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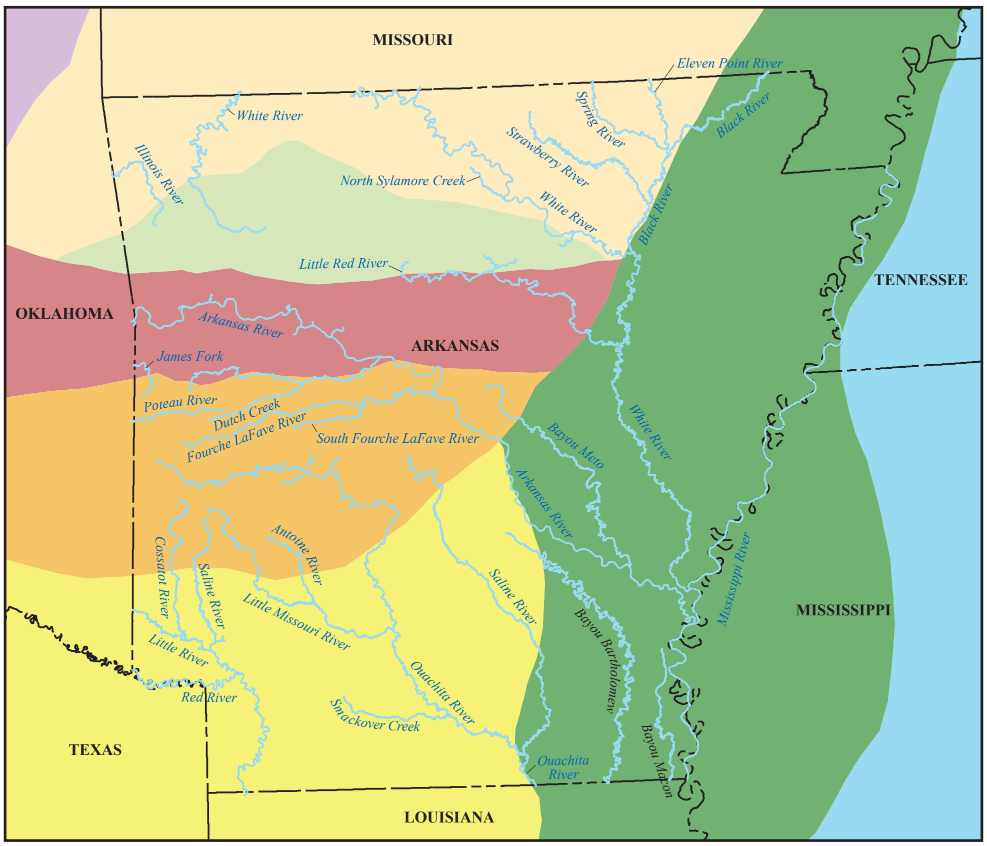

Scientific Investigations Report 2019–5131

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

Cover. Physiographic sections in Arkansas and surrounding States (modified from figure 1).

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DAVID BERNHARDT, Secretary

U.S. Geological Survey
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Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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).

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

Supplemental Information

A water year is the period from October 1 to September 30 and is designated by the year in which it ends; for example, water year 2015 was from October 1, 2014, to September 30, 2015.

Abbreviations

AEP	annual exceedance probability
AEPF	annual exceedance probability flood
EMA	Expected Moments Algorithm
LOESS	locally estimated scatterplot smoothing
PD	percentage difference
RI	recurrence interval
RRE	regional regression equation
USGS	U.S. Geological Survey

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Flood-Frequency Comparison from 1995 to 2016 and Trends in Peak Streamflow in Arkansas, Water Years 1930–2016

By Paul A. Ensminger and Brian K. Breaker

Abstract

In 2016, the U.S. Geological Survey, in cooperation with the U.S. Army Corps of Engineers and the Federal Emergency Management Agency, began a study in Arkansas to investigate possible increasing trends in annual peak streamflow data and the possible resulting increase in the annual exceedance probability flood (AEPF) predictions. Temporal trends of peak streamflow were investigated at 15 selected streamgages on unregulated streams in Arkansas having 30 or more years of peak streamflow data through the 2016 water year. For the period of record at each streamgage, the Mann-Kendall trend test indicated that 14 of the 15 streamgages had no statistically significant peak streamflow trends and 1 streamgage had a statistically significant decreasing peak streamflow trend. Visual examination of the locally estimated scatterplot smoothing technique trend lines of the peak streamflow data indicated a possible increasing peak streamflow trend at 8 of the 15 streamgages since the 1990s.

A sequential series analysis of the 1-percent AEPF at each of the 15 selected streamgages was completed by selecting an initial subset of the oldest peak streamflow data from each site to estimate the initial 1-percent AEPF. This initial peak streamflow data subset was subsequently appended with 10-year increments of additional peak streamflow data until the full period of peak streamflow data was analyzed. The maximum increase in the 1-percent AEPF was 113 percent, and the maximum decrease was 31.9 percent.

Percentage differences between the AEPFs derived from regional regression equations presented in the 1995 and 2016 Arkansas flood-frequency reports were compared. The average percentage differences for the 74 selected locations indicate that the 4-, 2-, 1-, and 0.2-percent AEPFs computed using the 2016 regional regression equations were higher by 3.52, 5.10, 8.59, and 13.31 percent, respectively (25-, 50-, 100-, and 500-year recurrence interval floods), than the same percentage AEPFs computed using the 1995 regional regression equations. The average percentage differences between the 1995 and 2016 AEPFs for the 10-percent AEPF (10-year recurrence interval flood) resulted in 2016 AEPF predictions being 0.41 percent higher. For the 50- and 20-percent AEPFs (2- and 5-year recurrence interval floods), the 2016 AEPFs were less than the 1995 AEPFs by 2.53 and 0.31 percent, respectively.

Introduction

Significantly increasing peak streamflow trends are of concern to local, State, and Federal agencies in Arkansas because of the corresponding increased flood risk to highway structures and surrounding communities. The risk of flooding can be characterized by annual exceedance probability flood (AEPF) predictions, which are developed from peak streamflow data and flood-frequency analysis. Transportation and drainage infrastructure, such as bridges, culverts, channels, canals, dams, and levees, generally is designed and operated under the assumption of stationarity (Milly and others, 2008), which implies that natural and anthropogenic-induced changes are too small to significantly affect statistical characteristics like annual peak streamflow (Walter and Vogel, 2010). However, substantial natural and anthropogenic changes might result in significant trends within the annual peak streamflow data.

When completing flood-frequency analyses, the peak streamflow data are assumed to be stationary and their statistical properties are unchanged over time, according to Bulletin 17B, “Guidelines for Determining Flood Flow Frequency” (Interagency Committee on Water Data, 1982). However, stationary and nonstationary peak streamflow data are effectively indistinguishable because of the paucity of observation records except where changes in the underlying processes are so dramatic that no statistical assessment is necessary (Lins and Cohn, 2011). Additionally, there can be multidecadal and century-scale variation in streamflow lending to multiyear periods in those records that may indicate uptrends and downtrends and, thus, are not necessarily indicative of a persistent change in the system (Cohn and Lins, 2005).

Hirsch (2011) denoted the importance of frequent updates to flood-frequency analyses to assist water-resources management in the design of structures that are dependent on the hydrologic variables that result from these analyses. In Arkansas, the two most recent flood-frequency reports were published in 1995 (Hodge and Tasker, 1995) and 2016 (Wagner and others, 2016) and documented the regional regression equations (RREs) used to calculate the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent AEPFs. The U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers and the Federal Emergency Management Agency, completed a study to determine if significant increasing trends exist in annual peak streamflow data from Arkansas and to compare the percentage differences (PDs) of the AEPF estimates from the two most recently published flood-frequency reports for Arkansas.

Purpose and Scope

This report presents (1) an analysis of trends within peak streamflow data for 15 selected streamgage sites in Arkansas and (2) the PDs between the 1995 and 2016 Arkansas AEPFs for the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent AEPFs at the 15 selected sites and at ungaged sites at the 0-, 10-, 50-, and 85-percent lengths of each of the 15 selected streams where those locations were within the boundaries of the State.

Study Area

The geographic scope of this report encompasses most of Arkansas (fig. 1). Arkansas is characterized by a diverse topography and contains parts of six physiographic sections: the Springfield-Salem Plateaus, Boston Mountains, Arkansas Valley, Ouachita Mountains, West Gulf Coastal Plain, and Mississippi Alluvial Plain (Wagner and others, 2016). The climate in Arkansas is mild and moderately humid. For the period 1951–2011, mean annual precipitation for the State was 49.8 inches (in.) and ranged from 44 in. in the Springfield-Salem Plateaus near the Missouri State line and the Arkansas Valley near the Oklahoma State line to 64 in. in the Ouachita Mountains (Pugh and Westerman, 2014).

Arkansas Flood-Frequency Reports from 1995 and 2016

Wagner and others (2016) used data collected through 2013 and the Expected Moments Algorithm (EMA) for fitting the Log-Pearson Type III distribution of the annual peak streamflow data that were used to estimate AEPFs (Cohn and others, 1997, 2001; Griffis and others, 2004). The use of the EMA method to estimate AEPF events was recommended by the Subcommittee on Hydrology as a revision to Bulletin 17B (Advisory Committee on Water Information, Subcommittee on Hydrology, Hydrologic Frequency Analysis Work Group, written commun., 2013). The EMA method applies the Grubbs-Beck test to screen multiple potentially influential low floods that are not relevant to the processes associated with larger floods (Cohn and others, 2013). The EMA addresses several methodological concerns identified in Bulletin 17B while retaining the essential structure and moments-based approach procedures for determining flood frequency (Interagency Committee on Water Data, 1982). The EMA can accommodate interval data, which simplifies the analysis of datasets containing censored observations, historical and (or) paleo data, low outliers, and uncertain data points while also providing enhanced confidence intervals for the estimated streamflows (Veilleux and others, 2014). The 2016 report (Wagner and others, 2016) also incorporated an updated regional skew coefficient, which was developed for Arkansas using Bayesian weighted least-squares/generalized least-squares regression (Veilleux, 2009, 2011).

The 1995 Arkansas flood-frequency analysis (Hodge and Tasker, 1995) defined four flood regions and used data collected through 1993 from 204 streamgages to develop the RREs. In comparison, the 2016 Arkansas flood-frequency analysis (Wagner and others, 2016) documented five flood regions (dividing region B of the 1995 report into subregions B1 and B2; fig. 2) and used data collected through 2013 from 281 streamgages to develop RREs. The 1995 and 2016 RREs included some similar basin characteristics; however, the 2016 RREs typically included additional basin and climatic variables compared to the 1995 RREs. As a result, for the same streamflow location, the AEPF estimates from the 1995 (Hodge and Tasker, 1995) and 2016 (Wagner and others, 2016) flood-frequency reports may be different.

With respect to floods, the annual exceedance probability estimates the likelihood, in percent, of a specific magnitude flood occurring in any given year. For instance, a 1-percent AEPF is a flood with a 1-percent probability of occurring during any given year. Traditionally, AEPFs have been expressed as a recurrence interval (RI), in years, where 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent AEPFs were reported as 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year RI floods, respectively (Holmes and Dinicola, 2010). In terms of probability of occurrence, this means there is a 1 in 100 chance (or 1-percent probability) that in any single year, the 100-year flood (1-percent AEPF) will occur at a given location. However, some have erroneously interpreted the “100-year flood” to mean that a flood of that magnitude would be expected to occur only once during a 100-year period. In fact, a 1-percent AEPF (100-year flood) has a 1-percent probability of occurring in any given year, regardless of past flooding events.

The probability P that a flood with an annual exceedance probability, in percent, will occur at least once in an N-year period is shown in the following equation:

$$P=(1-[1-(AEP)]^{N}) \quad (1)$$

where

P is the probability of the annual exceedance probability (AEP) flood occurring over N-year period;

AEP is the annual exceedance probability, in percent; and

N is the number of years.

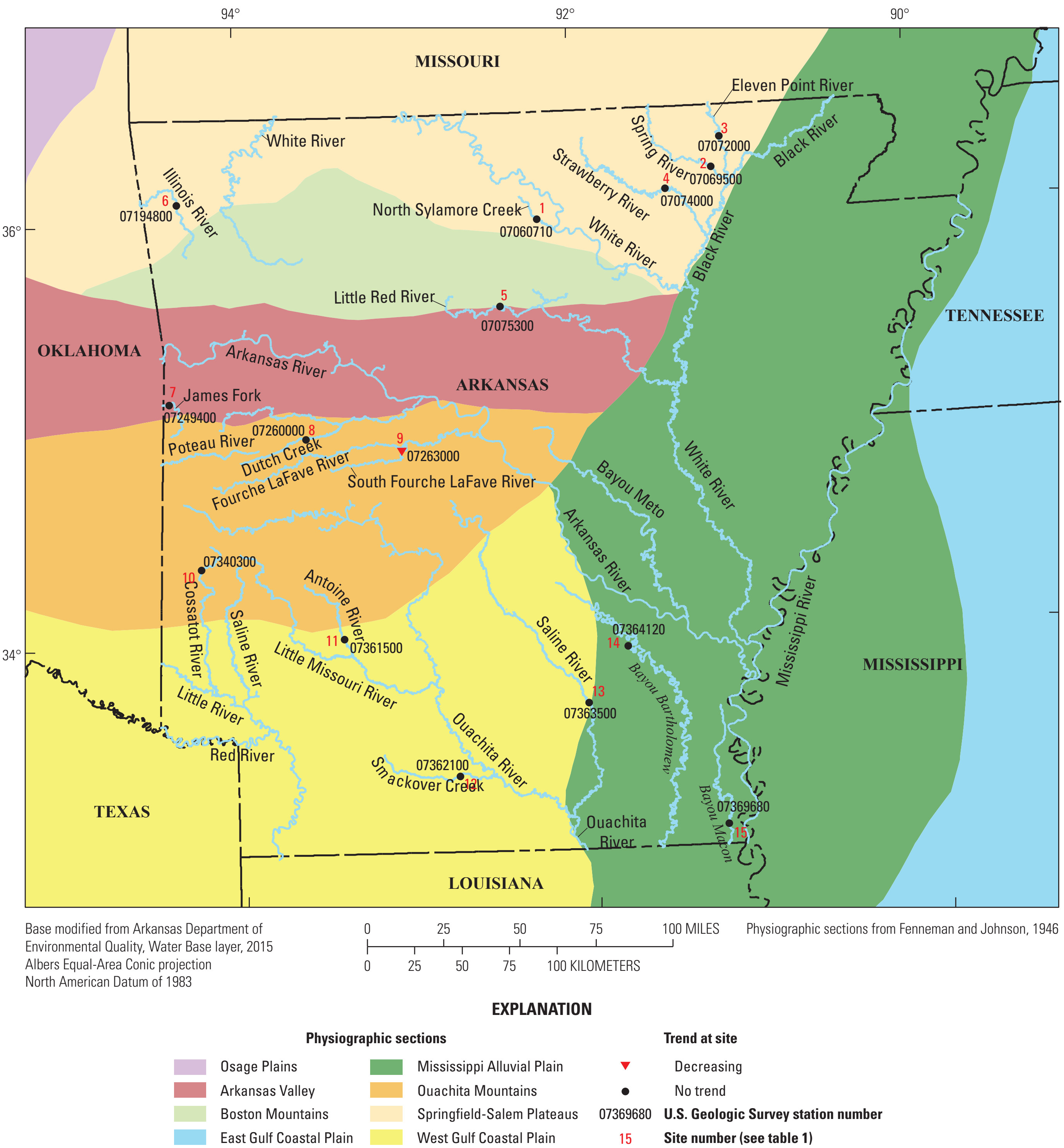


Figure 1. Locations of the 15 selected streamgages and physiographic sections in Arkansas and surrounding States.

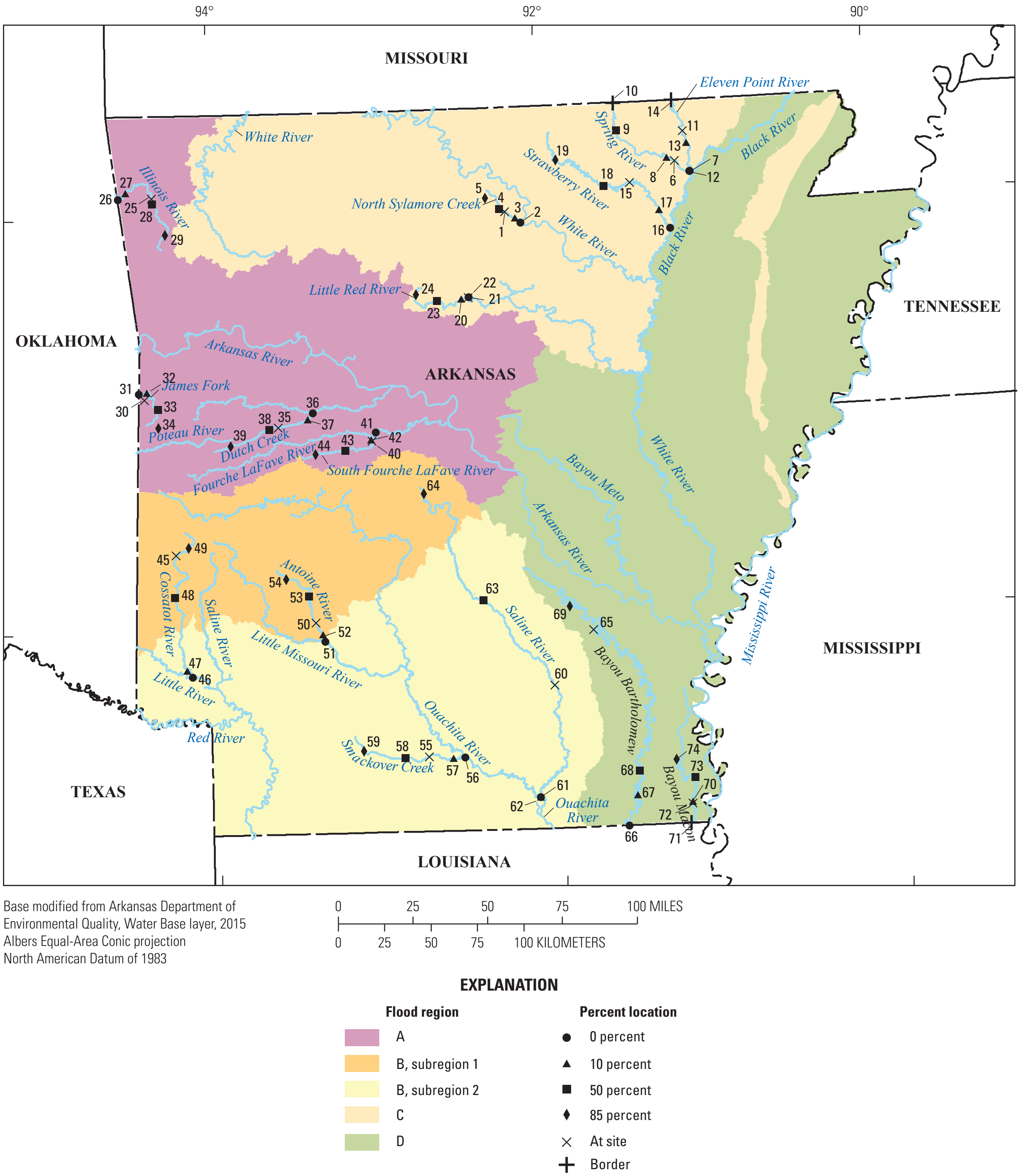


Figure 2. Flood regions (Wagner and others, 2016) and 74 selected locations where the 2016 and 1995 annual exceedance probability floods were computed. The 74 locations represent the 15 streamgages and the ungaged sites at the 0-, 10-, 50-, and 85-percent lengths along each of the 15 streams, terminating at the Arkansas border.

Using equation 1, a 1-percent AEP flood actually has a 26-percent probability of occurring within a 30-year period $\{P=(1-[1-(0.01)]^{30})\}$.

Methods and Results

The following sections describe the methods used to identify significantly increasing peak streamflow trends in Arkansas streams. The Mann-Kendall trend test and the locally estimated scatterplot smoothing (LOESS) technique were used to detect trends in the peak streamflow data at 15 selected streamgages for the period of 1930–2016. Temporal changes of the 1-percent AEPF that were attributed to the additional peak streamflow data resulting from increasing the period of record analyzed were investigated. In addition, the PDs in the 1-percent AEPFs derived using RREs from Hodge and Tasker (1995) and Wagner and others (2016) for 74 selected locations along 15 streams were compared for various annual exceedance probabilities, and the average PDs by flood region were analyzed. All streamflow data are publicly available from the USGS National Water Information System database (U.S. Geological Survey, 2016).

Mann-Kendall Tau Test for Trends in Peak Streamflows

Hydrologic data commonly have a nonnormal distribution, which means that statistical tests assuming an underlying normal distribution can be inadequate for trend detection (Kundzewicz and Robson, 2004). The nonparametric Mann-Kendall trend test assumes no underlying distribution and tests for the likelihood of an increasing or decreasing temporal peak streamflow trend. Annual peak streamflow data that were available for the 15 selected streamgages through the 2016 water year were analyzed for trends using the Mann-Kendall trend test. The Mann-Kendall trend test was used to compute the monotonic relation between peak streamflow and water year (Helsel and Hirsch, 2002) and resulted in a Kendall's tau coefficient that indicated the direction of the trend and the significance level or probability value (p-value). In this analysis, a trend was considered statistically significant if the p-value was less than or equal to 5 percent. Excluding the historic peak streamflow events and using the available peak streamflow record through 2016 for each streamgage, the p-value resulting from the Mann-Kendall trend test indicated 14 of the 15 selected streamgages had no statistically significant trends and 1 streamgage had a significant decreasing trend (fig. 1, table 1) as indicated from the p-value (p-values less than or equal to 0.05) and the negative value of Kendall's tau.

Locally Estimated Scatterplot Smoothing of Peak Streamflows

LOESS is a nonparametric regression technique for estimating regression surfaces (Cleveland and others, 1988, 1992) by smoothing a curve through a scatterplot and providing a visual representation of the trend pattern. For this study, the smoothing function attempts to capture the general patterns in the peak streamflow versus water-year relation. The LOESS trend line indicates the central tendency of the peak streamflow data with respect to water year and was evaluated using the LOESS function in R (R Core Team, 2016). The primary parameter affecting the smoothness of the fit is the span or window width. The span parameter controls how the data nearest to a specific point are weighted, and it affects the LOESS fit through that specific point. The selection of the span is determined subjectively according to the purpose of smoothing (Helsel and Hirsch, 2002). In this study, all LOESS trend lines were plotted using a span parameter of 0.75. Visual examination of LOESS trend line plots (fig. 3) indicated an increasing streamflow trend starting from the 1990s to the ending year for the period of record for eight streamgages (sites 1–3, 5, 7–8, 10, and 13 in fig. 1, fig. 3, and table 1). A similar trend could not be observed for site 14, Bayou Bartholomew near Star City (USGS station 07364120; table 1), because the period of record at that site ended in 1980.

One-Percent Annual Exceedance Probability Changes through Time

All annual peak streamflow events at a streamgage location throughout time are referred to as the "population" of peak streamflow data. The term "sample" refers to a part of this population that is representative of the population from which it was selected. The USGS peak streamflow data are "samples" of peak streamflow at a streamgage location. The length of a peak streamflow record used to estimate the 1-percent AEPF affects the accuracy and confidence limits in the estimates, and AEPF estimates become more accurate as the length of a peak streamflow record increases. In a short-term (10 to 20 years of annual peak streamflow data) record, the extreme peak streamflow events substantially affect the 1-percent AEPF statistics; however, as the length of the peak streamflow record increases, these extreme peak streamflow events have less effect, so the accuracy and confidence in the 1-percent AEPF estimates increases.

To evaluate temporal changes to the AEPF at streamgages, the 1-percent AEPFs (100-year RI floods) were calculated by sequentially apportioning the peak streamflow data from a short period-of-record segment to a longer segment and reevaluating the 1-percent AEPF using each longer segment. The initial 1-percent AEPF was derived from a 10- to

Table 1. The 15 selected streamgages and the associated Mann-Kendall trend results with probability (*p*) values for the designated period of record.

[*p*-values less than or equal to 0.05 are considered significant, and streamgages with significant trends are shaded in gray; USGS, U.S. Geological Survey; DA, contributing drainage area; mi^2, square mile; NPFSY, number of streamflow peaks (historic peak streamflow removed from trend analysis)]

Site number (fig. 1)	USGS station number (fig. 1)	USGS streamgage name	Period of record analyzed	DA (mi^2)	Latitude	Longitude	NPFSY	Mann-Kendall	
								Tau	*p*-value
1	07060710	North Sylamore Creek near Fifty Six, Arkansas	1966–2016	58.1	35.992	–92.214	50	0.145	0.139
2	07069500	Spring River at Imboden, Arkansas	1937–2016	1,180	36.206	–91.172	80	0.059	0.445
3	07072000	Eleven Point River near Ravenden Springs, Arkansas	1930–2016	1,130	36.346	–91.114	85	0.051	0.490
4	07074000	Strawberry River near Poughkeepsie, Arkansas	1937–2015	473	36.111	–91.449	79	–0.007	0.933
5	07075300	South Fork of Little Red River at Clinton, Arkansas	1962–2016	149	35.587	–92.451	55	0.075	0.425
6	07194800	Illinois River at Savoy, Arkansas	1980–2016	167	36.103	–94.344	24	0.105	0.487
7	07249400	James Fork near Hackett, Arkansas	1958–2016	147	35.163	–94.407	59	0.122	0.176
8	07260000	Dutch Creek at Waltreak, Arkansas	1946–2016	81.4	34.987	–93.613	71	0.025	0.766
9	07263000	South Fourche LaFave River near Hollis, Arkansas	1942–2014	210	34.912	–93.056	73	–0.207	0.010
10	07340300	Cossatot River near Vandervoort, Arkansas	1968–2016	89.6	34.380	–94.236	49	–0.023	0.823
11	07361500	Antoine River at Antoine, Arkansas	1951–2016	178	34.039	–93.418	65	0.077	0.365
12	07362100	Smackover Creek near Smackover, Arkansas	1939–2016	385	33.375	–92.777	78	0.003	0.976
13	07363500	Saline River near Rye, Arkansas	1938–2016	2,100	33.701	–92.025	79	–0.053	0.495
14	07364120	Bayou Bartholomew near Star City, Arkansas	1942–80	215	33.961	–91.785	32	–0.044	0.733
15	07369680	Bayou Macon at Eudora, Arkansas	1938–2016	500	33.100	–91.254	69	–0.052	0.531

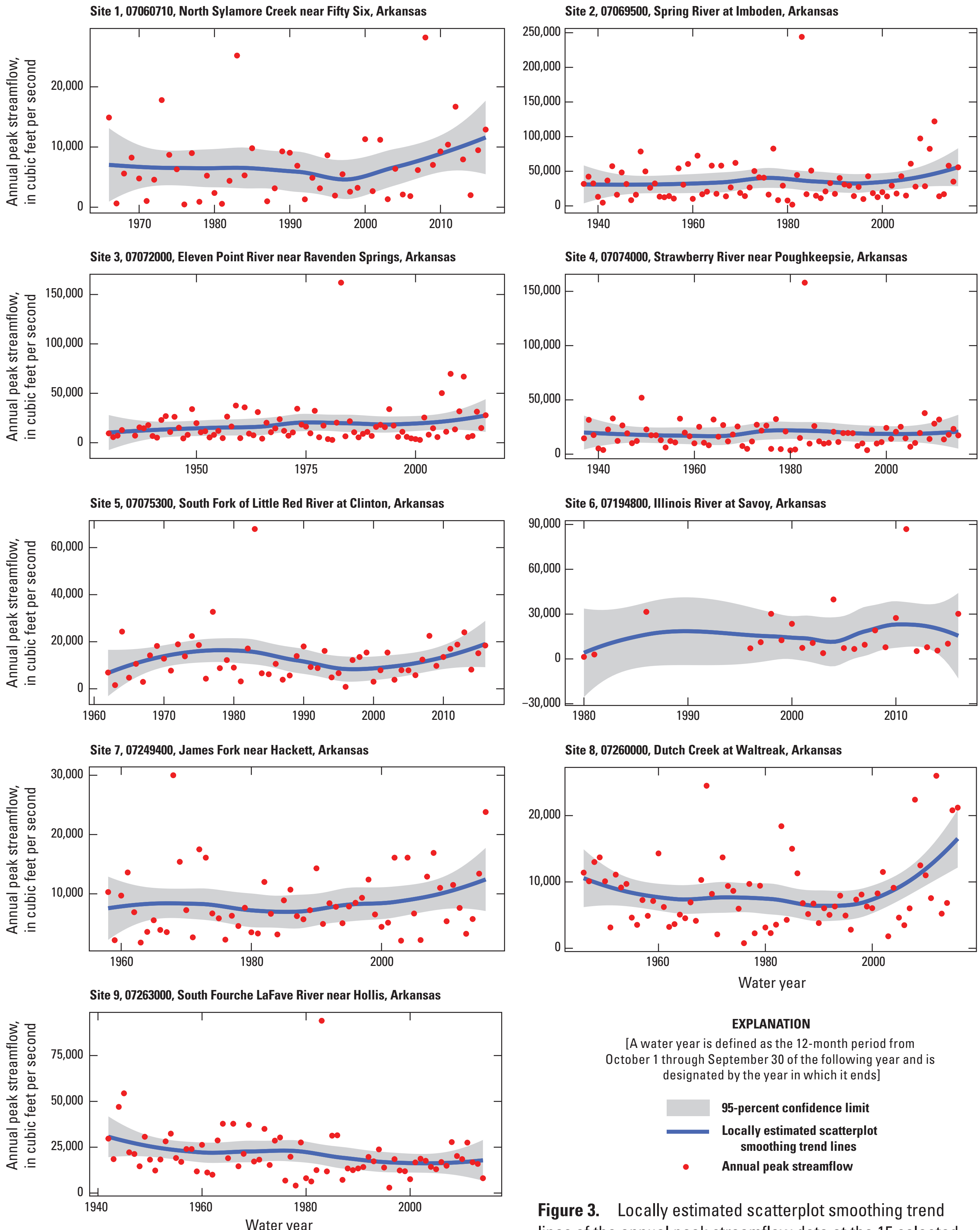


Figure 3. Locally estimated scatterplot smoothing trend lines of the annual peak streamflow data at the 15 selected streamgages for the full period of record.

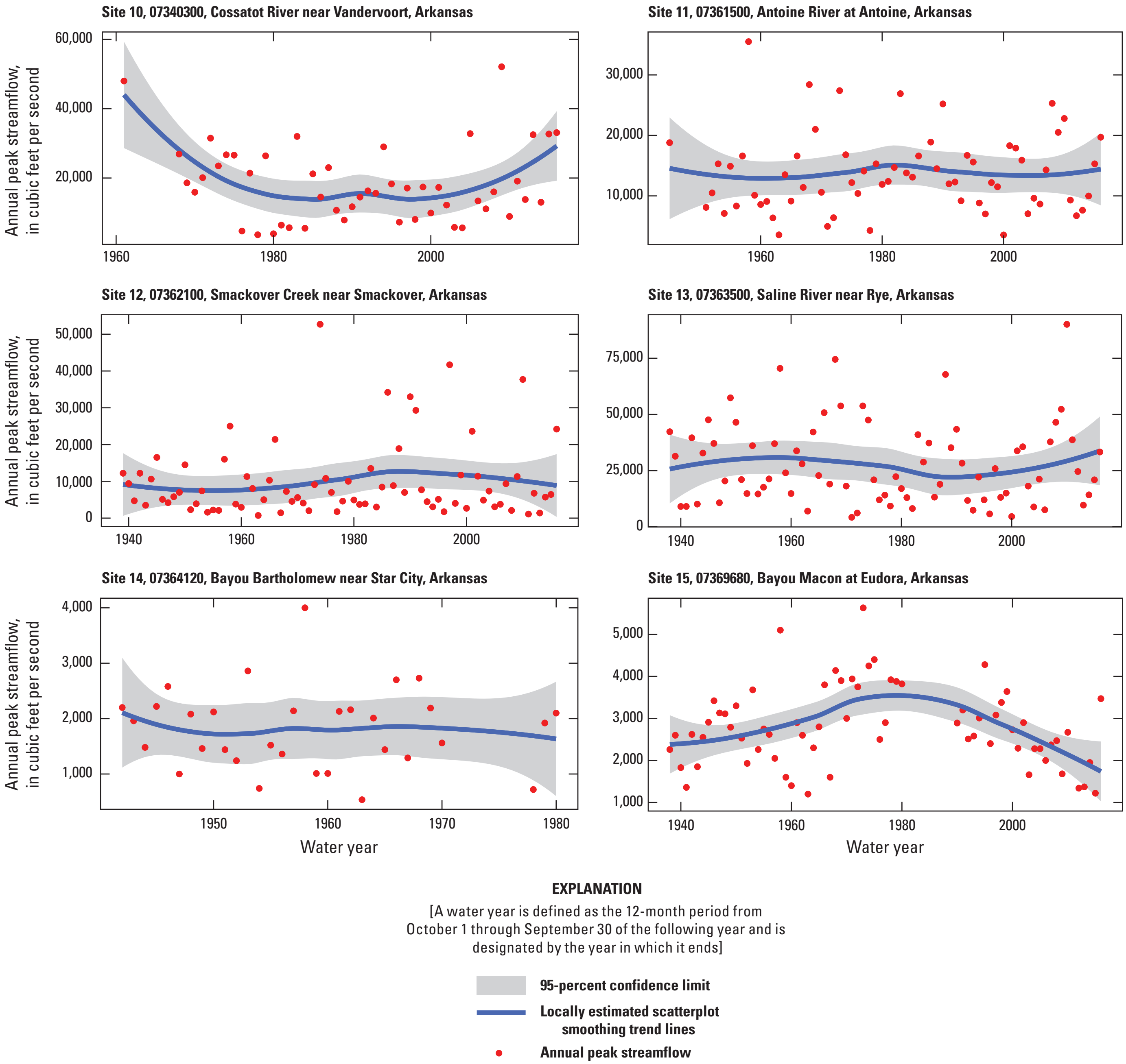


Figure 3. Graphs showing lLocally estimated scatterplot smoothing trend lines of the annual peak streamflow data at the 15 selected streamgages for the full period of record.–Continued

20-year annual peak streamflow subset of annual peak streamflow data that provided adequate number of peak streamflow data to initially estimate the initial 1-percent AEPF (table 2). Subsequently, the next 10 years of peak streamflow data were appended to this initial peak streamflow data subset, and the 1-percent AEPF was reevaluated. This process continued until the full period of record was analyzed for the 1-percent AEPF. The resulting sequential estimates of the 1-percent AEPF (table 2) were plotted with 90-percent confidence intervals and the annual peak streamflow data to document the temporal changes of the 1-percent AEPF with increasing peak streamflow record length at each streamgage location (fig. 4). The PDs of the sequential estimates from the initial 1-percent AEPF were calculated as follows:

$$PD:(Q_{1\%(N)}) = \frac{(Q_{1\%(N)} - Q_{1\%(I)})}{Q_{1\%(I)}} \times 100 \qquad (2)$$

where

PD: $(Q_{1\%(N)})$ is the percentage difference between the 1-percent AEPF from the Nth subset of peak streamflow data and the 1-percent AEPF ($Q_{1\%(I)}$) from the initial subset of peak streamflow data as listed in table 2;

$Q_{1\%(N)}$ is the 1-percent AEPF calculated from the Nth subset of peak streamflow data as listed in table 2; and

$Q_{1\%(I)}$ is the 1-percent AEPF calculated from the initial subset of peak streamflow data as listed in table 2.

This analysis indicated a maximum increase in the 1-percent AEPF of 113 percent at site 3 (fig. 1) on Eleven Point River in northeastern Arkansas and a maximum decrease in the 1-percent AEPF of 31.9 percent at site 7 (fig. 1) on James Fork in west-central Arkansas (table 2).

Arkansas Regional Regression Equations Comparison

The RREs were published for Arkansas in 1995 (Hodge and Tasker, 1995) for estimating AEPFs at ungaged locations in Arkansas. The RREs were updated in 2016 (Wagner and others, 2016) using 20 years of additional annual peak streamflow data, improved statistical techniques, and regionalized skews. The 2016 RREs also differed from the 1995 RREs by incorporating additional or different basin and climatic characteristics that were determined using geographic information systems and available digital datasets (Wagner and others, 2016).

The RREs from Hodge and Tasker (1995) and Wagner and others (2016) were used to estimate AEPFs at the 15 selected streamgages and compare PDs between the estimates. To broaden the range of the 2016 and 1995 AEPF comparisons, AEPFs also were computed at 59 ungaged sites that are 0-, 10-, 50-, and 85-percent locations along the 15 selected streams where these locations are within the Arkansas State boundary (fig. 4). The 0-percent location refers to the mouth of the stream on which the streamgage is located, and the 85-percent location refers to the distance 85 percent along the stream length, upstream from the mouth.

The PD change between AEPFs estimated from the 2016 and 1995 RREs at the 15 streamgage locations and the 59 percent locations along each of the selected streams (table 3) for each AEPF were calculated using the following equation:

$$PD_{(change)} = \frac{(AEPF_{(2016)} - AEPF_{(1995)})}{AEPF_{(1995)}} \times 100 \qquad (3)$$

where

$PD_{(change)}$ is the percentage difference change, which represents the percentage change between the 2016 AEPF estimates and the 1995 AEPF estimates;

$AEPF_{(2016)}$ is the AEPF calculated from the 2016 RRE (Wagner and others, 2016), in cubic feet per second; and

$AEPF_{(1995)}$ is the AEPF calculated from the 1995 RRE (Hodge and Tasker, 1995), in cubic feet per second.

PD change is positive when the 2016 AEPF estimates exceed the 1995 AEPF estimates. Conversely, PD change is negative when the 2016 AEPF estimates are less than the 1995 AEPF estimates. This analysis is based on a small sample size of 74 selected streamflow locations in Arkansas and, therefore, only reflects the actual PD changes that may exist between the 2016 and 1995 AEPFs. Also, the 2016 and 1995 AEPF standard error of estimate, in percent, far exceeds the PDs determined in this comparative analysis. Regardless, the average PD change between AEPFs at the 74 streamflow locations was calculated and plotted with the associated RI; the resulting graph shows a near linear relation between the average PD change and log base 10 transformed RI (fig. 5). The average PDs between the 2016 and 1995 AEPFs indicate the 2016 AEPF estimates were higher than the 1995 AEPFs by an average of 3.52, 5.10, 8.59, and 13.31 percent for the 4-, 2-, 1-, and 0.2-percent AEPFs (25-, 50-, 100-, and 500-year RI floods), respectively. The average PDs between the 2016 and 1995 AEPFs were similar for the 20-percent and 10-percent AEPFs (5-year and 10-year RI floods) and were 0.31 percent lower and 0.41 percent higher, respectively. For the 50-percent AEPF (2-year RI flood) estimate, the 2016 AEPFs were less than the 1995 AEPFs by an average PD of 2.53 percent (fig. 5).

The boxplots in figure 6 show the range of PDs from the 2016 and 1995 AEPFs and the differences between flood regions (fig. 2). The maximum PD of 112 percent was in region C at the 85-percent location at South Fork of Little Red River at Clinton (USGS station 07075300, site 5 in fig. 1 and sites 20–24 in fig. 2) for the 0.2-percent AEPF (500-year

Table 2. The 15 selected streamgages used in this study and the percentage differences from the initial 1-percent annual exceedance probability flood estimate for each subsequent 1-percent annual exceedance probability flood reevaluation.

[USGS, U.S. Geological Survey; %, percent; AEPF, annual exceedance probability flood; PD, percentage difference]

Site number (fig. 1)	USGS station number (fig. 1)	Period of record	1% AEPF	PD from 1% AEPF, in percent
1	07060710	1966–1976	26,200	0.00
		1966–1986	38,140	45.57
		1966–1996	34,010	29.81
		1966–2006	31,470	20.11
		1966–2016	35,950	37.21
2	[a]07069500	1915–1946	117,300	0.00
		1915–1956	134,800	14.92
		1915–1966	144,900	23.53
		1915–1976	118,900	1.36
		1915–1986	163,300	39.22
		1915–1996	149,800	27.71
		1915–2006	142,000	21.06
		1915–2016	154,500	31.71
3	07072000	1930–1946	40,440	0.00
		1930–1956	42,030	3.93
		1930–1966	55,050	36.13
		1930–1976	52,000	28.59
		1930–1986	78,340	93.72
		1930–1996	73,650	82.12
		1930–2006	75,270	86.13
		1930–2016	86,320	[b]113.45
4	07074000	1937–1955	61,730	0.00
		1937–1965	56,030	–9.23
		1937–1975	54,200	–12.20
		1937–1985	84,820	37.40
		1937–1995	75,890	22.94
		1937–2005	71,260	15.44
		1937–2015	68,720	11.32
5	07075300	1962–1976	51,530	0.00
		1962–1986	64,310	24.80
		1962–1996	55,220	7.16
		1962–2006	48,690	–5.51
		1962–2016	46,680	–9.41
6	07194800	1980–2006	78,230	0.00
		1980–2016	90,890	16.18
7	07249400	1958–1976	39,690	0.00
		1958–1986	31,520	–20.58
		1958–1996	27,040	[c]–31.87
		1958–2006	27,490	–30.74
		1958–2016	29,270	–26.25
8	[a]07260000	1927–1956	15,840	0.00
		1927–1966	19,710	24.43
		1927–1976	23,160	46.21
		1927–1986	24,910	57.26
		1927–1996	22,860	44.31
		1927–2006	21,790	37.56
		1927–2016	26,320	66.16
9	07263000	1942–1954	66,420	0.00
		1942–1964	60,540	–8.85
		1942–1974	58,220	–12.35
		1942–1984	73,850	11.19
		1942–1994	68,890	3.72
		1942–2004	65,550	–1.31
		1942–2014	61,770	–7.00
10	[a]07340300	1961–1976	69,390	0.00
		1961–1986	53,290	–23.20
		1961–1996	54,570	–21.36
		1961–2006	52,080	–24.95
		1961–2016	59,660	–14.02
11	[a]07361500	1905–1966	37,850	0.00
		1905–1976	39,710	4.91
		1905–1986	38,300	1.19
		1905–1996	36,930	–2.43
		1905–2006	35,280	–5.36
		1905–2016	36,000	–4.86
12	07362100	1939–1956	26,990	0.00
		1939–1966	36,810	36.38
		1939–1976	42,990	59.28
		1939–1986	43,710	61.95
		1939–1996	48,230	78.70
		1939–2006	51,250	89.89
		1939–2016	53,860	99.56
13	[a]07363500	1927–1946	112,800	0.00
		1927–1956	95,220	–15.59
		1927–1966	97,060	–13.95
		1927–1976	108,200	–4.08
		1927–1986	101,200	–10.28
		1927–1996	101,900	–9.66
		1927–2006	97,950	–13.16
		1927–2016	101,800	–9.75
14	07364120	1927–1960	4,297	0.00
		1927–1970	4,088	–4.86
		1927–1980	4,155	–3.30
15	[a]07369680	1932–1956	4,287	0.00
		1932–1966	4,920	14.77
		1932–1976	5,803	35.36
		1932–1986	5,810	35.53
		1932–1996	5,607	30.79
		1932–2006	5,427	26.59
		1932–2016	5,446	27.04

[a]Period of record includes historic peak streamflows.

[b]Value is the maximum increase in the 1-percent AEPF.

[c]Value is the maximum decrease in the 1-percent AEPF.

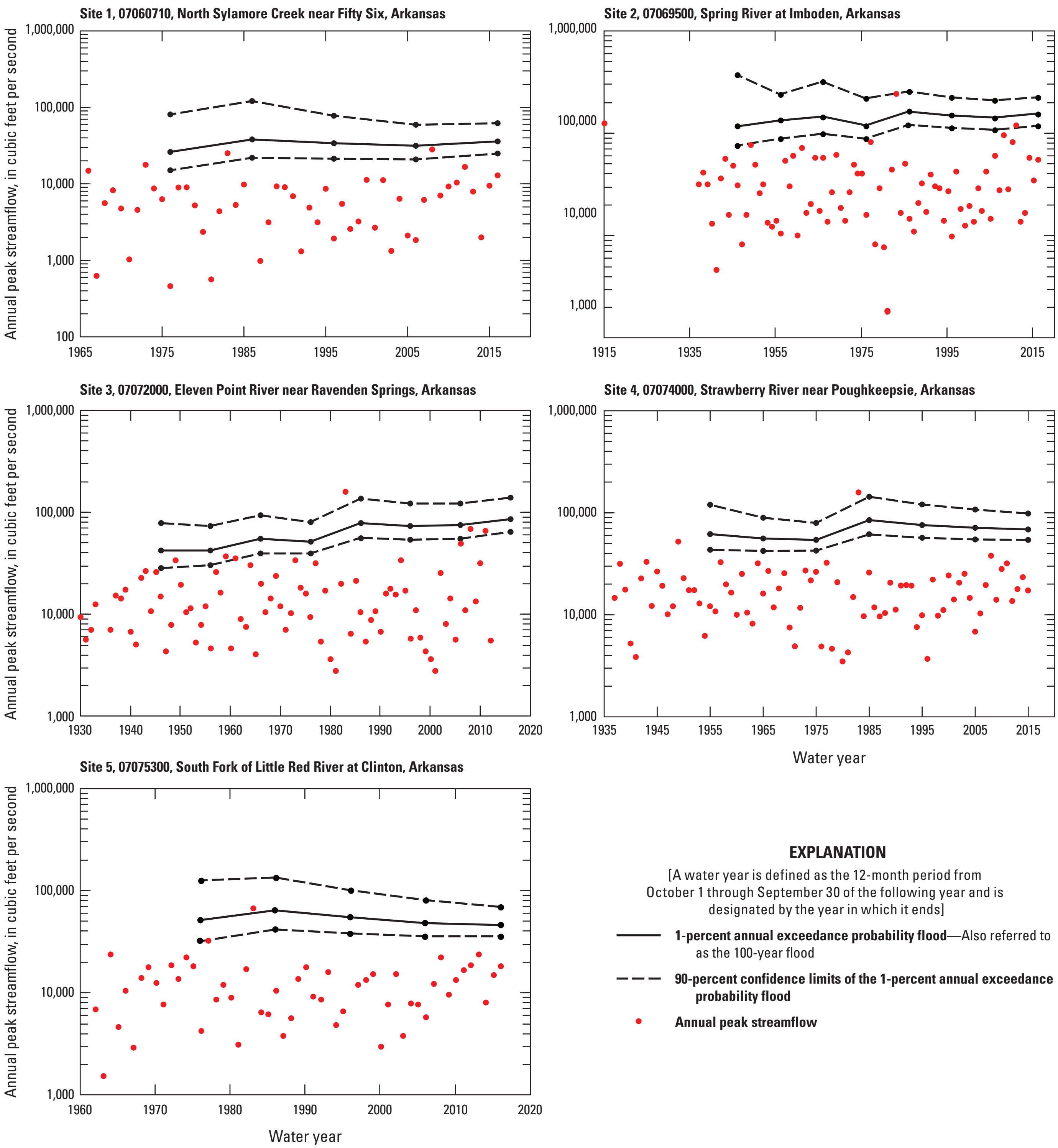


Figure 4. The 1-percent annual exceedance probability flood trend for the 15 selected streamgages plotted with the annual peak for the full period of record.

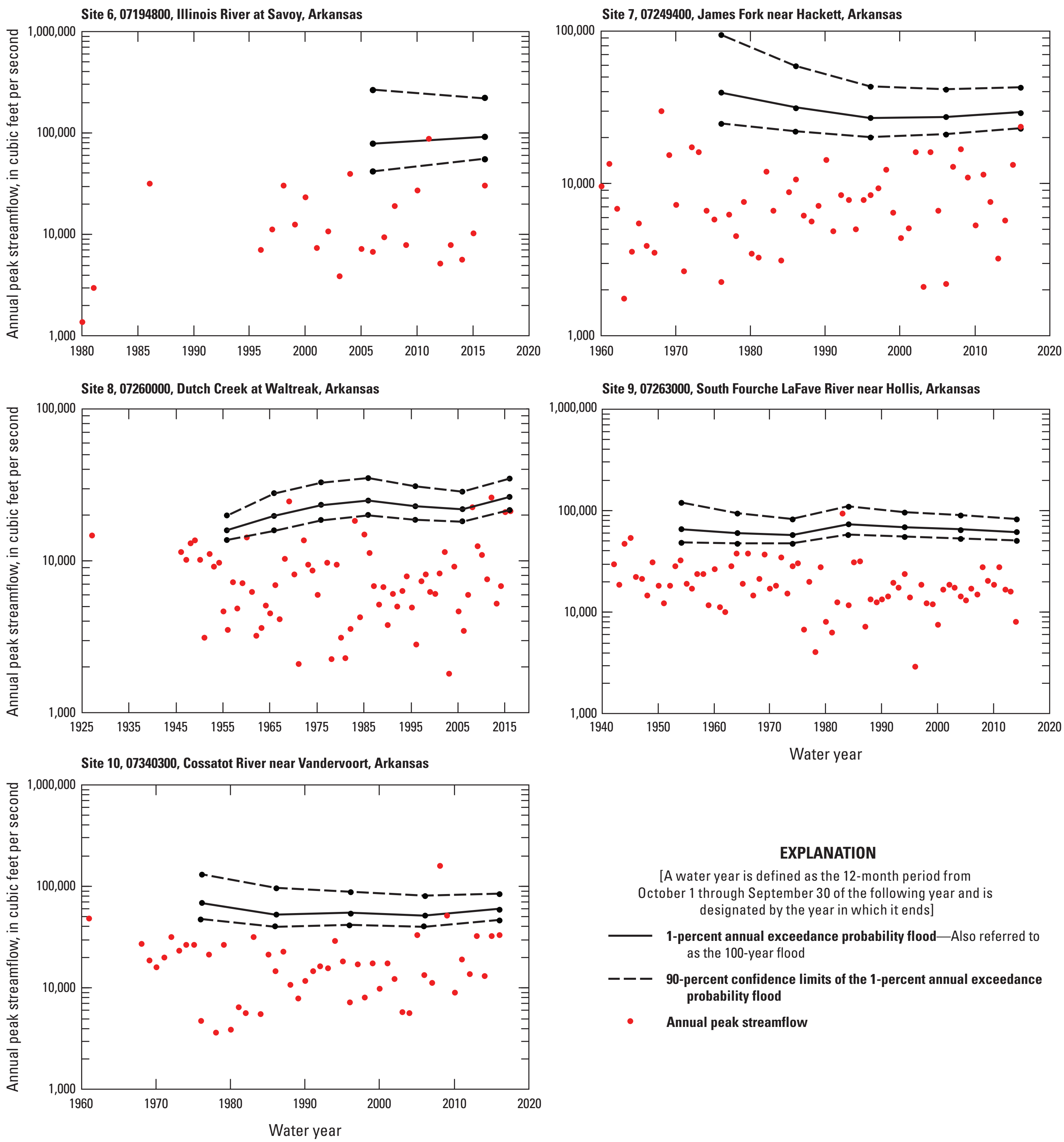


Figure 4. The 1-percent annual exceedance probability flood trend for the 15 selected streamgages plotted with the annual peak for the full period of record.–Continued

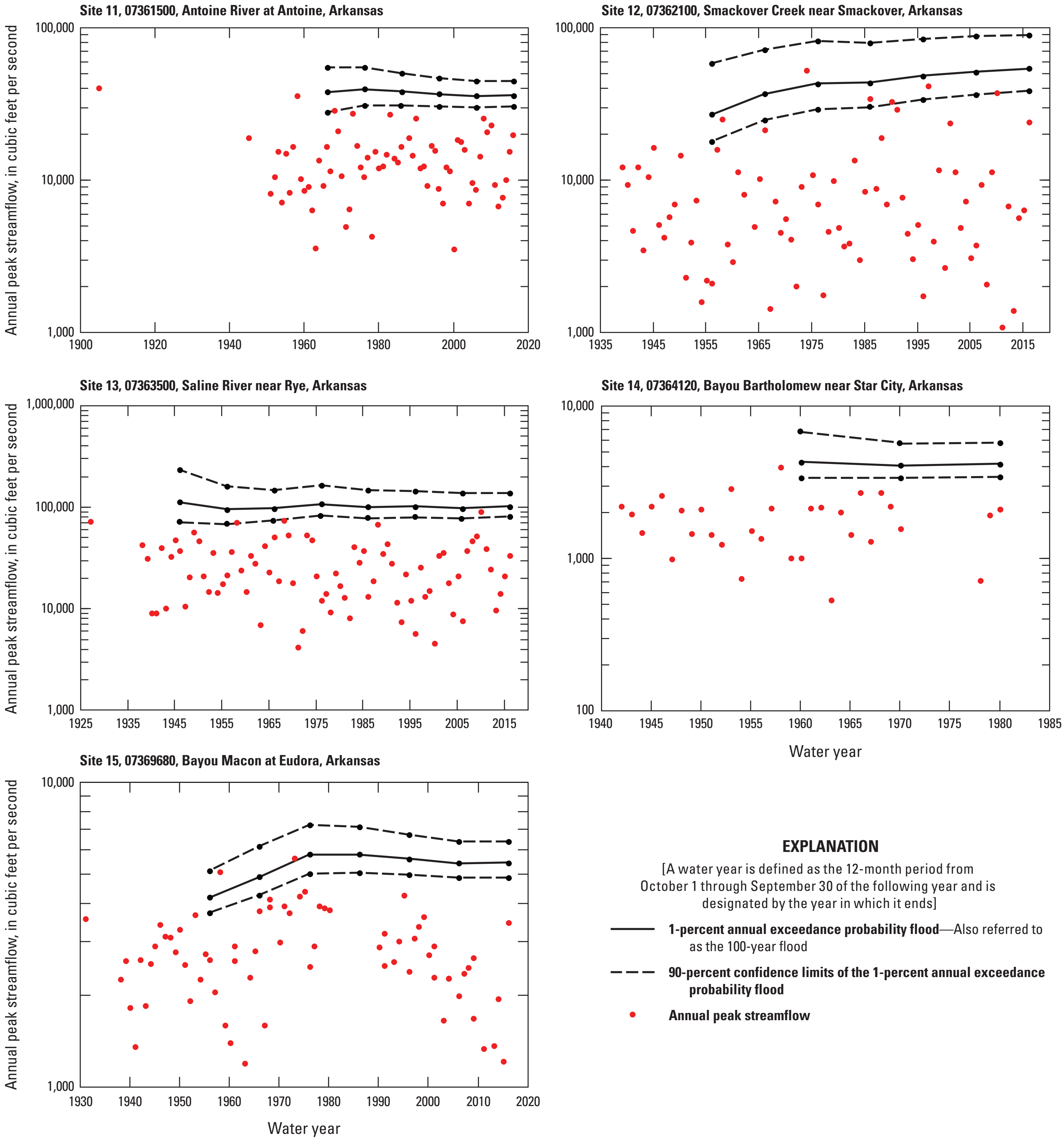
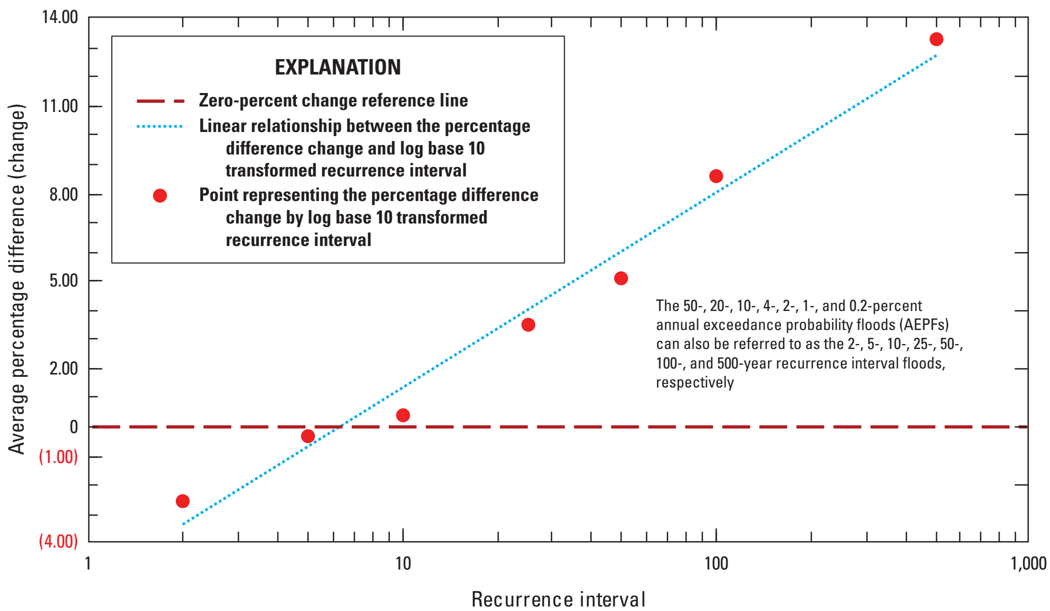


Figure 4. The 1-percent annual exceedance probability flood trend for the 15 selected streamgages plotted with the annual peak for the full period of record.—Continued



$$PD_{(change)}=((AEPF_{(2016)}-AEPF_{(1995)})/AEPF_{(1995)})\times100$$

$PD_{(change)}$ is the percentage difference change, which represents the percentage change between the 2016 AEPF estimates and the 1995 AEPF estimates;

$AEPF_{(2016)}$ is the AEPF calculated from the 2016 regional regression equation (Wagner and others, 2016), in cubic feet per second; and

$AEPF_{(1995)}$ is the AEPF calculated from the 1995 regional regression equation (Hodge and Tasker, 1995), in cubic feet per second.

Figure 5. Relation between the log base 10 transformed recurrence interval and the average percentage difference change between the 2016 and 1995 annual exceedance probability flood estimates for the 74 streamflow locations representing 15 streamgages and the 0-, 10-, 50-, and 85-percent locations along the stream, terminating at the Arkansas border.

Table 3. The percentage difference between the 2016 and 1995 annual exceedance probability floods for the 74 selected streamflow locations, which include the 15 selected streamgage locations and the 0-, 10-, 50-, and 85-percent locations along each of the selected streams, terminating at the Arkansas border, when applicable.

[A positive percentage difference change value denotes the 2016 annual exceedance probability flood is greater than the 1995 annual exceedance probability flood; therefore, a negative percentage difference change value (denoted in red with parentheses) denotes the 2016 annual exceedance probability flood is less than the 1995 annual exceedance probability flood; USGS, U.S. Geological Survey]

Site number (fig. 5)	Percent location	Flood region (fig. 2)	Latitude	Longitude	Annual exceedance probability, in percent						
					50	20	10	4	2	1	0.2
					Recurrence interval, in years						
					2	5	10	25	50	100	500
					Percentage differences in annual exceedance probability flood, in percent						
USGS station 07060710											
1	At site	C	35.995	–92.212	5.17	12.45	26.39	38.30	44.58	52.46	67.07
2	0%	C	35.9408	–92.120	3.89	11.12	1.29	3.88	4.90	6.81	9.89
3	10%	C	35.964	–92.152	4.30	11.52	9.40	13.77	16.67	19.75	25.88
4	50%	C	36.010	–92.244	3.70	10.68	32.60	46.51	55.54	65.22	83.59
5	85%	C	36.063	–92.328	(3.66)	5.81	18.12	26.90	31.95	38.40	48.52
USGS station 07069500											
6	At site	C	36.205	–91.172	(18.97)	(14.16)	(14.06)	(9.12)	(6.35)	(3.18)	3.73
7	0%	C	36.151	–91.083	(18.79)	(13.86)	(16.60)	(12.52)	(10.61)	(7.58)	(2.12)
8	10%	C	36.222	–91.218	(18.89)	(14.14)	(12.81)	(7.58)	(4.68)	(0.67)	6.49
9	50%	C	36.365	–91.515	(22.64)	(18.16)	(11.34)	(4.09)	(0.08)	4.67	14.14
10	Border	C	36.497	–91.528	(25.02)	(21.30)	(23.60)	(20.22)	(18.46)	(15.93)	(11.29)
USGS station 07072000											
11	At site	C	36.347	–91.114	(18.56)	(13.55)	(17.71)	(13.77)	(12.41)	(9.82)	(5.03)
12	0%	C	36.152	–91.083	(18.07)	(13.18)	(23.64)	(21.95)	(21.78)	(20.91)	(18.23)
13	10%	C	36.289	–91.096	(18.10)	(13.27)	(19.58)	(17.04)	(15.84)	(13.49)	(9.71)
14	Border	C	36.496	–91.172	(18.12)	(13.02)	(11.04)	(5.27)	(2.27)	1.24	9.55
USGS station 07074000											
15	At site	C	36.110	–91.450	(20.37)	(15.60)	(24.13)	(22.11)	(21.63)	(19.50)	(17.68)
16	0%	C	35.882	–91.218	(18.85)	(14.15)	(28.17)	(27.93)	(28.38)	(27.95)	(26.74)
17	10%	C	35.971	–91.279	(18.58)	(13.93)	(24.80)	(23.53)	(23.43)	(21.96)	(20.33)
18	50%	C	36.099	–91.609	(20.60)	(16.38)	(31.09)	(31.48)	(32.17)	(31.85)	(31.41)
19	85%	C	36.234	–91.891	(23.68)	(19.75)	(16.66)	(11.69)	(8.52)	(4.87)	1.66
USGS station 07075300											
20	At site	C	35.587	–92.452	20.44	32.95	21.42	25.10	26.98	30.72	36.41
21	0%	C	35.590	–92.448	20.03	32.07	20.15	23.73	25.55	28.84	34.14
22	10%	C	35.582	–92.493	20.57	33.09	26.98	32.74	36.08	40.84	48.71
23	50%	C	35.577	–92.639	23.17	35.49	42.52	52.60	58.96	66.38	80.14
24	85%	C	35.610	–92.764	23.30	34.45	55.41	70.57	80.39	91.43	112.07
USGS station 07194800											
25	At site	A	36.103	–94.344	(3.67)	4.03	9.79	18.39	20.58	30.17	40.96
26	0%	A	36.102	–94.549	(4.74)	1.37	6.35	13.96	14.96	24.27	34.54
27	10%	A	36.133	–94.503	(4.87)	1.22	6.22	13.73	14.64	24.04	33.87
28	50%	A	36.079	–94.342	(4.47)	3.25	8.84	17.18	19.28	28.85	39.19
29	85%	A	35.928	–94.267	(4.19)	8.52	16.18	27.65	32.87	45.49	58.08

Table 3. The percentage difference between the 2016 and 1995 annual exceedance probability floods for the 74 selected streamflow locations, which include the 15 selected streamgage locations and the 0-, 10-, 50-, and 85-percent locations along each of the selected streams, terminating at the Arkansas border, when applicable.—Continued

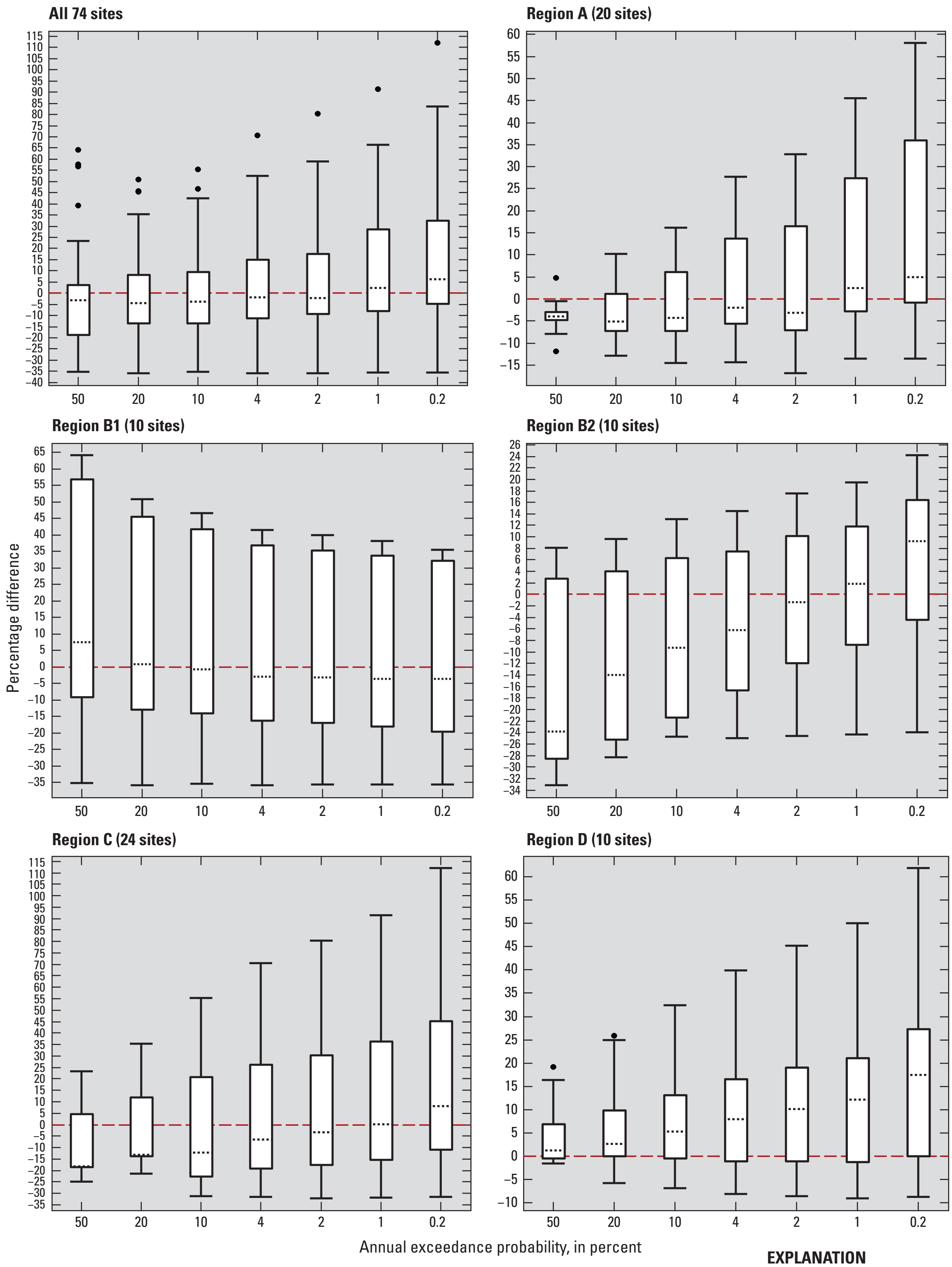
[A positive percentage difference change value denotes the 2016 annual exceedance probability flood is greater than the 1995 annual exceedance probability flood; therefore, a negative percentage difference change value (denoted in red with parentheses) denotes the 2016 annual exceedance probability flood is less than the 1995 annual exceedance probability flood; USGS, U.S. Geological Survey]

Site number (fig. 5)	Percent location	Flood region (fig. 2)	Latitude	Longitude	Annual exceedance probability, in percent						
					50	20	10	4	2	1	0.2
					Recurrence interval, in years						
					2	5	10	25	50	100	500
					Percentage differences in annual exceedance probability flood, in percent						
USGS station 07249400											
30	At site	A	35.133	–94.407	(5.41)	(12.52)	(13.94)	(14.04)	(16.59)	(13.15)	(13.29)
31	0%	A	35.163	–94.440	(2.72)	(9.50)	(10.88)	(10.71)	(12.98)	(9.76)	(9.26)
32	10%	A	35.169	–94.393	(5.77)	(12.83)	(14.46)	(14.40)	(16.83)	(13.47)	(13.62)
33	50%	A	35.086	–94.328	(7.96)	(10.23)	(9.53)	(7.88)	(7.99)	(3.04)	(1.47)
34	85%	A	34.996	–94.326	(11.84)	(2.19)	3.32	12.52	17.26	28.68	36.61
USGS station 07260000											
35	At site	A	34.987	–93.613	(2.83)	(5.04)	(3.79)	(1.23)	(2.15)	3.36	6.08
36	0%	A	35.054	–93.403	(0.45)	(5.26)	(5.82)	(4.69)	(6.56)	(2.56)	(0.91)
37	10%	A	35.022	–93.434	(1.20)	(5.28)	(5.84)	(4.14)	(5.99)	(1.67)	0.37
38	50%	A	34.978	–93.666	(2.86)	(3.66)	(2.21)	0.92	0.04	5.97	9.23
39	85%	A	34.902	–93.899	4.76	10.17	13.53	19.91	22.36	30.19	37.01
USGS station 07263000											
40	At site	A	34.911	–93.056	(3.55)	(5.58)	(4.72)	(2.42)	(3.72)	1.31	4.49
41	0%	A	34.953	–93.032	(4.27)	(7.66)	(7.76)	(5.90)	(7.52)	(3.00)	(0.72)
42	10%	A	34.917	–93.060	(3.72)	(5.88)	(5.15)	(2.88)	(4.21)	0.71	3.59
43	50%	A	34.870	–93.217	(2.06)	(4.42)	(3.88)	(1.62)	(2.57)	2.53	5.33
44	85%	A	34.854	–93.395	(4.76)	(6.35)	(6.00)	(3.48)	(3.61)	2.26	3.37
USGS station 07340300											
45	At site	B1	34.380	–94.236	(28.97)	(30.58)	(31.17)	(32.37)	(32.63)	(33.02)	(33.95)
46	0%	B1	33.791	–94.149	11.39	3.56	1.16	(1.73)	(2.44)	(3.16)	(3.92)
47	10%	B1	33.822	–94.183	1.82	(4.41)	(6.44)	(8.83)	(9.21)	(9.80)	(10.65)
48	50%	B1	34.177	–94.246	(2.65)	(6.98)	(8.50)	(11.18)	(12.03)	(13.14)	(15.26)
49	85%	B1	34.415	–94.160	(35.22)	(35.88)	(35.38)	(35.84)	(35.73)	(35.69)	(35.65)
USGS station 07361500											
50	At site	B1	34.039	–93.418	57.82	45.86	41.80	37.67	36.10	34.70	32.48
51	0%	B2	33.949	–93.367	(31.58)	(28.28)	(21.90)	(16.50)	(11.66)	(7.77)	0.09
52	10%	B1	33.983	–93.379	64.13	50.91	46.63	41.42	39.85	38.15	35.52
53	50%	B1	34.169	–93.455	56.77	45.50	41.84	36.91	35.28	33.78	30.37
54	85%	B1	34.253	–93.587	39.18	34.91	33.63	32.01	32.05	32.28	32.21
USGS station 07362100											
55	At site	B2	33.376	–92.777	(12.94)	(12.89)	(11.26)	(11.17)	(9.39)	(8.20)	(5.80)
56	0%	B2	33.368	–92.568	7.87	9.70	13.07	14.44	17.58	19.43	24.20
57	10%	B2	33.367	–92.637	1.22	2.70	5.14	6.51	9.37	11.29	14.98
58	50%	B2	33.375	–92.917	8.16	8.45	10.19	10.74	12.76	14.09	16.91
59	85%	B2	33.413	–93.157	(24.79)	(24.93)	(24.68)	(25.03)	(24.64)	(24.32)	(24.00)

Table 3. The percentage difference between the 2016 and 1995 annual exceedance probability floods for the 74 selected streamflow locations, which include the 15 selected streamgage locations and the 0-, 10-, 50-, and 85-percent locations along each of the selected streams, terminating at the Arkansas border, when applicable.—Continued

[A positive percentage difference change value denotes the 2016 annual exceedance probability flood is greater than the 1995 annual exceedance probability flood; therefore, a negative percentage difference change value (denoted in red with parentheses) denotes the 2016 annual exceedance probability flood is less than the 1995 annual exceedance probability flood; USGS, U.S. Geological Survey]

Site number (fig. 5)	Percent location	Flood region (fig. 2)	Latitude	Longitude	Annual exceedance probability, in percent						
					50	20	10	4	2	1	0.2
					Recurrence interval, in years						
					2	5	10	25	50	100	500
					Percentage differences in annual exceedance probability flood, in percent						
USGS station 07363500											
60	At site	B2	33.701	–92.026	(27.64)	(20.17)	(14.68)	(10.45)	(6.04)	(3.08)	3.98
61	0%	B2	33.163	–92.137	(24.18)	(13.92)	(6.78)	(0.99)	4.59	8.60	16.39
62	10%	B2	33.163	–92.137	(23.43)	(14.05)	(7.23)	(1.99)	3.25	6.82	14.44
63	50%	B2	34.124	–92.426	(33.16)	(26.22)	(21.40)	(17.59)	(13.50)	(10.48)	(4.14)
64	85%	B1	34.648	–92.756	3.32	(1.81)	(2.76)	(4.41)	(4.20)	(4.16)	(3.55)
USGS station 07364120											
65	At site	D	33.961	–91.785	16.37	25.88	32.47	39.91	45.14	50.11	61.88
66	0%	D	33.007	–91.627	–1.05	2.59	5.44	8.36	10.61	12.49	17.79
67	10%	D	33.154	–91.571	1.38	5.02	8.02	11.09	13.33	15.15	21.21
68	50%	D	33.27	–91.554	–0.39	2.56	5.16	7.71	9.71	11.27	15.88
69	85%	D	34.079	–91.919	19.22	24.90	28.85	33.16	36.44	39.38	46.19
USGS station 07369680											
70	At site	D	33.100	–91.253	3.87	0.91	0.52	0.21	0.20	0.21	1.67
71	Border	D	33.006	–91.266	–1.63	–5.82	–6.86	–8.12	–8.60	–9.04	–8.77
72	10%	D	33.110	–91.251	0.51	–3.09	–3.93	–4.78	–5.12	–5.35	–5.16
73	50%	D	33.225	–91.233	1.12	2.56	4.71	6.88	9.19	11.93	17.23
74	85%	D	33.315	–91.334	1.45	2.88	5.38	8.15	10.62	13.00	19.17



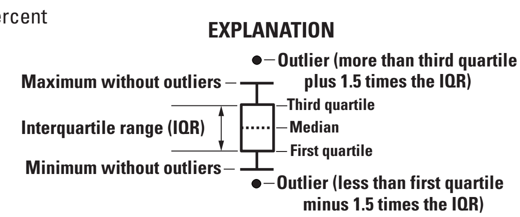


Figure 6. The range of percentage differences of annual exceedance probability flood estimates from the 1995 to the 2016 regional regression equations by peak streamflow region as designated by Wagner and others (2016).

RI flood; table 3). The minimum PD of −35.9 percent was in region B1 at the 85-percent location at Cossatot River near Vandervoort (USGS station 07340300, site 10 in fig. 1 and sites 45–49 in fig. 2) for the 20-percent AEPF (5-year RI flood) (table 3).

Summary

Concerns exist in Arkansas regarding possible increasing trends in annual peak streamflow and the resulting increase in annual exceedance probability flood (AEPF) estimates. An increasing peak streamflow trend would correspond to an increased flood risk to highway structures and surrounding communities. To address these concerns, the U.S. Geological Survey, in cooperation with the U.S. Army Corps of Engineers and the Federal Emergency Management Agency, completed a study in Arkansas to determine if significant increasing trends exist in annual peak streamflow data. The Mann-Kendall trend test was used to identify possible trends at 15 selected streamgages in Arkansas. Using the full period of record, results from the Mann-Kendall trend test indicate that 1 of the 15 streamgages had a significantly decreasing trend and the remaining 14 streamgages had no statistically significant trends. The full period-of-record trend analysis may obscure trends that may exist within peak streamflow data of a shorter duration; therefore, a locally estimated scatterplot smoothing trend line using a span window of 0.75 was used to visually explore for trends within peak streamflow data. The locally estimated scatterplot smoothing trend line generally indicated an increasing trend in the peak streamflow since the 1990s at 8 of the 15 streamgages.

The percentage differences (PDs) between AEPFs from the 1995 and 2016 Arkansas flood-frequency reports were calculated and compared. A summary of the PDs between the 1995 and 2016 AEPFs was derived for the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent AEPFs. This analysis was completed at the 15 selected streamgages and at the percent locations along the streams associated with these streamgages. The AEPFs for the 0-, 10-, 50-, and 85-percent locations along the 15 streams were computed using the regional regression equations from the 1995 and 2016 flood-frequency reports. A total of 74 locations consisting of streamgage locations and percent locations along the streams were evaluated for PDs between the 1995 and 2016 regional regression equations. The PDs between the 1995 and 2016 AEPFs indicate that the 2016 AEPFs estimated larger floods for the 4-, 2-, 1-, and 0.2-percent AEPFs by 3.52, 5.10, 8.59, and 13.31 percent, respectively. The PDs between the 1995 and 2016 AEPFs were similar for the 10- and 20-percent AEPFs with only 0.41 and 0.31 PDs, respectively; however, the PDs between the 1995 and 2016 AEPFs indicate that the 1995 regional regression equations estimated larger floods for the 50-percent AEPFs by 2.53 percent and vary between flood regions across Arkansas.

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