lines using available periods of record for sites 33-36.

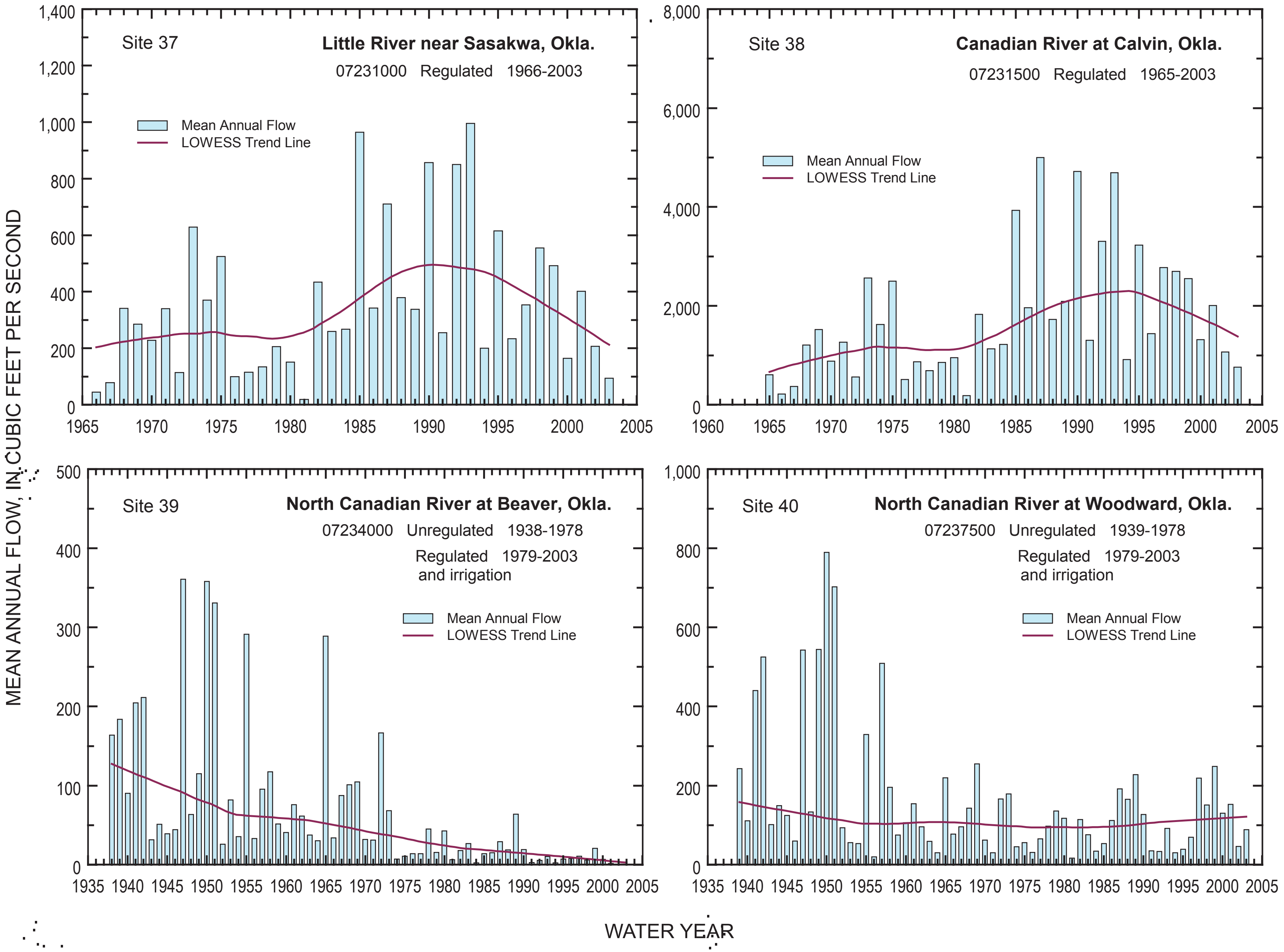

Figure 40. Mean annual flows and LOWESS trend lines using available periods of record for sites 37-40.

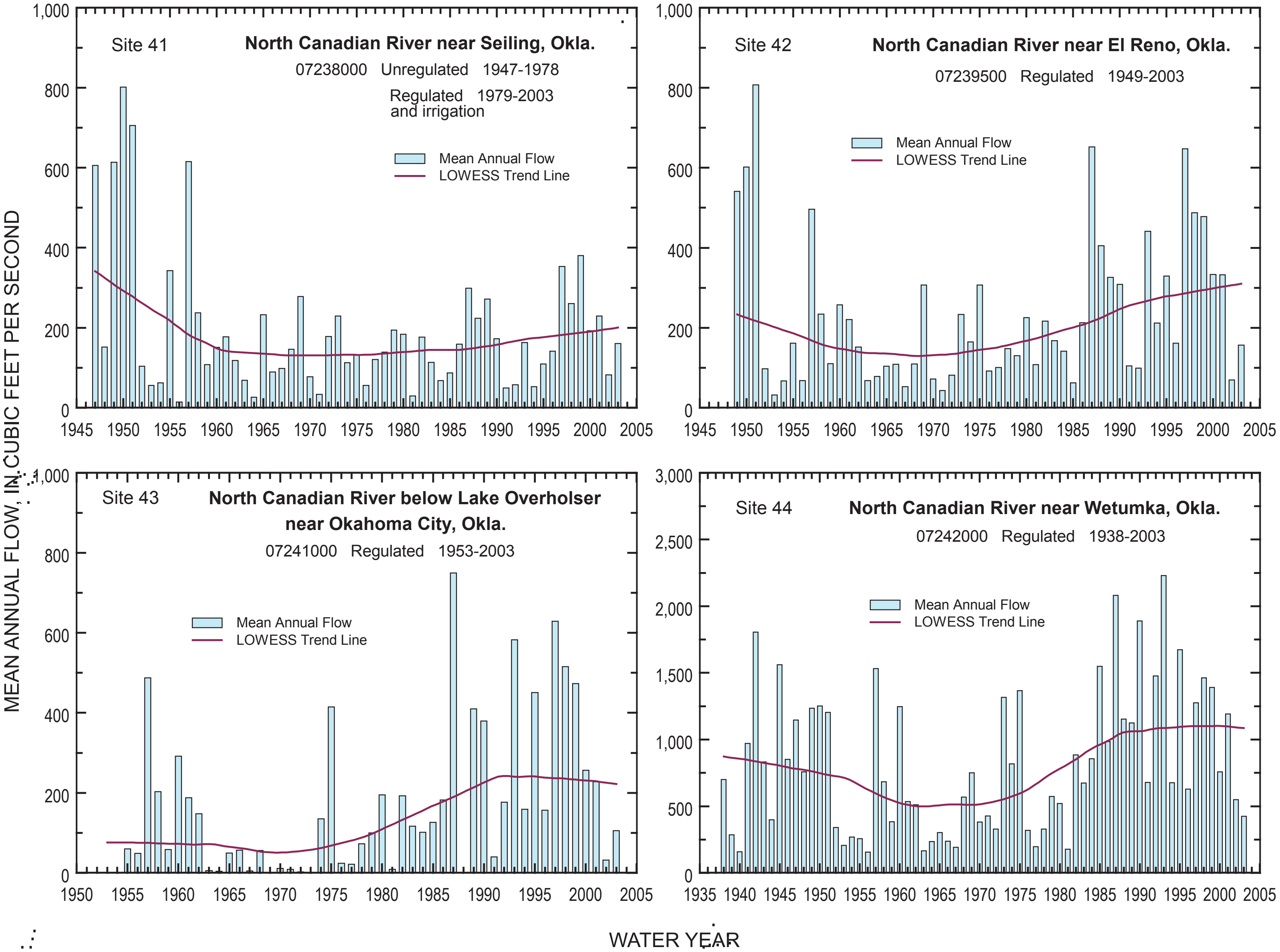

Figure 41. Mean annual flows and LOWESS trend lines using available periods of record for sites 41-44.

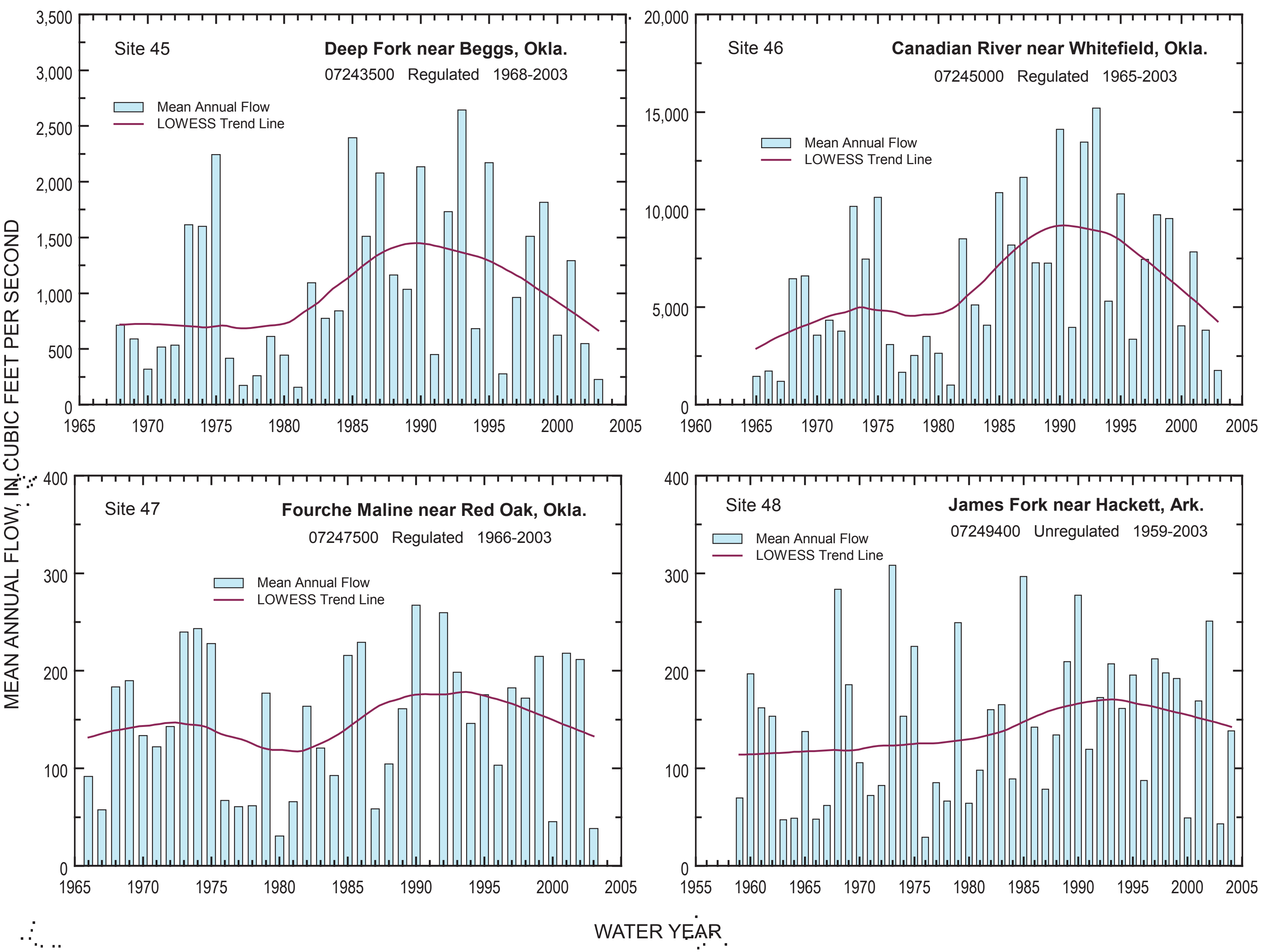

Figure 42. Mean annual flows and LOWESS trend lines using available periods of record for sites 45-48.

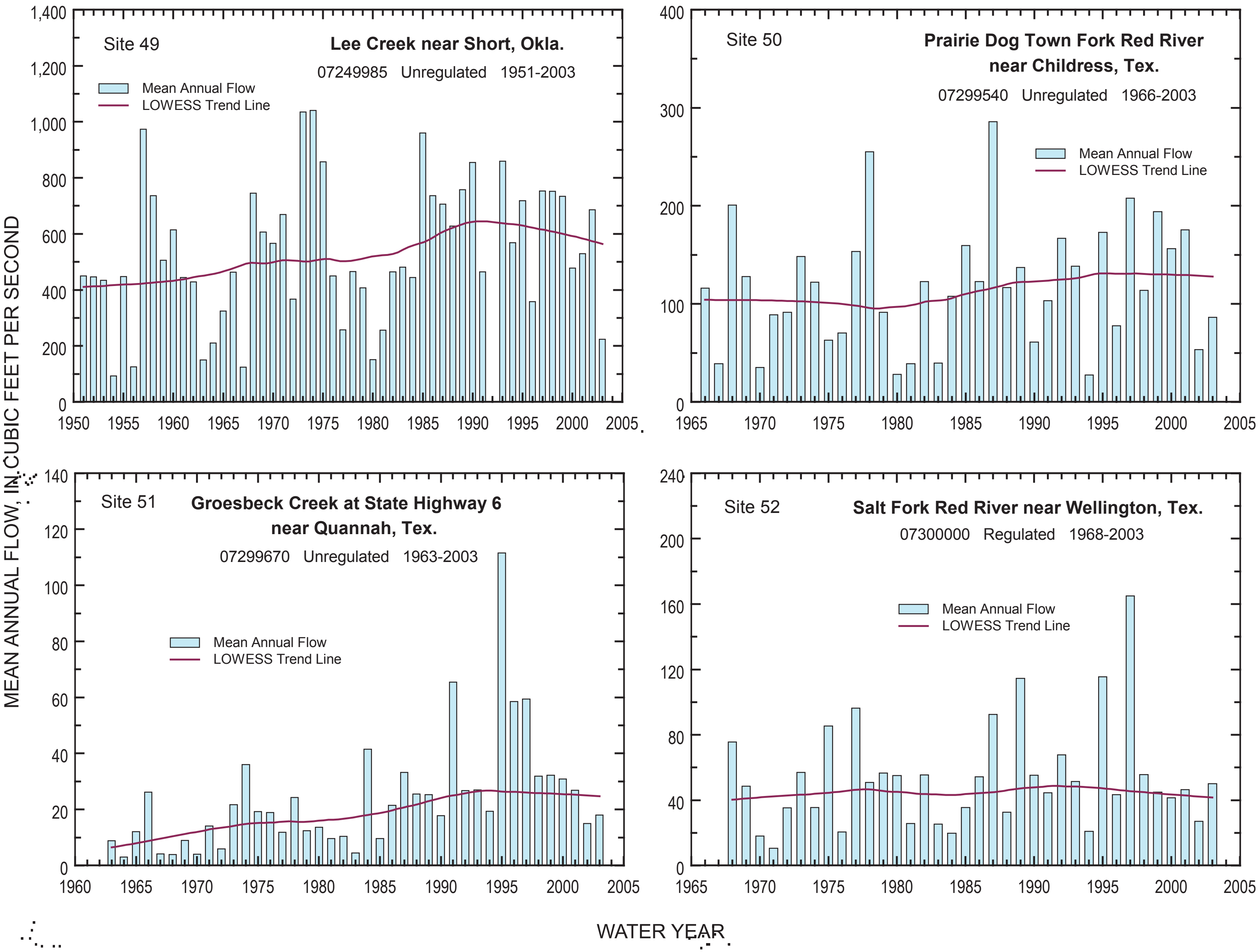

Figure 43. Mean annual flows and LOWESS trend lines using available periods of record for sites 49-52.

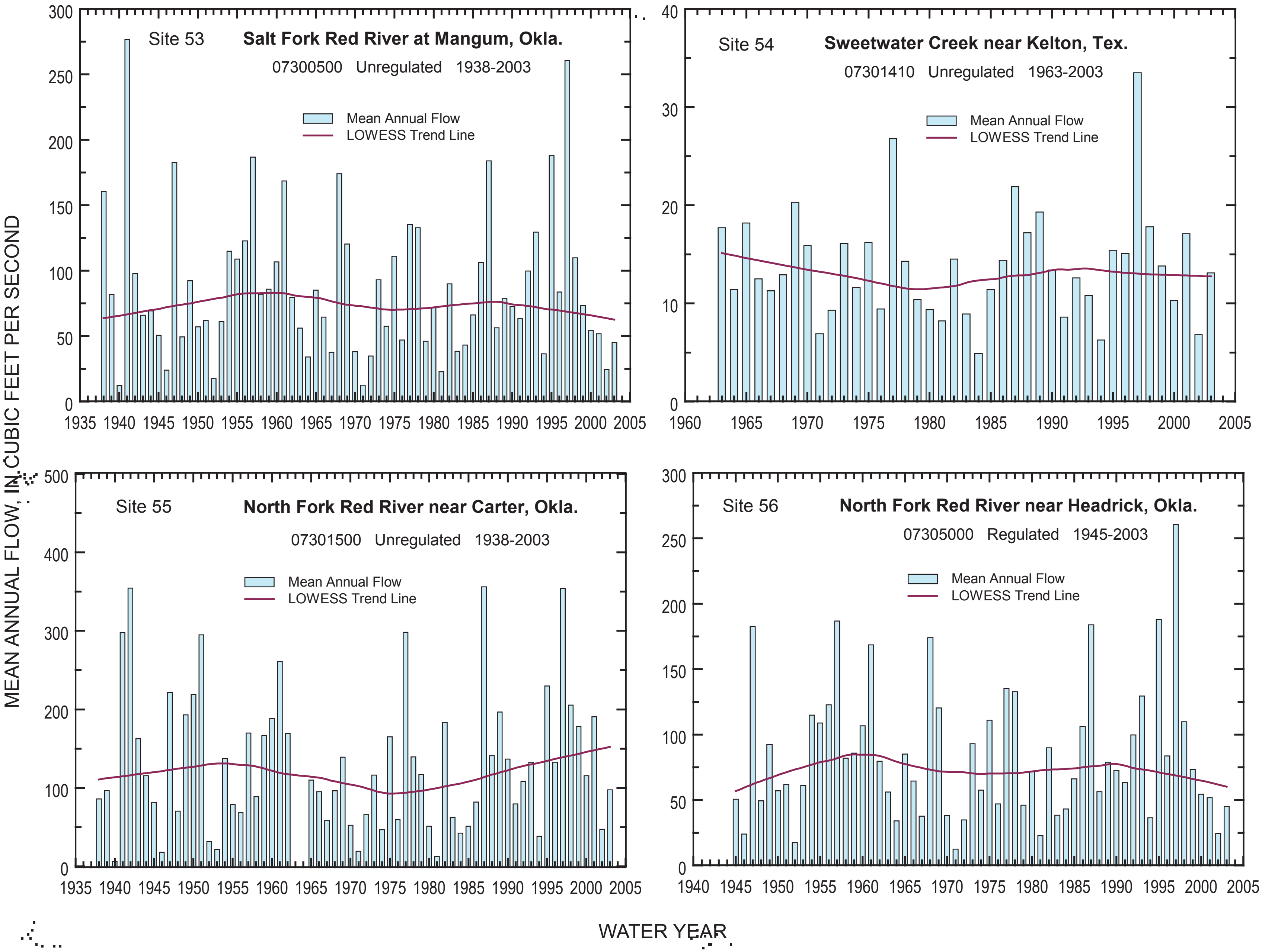

Figure 44. Mean annual flows and LOWESS trend lines using available periods of record for sites 53-56.

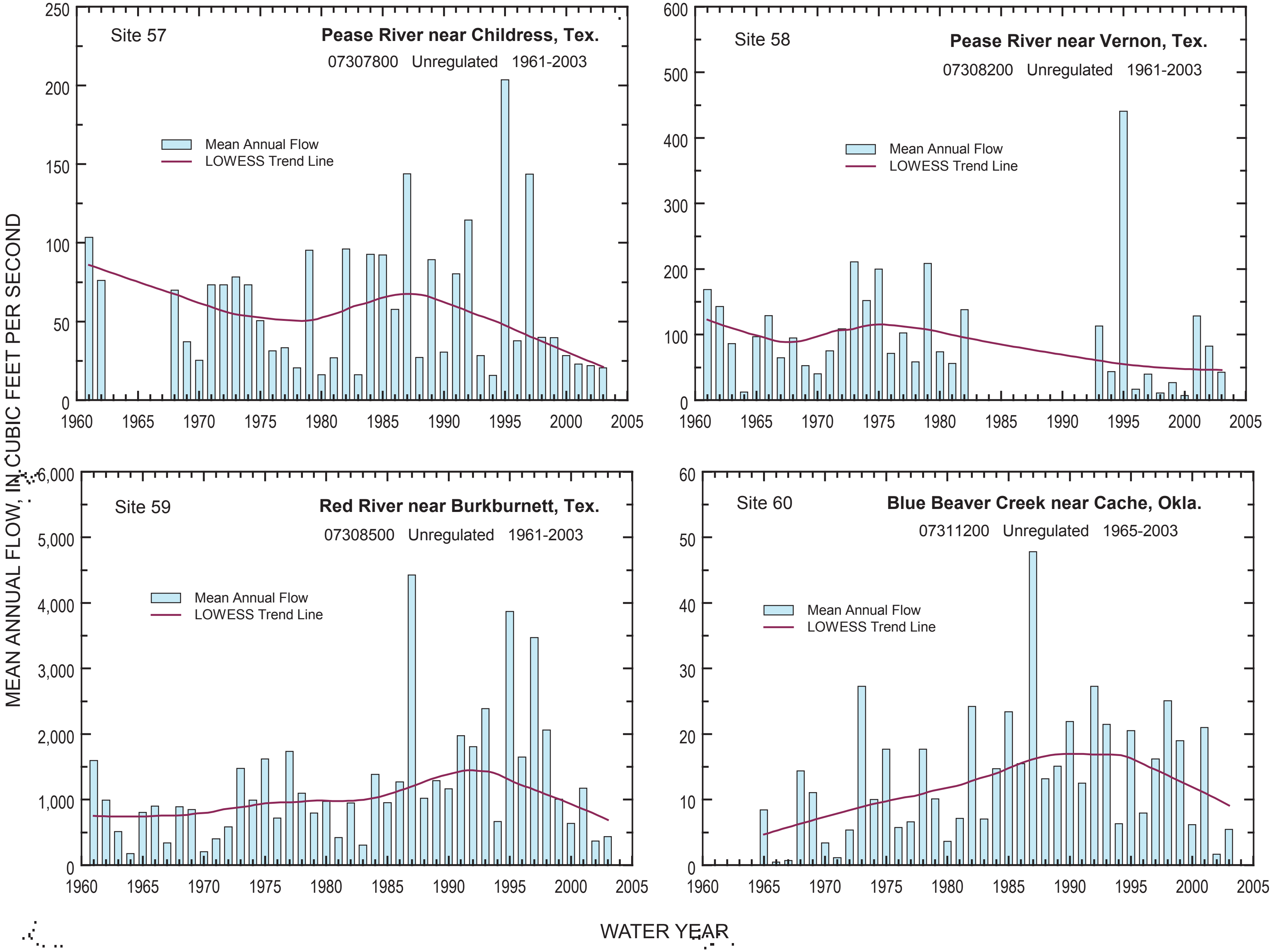

Figure 45. Mean annual flows and LOWESS trend lines using available periods of record for sites 57-60.

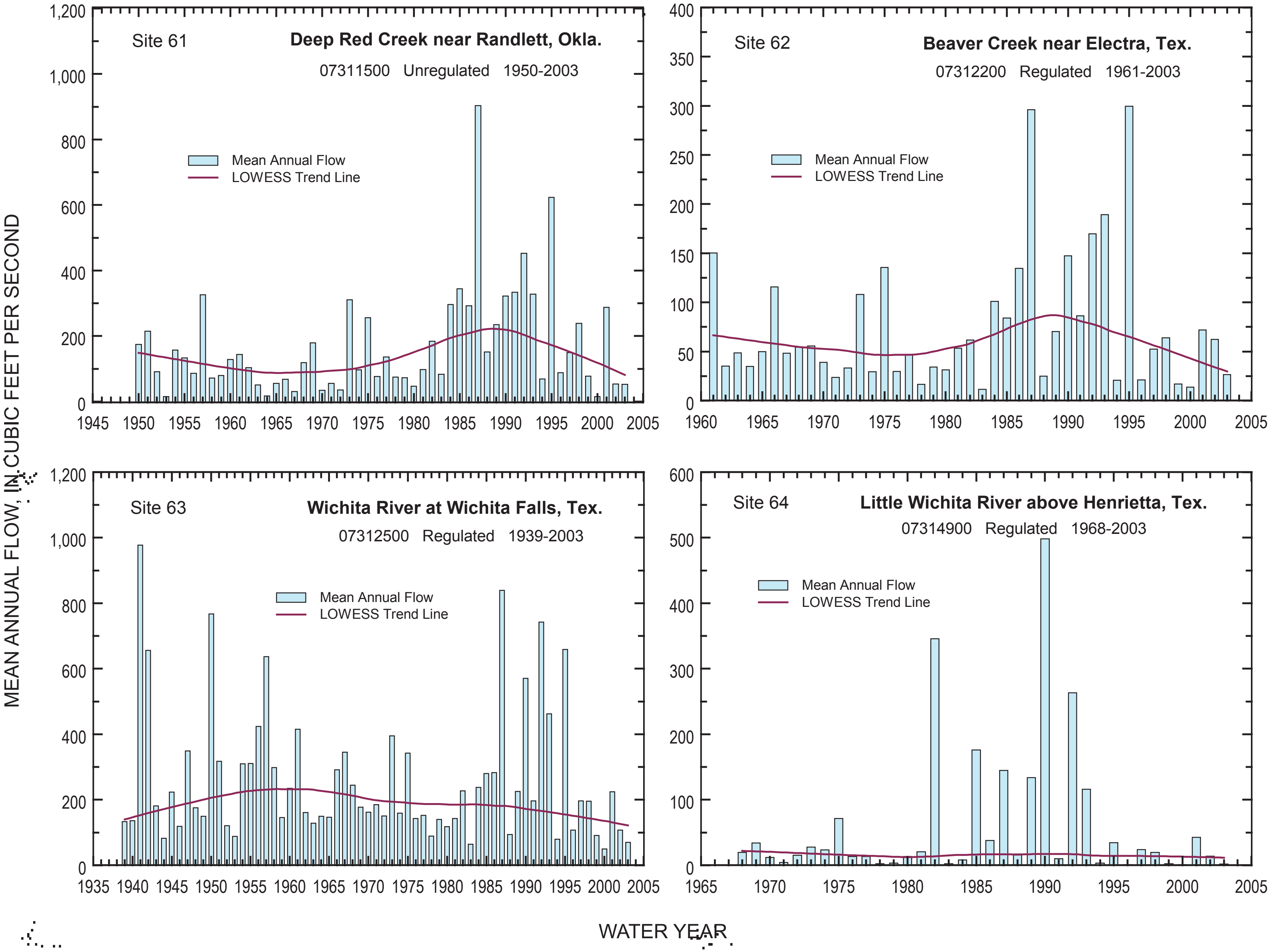

Figure 46. Mean annual flows and LOWESS trend lines using available periods of record for sites 61-64.

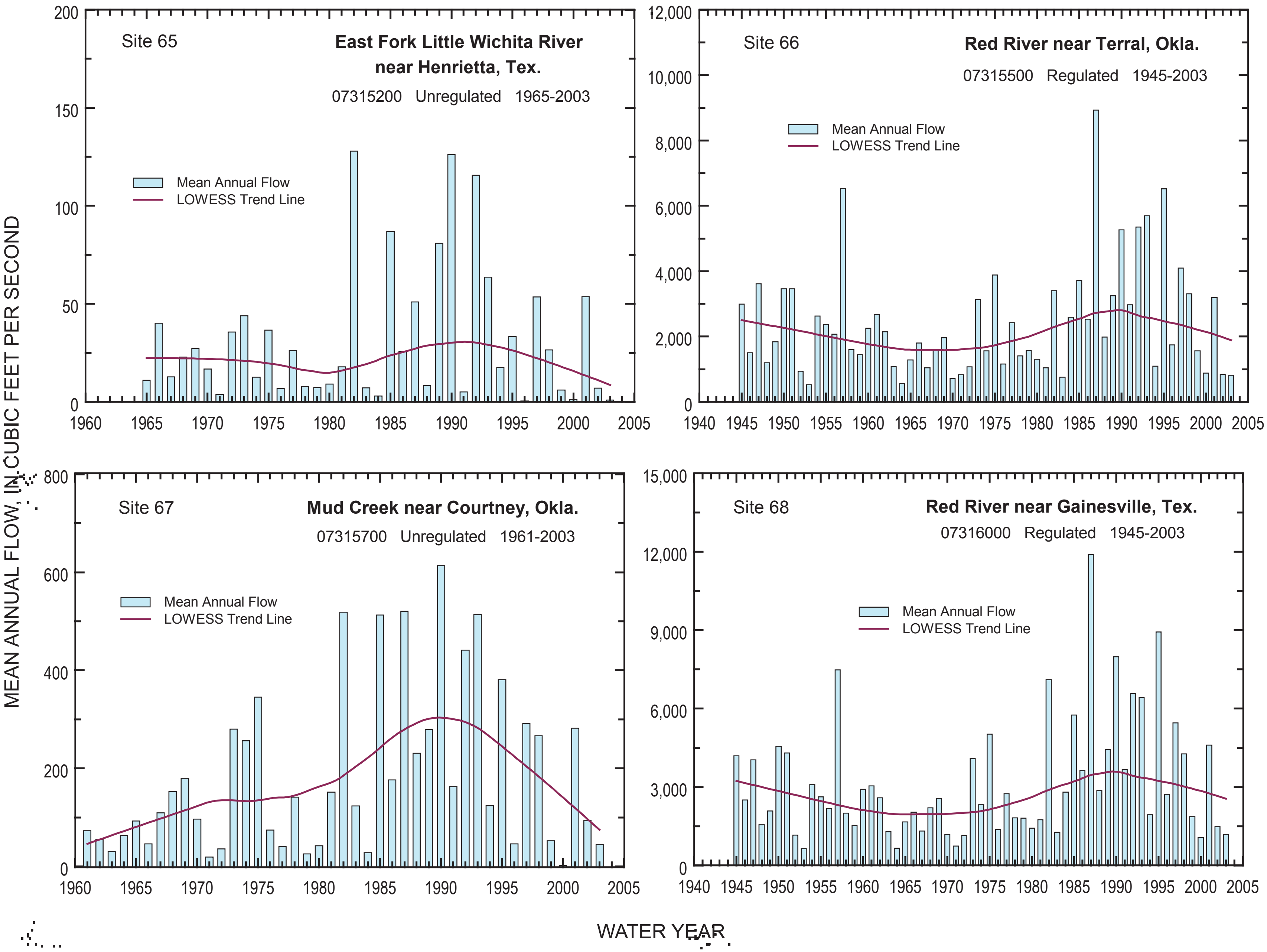

Figure 47. Mean annual flows and LOWESS trend lines using available periods of record for sites 65-68.

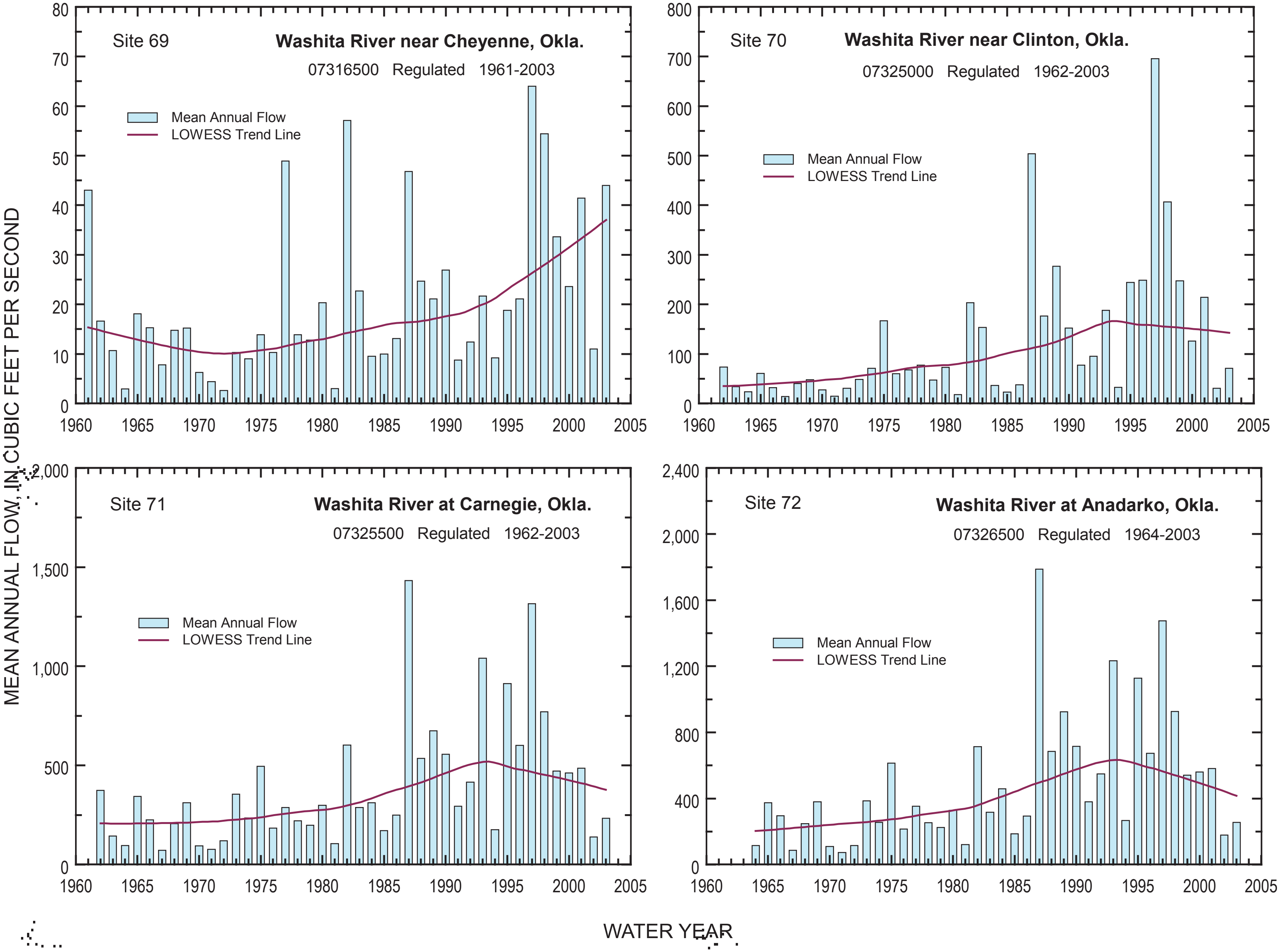

Figure 48. Mean annual flows and LOWESS trend lines using available periods of record for sites 69-72.

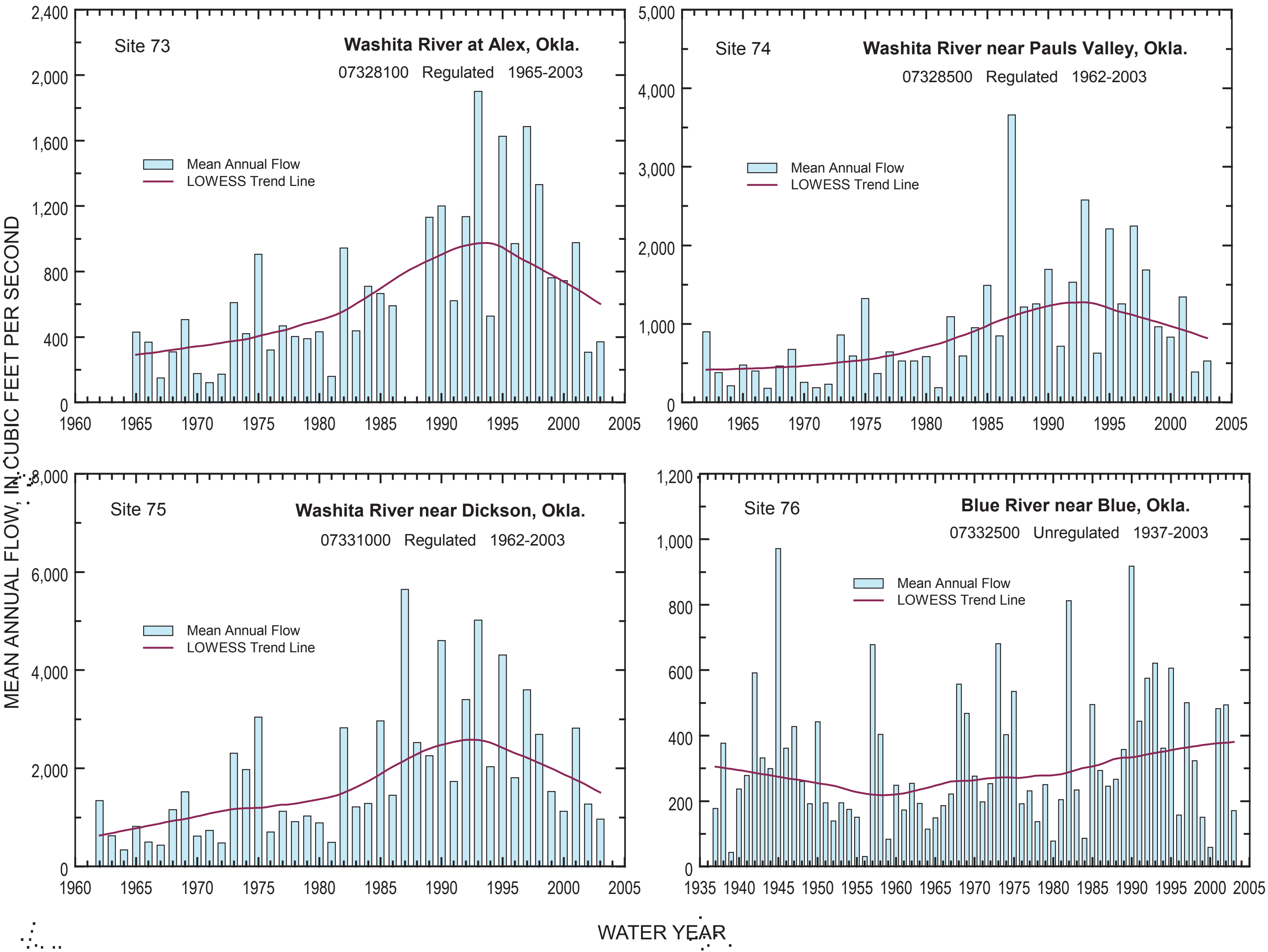

Figure 49. Mean annual flows and LOWESS trend lines using available periods of record for sites 73-76.

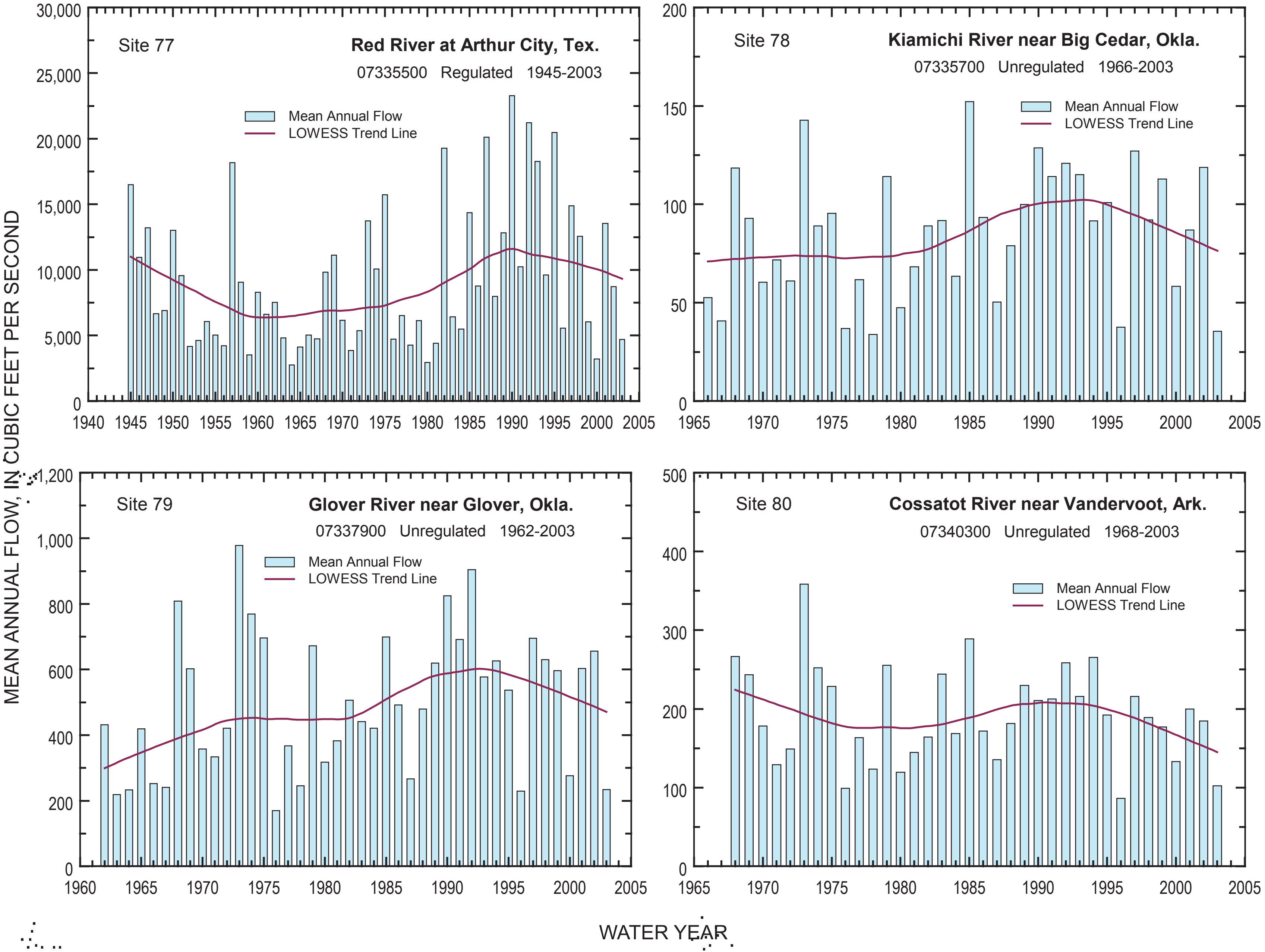

Figure 50. Mean annual flows and LOWESS trend lines using available periods of record for sites 77-80.

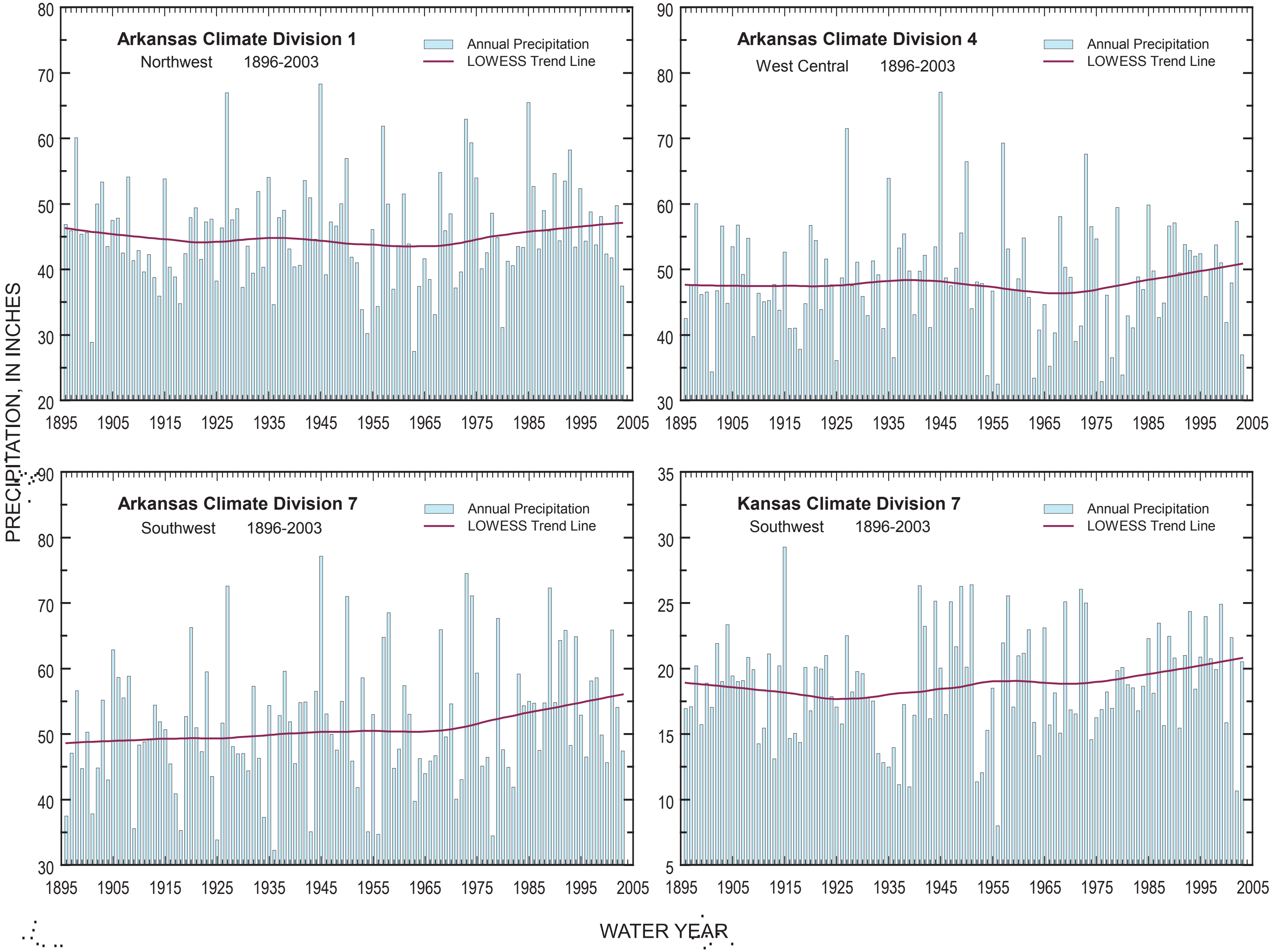

Figure 52. Annual precipitation and LOWESS trend lines water years 1896-2003. Arkansas Climate Divisions 1, 4, and 7 and Kansas Climate Division 7.

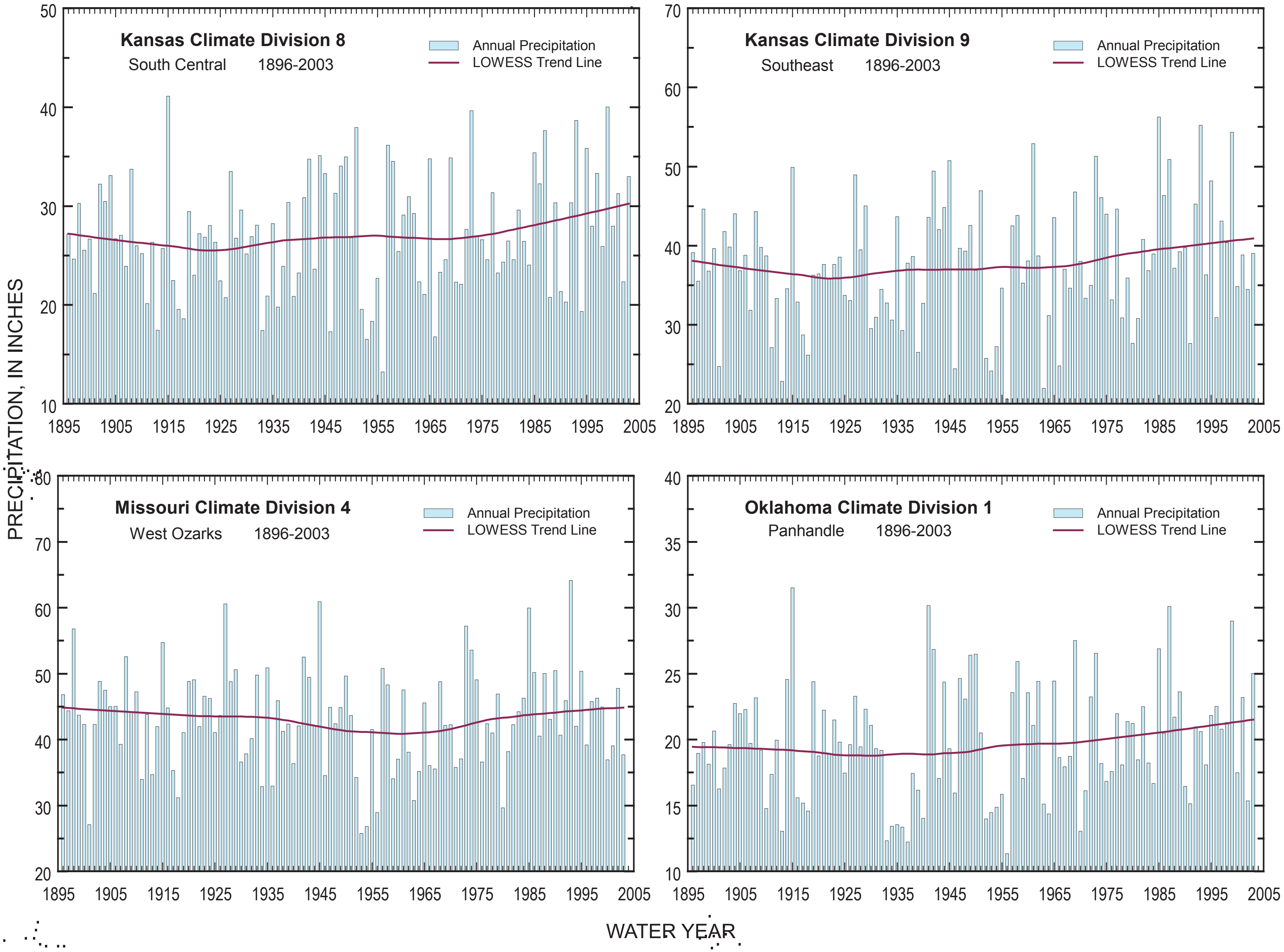

Figure 53. Annual precipitation and LOWESS trend lines water years 1896-2003. Kansas Climate Divisions 8 and 9, Missouri Climate Division 4, and Oklahoma Climate Division 1.

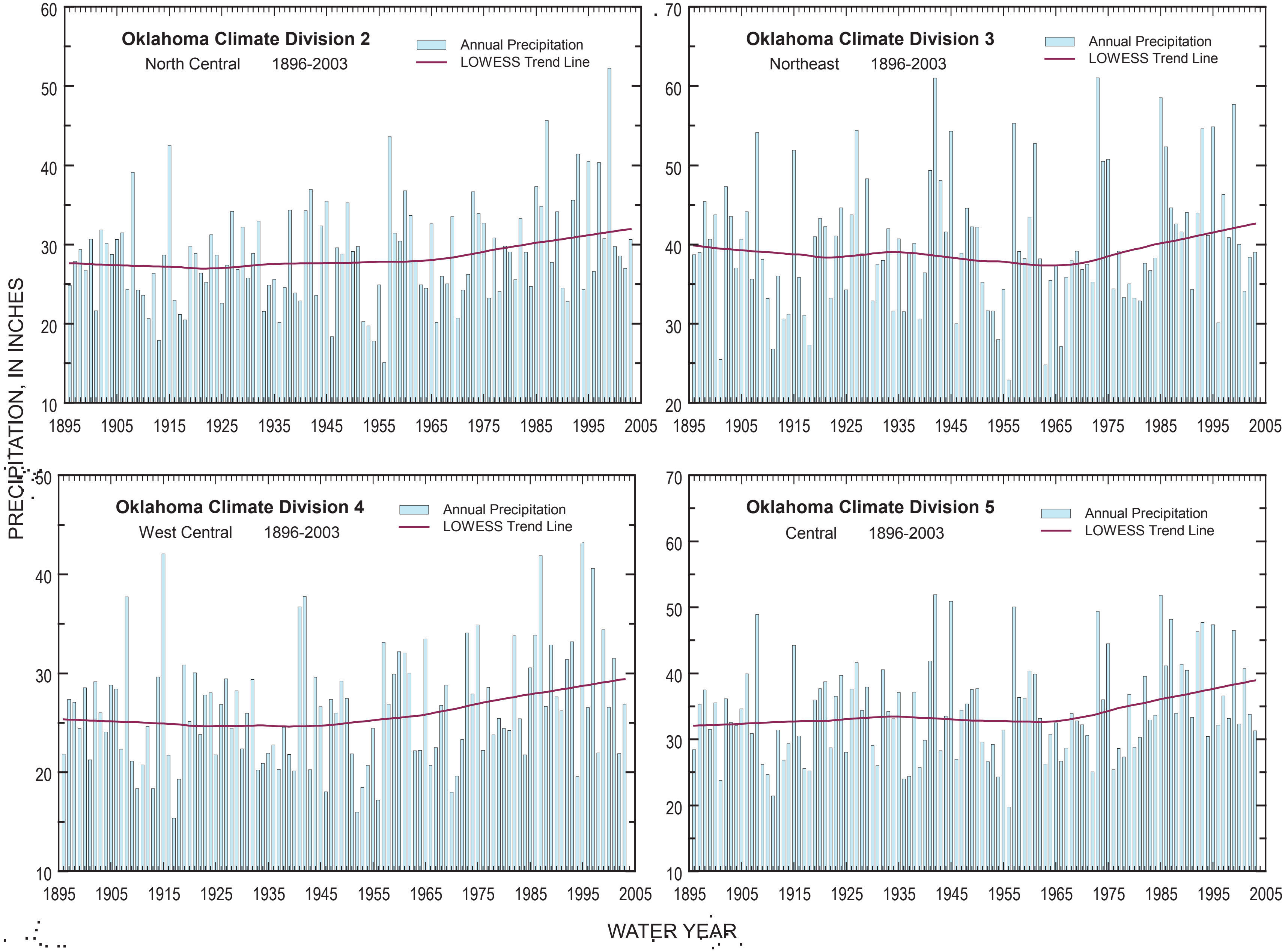

Figure 54. Annual precipitation and LOWESS trend lines water years 1896-2003. Oklahoma Climate Divisions 2-5.

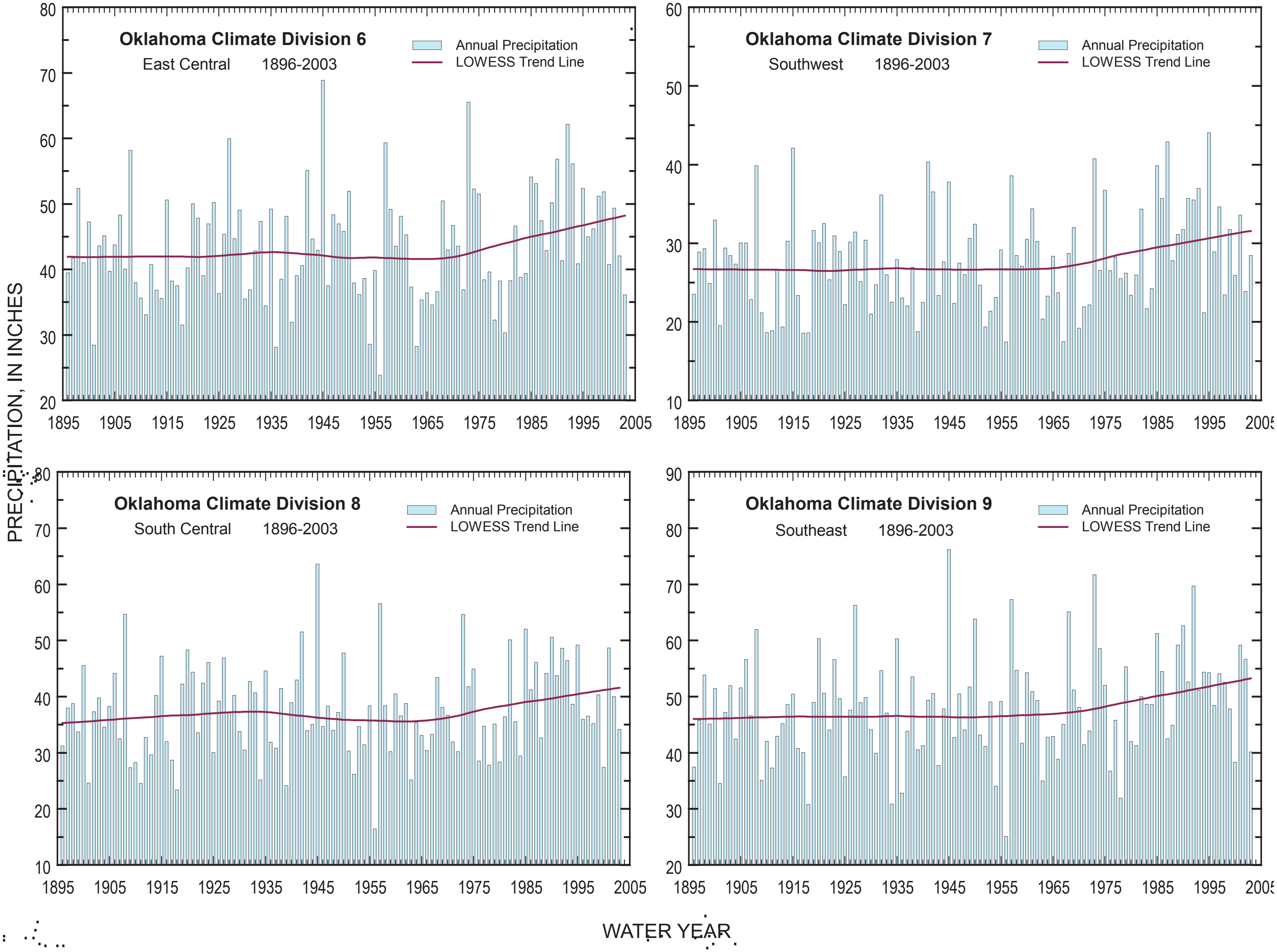

Figure 55. Annual precipitation and LOWESS trend lines water years 1896-2003. Oklahoma Climate Divisions 6-9.

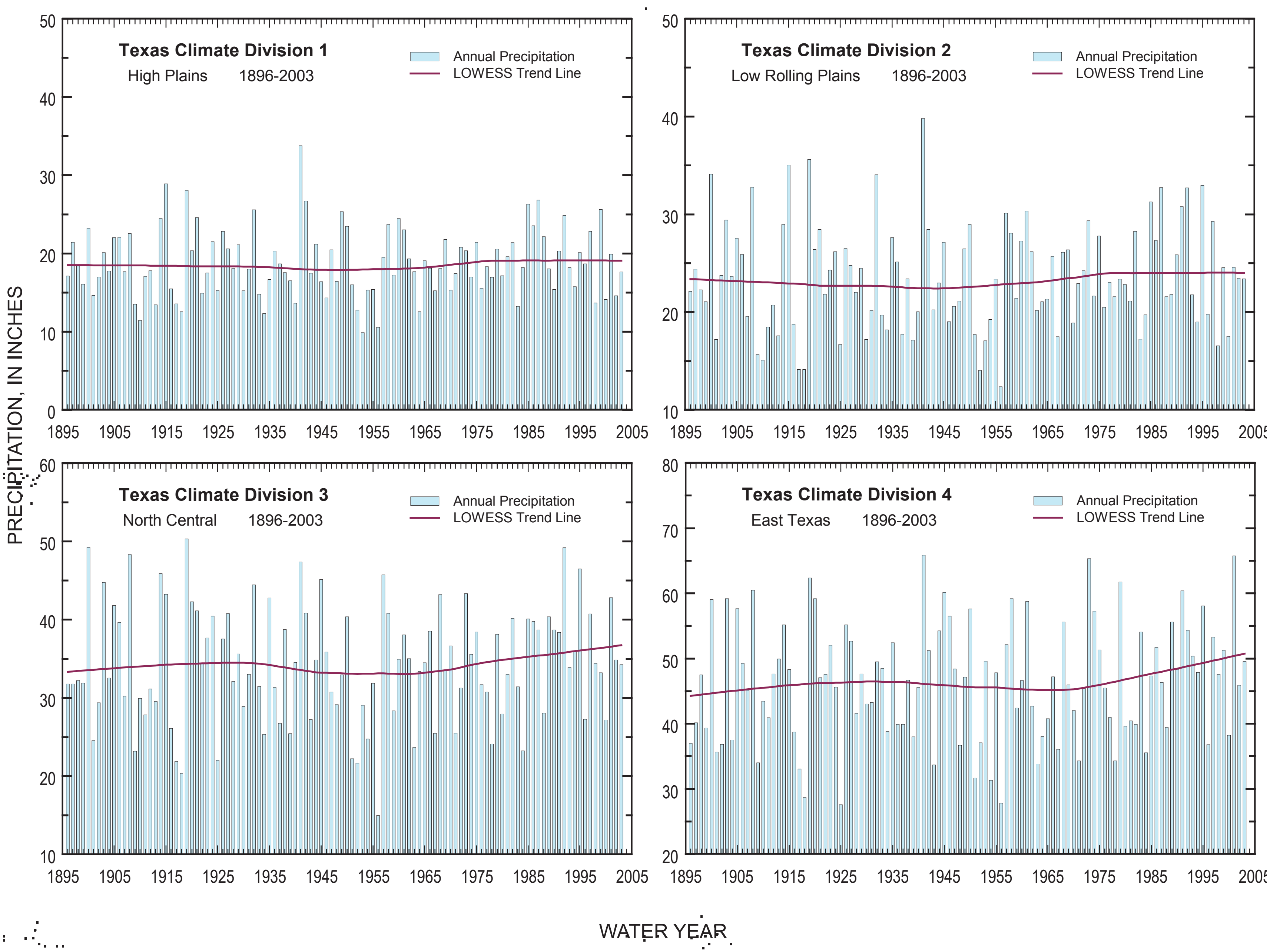

Figure 56. Annual precipitation and LOWESS trend lines water years 1896-2003. Texas Climate Divisions 1-4.

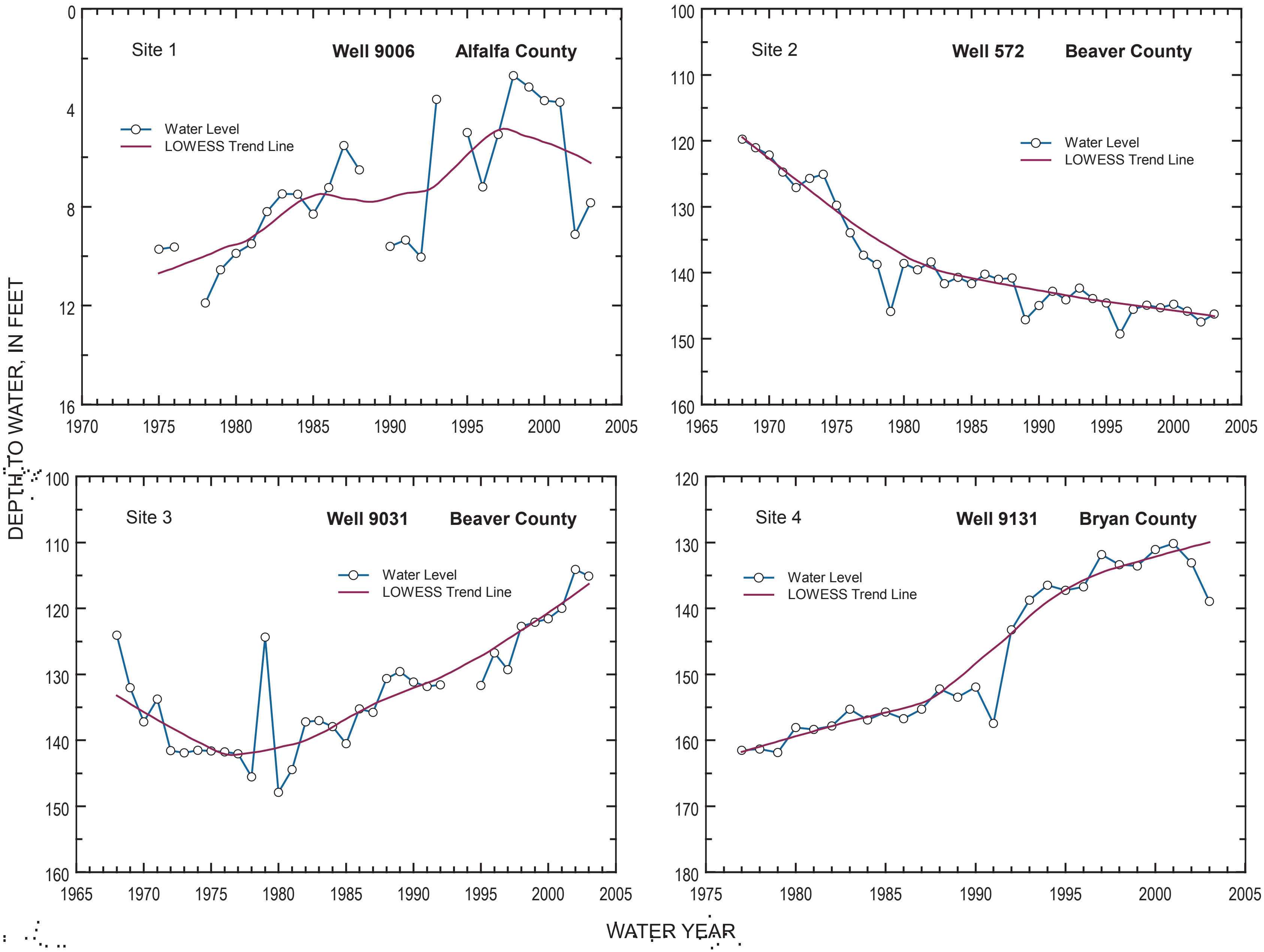

Figure 58. Water levels and LOWESS trend lines using available periods of record for well sites 1-4.

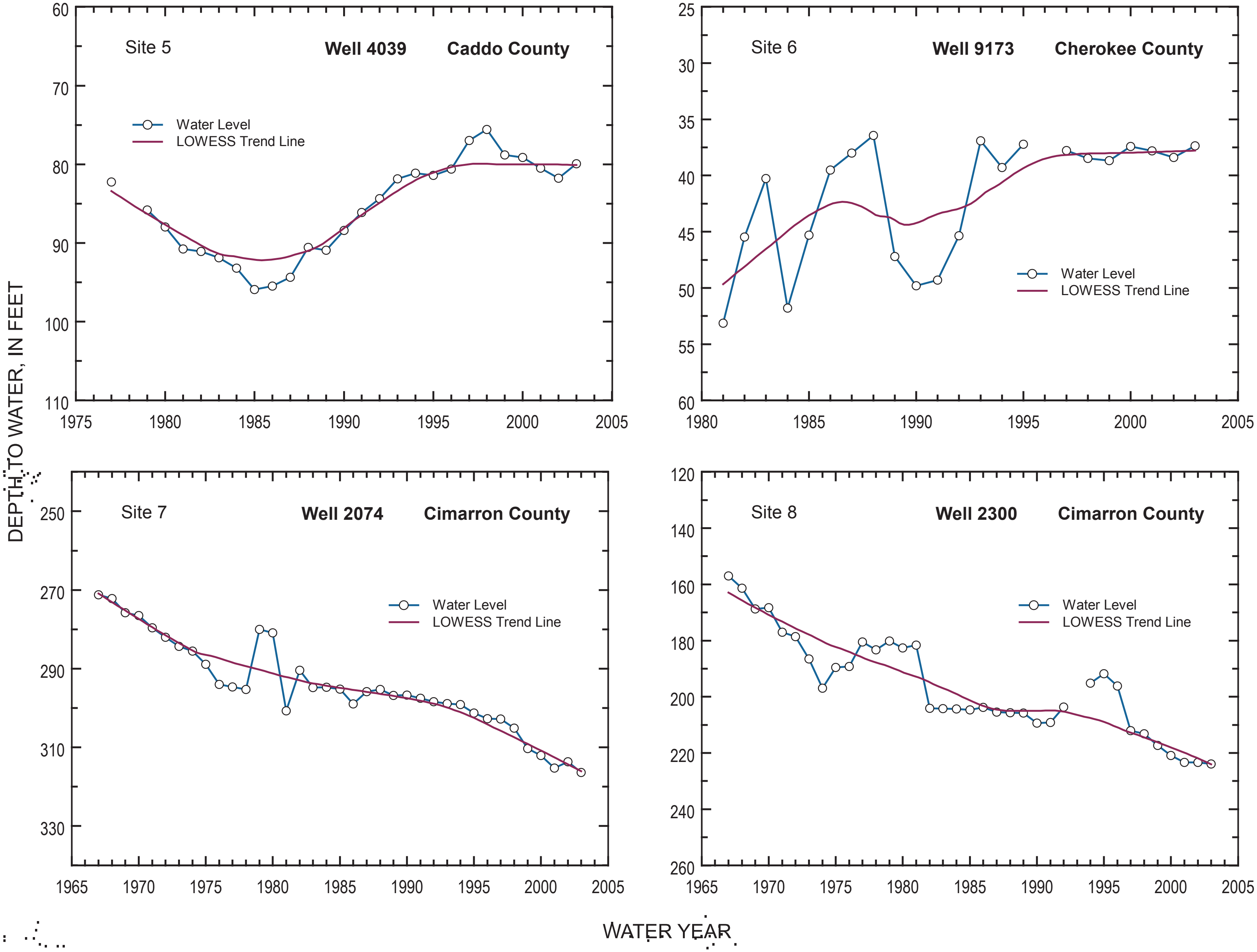

Figure 59. Water levels and LOWESS trend lines using available periods of record for well sites 5-8.

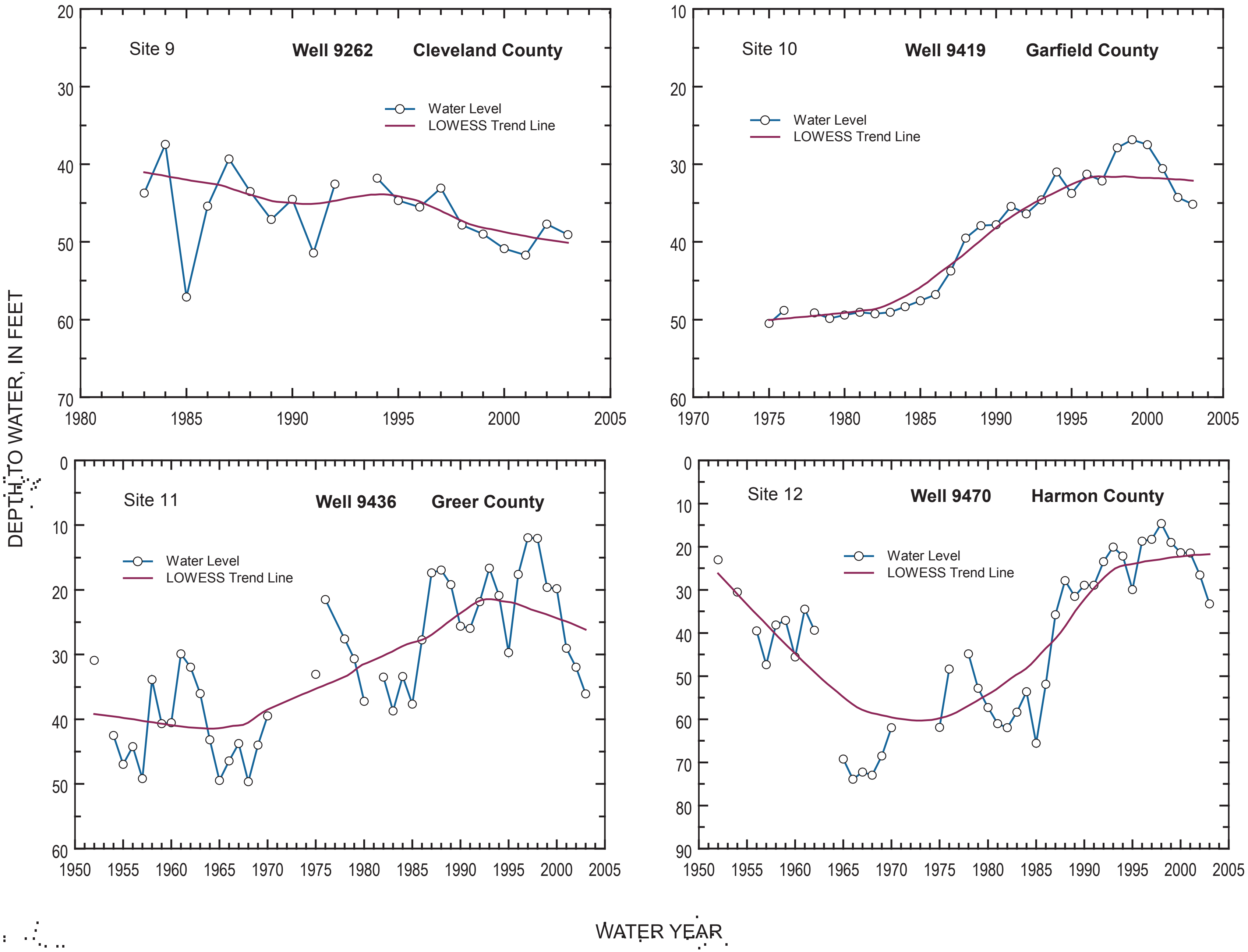

Figure 60. Water levels and LOWESS trend lines using available periods of record for well sites 9-12.

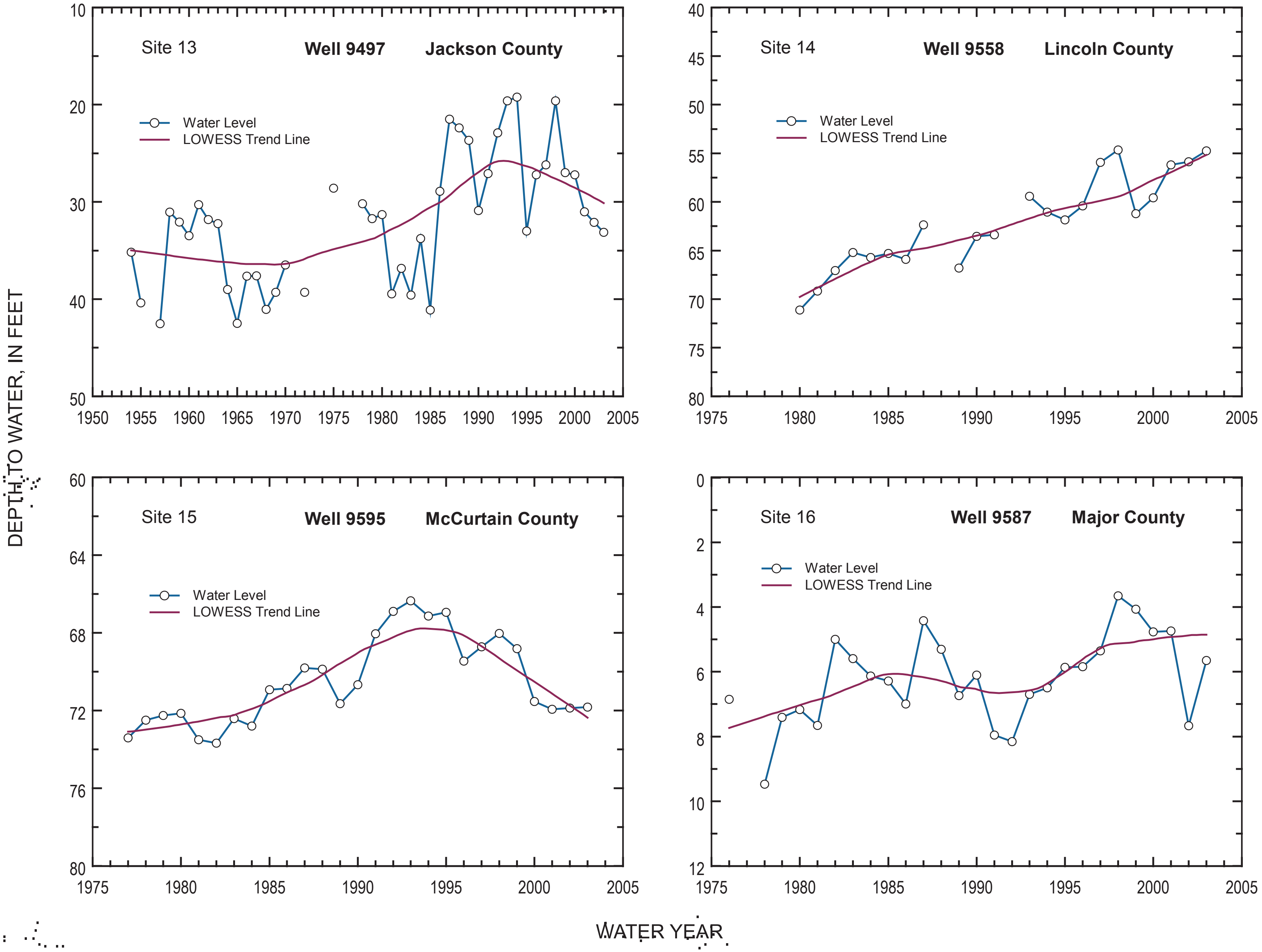

Figure 61. Water levels and LOWESS trend lines using available periods of record for well sites 13-16.

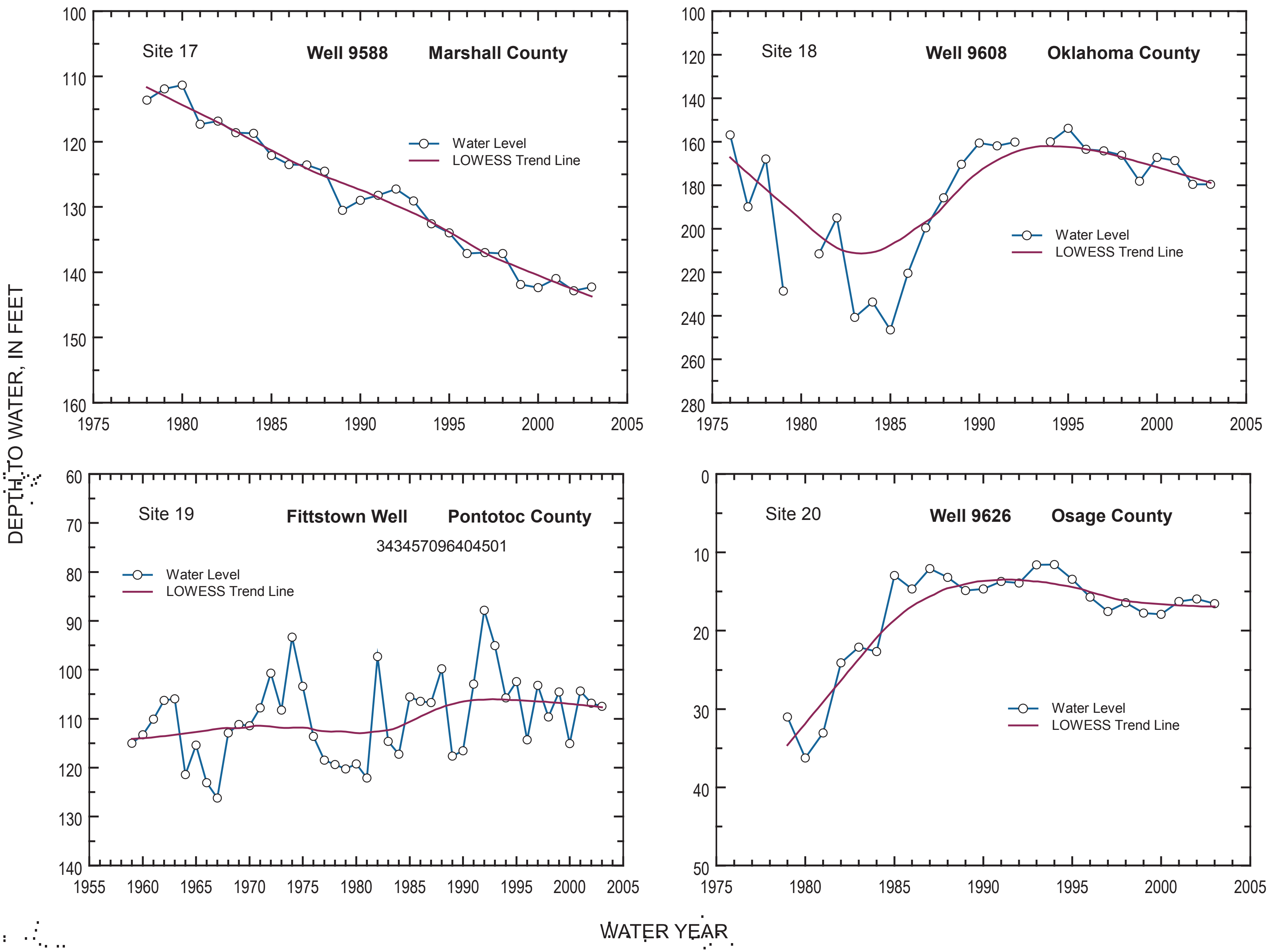

Figure 62. Water levels and LOWESS trend lines using available periods of record for well sites 17-20.

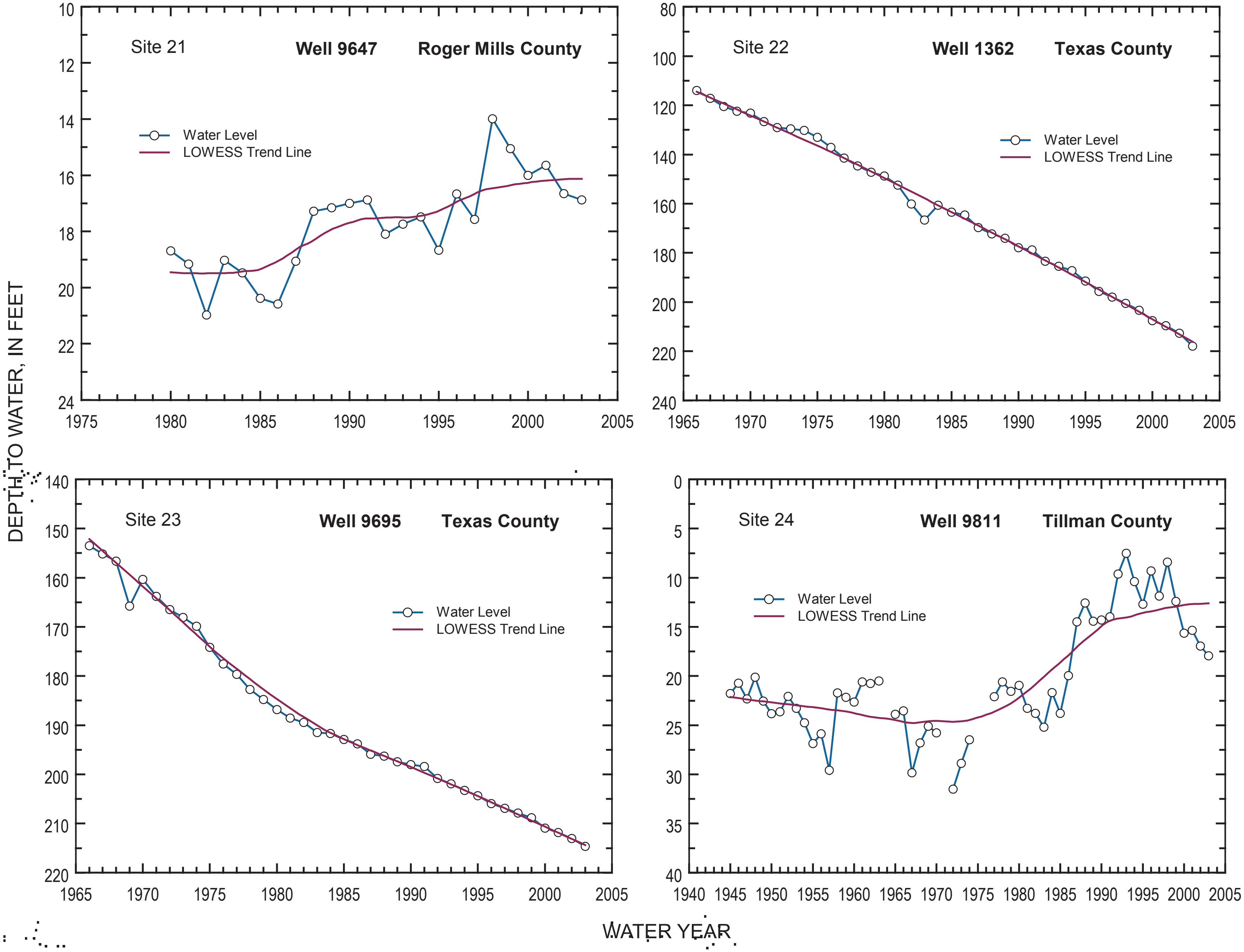

Figure 63. Water levels and LOWESS trend lines using available periods of record for well sites 21-24.

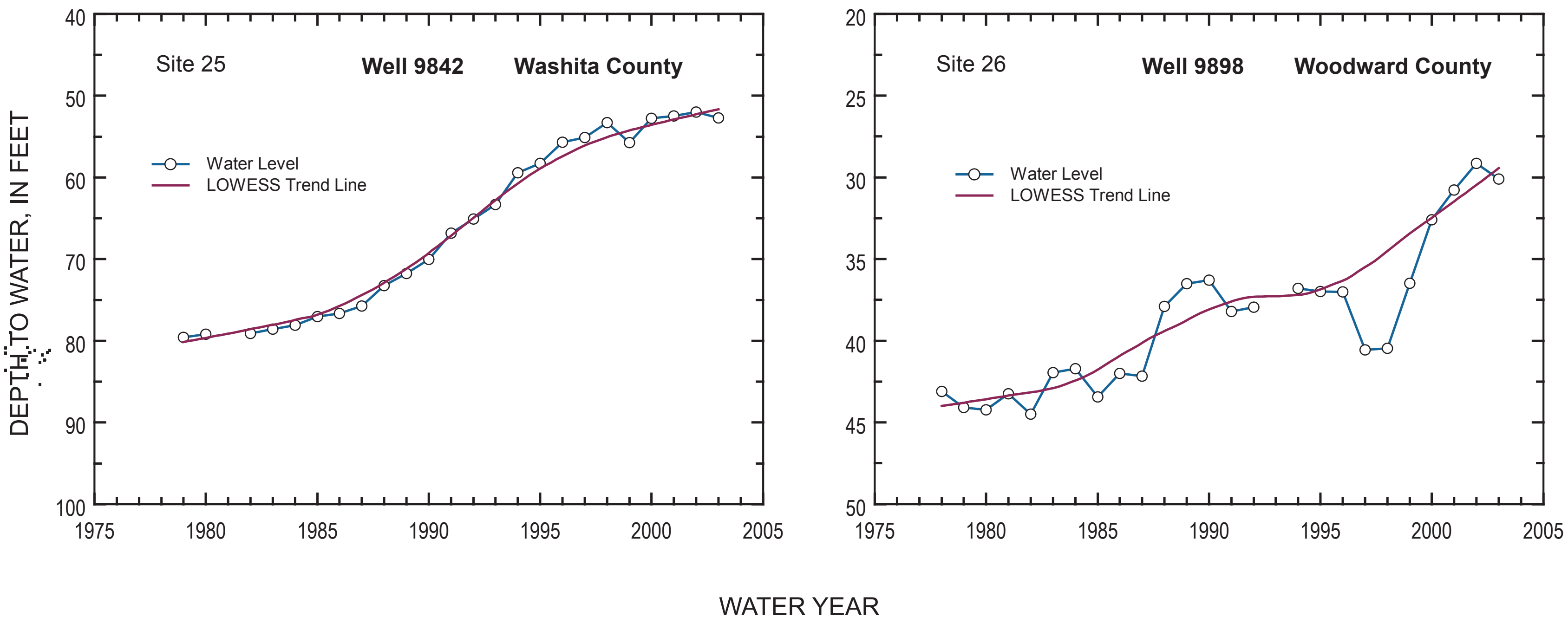

Figure 64. Water levels and LOWESS trend lines using available periods of record for well sites 25-26.