Prepared in cooperation with the Oklahoma Department of Transportation

Methods for Estimating the Magnitude and Frequency of Peak Streamflows at Ungaged Sites In and Near the Oklahoma Panhandle

Scientific Investigations Report 2015–5134

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

Front cover, Windmill and livestock supply well in the High Plains aquifer area, south of Hooker, Oklahoma (photograph by S. Jerrod Smith, July 28, 2015).

Back cover, Windmill and livestock pen in the Oklahoma Panhandle near Boise City, Oklahoma (photograph by William J. Andrews, February 2004).

Methods for Estimating the Magnitude and Frequency of Peak Streamflows at Ungaged Sites In and Near the Oklahoma Panhandle

By S. Jerrod Smith, Jason M. Lewis, and Grant M. Graves

Prepared in cooperation with the Oklahoma Department of Transportation

Scientific Investigations Report 2015–5134

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

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2015

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit http://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod/.

Suggested citation:
Smith, S.J., Lewis, J.M., and Graves, G.M., 2015, Methods for estimating the magnitude and frequency of peak streamflows at ungaged sites in and near the Oklahoma Panhandle: U.S. Geological Survey Scientific Investigations Report 2015–5134, 35 p., http://dx.doi.org/10.3133/sir20155134.

ISSN 2328-0328 (online)

Contents

Figures

Tables

Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
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)
inch per hour (in/h)	0.0254	meter per hour (m/h)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Supplemental Information

A water year is a period of 12 consecutive months that includes January through September of the named calendar year and October through December of the previous calendar year. The 2015 water year, for example, begins on October 1, 2014, and ends on September 30, 2015.

Abbreviations

BSLDEM10M	Mean drainage-basin slope
CANOPY_PCT	Percentage of forest-canopy cover
CONTDA	Contributing drainage area
CSL10_85FM	10–85 stream channel slope
GIS	Geographic information system
GLS	Generalized least squares
IACWD	Interagency Advisory Committee on Water Data
IMPNLCD01	Percentage of impervious cover
LC01CROP	Percentage of drainage area with crop cover
LPIII	Log-Pearson Type III
LOWESS	Locally weighted scatterplot smoothing
NWISWeb	National Water Information System Website
ODOT	Oklahoma Department of Transportation
OK_HIPERMA	Percentage of drainage area on the High Plains aquifer
OLS	Ordinary least squares
OUTLETELEV	Outlet elevation
PRCOUT61	Outlet mean annual precipitation from 1961 to 1990
PRCOUT71	Outlet mean annual precipitation from 1971 to 2000
PRECIP	Mean annual precipitation
Pseudo-R^2	Pseudo coefficient of determination
$Q_{50\%}$	Annual peak streamflow with a 50-percent annual exceedance probability
$Q_{20\%}$	Annual peak streamflow with a 20-percent annual exceedance probability
$Q_{10\%}$	Annual peak streamflow with a 10-percent annual exceedance probability
$Q_{4\%}$	Annual peak streamflow with a 4-percent annual exceedance probability
$Q_{2\%}$	Annual peak streamflow with a 2-percent annual exceedance probability
$Q_{1\%}$	Annual peak streamflow with a 1-percent annual exceedance probability
$Q_{0.2\%}$	Annual peak streamflow with a 0.2-percent annual exceedance probability
R^2	Coefficient of determination
RMSE	Root mean square error
SOILPERM	Mean soil permeability
S_p	Standard error of prediction
USGS	U.S. Geological Survey
WLS	Weighted least squares
WREG	Weighted-Multiple-Linear Regression

Methods for Estimating the Magnitude and Frequency of Peak Streamflows at Ungaged Sites In and Near the Oklahoma Panhandle

By S. Jerrod Smith, Jason M. Lewis, and Grant M. Graves

Abstract

This report presents the results of a cooperative study by the U.S. Geological Survey and the Oklahoma Department of Transportation to estimate the magnitude and frequency of peak streamflows from regional regression equations for ungaged stream sites in and near the Oklahoma Panhandle. These methods relate basin characteristics (physiographic and climatic attributes) to selected peak streamflow frequency statistics with the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probabilities. These relations were developed based on data from 32 selected streamflow-gaging stations in the Oklahoma Panhandle and in neighboring parts of Colorado, Kansas, New Mexico, and Texas. The basin characteristics for the selected streamflow-gaging stations were determined by using a geographic information system and the Oklahoma StreamStats application. Peak-streamflow frequency statistics were computed from annual peak-streamflow records from the irrigated period of record from water year 1978 through water year 2014.

Generalized-least-squares multiple-linear regression analysis was used to formulate regression relations between peak-streamflow frequency statistics and basin characteristics. Contributing drainage area was the only basin characteristic determined to be statistically significant for all percentage of annual exceedance probabilities and was the only basin characteristic used in regional regression equations for estimating peak-streamflow frequency statistics on unregulated streams in and near the Oklahoma Panhandle. The regression model pseudo-coefficient of determination, converted to percent, for the Oklahoma Panhandle regional regression equations ranged from about 38 to 63 percent. The standard errors of prediction and the standard model errors for the Oklahoma Panhandle regional regression equations ranged from about 84 to 148 percent and from about 76 to 138 percent, respectively. These errors were comparable to those reported for regional peak-streamflow frequency regression equations for the High Plains areas of Texas and Colorado. The root mean square errors for the Oklahoma Panhandle regional regression equations (ranging from 3,170 to 92,000 cubic feet per second) were less than the root mean square errors for the Oklahoma statewide regression equations (ranging from 18,900 to 412,000 cubic feet per second); therefore, the Oklahoma Panhandle regional regression equations produce more accurate peak-streamflow statistic estimates for the irrigated period of record in the Oklahoma Panhandle than do the Oklahoma statewide regression equations. The regression equations developed in this report are applicable to streams that are not substantially affected by regulation, impoundment, or surface-water withdrawals. These regression equations are intended for use for stream sites with contributing drainage areas less than or equal to about 2,060 square miles, the maximum value for the independent variable used in the regression analysis.

Introduction

Knowledge of the magnitude and frequency of peak streamflows (floods) is required for the safe and economical design of roads, bridges, and culverts near streams (Jennings and others, 1994). The Bridge Division of the Oklahoma Department of Transportation is tasked with reviewing and approving the bridge and culvert design plans for all major highways in Oklahoma (Oklahoma Department of Transportation, 2009). To properly design these structures, estimates of peak-streamflow frequency statistics commonly are needed at ungaged stream sites where these statistics are unknown; therefore, relating peak-streamflow frequency statistics from gaged stream sites to ungaged stream sites is necessary. This relation usually is achieved by defining regression relations between selected peak-streamflow frequency statistics (dependent variables) and selected basin characteristics (independent variables) (Jennings and others, 1994). To address this need, the U.S. Geological Survey (USGS) in cooperation with the Oklahoma Department of Transportation (ODOT) prepared regression equations to estimate peak-streamflow statistics at ungaged sites in the Oklahoma Panhandle.

Previous Studies

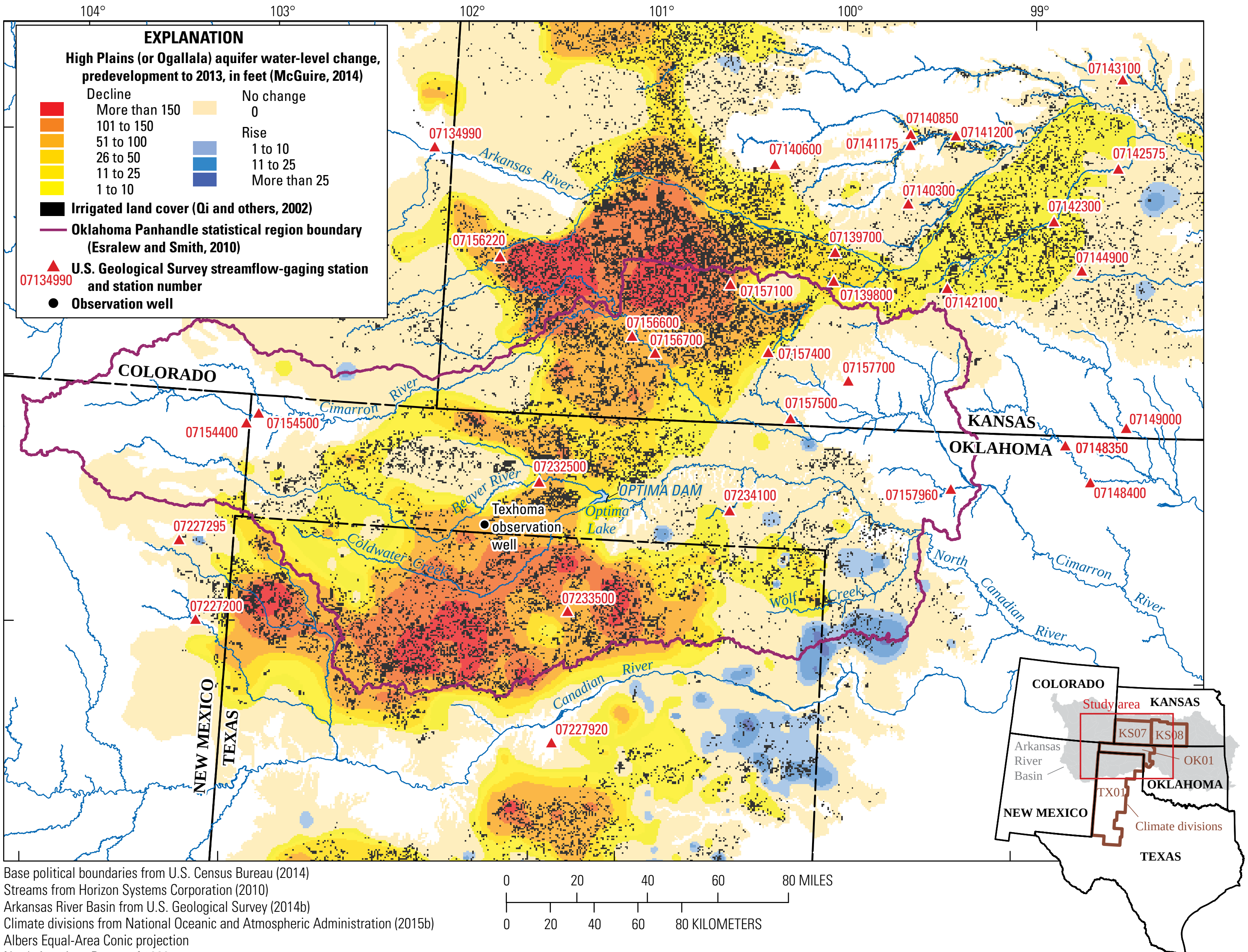
In 2010, updated statewide peak-streamflow frequency regression equations were published for Oklahoma (Lewis, 2010). These regression equations incorporated contributing drainage area, mean annual precipitation, and stream slope to compute estimates of peak-streamflow frequency statistics for ungaged streams. Those statewide regressions may have overestimated recent peak-streamflow frequency statistics in the Oklahoma Panhandle (fig. 1) because of changes to the hydrology of that area. If regression-computed peak-streamflow frequency statistics are overestimated in the Oklahoma Panhandle, engineers are designing structures to withstand greater peak streamflow than is necessary at a cost to the State that is greater than necessary.

In the late 20th century, the hydrology of the Oklahoma Panhandle changed as a result of development of the High Plains (or Ogallala) aquifer (fig. 1; Wahl and Wahl, 1988; Wahl and Tortorelli, 1997). Prior to the early 1960s (predevelopment), groundwater levels in the aquifer were relatively constant over time (Wahl and Wahl, 1988). For example, at the Texhoma observation well (fig. 1), completed at a depth of 386 feet (ft), the average annual depth to water was about 189 ft from 1956 to 1965 (fig. 2; U.S. Geological Survey, 2015b). The introduction of center-pivot irrigation in the 1960s prompted a rapid increase in high-capacity irrigation well construction and groundwater withdrawals in the 1960s and 1970s (Oklahoma Water Resources Board, 1984). Since that time, groundwater levels have steadily declined over much of the aquifer, and groundwater-level declines greater than 150 ft (as compared to predevelopment groundwater levels) have been measured recently in some areas of the Oklahoma Panhandle statistical region (fig. 1; McGuire, 2014). As early as the 1970s, area residents began to perceive a change in the streamflow characteristics of the Beaver River, the principal stream draining the Oklahoma Panhandle (fig. 1; Wahl and Wahl, 1988). During the 1970s, the Beaver River near Guymon, Okla. (U.S. Geological Survey streamflow-gaging station 07232500, fig. 1), transitioned from a stream that ceased flowing occasionally in summer to a stream that ceased flowing for about half of the year (fig. 2). The decreasing trend in streamflow continued into the 1990s, when the Beaver River near Guymon, Okla., ceased flowing for more than 90 percent of the year (fig. 2). The changes in streamflow, especially base flow and peak streamflow, observed at this and other stations prompted Lewis and Esralew (2009) and Esralew and Lewis (2010) to break the streamflow record into an irrigation-affected period of record beginning around 1978 for streamflow-gaging stations in and near the Oklahoma Panhandle.

Annual peak streamflows have decreased significantly at selected long-term streamflow-gaging stations on several large streams (including the Beaver River, North Canadian River, Cimarron River, Coldwater Creek, and Wolf Creek) that drain the High Plains aquifer (Wahl and Tortorelli, 1997; Esralew and Lewis, 2010) (fig. 1). Optima Lake on the Beaver River (fig. 1) is a good illustration of the degree to which the surface-water hydrology has changed in the Oklahoma Panhandle. Optima Dam is about 30 miles downstream from the Beaver River near Guymon, Okla. (U.S. Geological Survey streamflow-gaging station 07232500, fig. 1). Optima Dam was designed and authorized using streamflow data from the predevelopment period and was constructed from 1966 to 1978. Because of decreased streamflows in the irrigated period from 1978 to present (2015), Optima Lake never filled to more than 6 percent of the conservation pool storage and never met expectations for municipal water supply and recreation in the Oklahoma Panhandle (U.S. Army Corps of Engineers, 1966; Wahl and Wahl, 1988; fig. 3).

Purpose and Scope

This report presents the results of a cooperative study by the USGS and the ODOT to estimate the magnitude and frequency of peak streamflows from regional regression equations for ungaged stream sites in and near the Oklahoma Panhandle. This report describes revised methods for estimating peak-streamflow frequency statistics with the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probabilities. These methods apply to sites on unregulated streams with contributing drainage areas of less than or equal to about 2,060 square miles (mi^2). This report also provides computed basin characteristics (physiographic and climatic attributes) and peak-streamflow frequency statistics for 32 selected streamflow-gaging stations in the Oklahoma Panhandle and in neighboring parts of Colorado, Kansas, New Mexico, and Texas (table 1). Peak-streamflow frequency statistics were computed from annual peak-streamflow records from water year 1978 through water year 2014 (U.S. Geological Survey, 2015b). A water year is a period of 12 consecutive months that includes January through September of the named calendar year and October through December of the previous calendar year. Peak-streamflow frequency statistics from the 32 streamflow-gaging stations were related to basin characteristics by using generalized-least-squares multiple-linear-regression analysis. The regression equations derived from this analysis can be used to estimate peak-streamflow frequency statistics (flood magnitudes) over the irrigated period of record (1978 to present) for unregulated streams in the Oklahoma Panhandle. This report supersedes the report by Lewis (2010) for unregulated streams in the Oklahoma Panhandle. The revised regional regression equations in this report can be incorporated into the Oklahoma StreamStats application, a Web-based map tool that allows rapid delineation of drainage basins, computation of basin characteristics, and estimation of streamflow statistics at user-defined ungaged sites (Ries and others, 2004, 2008; Smith and Esralew, 2010).



Base political boundaries from U.S. Census Bureau (2014)
Streams from Horizon Systems Corporation (2010)
Arkansas River Basin from U.S. Geological Survey (2014b)
Climate divisions from National Oceanic and Atmospheric Administration (2015b)
Albers Equal-Area Conic projection
North American Datum of 1983

Figure 1. Selected U.S. Geological Survey streamflow-gaging stations and changes in water level of the High Plains (or Ogallala) aquifer in and near the Oklahoma Panhandle.

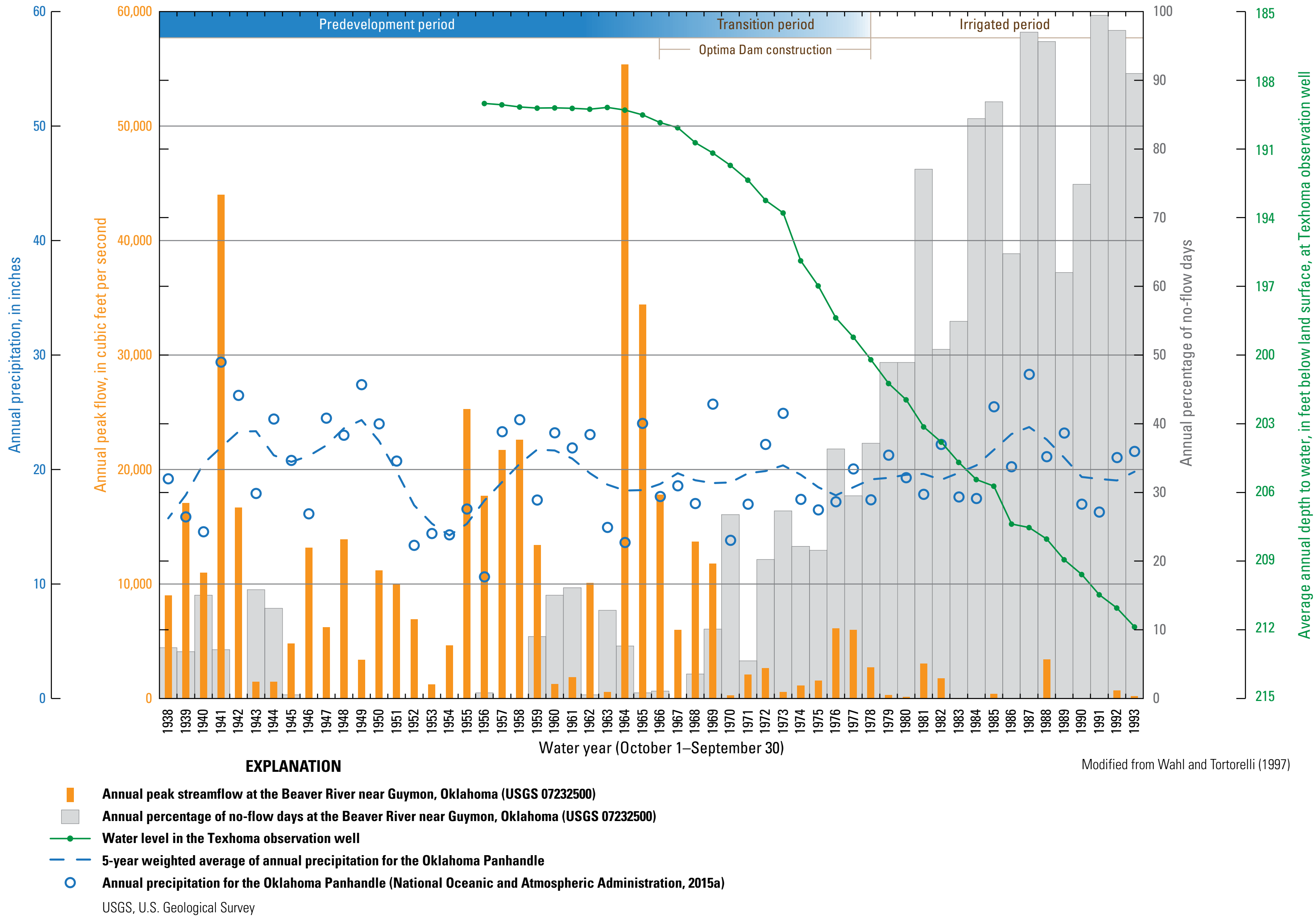


Figure 2. Changes in annual peak streamflow and annual percentage of no-flow days at the Beaver River near Guymon, Oklahoma (U.S. Geological Survey streamflow-gaging station 07232500), 1938–93.

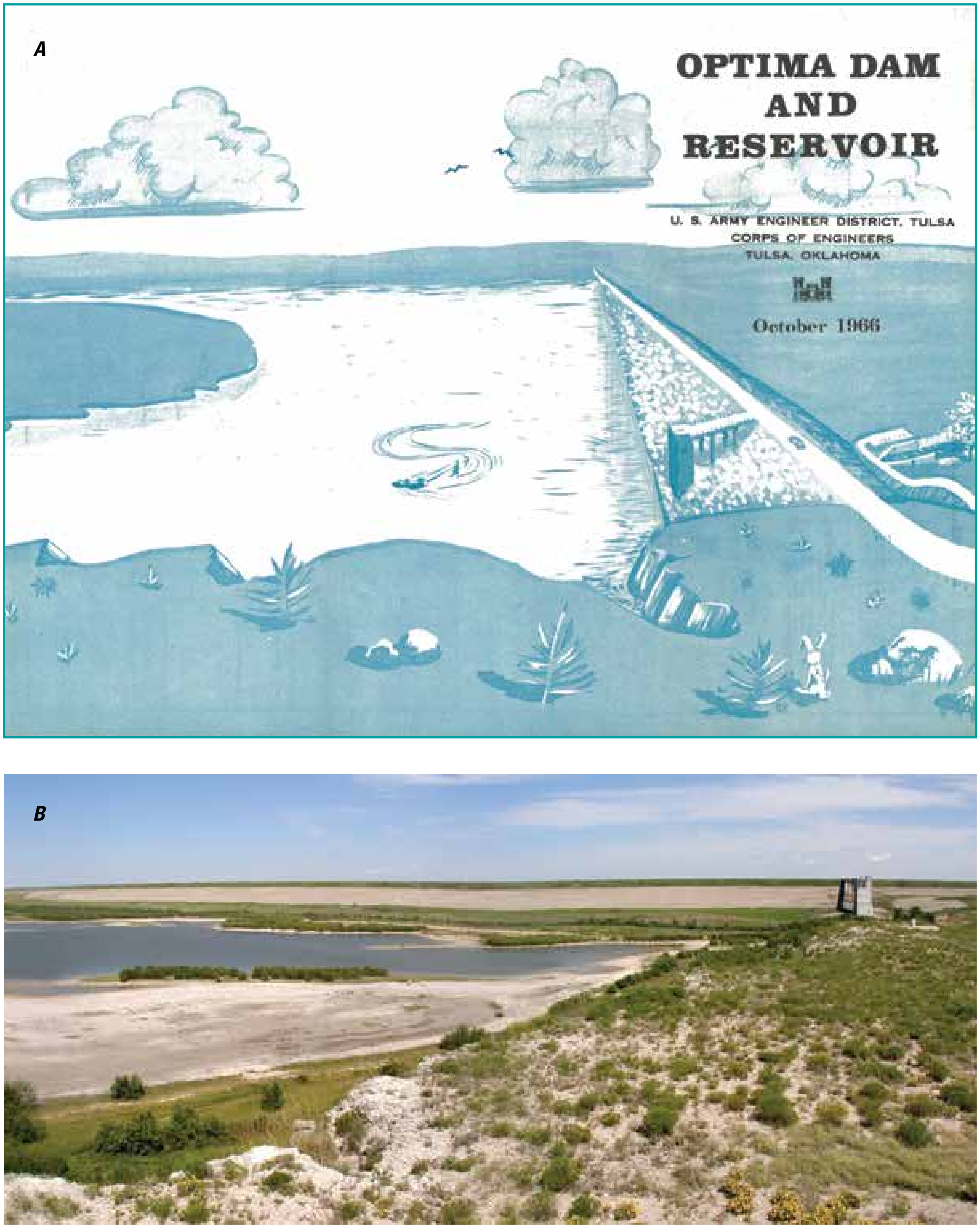


Figure 3. Images showing *A*, an artistic rendering of Optima Lake as it was expected to appear after construction (U.S. Army Corps of Engineers, 1966); and *B*, a panoramic photograph of Optima Lake in September 2004.

Table 1. Streamflow-gaging station information, basin characteristics, and peak-streamflow frequency statistics for unregulated drainage basins in and near the Oklahoma Panhandle.

[WBD, Watershed Boundary Dataset; NAVD 88, North American Vertical Datum of 1988; ft^3/s, cubic feet per second; --, not applicable; LP III, Log-Pearson Type III; RMSE, root mean square error]

Streamflow-gaging station information					
Site number	Station number (fig. 1)	Station name	Latitude (degrees)	Longitude (degrees)	WBD subbasin number
1	07134990	Wild Horse Creek above Holly, Colorado	38.057062	-102.138434	11020009
2	07139700	Arkansas River tributary near Dodge City, Kansas	37.714447	-100.015082	11030004
3	07139800	Mulberry Creek near Dodge City, Kansas	37.598078	-100.015187	11030004
4	07140300	Whitewoman Creek near Bellefont, Kansas	37.921854	-99.642931	11030004
5	07140600	Pawnee River tributary near Kalvesta, Kansas	38.059058	-100.3499	11030005
6	07140850	Pawnee River near Burdett, Kansas	38.207104	-99.643454	11030005
7	07141175	Buckner Creek near Burdett, Kansas	38.163015	-99.642884	11030006
8	07141200	Pawnee River at Rozel, Kansas	38.207397	-99.406266	11030005
9	07142100	Rattlesnake Creek tributary near Mullinville, Kansas	37.586383	-99.421775	11030009
10	07142300	Rattlesnake Creek near Macksville, Kansas	37.871248	-98.875751	11030009
11	07142575	Rattlesnake Creek near Zenith, Kansas	38.093477	-98.546204	11030009
12	07143100	Little Cheyenne Creek tributary near Claflin, Kansas	38.456756	-98.535914	11030011
13	07144900	South Fork Ninnescah River tributary near Pratt, Kansas	37.675063	-98.723389	11030015
14	07148350	Salt Fork Arkansas River near Winchester, Oklahoma	36.961691	-98.781906	11060002
15	07148400	Salt Fork Arkansas River near Alva, Oklahoma	36.814972	-98.647982	11060002
16	07149000	Medicine Lodge River near Kiowa, Kansas	37.039373	-98.469518	11060003
17	07154400	Carrizozo Creek near Kenton, Oklahoma	36.883418	-103.018143	11040001
18	07154500	Cimarron River near Kenton, Oklahoma	36.926584	-102.959022	11040001
19	07156220	Bear Creek near Johnson, Kansas	37.628442	-101.761683	11040005
20	07156600	Cimarron River tributary near Moscow, Kansas	37.336123	-101.050162	11040006
21	07156700	Cimarron River tributary near Satanta, Kansas	37.271424	-100.926528	11040006
22	07157100	Crooked Creek near Copeland, Kansas	37.565336	-100.554344	11040007
23	07157400	Crooked Creek tributary at Meade, Kansas	37.296355	-100.339968	11040007
24	07157500	Crooked Creek near Englewood, Kansas	37.031644	-100.209176	11040007
25	07157700	Keiger Creek near Ashland, Kansas	37.193987	-99.918292	11040008
26	07157960	Buffalo Creek near Lovedale, Oklahoma	36.77067	-99.36689	11050001
27	07227200	Tramperos Creek near Stead, New Mexico	36.070833	-103.203344	11090102
28	07227295	Sandy Arroyo tributary near Clayton, New Mexico	36.387354	-103.319956	11090103
29	07227920	Dixon Creek near Borger, Texas	35.664756	-101.350894	11090106
30	07232500	Beaver River near Guymon, Oklahoma	36.721457	-101.489782	11100101
31	07233500	Palo Duro Creek near Spearman, Texas	36.202169	-101.306342	11100104
32	07234100	Clear Creek near Elmwood, Oklahoma	36.645486	-100.503058	11100201

Table 1. Streamflow-gaging station information, basin characteristics, and peak-streamflow frequency statistics for unregulated drainage basins in and near the Oklahoma Panhandle.—Continued

[WBD, Watershed Boundary Dataset; NAVD 88, North American Vertical Datum of 1988; ft^3/s, cubic feet per second; --, not applicable; LP III, Log-Pearson Type III; RMSE, root mean square error]

	Basin characteristics[1]						
Site number	**Contributing drainage area (square miles) (CONTDA)**	**Mean annual precipitation (inches) (PRECIP)**	**10–85 stream channel slope (feet per mile) (CSL10_85FM)**	**Mean soil permeability (inches per hour) (SOILPERM)**	**Outlet elevation (feet above NAVD 88) (OUTLETELEV)**	**Outlet mean annual precipitation (1961–90) (inches) (PRCOUT61)**	**Outlet mean annual precipitation (1971–2000) (inches) (PRCOUT71)**
1	126.53	16.57	17.68	1.43	3,402.84	15.53	16.88
2	9.40	22.50	14.16	1.49	2,502.74	21.72	22.45
3	68.50	22.37	7.93	1.38	2,519.59	22.05	22.62
4	17.39	23.32	11.29	1.06	2,300.07	23.17	23.49
5	8.30	20.92	13.03	0.79	2,647.83	19.94	20.98
6	1,038.62	21.15	4.32	1.12	2,109.42	21.78	22.64
7	717.27	22.49	6.35	1.03	2,115.69	21.84	22.81
8	2,057.39	21.87	4.06	1.09	2,052.80	22.15	23.71
9	10.19	25.05	8.88	1.06	2,289.48	23.97	25.00
10	474.66	25.38	3.99	4.18	1,970.00	24.55	26.38
11	729.11	25.67	3.82	4.40	1,797.51	25.12	26.84
12	1.45	26.91	18.99	1.03	1,785.86	25.82	26.94
13	1.58	27.32	24.40	2.09	1,892.40	25.75	27.36
14	827.23	26.46	9.30	2.63	1,413.85	25.13	27.59
15	982.10	26.67	8.45	2.71	1,297.93	26.45	28.94
16	885.08	27.35	7.97	2.42	1,289.63	27.50	29.52
17	112.28	16.60	26.95	1.70	4,361.96	16.95	17.21
18	1,111.61	16.84	23.55	1.73	4,281.76	16.90	17.21
19	826.15	17.05	13.44	1.20	3,302.24	15.75	16.87
20	21.42	18.62	23.02	1.96	2,811.00	18.25	18.84
21	4.23	19.30	25.88	2.44	2,740.96	18.97	19.25
22	47.74	20.26	13.06	0.94	2,695.94	20.31	20.65
23	6.89	21.63	38.24	1.04	2,458.39	21.64	21.66
24	821.97	21.35	3.99	1.84	2,168.28	21.71	22.37
25	34.57	23.15	26.95	1.55	2,066.97	22.28	23.31
26	401.31	25.21	11.68	2.49	1,618.27	24.40	25.66
27	461.88	16.28	14.33	1.17	4,485.35	15.23	15.96
28	1.21	16.24	53.32	1.84	5,108.80	15.47	16.23
29	133.02	22.00	19.94	2.33	2,838.22	19.99	21.83
30	1,611.86	17.28	14.02	1.57	2,980.01	17.39	18.11
31	624.68	18.25	8.00	0.79	2,973.65	18.66	19.96
32	161.87	21.25	11.36	0.96	2,545.42	21.08	21.72
Average for all stations:	**448.05**	**21.67**	**15.38**	**1.73**	**2,588.28**	**21.17**	**22.22**

Table 1. Streamflow-gaging station information, basin characteristics, and peak-streamflow frequency statistics for unregulated drainage basins in and near the Oklahoma Panhandle.—Continued

[WBD, Watershed Boundary Dataset; NAVD 88, North American Vertical Datum of 1988; ft^3/s, cubic feet per second; --, not applicable; LP III, Log-Pearson Type III; RMSE, root mean square error]

Site number	Basin characteristics[1]				
	Percentage of forest-canopy cover (CANOPY_PCT)	Percentage of impervious cover (IMPNLCD01)	Percentage of drainage area on the High Plains aquifer (OK_HIPERMA)	Percentage of drainage area with crop cover (LC01CROP)	Mean drainage-basin slope (percent) (BSLDEM10M)
1	0.10	0.28	69.89	42.73	1.79
2	0.04	0.09	100.00	81.32	1.77
3	0.04	0.13	100.00	77.44	2.14
4	0.16	0.34	100.00	79.57	1.15
5	0.00	0.07	84.32	67.00	1.20
6	0.19	0.10	27.93	56.29	2.61
7	0.18	0.29	71.07	55.74	2.85
8	0.19	0.18	43.42	56.17	2.42
9	0.05	0.22	100.00	75.61	2.15
10	0.40	0.37	100.00	63.35	1.81
11	0.77	0.40	100.00	63.48	1.07
12	1.32	0.28	100.00	82.21	1.27
13	0.00	0.79	100.00	88.56	2.01
14	0.64	0.10	19.03	13.10	5.97
15	0.71	0.21	16.03	14.26	6.07
16	1.68	0.25	41.67	22.64	5.95
17	6.43	0.06	0.00	0.00	11.77
18	11.22	0.09	0.24	0.32	13.25
19	0.04	0.24	91.90	42.98	1.53
20	0.00	0.37	100.00	67.63	1.71
21	0.01	0.14	100.00	79.08	1.90
22	0.06	0.33	100.00	88.63	1.22
23	0.24	0.22	100.00	40.61	4.68
24	0.23	0.18	99.50	60.94	2.54
25	0.06	0.05	67.73	11.48	6.69
26	0.38	0.22	10.93	20.52	5.94
27	1.57	0.06	8.09	0.27	6.26
28	0.00	0.11	100.00	0.00	2.01
29	0.12	0.73	87.94	3.75	5.86
30	0.47	0.24	78.12	10.83	3.53
31	0.01	0.47	100.00	49.90	1.61
32	0.07	0.23	100.00	38.14	2.67
Average for all stations:	**0.86**	**0.24**	**72.43**	**45.45**	**3.61**

Table 1. Streamflow-gaging station information, basin characteristics, and peak-streamflow frequency statistics for unregulated drainage basins in and near the Oklahoma Panhandle.—Continued

[WBD, Watershed Boundary Dataset; NAVD 88, North American Vertical Datum of 1988; ft³/s, cubic feet per second; --, not applicable; LP III, Log-Pearson Type III; RMSE, root mean square error]

	Streamflow-gaging station information			Peak-streamflow frequency analysis information					
Site number	Station number (fig. 1)	Station name	Entire period of record (water years)[2]	Irrigated period of record length (1978–2014; years)	Number of no-flow years (1978–2014)	Historical record length (years)	Number of high outliers	High-outlier threshold (ft^3/s)	Low-outlier threshold (ft^3/s)
1	07134990	Wild Horse Creek above Holly, Colorado	1996–2014	19	0	--	--	--	--
2	07139700	Arkansas River tributary near Dodge City, Kansas	1957–2012	33	0	--	--	--	--
3	07139800	Mulberry Creek near Dodge City, Kansas	1969–90	13	1	--	--	--	--
4	07140300	Whitewoman Creek near Bellefont, Kansas	1957–89	12	1	--	--	--	--
5	07140600	Pawnee River tributary near Kalvesta, Kansas	1957–89	12	0	--	--	--	--
6	07140850	Pawnee River near Burdett, Kansas	1982–2014	33	2	--	--	--	--
7	07141175	Buckner Creek near Burdett, Kansas	1996–2012	17	0	--	--	--	--
8	07141200	Pawnee River at Rozel, Kansas	1925–2014	37	1	--	--	--	--
9	07142100	Rattlesnake Creek tributary near Mullinville, Kansas	1957–89	12	2	--	--	--	--
10	07142300	Rattlesnake Creek near Macksville, Kansas	1960–2014	37	0	--	--	--	--
11	07142575	Rattlesnake Creek near Zenith, Kansas	1973–2014	37	0	--	--	--	--
12	07143100	Little Cheyenne Creek tributary near Claflin, Kansas	1957–2012	35	3	--	--	--	--
13	07144900	South Fork Ninnescah River tributary near Pratt, Kansas	1957–89	12	0	--	--	--	--
14	07148350	Salt Fork Arkansas River near Winchester, Oklahoma	1957–93	16	0	--	--	--	--
15	07148400	Salt Fork Arkansas River near Alva, Oklahoma	1938–2014	35	0	--	--	--	--
16	07149000	Medicine Lodge River near Kiowa, Kansas	1938–2014	37	0	--	--	--	--
17	07154400	Carrizozo Creek near Kenton, Oklahoma	1953–2014	37	2	--	--	--	--
18	07154500	Cimarron River near Kenton, Oklahoma	1951–2014	37	0	--	--	--	--
19	07156220	Bear Creek near Johnson, Kansas	1967–98	21	3	--	--	--	--
20	07156600	Cimarron River tributary near Moscow, Kansas	1957–89	12	3	--	--	--	--
21	07156700	Cimarron River tributary near Satanta, Kansas	1957–2010	28	4	--	--	--	--
22	07157100	Crooked Creek near Copeland, Kansas	1957–89	12	0	--	--	--	--
23	07157400	Crooked Creek tributary at Meade, Kansas	1957–89	12	2	--	--	--	--
24	07157500	Crooked Creek near Englewood, Kansas	1943–2014	37	0	--	--	--	--
25	07157700	Keiger Creek near Ashland, Kansas	1957–1989	12	1	--	--	--	--
26	07157960	Buffalo Creek near Lovedale, Oklahoma	1966–93	16	0	--	--	--	--
27	07227200	Tramperos Creek near Stead, New Mexico	1965–2014	35	4	--	--	--	--
28	07227295	Sandy Arroyo tributary near Clayton, New Mexico	1952–1996	17	3	--	--	--	--
29	07227920	Dixon Creek near Borger, Texas	1975–1989	12	0	--	--	--	--
30	07232500	Beaver River near Guymon, Oklahoma	1937–1993	16	0	--	--	--	--
31	07233500	Palo Duro Creek near Spearman, Texas	1936–2014	16	0	36	--	--	--
32	07234100	Clear Creek near Elmwood, Oklahoma	1966–1993	16	0	--	--	--	--

Table 1. Streamflow-gaging station information, basin characteristics, and peak-streamflow frequency statistics for unregulated drainage basins in and near the Oklahoma Panhandle.—Continued

[WBD, Watershed Boundary Dataset; NAVD 88, North American Vertical Datum of 1988; ft³/s, cubic feet per second; --, not applicable; LP III, Log-Pearson Type III; RMSE, root mean square error]

Site number	Skew coefficient for LP III distribution			Gener-alized skew source[3]	Computed peak-streamflow frequency statistics, in cubic feet per second, for indicated annual exceedance probability (percent), irrigated period of record (1978–2014)						
	Station	Gener-alized	Weighted		50	20	10	4	2	1	0.2
1	0.268	-0.408	-0.331	a	208	447	647	941	1,180	1,450	2,120
2	-1.221	-0.413	-0.420	a	103	315	543	940	1,320	1,770	3,090
3	-1.173	-0.365	-0.408	a	36.8	272	704	1,820	3,230	5,290	13,400
4	0.648	-0.361	-0.287	a	103	409	803	1,590	2,440	3,530	7,230
5	-0.878	-0.405	-0.406	a	300	1,110	2,070	3,860	5,630	7,780	14,300
6	-1.351	-0.213	-0.280	a	429	1,310	2,270	3,970	5,610	7,590	13,600
7	-1.145	-0.229	-0.198	a	489	1,380	2,320	3,960	5,540	7,450	13,400
8	-0.666	-0.182	-0.149	a	1,040	2,300	3,440	5,230	6,810	8,620	13,700
9	-0.126	-0.390	-0.368	a	410	772	1,050	1,420	1,710	2,010	2,730
10	-0.030	-0.236	-0.193	a	159	583	1,120	2,200	3,360	4,880	10,200
11	1.305	-0.188	-0.044	a	340	918	1,540	2,650	3,760	5,140	9,650
12	-0.229	-0.316	-0.157	a	78.4	159	227	328	415	510	769
13	-1.337	-0.399	-0.317	a	515	917	1,220	1,620	1,920	2,240	3,000
14	-1.144	-0.142	-0.271	b	5,630	10,400	14,100	19,300	23,400	27,600	38,300
15	-0.663	-0.128	-0.281	b	3,790	7,100	9,660	13,200	16,100	19,000	26,500
16	-0.765	-0.408	-0.303	a	2,910	4,810	6,150	7,890	9,200	10,500	13,600
17	0.383	0.320	0.340	b	1,470	2,750	3,920	5,820	7,600	9,740	16,400
18	-0.039	0.284	0.168	b	2,330	6,390	11,000	19,900	29,400	42,000	87,500
19	-0.987	-0.385	-0.407	a	708	2,880	5,610	10,900	16,300	23,100	44,400
20	-0.545	-0.505	-0.508	a	167	645	1,210	2,230	3,210	4,360	7,710
21	-0.054	-0.538	-0.440	a	50.7	266	582	1,260	2,020	3,010	6,350
22	-1.221	-0.410	-0.428	a	89.1	532	1,230	2,830	4,660	7,130	15,800
23	-0.052	-0.477	-0.442	a	255	1,130	2,280	4,550	6,920	9,890	19,300
24	0.139	-0.361	-0.264	a	139	499	938	1,790	2,680	3,810	7,550
25	-0.421	-0.419	-0.419	a	339	542	677	845	966	1,080	1,340
26	-0.672	-0.329	-0.390	b	915	3,830	7,600	15,100	22,800	32,700	64,300
27	-0.391	0.455	0.261	b	769	1,860	3,040	5,210	7,470	10,400	20,800
28	0.456	0.471	0.468	b	32.3	63	92.5	143	193	254	459
29	-0.491	0.000	-0.131	c	746	1,980	3,240	5,440	7,560	10,100	18,000
30	-1.119	-0.290	-0.227	b	167	993	2,410	6,000	10,600	17,500	46,600
31	-1.189	0.000	0.231	c	716	2,400	4,660	9,670	15,700	24,500	61,900
32	-0.998	-0.271	-0.339	b	950	3,950	7,880	15,800	24,200	35,100	71,300
Average for all stations:					**824**	**2,000**	**3,260**	**5,580**	**7,940**	**10,900**	**21,100**

Table 1. Streamflow-gaging station information, basin characteristics, and peak-streamflow frequency statistics for unregulated drainage basins in and near the Oklahoma Panhandle.—Continued

[WBD, Watershed Boundary Dataset; NAVD 88, North American Vertical Datum of 1988; ft³/s, cubic feet per second; --, not applicable; LP III, Log-Pearson Type III; RMSE, root mean square error]

Site number	Streamflow-gaging station information: Station number (fig. 1)	Streamflow-gaging station information: Station name	Estimated peak-streamflow frequency statistics, in cubic feet per second, for indicated annual exceedance probability (percent) — Oklahoma statewide regression estimates (Lewis, 2010): 50	20	10	4	2	1	0.2
1	07134990	Wild Horse Creek above Holly, Colorado	804	2,350	4,180	7,530	11,200	15,100	29,100
2	07139700	Arkansas River tributary near Dodge City, Kansas	262	667	1,110	1,880	2,650	3,530	6,420
3	07139800	Mulberry Creek near Dodge City, Kansas	875	2,190	3,610	6,060	8,660	11,300	20,400
4	07140300	Whitewoman Creek near Bellefont, Kansas	408	1,020	1,670	2,800	3,940	5,190	9,320
5	07140600	Pawnee River tributary near Kalvesta, Kansas	205	537	905	1,550	2,230	3,000	5,570
6	07140850	Pawnee River near Burdett, Kansas	4,260	10,700	17,700	29,600	43,200	55,400	100,000
7	07141175	Buckner Creek near Burdett, Kansas	4,020	10,000	16,400	27,300	39,200	49,900	88,300
8	07141200	Pawnee River at Rozel, Kansas	7,080	17,600	28,700	47,700	69,400	87,900	156,000
9	07142100	Rattlesnake Creek tributary near Mullinville, Kansas	320	767	1,230	2,030	2,840	3,730	6,620
10	07142300	Rattlesnake Creek near Macksville, Kansas	3,650	8,490	13,400	21,700	30,700	38,700	67,000
11	07142575	Rattlesnake Creek near Zenith, Kansas	4,920	11,400	17,900	28,900	40,900	51,200	88,100
12	07143100	Little Cheyenne Creek tributary near Claflin, Kansas	116	275	443	731	991	1,310	2,300
13	07144900	South Fork Ninnescah River tributary near Pratt, Kansas	131	313	505	835	1,120	1,490	2,580
14	07148350	Salt Fork Arkansas River near Winchester, Oklahoma	6,560	15,400	24,500	40,000	55,300	68,900	115,000
15	07148400	Salt Fork Arkansas River near Alva, Oklahoma	7,360	17,200	27,200	44,300	61,200	76,100	127,000
16	07149000	Medicine Lodge River near Kiowa, Kansas	7,170	16,500	26,000	42,100	57,900	71,900	119,000
17	07154400	Carrizozo Creek near Kenton, Oklahoma	797	2,360	4,230	7,680	11,300	15,300	29,200
18	07154500	Cimarron River near Kenton, Oklahoma	3,650	10,700	19,100	34,400	50,800	67,000	125,000
19	07156220	Bear Creek near Johnson, Kansas	2,810	8,060	14,200	25,300	37,600	49,700	93,300
20	07156600	Cimarron River tributary near Moscow, Kansas	330	925	1,620	2,860	4,150	5,610	10,600
21	07156700	Cimarron River tributary near Satanta, Kansas	124	344	597	1,050	1,510	2,070	3,910
22	07157100	Crooked Creek near Copeland, Kansas	609	1,620	2,740	4,730	6,830	9,070	16,700
23	07157400	Crooked Creek tributary at Meade, Kansas	231	615	1,050	1,830	2,550	3,430	6,190
24	07157500	Crooked Creek near Englewood, Kansas	3,670	9,200	15,100	25,200	36,800	47,200	85,300
25	07157700	Keiger Creek near Ashland, Kansas	727	1,860	3,120	5,330	7,390	9,680	17,000
26	07157960	Buffalo Creek near Lovedale, Oklahoma	3,820	9,220	14,900	24,700	34,200	43,200	73,500
27	07227200	Tramperos Creek near Stead, New Mexico	1,760	5,150	9,170	16,500	24,700	33,000	63,200
28	07227295	Sandy Arroyo tributary near Clayton, New Mexico	42.8	130	238	440	644	913	1,810
29	07227920	Dixon Creek near Borger, Texas	1,520	3,940	6,630	11,400	16,000	20,800	36,800
30	07232500	Beaver River near Guymon, Oklahoma	4,530	12,900	22,700	40,300	59,800	78,300	146,000
31	07233500	Palo Duro Creek near Spearman, Texas	2,480	6,790	11,700	20,300	30,100	39,500	73,900
32	07234100	Clear Creek near Elmwood, Oklahoma	1,470	3,810	6,380	10,900	15,600	20,300	36,700
Average for all stations:			**2,400**	**6,030**	**9,970**	**16,800**	**24,100**	**30,900**	**55,100**
RMSE, in ft³/s			**18,900**	**46,500**	**76,100**	**128,000**	**183,000**	**233,000**	**412,000**

Table 1. Streamflow-gaging station information, basin characteristics, and peak-streamflow frequency statistics for unregulated drainage basins in and near the Oklahoma Panhandle.—Continued

[WBD, Watershed Boundary Dataset; NAVD 88, North American Vertical Datum of 1988; ft³/s, cubic feet per second; --, not applicable; LP III, Log-Pearson Type III; RMSE, root mean square error]

Site number	Estimated peak-streamflow frequency statistics, in cubic feet per second, for indicated annual exceedance probability (percent)						
	Oklahoma Panhandle regional regression estimates (Smith and others, 2015; this report)						
	50	20	10	4	2	1	0.2
1	402	1,140	1,940	3,210	4,550	6,290	10,700
2	166	458	760	1,260	1,740	2,340	3,880
3	327	918	1,550	2,570	3,630	4,980	8,420
4	205	568	948	1,570	2,180	2,960	4,930
5	159	438	726	1,200	1,660	2,240	3,700
6	823	2,380	4,130	6,850	9,920	14,000	24,300
7	726	2,090	3,620	6,000	8,650	12,200	21,000
8	1,040	3,020	5,280	8,760	12,800	18,200	31,700
9	171	471	782	1,300	1,790	2,420	4,010
10	631	1,810	3,120	5,170	7,420	10,400	17,900
11	730	2,100	3,640	6,030	8,700	12,200	21,200
12	88.0	238	387	642	871	1,150	1,870
13	90.7	245	400	663	899	1,190	1,940
14	762	2,190	3,810	6,310	9,120	12,800	22,300
15	808	2,330	4,050	6,710	9,710	13,700	23,800
16	780	2,250	3,900	6,470	9,350	13,200	22,800
17	386	1,090	1,860	3,080	4,350	6,010	10,200
18	842	2,430	4,230	7,020	10,200	14,400	25,000
19	761	2,190	3,810	6,310	9,110	12,800	22,200
20	220	611	1,020	1,690	2,360	3,200	5,350
21	127	346	570	944	1,290	1,730	2,840
22	289	809	1,360	2,260	3,170	4,350	7,320
23	150	411	679	1,130	1,550	2,080	3,440
24	760	2,190	3,800	6,300	9,090	12,800	22,200
25	259	722	1,210	2,010	2,820	3,840	6,450
26	596	1,700	2,930	4,860	6,980	9,760	16,800
27	625	1,790	3,090	5,120	7,350	10,300	17,700
28	82.8	224	363	602	815	1,080	1,750
29	409	1,160	1,970	3,270	4,640	6,410	10,900
30	956	2,770	4,840	8,020	11,700	16,500	28,900
31	692	1,990	3,440	5,700	8,220	11,500	19,900
32	437	1,240	2,120	3,510	4,990	6,910	11,800
Average for all stations:	**484**	**1,390**	**2,390**	**3,950**	**5,680**	**7,940**	**13,700**
RMSE, in ft³/s	**3,170**	**9,110**	**15,800**	**26,200**	**37,800**	**53,100**	**92,000**

Table 1. Streamflow-gaging station information, basin characteristics, and peak-streamflow frequency statistics for unregulated drainage basins in and near the Oklahoma Panhandle.—Continued

[WBD, Watershed Boundary Dataset; NAVD 88, North American Vertical Datum of 1988; ft^3/s, cubic feet per second; --, not applicable; LP III, Log-Pearson Type III; RMSE, root mean square error]

Site number	Oklahoma statewide regression estimates (Lewis, 2010) percent error from computed peak-streamflow frequency statistics for the irrigated period of record (1978–2014)						
	50	20	10	4	2	1	0.2
1	287	426	546	700	849	941	1,270
2	154	112	104	100	101	99	108
3	2,280	705	413	233	168	114	52
4	296	149	108	76	61	47	29
5	-32	-52	-56	-60	-60	-61	-61
6	893	717	680	646	670	630	635
7	722	625	607	589	608	570	559
8	581	665	734	812	919	920	1,040
9	-22	-1	17	43	66	86	142
10	2,200	1,360	1,100	886	814	693	557
11	1,350	1,140	1,060	991	988	896	813
12	48	73	95	123	139	157	199
13	-75	-66	-59	-48	-42	-33	-14
14	17	48	74	107	136	150	200
15	94	142	182	236	280	301	379
16	146	243	323	434	529	585	775
17	-46	-14	8	32	49	57	78
18	57	67	74	73	73	60	43
19	297	180	153	132	131	115	110
20	98	43	34	28	29	29	37
21	145	29	3	-17	-25	-31	-38
22	584	205	123	67	47	27	6
23	-9	-46	-54	-60	-63	-65	-68
24	2,540	1,740	1,510	1,310	1,270	1,140	1,030
25	114	243	361	531	665	796	1,170
26	317	141	96	64	50	32	14
27	129	177	202	217	231	217	204
28	32	106	157	208	234	259	294
29	104	99	105	110	112	106	104
30	2,610	1,200	842	572	464	347	213
31	246	183	151	110	92	61	19
32	55	-4	-19	-31	-36	-42	-49
Average for all stations:	**507**	**332**	**302**	**288**	**298**	**288**	**308**

[1]Basin characteristic names used in the StreamStats Web application are in uppercase and parentheses. Values for basin characteristics may vary slightly from the StreamStats Web application because of differences in rounding and the exact locations clicked.

[2]A water year is a period of 12 consecutive months that includes January through September of the named calendar year and October through December of the previous calendar year.

[3]Generalized skew obtained from (a) Rasmussen and Perry (2000), (b) Lewis (2010), or (c) Judd and others (1996).

In this report, the Oklahoma Panhandle refers to the portion of Oklahoma that extends west of the 100th meridian (100 degrees west longitude; fig. 1). The larger Oklahoma Panhandle statistical region includes the Oklahoma Panhandle, a part of Oklahoma east of the 100th meridian, and parts of several neighboring States. The Oklahoma Panhandle statistical region was delineated by Esralew and Smith (2010) for use in the Oklahoma StreamStats application (Smith and Esralew, 2010) to group streamflow-gaging stations with similar relations (regional regressions) between basin characteristics and streamflow statistics. The eastern boundary of the Oklahoma Panhandle statistical region approximately follows the boundary for flood-region 12 delineated by Crippen and Bue (1977). Though regional regressions described in this report apply to the Oklahoma Panhandle statistical region, only locations in Oklahoma are accessible in the Oklahoma StreamStats application (Smith and Esralew, 2010).

Streamflow-Gaging Station Selection and Data Analysis

Few streamflow-gaging stations currently (2015) are in operation in the Oklahoma Panhandle or the larger Oklahoma Panhandle statistical region (fig. 1). Many streamflow-gaging stations, like the Beaver River near Guymon, Okla., (07232500, fig. 2), were discontinued in the 1980s or 1990s when no-flow conditions became prevalent in the Oklahoma Panhandle (fig. 4, table 1). Therefore, streamflow-gaging stations with similar physical and hydrologic settings in neighboring States were included to compile a statistically representative dataset for the Oklahoma Panhandle statistical region (fig. 1).

U.S. Geological Survey streamflow-gaging stations with annual peak-streamflow data were selected for computation of basin (physical and climatic) characteristics and peak-streamflow frequency statistics over the entire period of record and the irrigated period of record. The entire period of record was defined to begin in the first year of peak-streamflow record (1925) and continue to 2014; the irrigated period of record was defined to begin in 1978 (Wahl and Tortorelli, 1997; Lewis and Esralew, 2009; Esralew and Lewis, 2010) and continue to 2014. Only peak-streamflow data from streamflow-gaging stations in the Arkansas River drainage basin (fig. 1) with at least 10 years of peak-streamflow data in the irrigated period of record were selected for analysis. Gaps in the irrigated period of record were accepted. Data from some streamflow-gaging stations were excluded because of substantial regulation by large dams or because of surface-water diversions upstream as described in station descriptions (Lewis and Esralew, 2009; U.S. Geological Survey, 2015a). Substantial regulation was defined as a contributing drainage basin where 20 percent or more of the basin is upstream from large dams (including floodwater retarding structures) (Heimann and Tortorelli, 1988). Most of the streamflow-gaging stations selected for data analysis have drainage-basin area on the High Plains aquifer as defined by Qi (2010) (table 1).

Basin Characteristics

Peak-streamflow frequency statistics (such as the peak-streamflow magnitude with a 1-percent annual exceedance probability) are influenced by a number of drainage-basin characteristics, though the most influential drainage-basin characteristics vary regionally; for example, many statewide studies of peak-streamflow frequency have concluded that drainage area, mean annual precipitation, and stream channel slope are useful basin characteristics (independent variables) for estimating peak-streamflow frequency statistics by using regionalized regression methods (Jennings and others, 1994). Peak-streamflow frequency regression equations have been developed for all 50 U.S. States and Puerto Rico; all 51 sets of regression equations use drainage area, 27 use stream channel slope, and 19 use mean annual precipitation as independent variables in computations of peak-streamflow frequency statistics (Jennings and others, 1994).

For each selected streamflow-gaging station, selected basin characteristics were computed for use as independent variables in peak-streamflow frequency regression equations for the areas in and near the Oklahoma Panhandle (table 1). Percentage of drainage area on the High Plains aquifer (OK_HIPERMA) was computed in a geographic information system (GIS) as the percentage of the contributing drainage basin area that intersected the aquifer as defined by Qi (2010). Percentage of drainage area with crop cover (LC01CROP) was computed in a GIS as the percentage of the contributing drainage basin area that intersected cropland cover as defined by the 2006 National Land Cover Database (Fry and others, 2011; Multi-Resolution Land Characteristics Consortium, 2011). Contributing drainage area (CONTDA), mean annual precipitation (PRECIP), 10–85 stream channel slope (CSL10_85FM), mean soil permeability (SOILPERM), outlet elevation (OUTLETELEV), outlet mean annual precipitation from 1961 to 1990 (PRCOUT61), outlet mean annual precipitation from 1971 to 2000 (PRCOUT71), percentage of forest-canopy cover (CANOPY_PCT), percentage of impervious cover (IMPNLCD01), and mean drainage-basin slope (BSLDEM10M) were computed using methods described in Esralew and Smith (2010) and Smith and Esralew (2010); these methods are the foundation of the Web-based Oklahoma StreamStats application. The Oklahoma StreamStats application was designed to automatically compute selected drainage-basin characteristics for user-selected sites of interest in Oklahoma. For selected streamflow-gaging stations in Oklahoma, basin characteristics

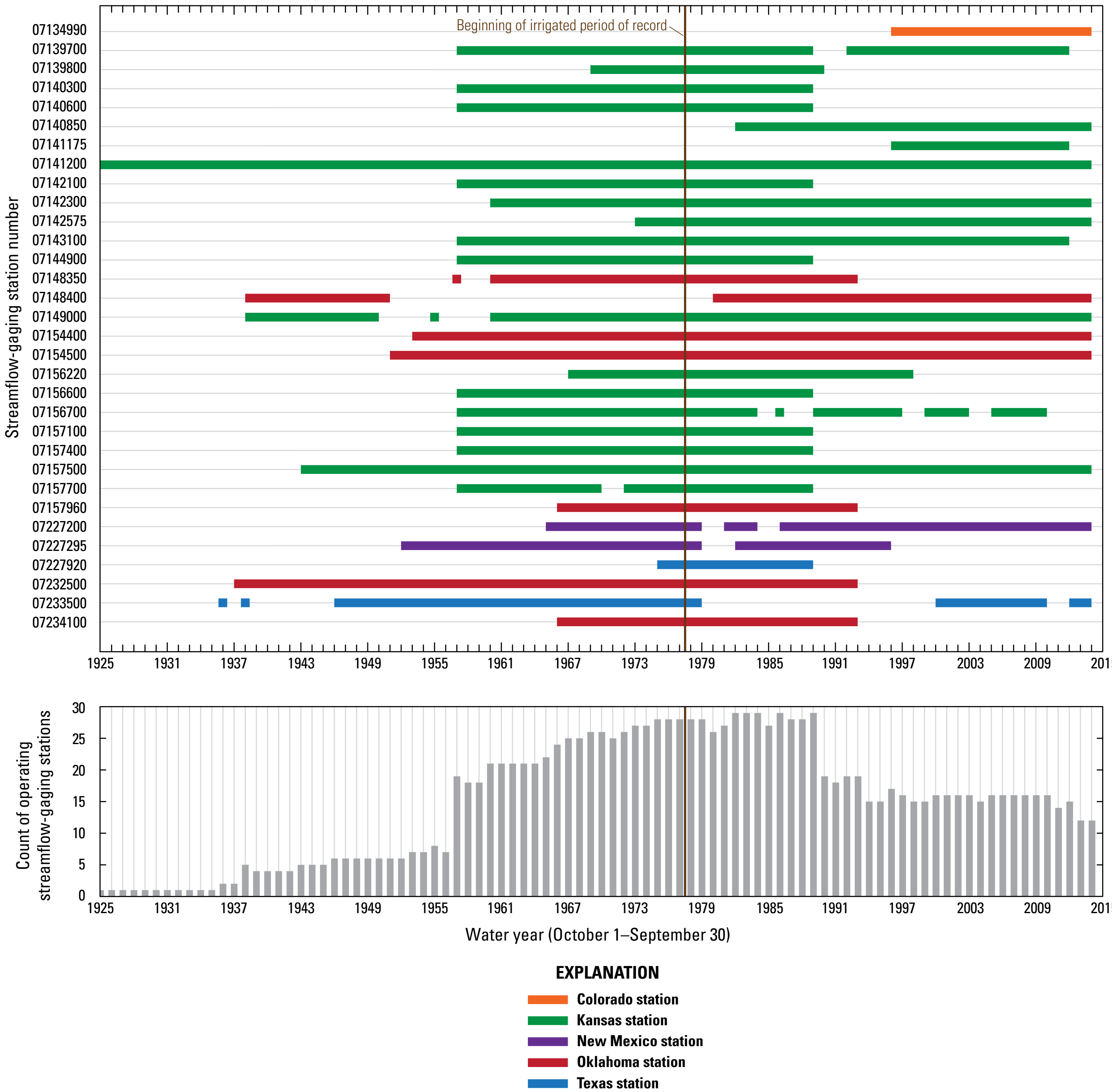


Figure 4. Period of record and count of selected operating streamflow-gaging stations in and near the Oklahoma Panhandle, 1925–2014.

were computed by using the Oklahoma StreamStats application (Smith and Esralew, 2010). For the remaining selected stations, basin characteristics were computed by using a desktop version of the Oklahoma StreamStats application, which uses the same data and methods as the Web-based version but enables computations to be made for areas outside of Oklahoma. Values for basin characteristics computed from the desktop version of the Oklahoma StreamStats application (table 1) may vary slightly from those computed by the Web-based Oklahoma StreamStats application because of differences in rounding and the exact locations selected on that application. Contributing drainage area values computed by using the Oklahoma StreamStats application may not match the values published on the National Water Information System Website (NWISWeb; U.S. Geological Survey, 2015b) because the methods used to compute contributing drainage area differ between States.

The study area in Colorado, Kansas, New Mexico, Oklahoma, and Texas (fig. 1) contains numerous playa lakes that accumulate runoff during precipitation (Smith and Esralew, 2010). Accumulated runoff is slowly released from these lakes by infiltration and evapotranspiration (Gurdak and Roe, 2009). The areas that drain to these lakes are noncontributing areas because they do not directly contribute runoff to a stream. Noncontributing areas in and near the Oklahoma Panhandle statistical region were modeled by using drains (sinks) at playa lakes and large depressions (greater than about 0.06 mi^2 in area) to subtract playa drainage areas from the main stem drainage areas. These methods match those used by the Oklahoma StreamStats application (Smith and Esralew, 2010). Noncontributing areas also were excluded during computation of basin characteristics. Areas upstream from manmade dams were not modeled as noncontributing areas because those dams provide outlet works and spillways that allow runoff to flow downstream.

Trend Analysis

Trend analysis of relevant hydrologic data is prudent prior to performing regression analysis on peak streamflow data. Kendall's tau (Kendall, 1938; Kendall, 1975) is a robust rank based statistic that tests for the presence of trend in a data series. The value of the Kendall's tau statistic is a number between -1 and 1; endpoints that indicate strong decreasing and increasing trends, respectively. In this report, a probability (p) value is reported with each Kendall tau statistic, and a 95-percent confidence level or greater ($p \leq 0.05$) was deemed to indicate a significant trend with time. The Sen slope (Sen, 1968) also was computed to estimate the general slope (rate) of the trend. Trends are graphically represented in figures in this report using locally weighted scatterplot smoothing (LOWESS; Cleveland and McGill, 1984; Cleveland, 1985) trend lines.

Precipitation Trend Analysis

Trends in annual peak streamflows could be caused by trends in annual precipitation. Because of this possibility, the annual precipitation records from four climate divisions (Vose and others, 2014; National Oceanic and Atmospheric Administration, 2015a; National Oceanic and Atmospheric Administration, 2015b) were examined for trends (fig. 1). One significant trend, an increase of 0.05 inch per year for the South Central Kansas climate division (KS08, fig. 1), was observed over the entire (streamflow) period of record (1925–2014) (fig. 5, table 2). No significant trends in annual precipitation were observed over the irrigated (streamflow) period of record (1978–2014) (fig. 5, table 2); therefore, any trends observed in streamflow over the irrigated period of record are not likely to have been related to trends in annual precipitation.

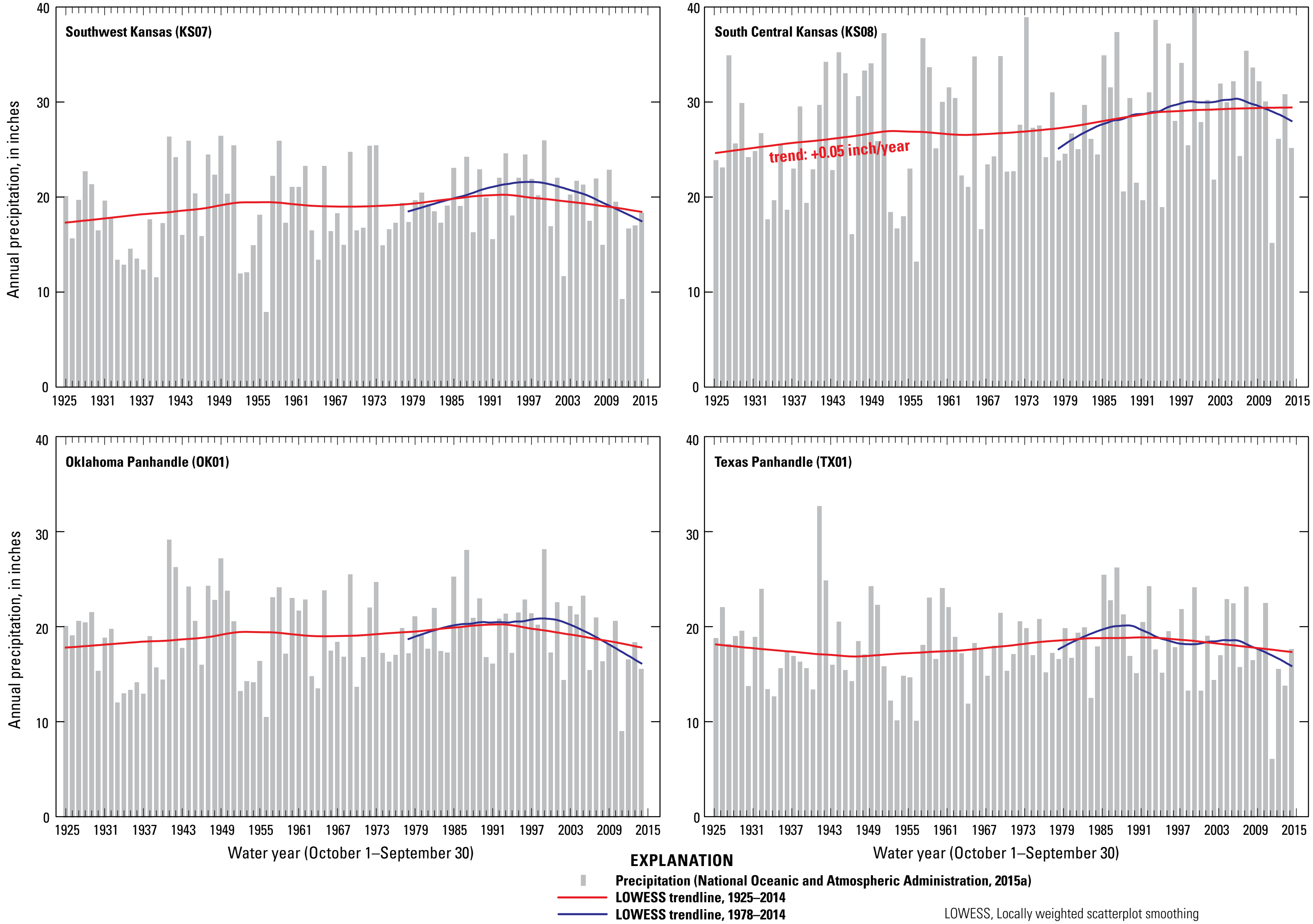


Figure 5. Annual precipitation trends for the entire period of record (1925–2014) and the irrigated period of record (1978–2014) for selected climate divisions in and near the Oklahoma Panhandle.

Table 2. Results of trend tests on annual precipitation for the entire period of record (1925–2014) and the irrigated period of record (1978–2014) for selected climate divisions in and near the Oklahoma Panhandle.

[Precipitation data from National Oceanic and Atmospheric Administration (2015a); in/yr, inches per year; shaded values are statistically significant at the 95-percent confidence level or greater (p≤0.05); ≤, less than or equal to]

Climate division (fig. 1)	Entire period of record (1925–2014)					Irrigated period of record (1978–2014)				
	Record length (water years)[1]	Median (in/yr)	Kendall tau	p-value	Trend slope (in/yr)	Record length (water years)[1]	Median (in/yr)	Kendall tau	p-value	Trend slope (in/yr)
Southwest Kansas (KS07)	90	19.15	0.0752	0.3364	0.02	37	19.62	-0.0977	0.3364	-0.04
South Central Kansas (KS08)	90	26.71	0.1443	0.0304	0.05	37	29.70	0.0917	0.3437	0.08
Oklahoma Panhandle (OK01)	90	19.28	0.0550	0.5108	0.01	37	20.40	-0.1441	0.1624	-0.06
Texas Panhandle (TX01)	90	17.74	0.0345	0.6661	0.01	37	17.97	-0.1141	0.2761	-0.07

[1]A water year is a period of 12 consecutive months that includes January through September of the named calendar year and October through December of the previous calendar year.

Annual Peak Data Trend Analysis

Annual peak-streamflow data from selected streamflow-gaging stations were obtained from NWISWeb (U.S. Geological Survey, 2015b) and examined for trends over the entire period of record and the irrigated period of record (fig. 6). Eighteen significant streamflow trends were identified in the entire period of record; 17 of those 18 significant trends were decreasing (table 3). Because peak-streamflow data from more than half of the streamflow-gaging stations significantly decreased with no coincident decreasing trends in precipitation, this finding reinforces the conclusions of previous studies that the hydrology of the Oklahoma Panhandle statistical region has changed primarily as a result of groundwater withdrawals. Six significant streamflow trends were determined in the irrigated period of record at selected streamflow-gaging stations; 5 of those 6 significant trends were decreasing (table 3). The decreasing trends in peak streamflow during the irrigated period of record indicate that the hydrologic balance of the area in and near the Oklahoma Panhandle has continued to change since 1978 and has not reached a long-term equilibrium. Though the presence of some trends was statistically confirmed, the type or pattern of these trends was not clear. Hydrologic trends may be gradual or step-change or a complex combination or series of both. If the type of trend is well characterized for each station, a statistical model of the trend can be used to remove the effects of the trend from the time-series data (Ries and Dillow, 2006; Sherwood and others, 2007). No attempt was made to remove trends from the annual peak-streamflow record in this report; however, this technique could be used in future reports to adjust pre-1978 peak-streamflow data and add them to the irrigated period of record.

Peak-Streamflow Frequency Analysis

The USGS computer program PeakFQ version 7.1 (U.S. Geological Survey, 2014a) was used to compute peak-streamflow frequency statistics from annual peak-streamflow data for the selected streamflow-gaging stations. PeakFQ automates many of the analytical procedures recommended in USGS Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). Computed peak-streamflow frequency statistics of the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probabilities are listed in table 1. To reduce errors resulting from a poor log-Pearson Type III (LPIII) fit, peak-streamflow frequency statistics were adjusted based on historical flood information (where available), skew coefficients, and Interagency Advisory Committee on Water Data (1982) guidelines (table 1; Lewis, 2010).

The computed peak-streamflow frequency statistics can be compared to estimated peak-streamflow frequency statistics by using the statewide regression equations for Oklahoma (Lewis, 2010) to evaluate the suspected bias in the previous regression estimates for the Oklahoma Panhandle. The statewide regression equations for Oklahoma (Lewis, 2010) estimated greater peak-streamflow frequency statistics, on average, than those computed for the irrigated period of record (fig. 7, table 1). The Oklahoma statewide regression-estimated peak-streamflow frequency statistics (Lewis, 2010) for the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probabilities were, on average, 507, 332, 302, 288, 298, 288, and 308 percent greater, respectively, than the computed peak-streamflow frequency statistics for the irrigated period of record (fig. 7, table 1).

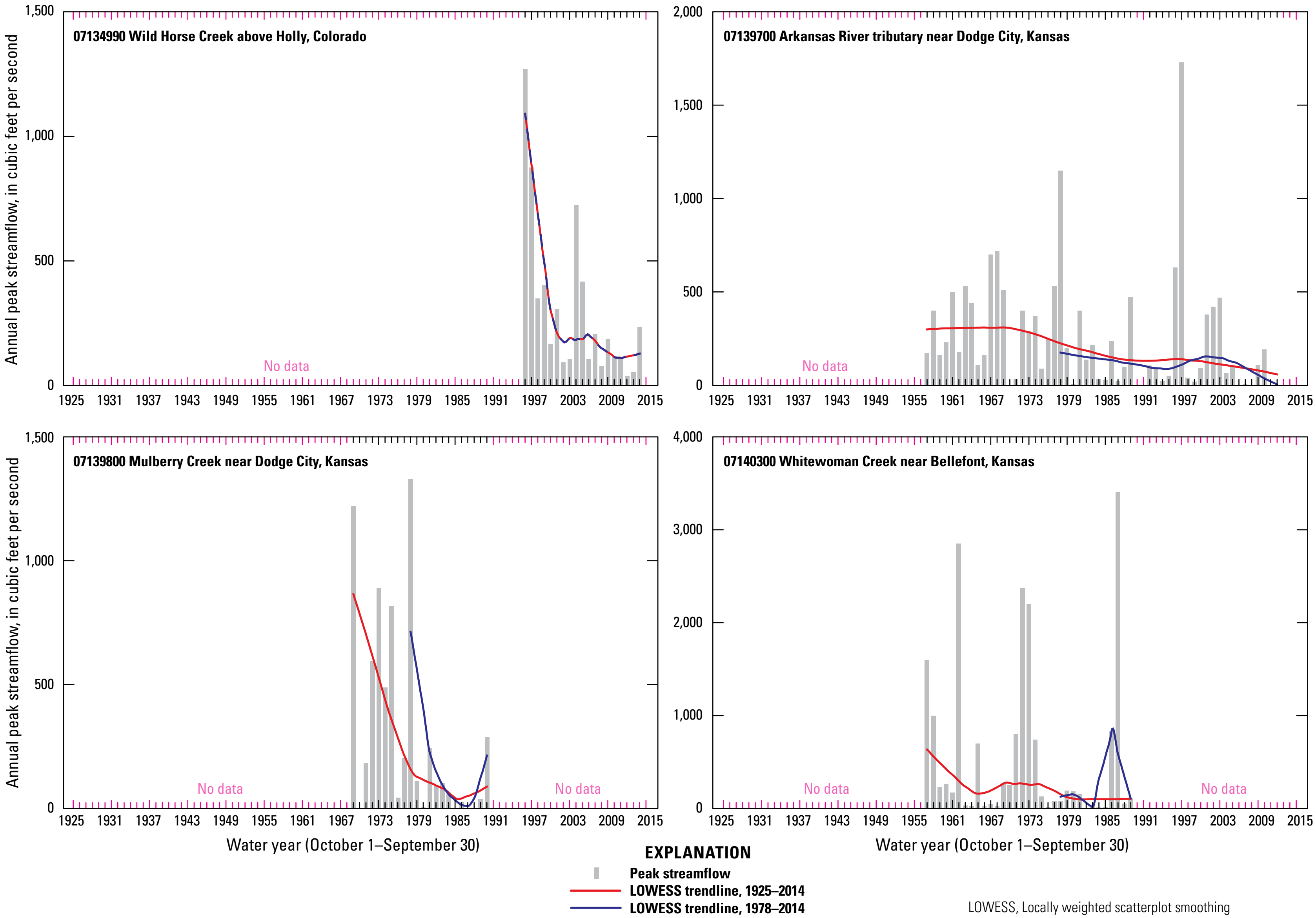


Figure 6. Annual peak-streamflow trends for the entire period of record (1925–2014) and the irrigated period of record (1978–2014) for selected streamflow-gaging stations in and near the Oklahoma Panhandle.

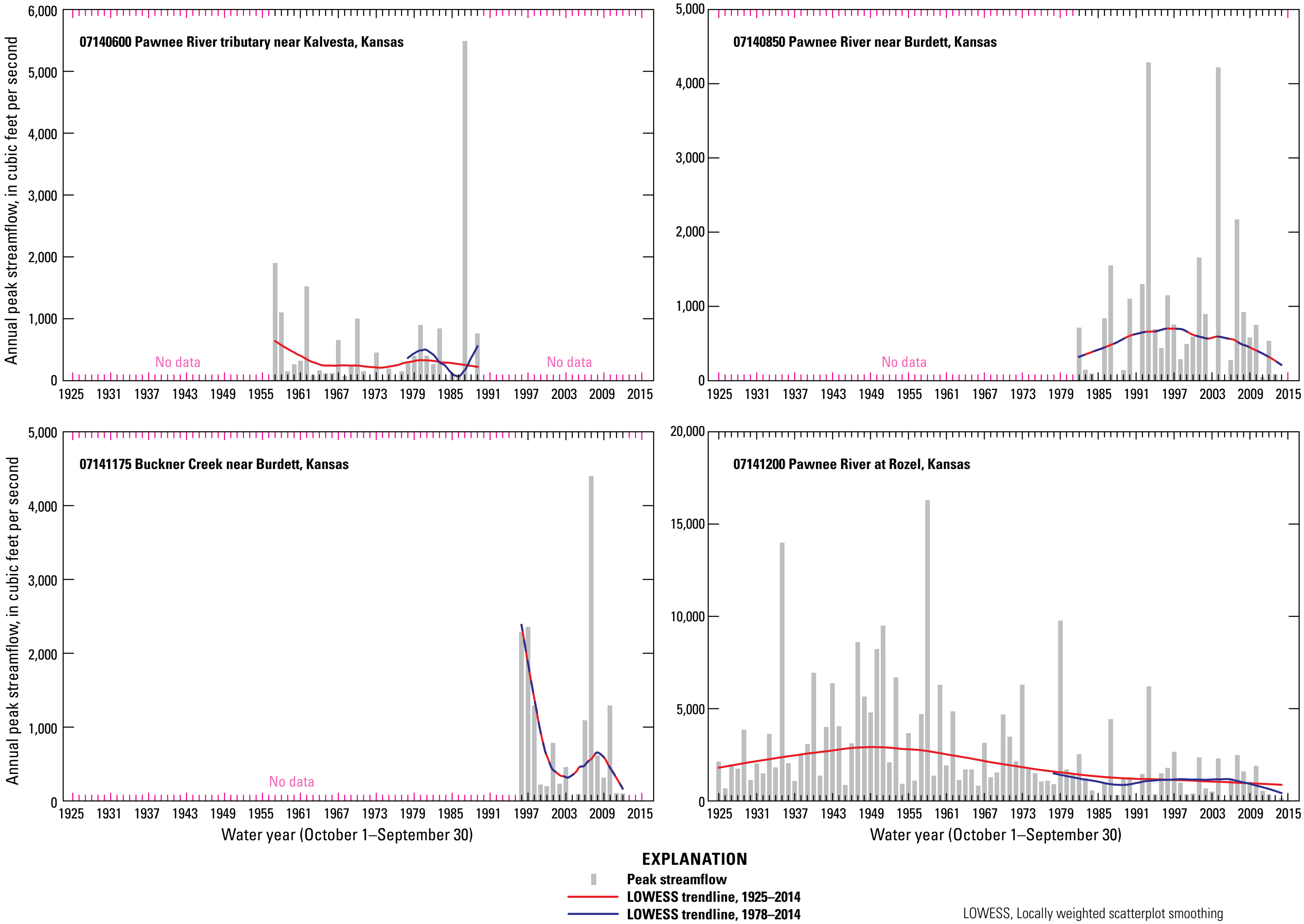


Figure 6. Annual peak-streamflow trends for the entire period of record (1925–2014) and the irrigated period of record (1978–2014) for selected streamflow-gaging stations in and near the Oklahoma Panhandle.—Continued

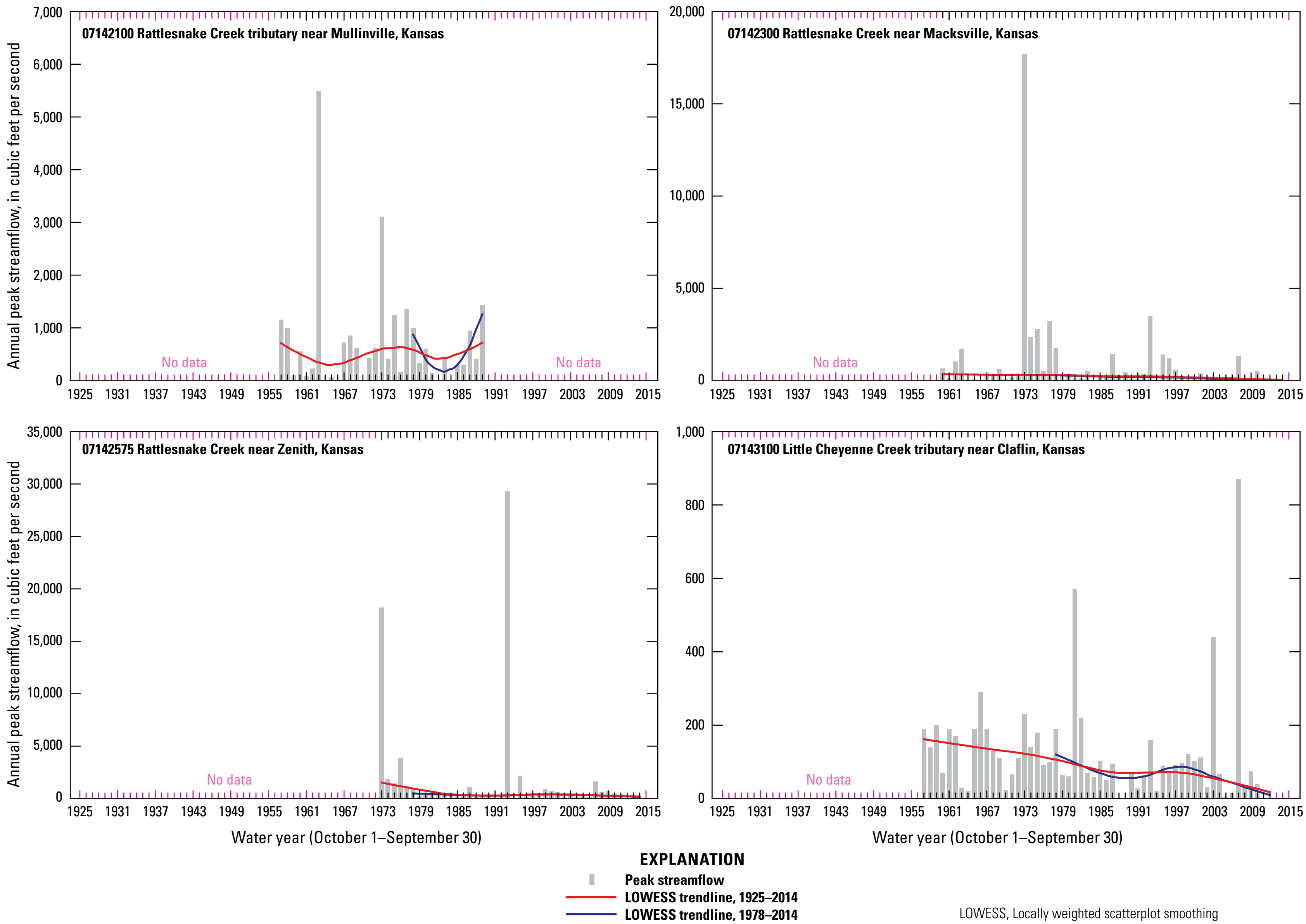


Figure 6. Annual peak-streamflow trends for the entire period of record (1925–2014) and the irrigated period of record (1978–2014) for selected streamflow-gaging stations in and near the Oklahoma Panhandle.—Continued

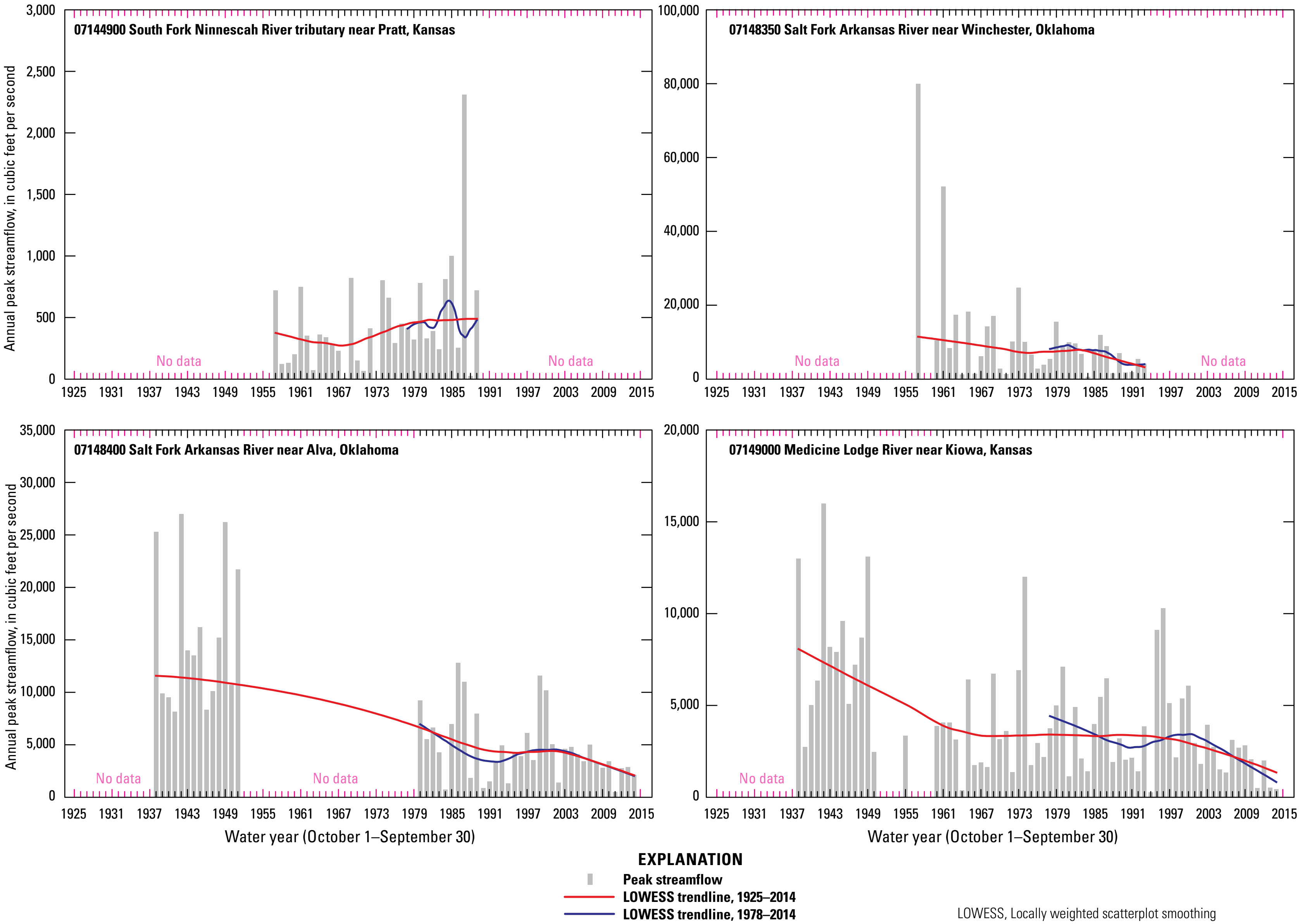


Figure 6. Annual peak-streamflow trends for the entire period of record (1925–2014) and the irrigated period of record (1978–2014) for selected streamflow-gaging stations in and near the Oklahoma Panhandle.—Continued

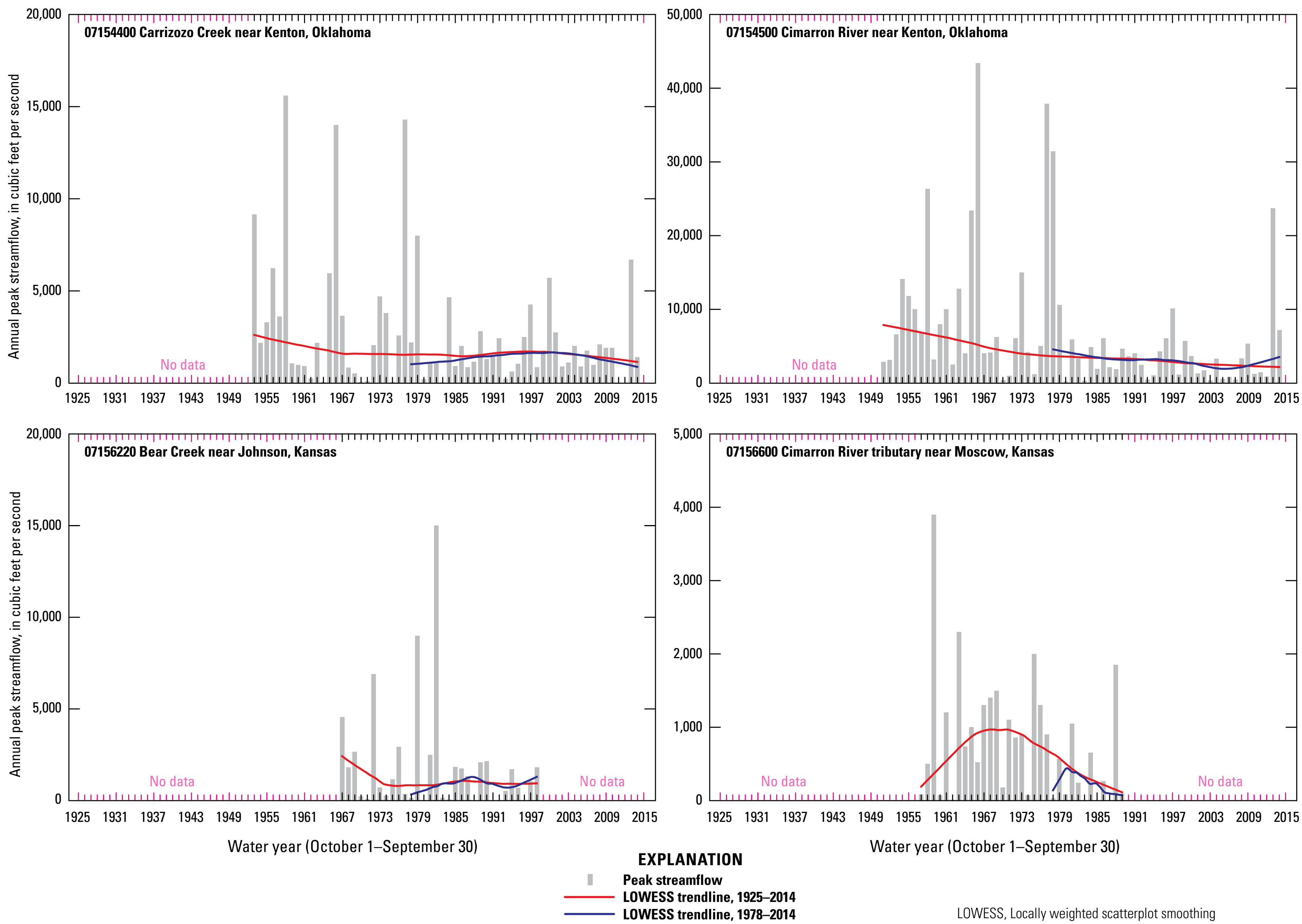


Figure 6. Annual peak-streamflow trends for the entire period of record (1925–2014) and the irrigated period of record (1978–2014) for selected streamflow-gaging stations in and near the Oklahoma Panhandle.—Continued

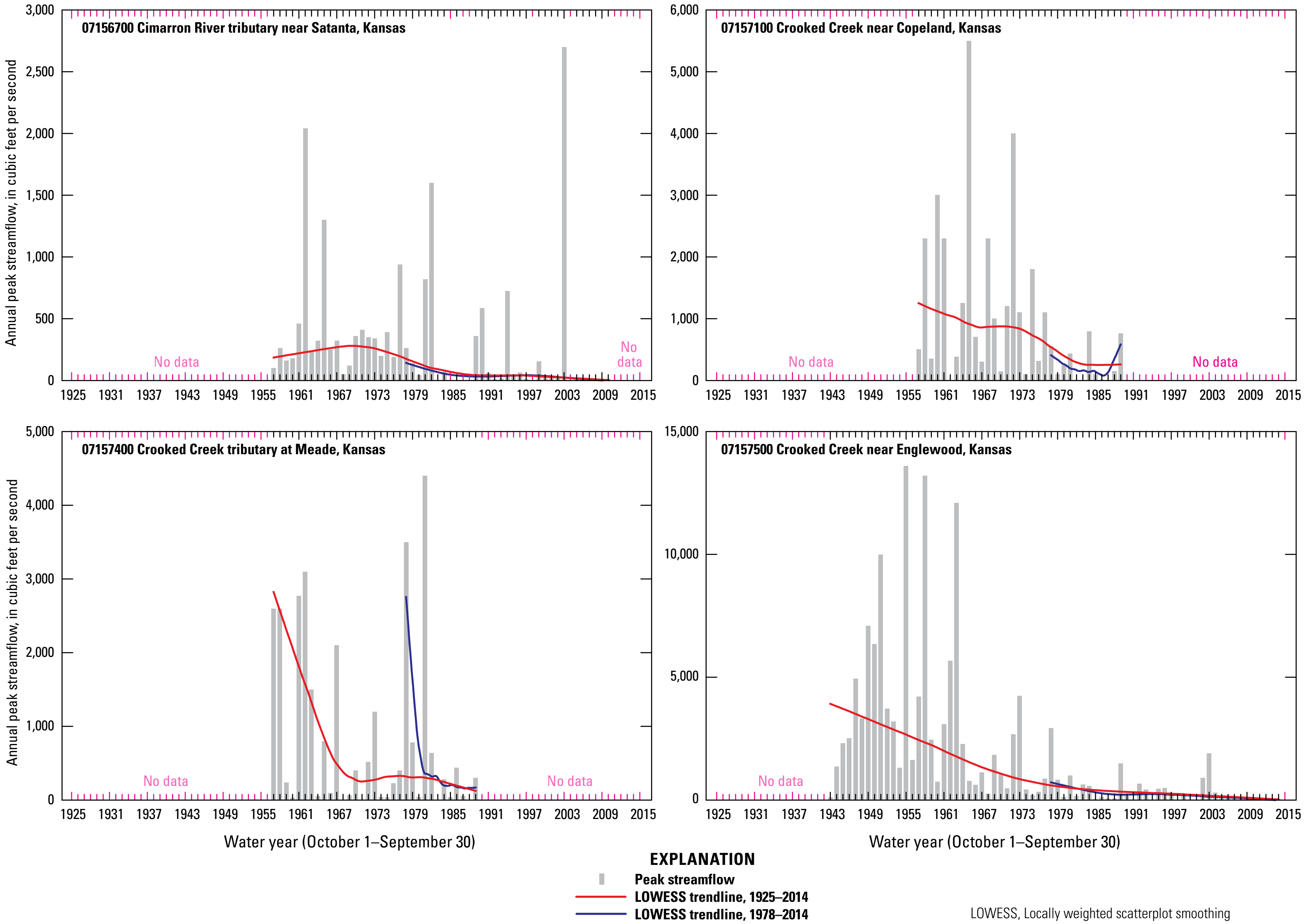


Figure 6. Annual peak-streamflow trends for the entire period of record (1925–2014) and the irrigated period of record (1978–2014) for selected streamflow-gaging stations in and near the Oklahoma Panhandle.—Continued

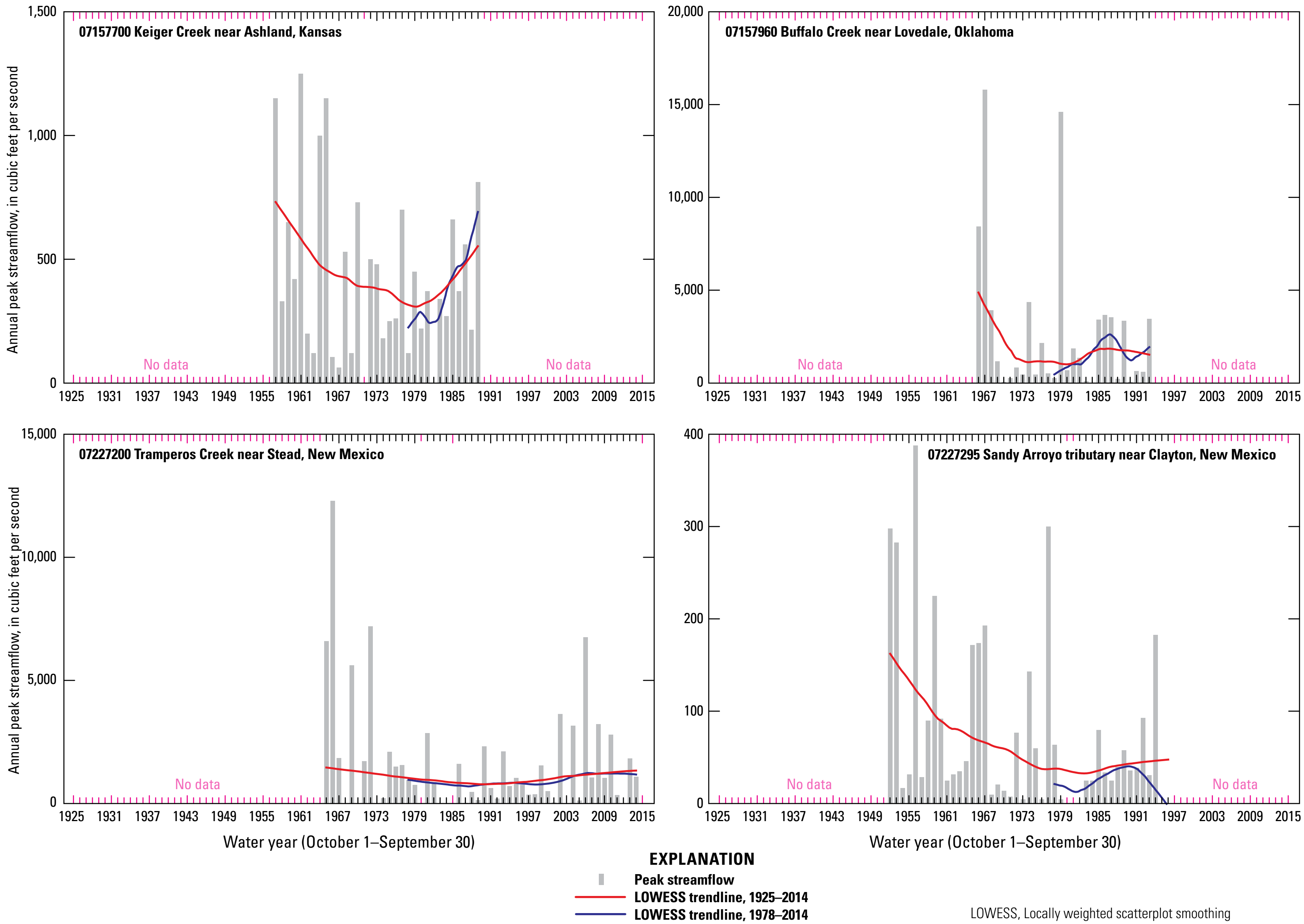


Figure 6. Annual peak-streamflow trends for the entire period of record (1925–2014) and the irrigated period of record (1978–2014) for selected streamflow-gaging stations in and near the Oklahoma Panhandle.—Continued

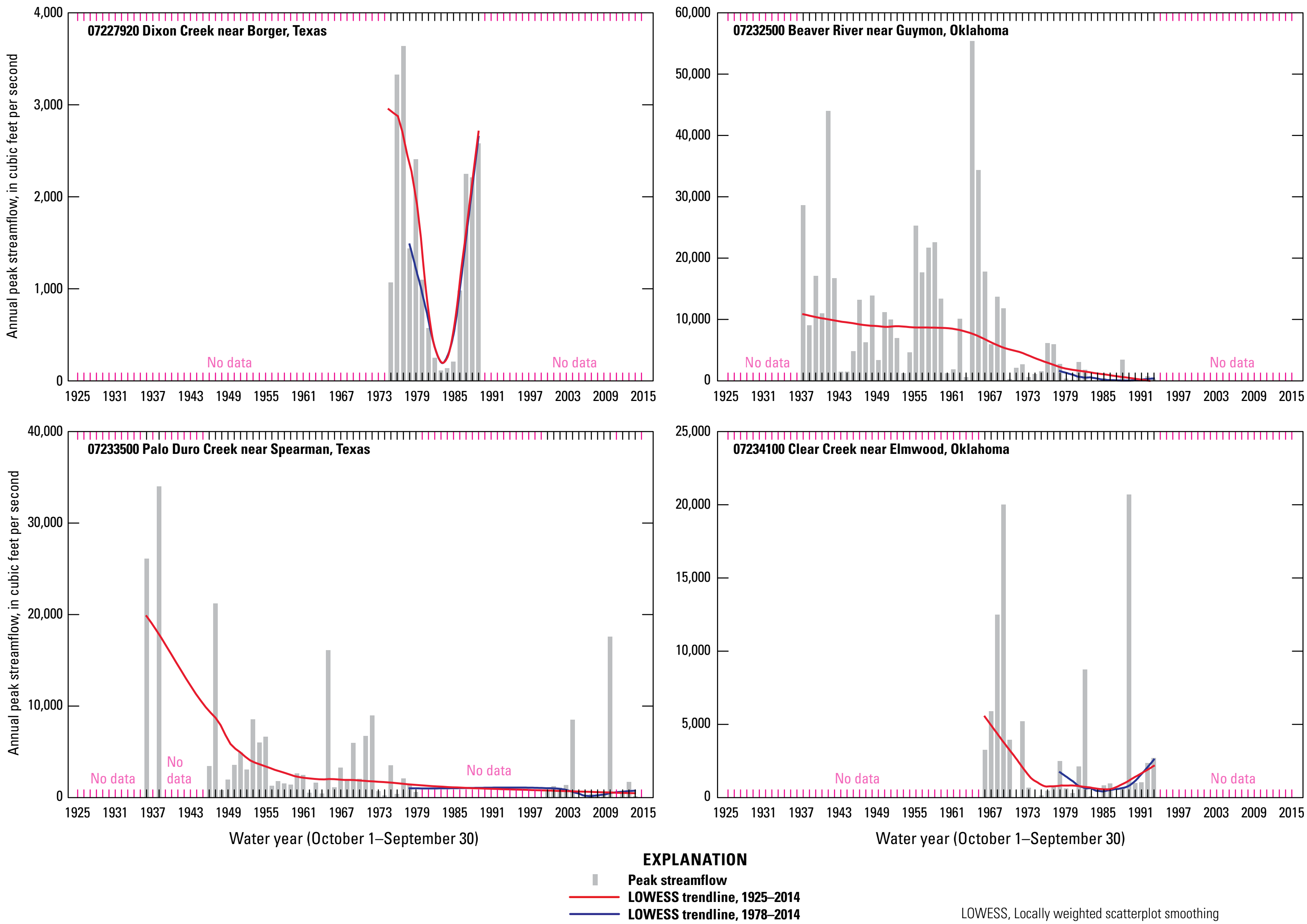


Figure 6. Annual peak-streamflow trends for the entire period of record (1925–2014) and the irrigated period of record (1978–2014) for selected streamflow-gaging stations in and near the Oklahoma Panhandle.—Continued

Table 3. Results of trend tests on annual peak streamflow for the entire period of record (1925–2014) and the irrigated period of record (1978–2014) at selected streamflow-gaging stations in and near the Oklahoma Panhandle.

[ft³/s, cubic feet per second; ft³/s/yr, cubic feet per second per year; shaded values are statistically significant at the 95-percent confidence level or greater (p≤0.05); ≤, less than or equal to]

Site number	Station number (fig. 1)	Station name	Record span (water year)[1]	Entire period of record (1925–2014)				
				Record length (water years)[1]	Median annual peak flow (ft³/s)	Kendall's tau	p-value	Trend slope (ft³/s/yr)
1	07134990	Wild Horse Creek above Holly, Colo.	1996–2014	19	185	-0.4620	0.0368	-23.25
2	07139700	Arkansas River Trib. near Dodge City, Kans.	1957–2012	54	165	-0.2872	0.0023	-3.91
3	07139800	Mulberry Creek near Dodge City, Kans.	1969–90	22	106	-0.3818	0.0056	-19.67
4	07140300	Whitewoman Creek near Bellefont, Kans.	1957–89	33	170	-0.1856	0.2066	-6.16
5	07140600	Pawnee River Trib. near Kalvesta, Kans.	1957–89	33	250	-0.0858	0.4512	-3.43
6	07140850	Pawnee River near Burdett, Kans.	1982–2014	33	581	-0.0246	0.8395	-0.77
7	07141175	Buckner Creek near Burdett, Kans.	1996–2012	17	457	-0.2288	0.3047	-43.59
8	07141200	Pawnee River at Rozel, Kans.	1925–2014	90	1,710	-0.3084	0.0000	-23.61
9	07142100	Rattlesnake Creek Trib. near Mullinville, Kans.	1957–89	33	420	-0.0229	0.8458	-0.57
10	07142300	Rattlesnake Creek near Macksville, Kans.	1960–2014	55	218	-0.2883	0.0041	-6.42
11	07142575	Rattlesnake Creek near Zenith, Kans.	1973–2014	42	384.5	-0.3101	0.0028	-12.62
12	07143100	Little Cheyenne Creek Trib. near Claflin, Kans.	1957–2012	56	92	-0.2803	0.0018	-2.02
13	07144900	South Fork Ninnescah River Trib. near Pratt, Kans.	1957–89	33	340	0.1953	0.0248	8.00
14	07148350	Salt Fork Arkansas River near Winchester, Okla.	1957–93	35	7,770	-0.2826	0.0177	-290.00
15	07148400	Salt Fork Arkansas River near Alva, Okla.	1938–2014	49	5,040	-0.4983	0.0000	-150.91
16	07149000	Medicine Lodge River near Kiowa, Kans.	1938–2014	69	3,200	-0.3241	0.0001	-55.98
17	07154400	Carrizozo Creek near Kenton, Okla.	1953–2014	62	1,750	-0.1199	0.1921	-15.00
18	07154500	Cimarron River near Kenton, Okla.	1951–2014	64	4,020	-0.2695	0.0171	-84.10
19	07156220	Bear Creek near Johnson, Kans.	1967–98	32	1,105	-0.1638	0.1357	-17.46
20	07156600	Cimarron River Trib. near Moscow, Kans.	1957–89	33	650	-0.1884	0.0315	-18.43
21	07156700	Cimarron River Trib. near Satanta, Kans.	1957–2010	49	160	-0.3614	0.0003	-5.09
22	07157100	Crooked Creek near Copeland, Kans.	1957–89	33	500	-0.3597	0.0016	-30.00
23	07157400	Crooked Creek Trib. at Meade, Kans.	1957–89	33	300	-0.2019	0.1285	-12.50
24	07157500	Crooked Creek near Englewood, Kans.	1943–2014	72	637.5	-0.5753	0.0000	-36.84
25	07157700	Keiger Creek near Ashland, Kans.	1957–89	32	370	-0.0871	0.4955	-5.00
26	07157960	Buffalo Creek near Lovedale, Okla.	1966–93	28	1,020	-0.1217	0.4404	-24.10
27	07227200	Tramperos Creek near Stead, New Mex.	1965–2014	48	992.5	-0.0604	0.5514	-5.87
28	07227295	Sandy Arroyo Trib. near Clayton, New Mex.	1952–96	43	36	-0.2008	0.0608	-1.12
29	07227920	Dixon Creek near Borger, Tex.	1975–89	15	1,100	-0.1429	0.6773	-57.50
30	07232500	Beaver River near Guymon, Okla.	1937–93	57	3,410	-0.4790	0.0001	-220.44
31	07233500	Palo Duro Creek near Spearman, Tex.	1936–2014	50	1,755	-0.3861	0.0001	-47.73
32	07234100	Clear Creek near Elmwood, Okla.	1966–93	28	976.5	-0.0529	0.7545	-17.24

Table 3. Results of trend tests on annual peak streamflow for the entire period of record (1925–2014) and the irrigated period of record (1978–2014) at selected streamflow-gaging stations in and near the Oklahoma Panhandle.—Continued

[ft³/s, cubic feet per second; ft³/s/yr, cubic feet per second per year; shaded values are statistically significant at the 95-percent confidence level or greater (p≤0.05); ≤, less than or equal to]

Site number	Irrigated period of record (1978–2014)				
	Record length (water years)[1]	Median annual peak flow (ft³/s)	Kendall's tau	p-value	Trend slope (ft³/s/yr)
1	19	185	-0.4620	0.0368	-23.25
2	33	100	-0.2315	0.0608	-2.92
3	13	64	-0.3590	0.0926	-12.36
4	12	94	0.0303	0.9491	2.86
5	12	350	-0.1679	0.4070	-17.78
6	33	581	-0.0246	0.8395	-0.77
7	17	457	-0.2288	0.3047	-43.59
8	37	1,150	-0.1592	0.1169	-22.84
9	12	370	0.0923	0.7212	28.75
10	37	145	-0.3140	0.0041	-6.63
11	37	321	-0.1441	0.1913	-5.56
12	35	69	-0.1485	0.1830	-1.59
13	12	400	0.0606	0.7479	6.25
14	16	6,880	-0.3333	0.0414	-436.88
15	35	4,070	-0.2672	0.0712	-102.73
16	37	2,730	-0.2583	0.0752	-75.33
17	37	1,400	0.0030	0.9879	0.00
18	37	3,270	-0.1201	0.3717	-50.69
19	21	1,050	-0.1103	0.4524	-11.77
20	12	168	0.0155	1.0000	0.00
21	28	42.5	-0.3423	0.0119	-3.42
22	12	121.5	-0.1069	0.6254	-4.08
23	12	290	-0.3817	0.0551	-71.33
24	37	128	-0.3759	0.0034	-9.50
25	12	355	0.3206	0.0274	36.02
26	16	1,029.5	-0.0333	0.8695	-4.48
27	35	755	0.1166	0.3338	13.54
28	17	34	0.1053	0.5900	1.00
29	12	1,040	0.0909	0.8595	58.25
30	16	177.5	-0.3333	0.0549	-14.58
31	16	633.5	-0.1167	0.5584	-10.04
32	16	976.5	0.2167	0.1999	46.53

[1]A water year is a period of 12 consecutive months that includes January through September of the named calendar year and October through December of the previous calendar year.

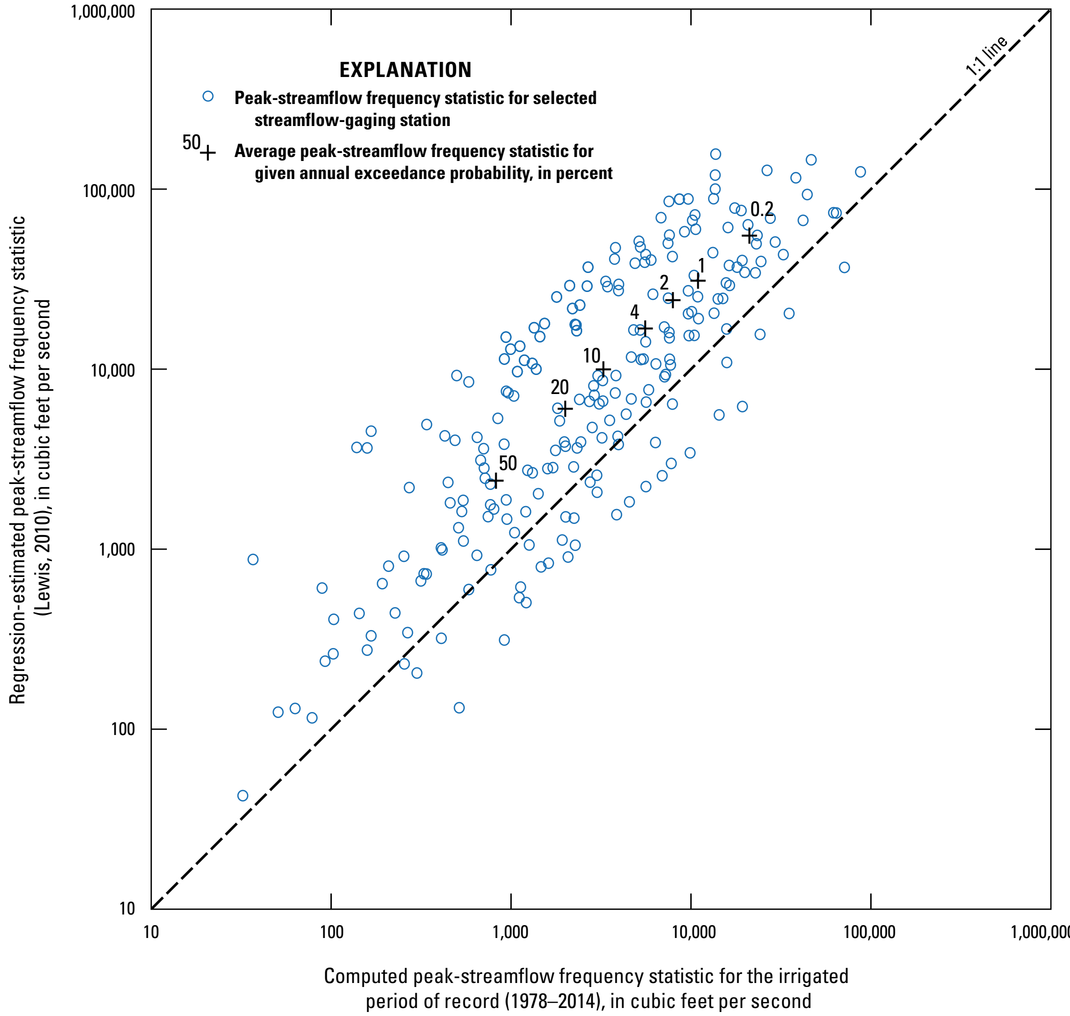


Figure 7. Computed and regression-estimated peak-streamflow frequency statistics for the irrigated period of record (1978–2014) at selected streamflow-gaging stations in and near the Oklahoma Panhandle.

Estimates of Magnitude and Frequency of Peak Streamflows at Ungaged Sites

The regression analysis used in this report incorporated logarithmic (base 10) transformations of the peak-streamflow frequency statistics and basin characteristics to obtain a constant variance of the residuals about the regression line and to make the relation between the dependent variable (peak-streamflow frequency statistics) and independent variables (basin characteristics) acceptable for linear least-squares regression procedures. The multiple-linear regression equations based on logarithmic transformation of the variables has the following form:

$$\mathrm{Log}_{10}Y = b_0 + b_1\log_{10}X_1 + b_2\log_{10}X_2 + \ldots\ldots + b_n\log_{10}X_n, \quad (1)$$

and the following form after taking antilogs,

$$Y = 10^{b0}\,(X_1^{\,b1})\,(X_2^{\,b2})\ldots\ldots(X_n^{\,bn}) \quad (2)$$

where

Y is the dependent variable (peak-streamflow frequency statistic for selected annual exceedance probability),

b_0 to b_n are the regression model coefficients, and

X_1 to X_n are independent variables (basin characteristics).

Regression Analysis

Previous regression analysis of peak-streamflow frequency for Oklahoma (Lewis, 2010) used a combination of ordinary-least-squares (OLS), weighted-least-squares (WLS), and generalized-least-squares (GLS) multiple-linear regression analysis methods to formulate statewide regression equations for Oklahoma; this report used the same methods as Lewis (2010) to formulate regional regression equations for the Oklahoma Panhandle statistical region. The USGS Weighted-Multiple-Linear Regression (WREG) computer program

(Eng and others, 2009) facilitated OLS, WLS, and GLS regression analysis by performing logarithmic transformations on the dependent and independent variables, estimating regression model coefficients, and graphing performance metrics.

The OLS and WLS regression analysis methods were used to eliminate statistically insignificant ($p > 0.05$) independent variables from consideration (Ries and Dillow, 2006), and the GLS regression analysis method was used to formulate the final regression equations. The GLS regression analysis method entails weighting each basin in accordance with the variance (time-sampling error) and spatial-correlation structure of the peak-streamflow frequency statistic (among streamflow-gaging stations) (Lumia and others, 2006). The residual error is portioned into regression model error (error in assuming an incomplete regression form) and sampling error (time- and spatial-sampling errors). When using the GLS regression analysis method, the variance of prediction (and the square root, the standard error of prediction) is the sum of the model error variance and an additional term. This additional term has been called a sampling error variance (of the regression model coefficients), but it is different from the time-sampling and spatial-sampling error. The GLS regression analysis method can be used to assign weights to the streamflow-gaging station data used in the regression analysis to adjust not only for differences in record length but also for cross-correlation of the annual time series on which the peak-streamflow frequency statistics for the streamflow-gaging station data are based and for spatial correlation among the streamflow-gaging station data (Stedinger and Tasker, 1985). Annual peak streamflows of basins were cross-correlated because a single storm can cause the annual peak in several basins. An advantage of using the GLS regression analysis method is that cross-correlation among basins is taken into account.

Several performance metrics from the WREG computer program were used to identify data points with unusual weight or control on the regression relation. The residuals metric shows differences between regression-estimated and computed peak-streamflow frequency statistics; homoscedastic residuals (residuals randomly distributed around zero) are preferred. The leverage metric is used to measure how distant the values of independent variables at one streamflow-gaging station are from the centroid of values of the same variables at all other streamflow-gaging stations. The influence metric indicates whether data from a streamflow-gaging station had a large influence on the estimated regression model coefficients (Eng and others, 2009). Data from streamflow-gaging stations identified as having high influence and leverage (for example, fig. 8) were not necessarily removed from the dataset because a station may have been the only streamflow-gaging station in a particular geographic area. The high-leverage and high-influence limits were computed by the WREG computer program by using equations from Eng and others (2009). The final performance metrics for the 10-percent annual exceedance probability regression model are shown in figure 8 as an example.

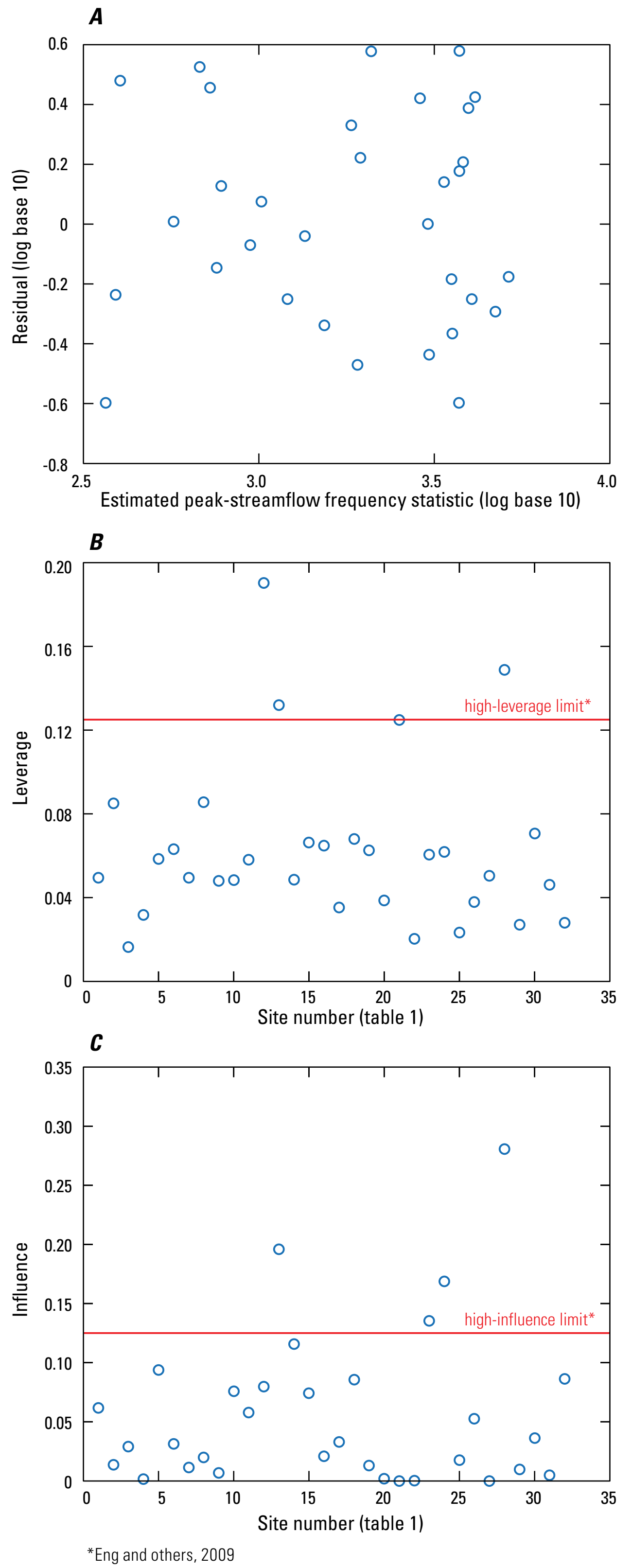


Figure 8. Performance metrics from the Weighted-Multiple-Linear Regression (WREG) computer program for the 32 selected streamflow-gaging stations including *A*, residuals; *B*, leverage; and *C*, influence for a 10-percent annual exceedance probability peak-streamflow generalized-least-squares (GLS) regression model.

Regression Equations

Regression equations were developed for use in estimating peak-streamflow frequency statistics associated with the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probabilities. Combinations of independent variables were tested to minimize leverage or influence of individual data points and to avoid multicollinearity (correlation between independent variables), but most independent variables that were tested did not have a statistically significant relation with the dependent variable. Mean annual precipitation (PRECIP), 10–85 stream channel slope (CSL10_85FM), mean soil permeability (SOILPERM), outlet elevation (OUTLETELEV), outlet mean annual precipitation from 1961 to 1990 (PRCOUT61), outlet mean annual precipitation from 1971 to 2000 (PRCOUT71), percentage of forest-canopy cover (CANOPY_PCT), percentage of impervious cover (IMPNLCD01), and percentage of drainage area with crop cover (LC01CROP) were rejected as insignificant independent variables. Mean drainage-basin slope (BSLDEM10M) and percentage of drainage area on the High Plains aquifer (OK_HIPERMA) were statistically significant independent variables but only for percentage exceedance probabilities greater than 2 and 10 percent, respectively. Contributing drainage area (CONTDA) was the only basin characteristic determined to be statistically significant for all annual exceedance probabilities and was the only basin characteristic used for estimating peak-streamflow frequency statistics on unregulated streams in this report. The following regression equations were computed for unregulated streams from the results of the GLS regression analysis in the WREG computer program:

$$Q_{50\%} = 77.6\,(CONTDA)^{0.34} \quad (3)$$

$$Q_{20\%} = 209\,(CONTDA)^{0.35} \quad (4)$$

$$Q_{10\%} = 339\,(CONTDA)^{0.36} \quad (5)$$

$$Q_{4\%} = 562\,(CONTDA)^{0.36} \quad (6)$$

$$Q_{2\%} = 759\,(CONTDA)^{0.37} \quad (7)$$

$$Q_{1\%} = 1{,}000\,(CONTDA)^{0.38} \quad (8)$$

$$Q_{0.2\%} = 1{,}620\,(CONTDA)^{0.39} \quad (9)$$

where

$Q_{50\%}$, $Q_{20\%}$,…, and $Q_{0.2\%}$ are the peak-streamflow frequency statistics with annual exceedance probabilities of 50 percent, 20 percent, …, and 0.2 percent, in cubic feet per second; and

CONTDA is the contributing drainage area, in square miles.

For estimating peak-streamflow frequency statistics at urban sites or sites that are affected by floodwater retarding structures, refer to procedures described by Lewis (2010). For sites on large streams that have long-term streamflow-gaging stations upstream and downstream from the site of interest, the drainage-area ratio method is preferred for estimating peak-streamflow frequency statistics (Lewis, 2010).

Accuracy and Limitations

Regression equations that produce estimates of streamflow statistics are statistical models that minimize differences between regression-estimated and computed streamflow statistics (residual errors).The accuracy of a regression equation depends on the combined model error and sampling error. Model error is the variability in the dependent variable that is unexplained by the selected dependent variables. Sampling error, which is more difficult to quantify, results from the limitations on the number of years of available streamflow-gaging station period of record and the assumption that streamflow measured during the available streamflow-gaging station period of record is representative of long-term streamflow characteristics. The use of GLS regression analysis methods allows separation of the sampling error variance from the model error variance.

Three performance metrics were used to evaluate the accuracy of a regression-estimated peak-streamflow frequency statistic: the pseudo coefficient of determination (pseudo-R^2), the average standard error of prediction (S_p), and the standard model error (table 4); the WREG computer program reports these performance metrics in the model output. The coefficient of determination (R^2) is the proportion of the variability in the dependent variable (station computed peak-streamflow frequency statistic, $Q_{x[s]}$) that is explained by the independent variable (the basin characteristic, CONTDA). A greater value for R^2 indicates a better fit of the model, with a maximum value of 1.00 indicating that 100 percent of the variability in the dependent variable is explained by the independent variable (Helsel and Hirsch, 2002). The pseudo-R^2 (Griffis and Stedinger, 2007), however, is a more appropriate performance metric for GLS regressions; the pseudo-R^2 is a measure of the variability in the dependent variable explained by the regression after removing the effect of the time-sampling error (Eng and others, 2009). The pseudo-R^2 values converted to percent (table 4) for the Oklahoma Panhandle regional regression equations ranged from about 38 to 63 percent and were less than the corresponding pseudo-R^2 (which ranged from about 92 to 96 percent) for the Oklahoma statewide regression equations of Lewis (2010). However, the pseudo-R^2 for the Oklahoma Panhandle regional regression equations were comparable to those reported by Capesius and Stephens (2009) for regional peak-streamflow frequency regression equations for the High Plains area of Colorado.

The standard error of prediction is derived from the sum of the model error variance and the sampling error of the regression model coefficients and is a measure of the

Table 4. Accuracy of regression-estimated peak-streamflow frequency statistics for sites on unregulated streams in and near the Oklahoma Panhandle.

Annual exceedance probability (percent)	Recurrence interval (years)	Pseudo-R^2, (coefficient of determination) (percent)	Average S_p (standard error of prediction) (percent)	Standard model error (percent)
50	2	38.48	147.82	138.48
20	5	51.30	103.99	97.52
10	10	56.42	92.64	86.40
4	25	60.61	85.76	79.24
2	50	62.14	84.01	77.09
1	100	63.10	83.72	76.33
0.2	500	61.38	91.87	83.62

expected accuracy of the regression estimates for the selected annual exceedance probabilities. The standard error of prediction generally ranges from 30 to 60 percent for most regional and statewide peak-streamflow frequency regression equations in the United States but often exceeds 60 percent for regions in the western United States where the network of streamflow-gaging stations is less dense and the periods of record are generally shorter (Jennings and others, 1994). The standard errors of prediction for the Oklahoma Panhandle regional regression equations ranged from about 84 to 148 percent (table 4) and were greater than the corresponding standard error of prediction (which ranged from about 32 to 47 percent) for the Oklahoma statewide regression equations of Lewis (2010). However, standard errors of prediction for the Oklahoma Panhandle regional regression equations were comparable to those reported by Asquith and Slade (1997) and Capesius and Stephens (2009) for regional peak-streamflow frequency regression equations for the High Plains areas of Texas and Colorado, respectively.

The standard model error, which depends on the number and predictive power of the independent variables, measures the ability of these variables to estimate peak-streamflow frequency statistics from the station records that were used to develop the equation. The standard model error typically is slightly smaller than the standard error of prediction (Jennings and others, 1994) for the same peak-streamflow frequency regression equation. The standard model errors for the Oklahoma Panhandle regional regression equations ranged from about 76 to 138 percent (table 4) and were greater than the corresponding standard model errors (which ranged from about 31 to 46 percent) for the Oklahoma statewide regression equations of Lewis (2010). However, standard model errors for the Oklahoma Panhandle regional regression equations were comparable to those reported by Capesius and Stephens (2009) for regional peak-streamflow frequency regression equations for the High Plains area of Colorado.

These three performance metrics, as presented in table 4, quantify the fit of a regression model with respect to the set of observations used to formulate the regression model. Because the Oklahoma Panhandle regional regression equations and the Oklahoma statewide regression equations were formulated using different sets of observations, these three performance metrics are not ideal for direct comparisons of accuracy between table 4 of this report and the corresponding table 4 of Lewis (2010); therefore, a fourth performance metric, the root mean square error (RMSE) (Helsel and Hirsch, 2002) was calculated to directly compare the accuracy of the estimated peak streamflow statistics for the irrigated period of record in the Oklahoma Panhandle using the Oklahoma Panhandle regional regression equations and the Oklahoma statewide regression equations. The RMSEs for the Oklahoma Panhandle regional regression equations (ranging from 3,170 to 92,000 cubic feet per second [ft^3/s]; table 1) were less than the RMSEs for the Oklahoma statewide regression equations (ranging from 18,900 to 412,000 ft^3/s; table 1); therefore, the Oklahoma Panhandle regional regression equations produce more accurate peak-streamflow statistic estimates for the irrigated period of record in the Oklahoma Panhandle than do the Oklahoma statewide regression equations.

The regression equations developed in this report are applicable to streams in the Oklahoma Panhandle statistical region that are not substantially affected by regulation, impoundment, or surface-water withdrawals. These regression equations are intended for use for stream sites with contributing drainage areas less than or equal to about 2,060 mi^2, the maximum value for the independent variable used in the regression analysis (table 1).

Summary

This report presents the results of a cooperative study by the U.S. Geological Survey and the Oklahoma Department of Transportation to estimate the magnitude and frequency of peak streamflows from regional regression equations for ungaged stream sites in and near the Oklahoma Panhandle. These methods relate basin characteristics (physiographic and climatic attributes) to selected peak-streamflow frequency statistics with the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probabilities. These relations were developed based on data from 32 selected streamflow-gaging stations in the Oklahoma Panhandle and in neighboring parts of Colorado, Kansas, New Mexico, and Texas. The basin characteristics for the selected streamflow-gaging stations were determined by using a geographic information system and the Oklahoma StreamStats application. Peak-streamflow frequency statistics were computed from annual peak-streamflow records from the irrigated period of record from water year 1978 through water year 2014.

Generalized-least-squares multiple-linear regression analysis was used to formulate regression relations between peak-streamflow frequency statistics and basin characteristics. Contributing drainage area was the only basin characteristic determined to be statistically significant for all percentage of annual exceedance probabilities and was the only basin characteristic used in this report for regional regression equations for estimating peak-streamflow frequency statistics on unregulated streams in and near the Oklahoma Panhandle. The regression model pseudo-coefficient of determination, converted to percent, for the Oklahoma Panhandle regional regression equations ranged from about 38 to 63 percent. The standard errors of prediction and the standard model errors for the Oklahoma Panhandle regional regression equations ranged from about 84 to 148 percent and from about 76 to 138 percent, respectively. These errors were comparable to those reported for regional peak-streamflow frequency regression equations for the High Plains areas of Texas and Colorado. The root mean square errors for the Oklahoma Panhandle regional regression equations (ranging from 3,170 to 92,000 cubic feet per second) were less than the root mean square errors for the Oklahoma statewide regression equations (ranging from 18,900 to 412,000 cubic feet per second); therefore, the Oklahoma Panhandle regional regression equations produce more accurate peak-streamflow statistic estimates for the irrigated period of record in the Oklahoma Panhandle than do the Oklahoma statewide regression equations. The regression equations developed in this report are applicable to streams that are not substantially affected by regulation, impoundment, or surface-water withdrawals. These regression equations are intended for use on stream sites with contributing drainage areas less than or equal to about 2,060 square miles, the maximum value for the independent variable used in the regression analysis.

References Cited

Asquith, W.H., and Slade, R.M., Jr., 1997, Regional equations for estimation of peak-streamflow frequency for natural basins in Texas: U.S. Geological Survey Water-Resources Investigations Report 96–4307, 68 p.

Capesius, J.P., and Stephens, V.C., 2009, Regional regression equations for estimation of natural streamflow statistics in Colorado: U.S. Geological Survey Scientific Investigations Report 2009–5136, 46 p.

Cleveland, W.S., 1985, The elements of graphing data: Monterey, Calif., Wadsworth Books, 323 p.

Cleveland, W.S., and McGill, Robert, 1984, Graphical perception—Theory, experimentation, and application to the development of graphical methods: Annals of Mathematical Statistics, v. 21, p. 557–569.

Crippen, J.R., and Bue, C.D., 1977, Maximum floodflows in the conterminous United States: U.S. Geological Survey Water-Supply Paper 1887, 52 p.

Eng, Ken, Chen, Yin-Yu, and Kiang, J.E., 2009, User's guide to the weighted-multiple-linear-regression program (WREG version 1.0): U.S. Geological Survey Techniques and Methods, book 4, chap. A8, 21 p.

Esralew, R.A., and Lewis, J.M., 2010, Trends in base flow, total flow, and base-flow index of selected streams in and near Oklahoma through 2008: U.S. Geological Survey Scientific Investigations Report 2010–5104, 143 p.

Esralew, R.A., and Smith, S.J., 2010, Methods for estimating flow-duration and annual mean-flow statistics for ungaged streams in Oklahoma: U.S. Geological Survey Scientific Investigations Report 2009–5267, 131 p.

Fry, J.A., Xian, George, Jin, Suming, Dewitz, J.A., Homer, C.G., Yang, Limin, Barnes, C.A., Herold, N.D., and Wickham, J.D., 2011, Completion of the 2006 National Land Cover Database for the conterminous United States, Photogrammetric Engineering and Remote Sensing, v. 77, no. 9, p. 858–864.

Griffis, V.W., and Stedinger, J.R., 2007, The use of GLS regression in regional hydrologic analyses: Journal of Hydrology, v. 344, p. 82–95.

Gurdak, J.J., and Roe, C.D., 2009, Recharge rates and chemistry beneath playas of the High Plains aquifer—A literature review and synthesis: U.S. Geological Survey Circular 1333, 39 p.

Heimann, D.C., and Tortorelli, R.L., 1988, Statistical summaries of streamflow records in Oklahoma and parts of Arkansas, Missouri, and Texas through 1984: U.S. Geological Survey Water-Resources Investigations Report 87–4205, 387 p.

Helsel, D.R., and Hirsch, R.M., 2002. Statistical methods in water resources: U.S. Geological Survey Techniques of Water Resources Investigations, book 4, chap. A3, 522 p.

Horizon Systems Corporation, 2010, National Hydrography Dataset Plus (NHDPlus): Horizon Systems Corporation, accessed November 1, 2010, at http://www.horizon-systems.com/nhdplus/.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flow frequency: Reston, Va., U.S. Geological Survey, Office of Water Data Coordination, Hydrology Subcommittee Bulletin 17B [variously paged].

Jennings, M.E., Thomas, W.O., Jr., and Riggs, H.C., 1994, Nationwide summary of U.S. Geological Survey regional regression equations for estimating magnitude and frequency of floods for ungaged sites, 1993: U.S. Geological Survey Water-Resources Investigations Report 94–4002, 196 p., floppy disk.

Judd, L.J., Asquith, W.H., and Slade, R.M., Jr., 1996, Techniques to estimate generalized skew coefficients of annual peak streamflow for natural basins in Texas: U.S. Geological Survey Water-Resources Investigations Report 96–4117, 28 p.

Kendall, M.G., 1938, A new measure of rank correlation: Biometrika, v. 30, p. 81–93.

Kendall, M.G., 1975, Rank correlation methods (4th ed.): London, U.K., Charles Griffin.

Lewis, J.M., 2010, Methods for estimating the magnitude and frequency of peak streamflows for unregulated streams in Oklahoma: U.S. Geological Survey Scientific Investigations Report 2010–5137, 41 p.

Lewis, J.M., and Esralew, R.A., 2009, Statistical summaries of streamflow in and near Oklahoma through 2007: U.S. Geological Survey Scientific Investigations Report 2009–5135, 633 p.

Lumia, Richard, Freehafer, D.A., and Smith, M.J., 2006, Magnitude and frequency of floods in New York: U.S. Geological Survey Scientific Investigations Report 2006–5112, 152 p.

McGuire, V.L., 2014, Water-level changes and change in water in storage in the High Plains aquifer, predevelopment to 2013 and 2011–13: U.S. Geological Survey Scientific Investigations Report 2014–5218, 14 p., http://dx.doi.org/10.3133/sir20145218.

Multi-Resolution Land Characteristics Consortium, 2011, National Land Cover Database 2006 (NLCD 2006): U.S. Geological Survey, accessed October 3, 2011, at http://www.mrlc.gov/nlcd2006.php.

National Oceanic and Atmospheric Administration, 2015a, National Climatic Data Center climate data online, accessed June 17, 2015, at http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp.

National Oceanic and Atmospheric Administration, 2015b, U.S. Climate Divisions, accessed June 17, 2015, at http://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php.

Oklahoma Department of Transportation, 2009, Preliminary hydraulic report requirements: Oklahoma Department of Transportation, July 2009, Oklahoma City, Oklahoma, 6 p.

Oklahoma Water Resources Board, 1984, Oklahoma's water atlas: Norman, Oklahoma, Publication 120, 186 p.

Qi, S.L., 2010, Digital map of the aquifer boundary of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Data Series 543.

Qi, S.L., Konduris, Alexandria, Litke, D.W., Dupree, Jean, 2002, Location of irrigated land classified from satellite imagery - High Plains area, nominal date 1992: U.S. Geological Survey Open-File Report 2002–441, accessed June 29, 2015, at http://pubs.er.usgs.gov/publication/ofr2002441.

Rasmussen, P.P., and Perry, C.A., 2000, Estimation of peak streamflows for unregulated rural streams in Kansas: U.S. Geological Survey Water-Resources Investigations Report 2000–4079, 33 p.

Ries, K.G., III, and Dillow, J.A., 2006, Magnitude and frequency of floods on nontidal streams in Delaware: U.S. Geological Survey Scientific Investigations Report 2006–5146, 57 p.

Ries, K.G., III, Guthrie, J.G., Rea, A.H., Steeves, P.A., Stewart, D.W., 2008, StreamStats—A water resources web application: U.S. Geological Survey Fact Sheet 2008–3067, 6 p. (Also available at http://pubs.usgs.gov/fs/2008/3067/.)

Ries, K.G., III, Steeves, P.A., Coles, J.D., Rea, A.H., and Stewart, D.W., 2004, StreamStats—A U.S. Geological Survey web application for stream information: U.S. Geological Survey Fact Sheet 2004–3115, 4 p.

Sen, P.K., 1968, Estimates of the regression coefficient based on Kendall's Tau: Journal American Statistics Association, v. 63, p. 1379–1389.

Sherwood, J.M., Ebner, A.E., Koltun, G.F., and Astifan, B.M., 2007, Flood of June 22–24, 2006, in north-central Ohio, with emphasis on the Cuyahoga River near Independence: U.S. Geological Survey Scientific Investigations Report 2007–5161, 18 p.

Smith, S.J., and Esralew, R.A., 2010, StreamStats in Oklahoma—Drainage-basin characteristics and peak-flow frequency statistics for ungaged streams: U.S. Geological Survey Scientific Investigations Report 2009–5255, 59 p.

Stedinger, J.R., and Tasker, G.D., 1985, Regional hydrologic analysis 1. Ordinary, weighted, and generalized least squares compared: Water Resources Research, v. 21, p. 1421–1432.

U.S. Army Corps of Engineers, 1966, Optima dam and reservoir: U.S. Army Corps of Engineers tri-fold brochure and map, October 1966.

U.S. Census Bureau, 2014, TIGER/Line shapefiles and TIGER/Line files, accessed December 30, 2014, at https://www.census.gov/geo/maps-data/data/tiger-line.html.

U.S. Geological Survey, 2014a, PeakFQ: Computer program, ver. 7.1., accessed January 8, 2015, at http://water.usgs.gov/software/PeakFQ/.

U.S. Geological Survey, 2014b, The national map viewer, accessed December 30, 2014, at http://viewer.nationalmap.gov/viewer/.

U.S. Geological Survey, 2015a, Annual water data report, accessed January 12, 2015, at http://wdr.water.usgs.gov/.

U.S. Geological Survey, 2015b, USGS water data for the Nation: National Water Information System, accessed January 12, 2015, at http://waterdata.usgs.gov/nwis/.

Vose, R.S., Applequist, Scott, Squires, Mike, Durre, Imke, Menne, M.J., Williams, C.N., Jr., Fenimore, Chris, Gleason, Karin, Arndt, Derek, 2014, Improved historical temperature and precipitation time series for U.S. climate divisions: Journal of Applied Meteorology and Climatology, accessed January 8, 2015, at http://dx.doi.org/10.1175/JAMC-D-13-0248.1.

Wahl, K.L., and Tortorelli, R.L., 1997, Changes in flow in the Beaver-North Canadian River Basin upstream from Canton Lake, western Oklahoma: U.S. Geological Survey Scientific Investigations Report 96–4304, 58 p.

Wahl, K.L., and Wahl, T.L., 1988, Effects of regional groundwater level declines on streamflow in the Oklahoma Panhandle: American Water Resources Association Proceeding of Symposium on Water-Use Data for Water Resources Management, August 1988, Tucson, Arizona, p. 239–249.

Publishing support provided by
Lafayette Publishing Service Center

Smith and others—**Methods for Estimating the Magnitude and Frequency of Peak Streamflows at Ungaged Sites**—SIR 2015–5134

ISSN 2328-0328 (online)
http://dx.doi.org/10.3133/sir20155134