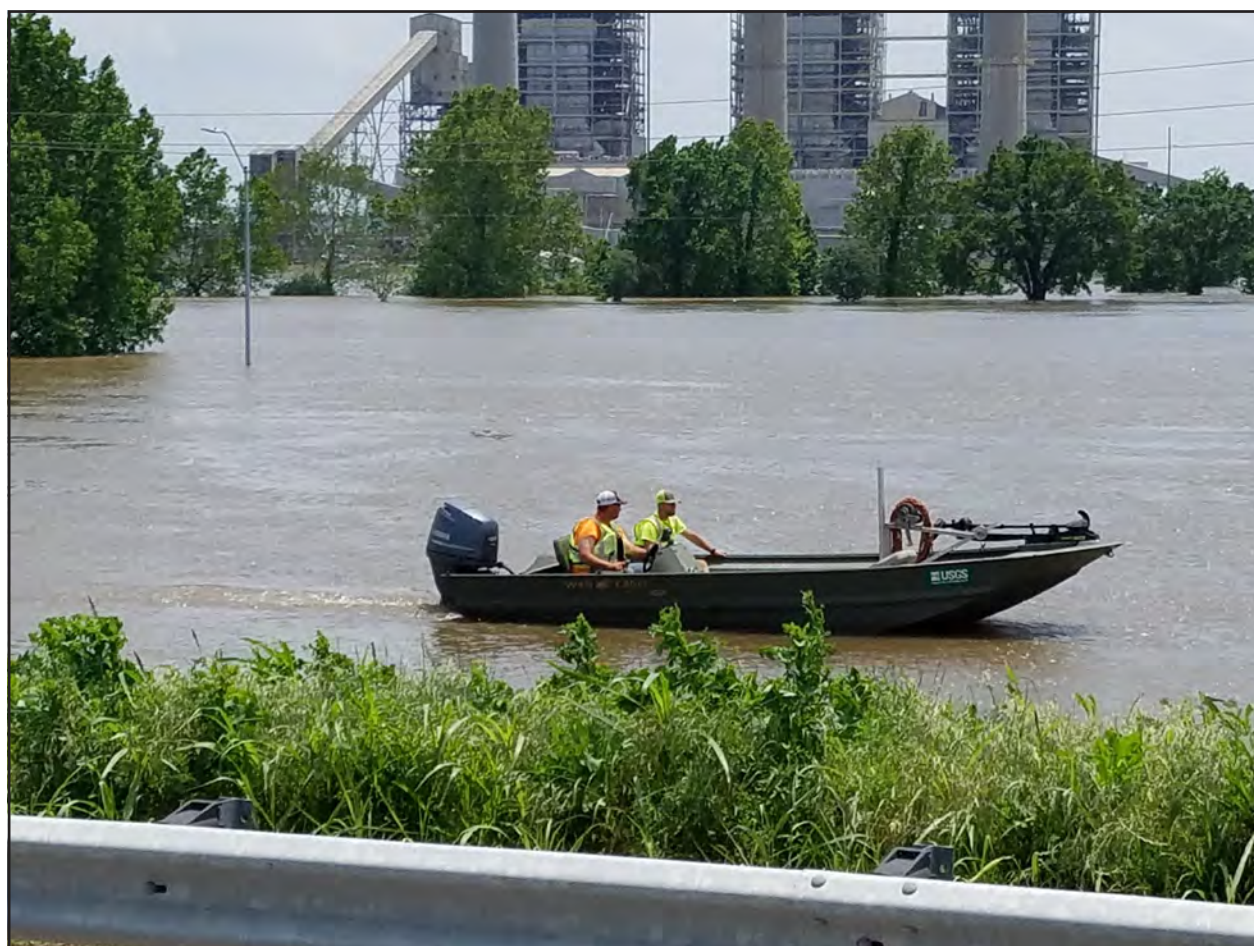


Prepared in cooperation with the Federal Emergency Management Agency and the
U.S. Army Corps of Engineers

Peak Streamflow and Stages at Selected Streamgages on the Arkansas River in Oklahoma and Arkansas, May to June 2019



Open-File Report 2019–1129

Cover. Photograph showing two U.S. Geological Survey hydrographers navigating floodwaters downstream from the U.S. Highway 62 bridge on the Arkansas River near Muskogee, Oklahoma, May 23, 2019. Photograph by Scott Strong, U.S. Geological Survey.

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By Jason M. Lewis and Adam R. Trevisan

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

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DAVID BERNHARDT, Secretary

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Conversion Factors

Inch/Pound to SI

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		
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)

Datum

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

Abbreviations

AEP	annual exceedance probability
FEMA	Federal Emergency Management Agency
NOAA	National Oceanic and Atmospheric Administration
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

Peak Streamflow and Stages at Selected Streamgages on the Arkansas River in Oklahoma and Arkansas, May to June 2019

By Jason M. Lewis and Adam R. Trevisan

Abstract

As much as 22 inches of rain fell in Oklahoma in May 2019, resulting in historic flooding along the Arkansas River in Oklahoma and Arkansas. The flooding along the Arkansas River and its tributaries that began in May continued into June 2019. Peaks of record were measured at 12 U.S. Geological Survey (USGS) streamgages on various streams in eastern and northeastern Oklahoma. This report documents the peak streamflows and stages for seven selected streamgages along the Arkansas River in Oklahoma and Arkansas. Most of the flood peaks occurred from May 26 to June 4, 2019. The historic flooding caused homes to fall into the river as a result of bank erosion, forced some towns to be evacuated, and resulted in the highest flood depths in Tulsa, Oklahoma, since 1986. Along the Arkansas River, peak streamflows were recorded at six of the seven selected USGS streamgages, with the seventh streamgage on the Arkansas River having the second highest peak of record at that site since regulation began.

Introduction

Heavy rainfall resulted in major flooding across parts of Oklahoma and Arkansas during May 2019, with some areas receiving more than 22 inches of rainfall for the month (Mesonet, 2019). Most of the rain fell in a 36-hour period during May 19–May 21 in a large swath across northeastern Oklahoma and southeastern Kansas (fig. 1). Most of the flood peaks occurred from May 26 to June 4, 2019. Along the Arkansas River, at least three levees were breached between Fort Smith and Little Rock, Arkansas, and an additional five levees suffered substantial damage (U.S. Army Corps of Engineers, Little Rock District, written commun., 2019). Maps of floods and high-flow conditions can be accessed at the U.S. Geological Survey (USGS) WaterWatch website (<https://waterwatch.usgs.gov/>; USGS, 2019a).

The Arkansas River Basin has flooded, sometimes catastrophically, in the past. Examples include the 1986 flood on the Arkansas River, which killed 1 person and caused 1,800 homes and business to be inundated (Jackson and Pittman, 2019).

Flooding in the reach of the Arkansas River near the city of Tulsa, Oklahoma, is usually caused by large amounts of rain and large releases from the upstream reservoirs. South of Tulsa, the Arkansas River reaches flatter topography, where the “backwater” effect of numerous tributaries dumping water into the lower gradient Arkansas River results in the slower movement of floodwaters and increased flood heights (fig. 2).

The historic flooding in 2019 caused homes to fall into the river as a result of bank erosion, forced some towns to be evacuated, and resulted in the highest flood peaks in Tulsa since 1986 (PBS News Hour, 2019; Stanglin and Hughes, 2019). Several USGS streamgages along the Arkansas River recorded new peaks of record. As a result of the magnitude of the Arkansas River flooding, the USGS, in cooperation with the Federal Emergency Management Agency (FEMA) and the U.S. Army Corps of Engineers (USACE), assessed the meteorological and hydrological conditions prior to and during the flood and determined flood peak gage heights, streamflows, and flood exceedance probabilities at USGS and USACE streamgages.

The USGS collects and disseminates streamflow data for more than 8,000 streamgages nationwide (USGS, 2019b). In Oklahoma and Arkansas, the USGS operates 290 streamgages in cooperation with numerous local, State, and Federal agencies. Other agencies in Oklahoma and Arkansas, such as the USACE, also operate streamgages. Streamflow data collection serves a variety of purposes including flood monitoring. Leading up to and during flooding events, streamflow data are vital for flood warning, forecasting, and emergency management. Long-term systematic streamflow data are used to help mitigate the damage caused by floods in the design or repair of infrastructure (for example, roads, bridges, reservoirs, and pipelines), houses, and buildings (Congressional Research Service, 2019).

Purpose and Scope

The purpose of this report is to document the peak streamflows and stages for selected streamgages along the Arkansas River in Oklahoma and Arkansas that recorded the May–June 2019 flood event. This includes both USGS and USACE streamgages. The 2019 flood peak flows are placed into context by ranking the 2019 data with the annual peak flood data for the regulated period of record at each streamgage.

2 Peak Streamflow and Stages at Selected Streamgages on the Arkansas River in Oklahoma and Arkansas

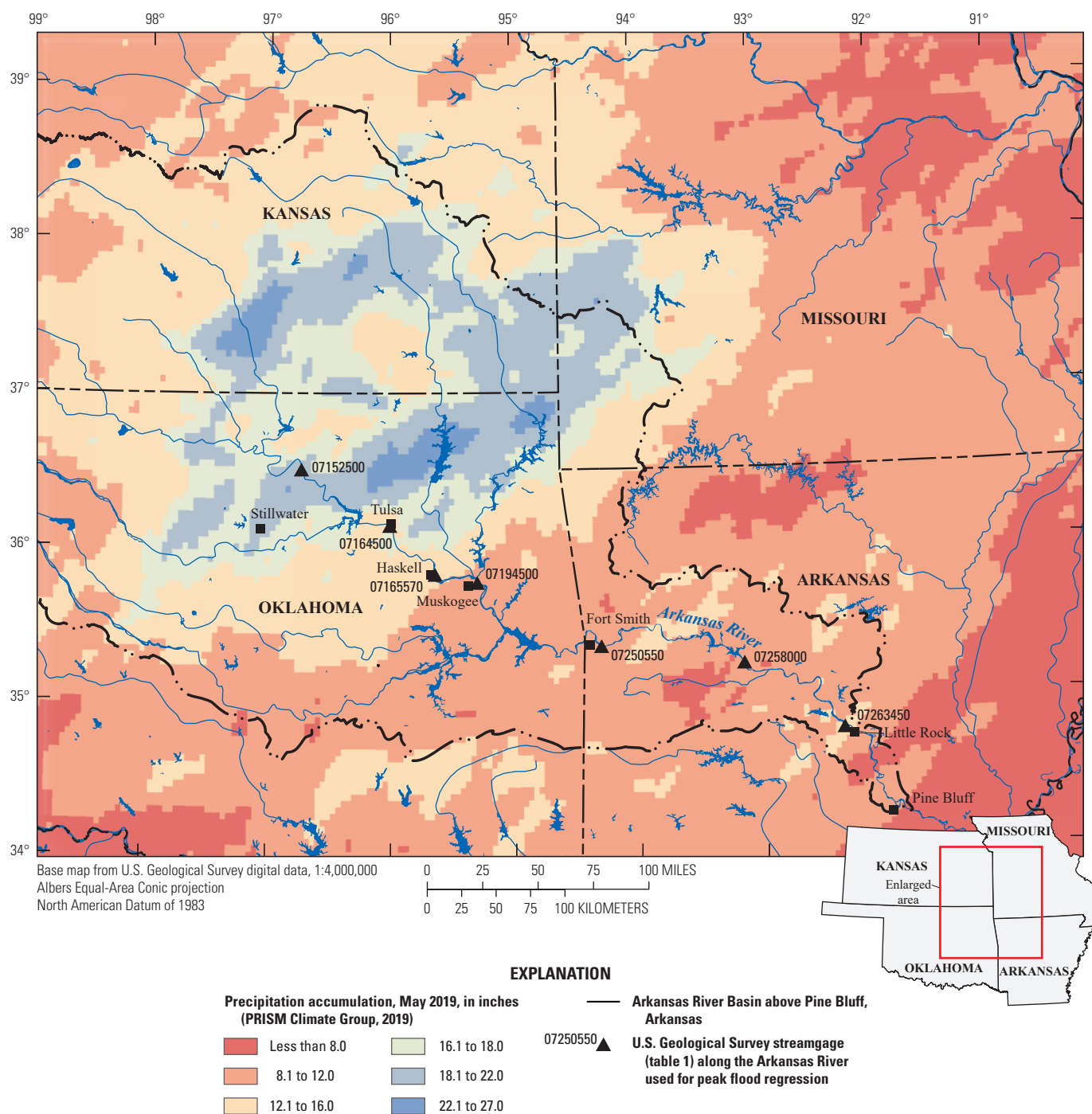


Figure 1. Location of selected U.S. Geological Survey streamgages along the Arkansas River and the total rainfall accumulation that occurred during May 2019.



Figure 2. Looking downstream from U.S. Highway 62 bridge at the widespread flooding and backwater conditions on the Arkansas River near Muskogee, Oklahoma, May 31, 2019.

Study Area

The streamflow data (peak stage and streamflow) documented in this report were obtained from streamgages in the Arkansas River Basin, which drains large parts of Colorado, Kansas, Oklahoma, and Arkansas. The Arkansas River Basin has headwater streams along the eastern slope of the Rocky Mountains in Colorado; the Arkansas River crosses eastern Colorado and a large part of Kansas before continuing in an easterly to southeasterly direction through Oklahoma and Arkansas (fig. 3).

Land-use types in the study area include forest and woodlands, grass and rangelands, and urban (National Agricultural Statistics Service, 2016). Some parts of the Arkansas River in the study area are dredged for sand and gravel (USACE, 2010). The McClellan-Kerr Arkansas River Navigation System is an important infrastructure feature in the study area that facilitates interstate barge traffic; it starts at the Port of Catoosa in Catoosa, Okla. The McClellan-Kerr Arkansas River Navigation System follows the Verdigris River downstream from Catoosa to the confluence of the Verdigris and Arkansas Rivers near Muskogee, Okla., then follows the Arkansas River downstream through eastern Oklahoma and Arkansas, terminating at the confluence of the Arkansas and Mississippi Rivers (USACE, 2019).

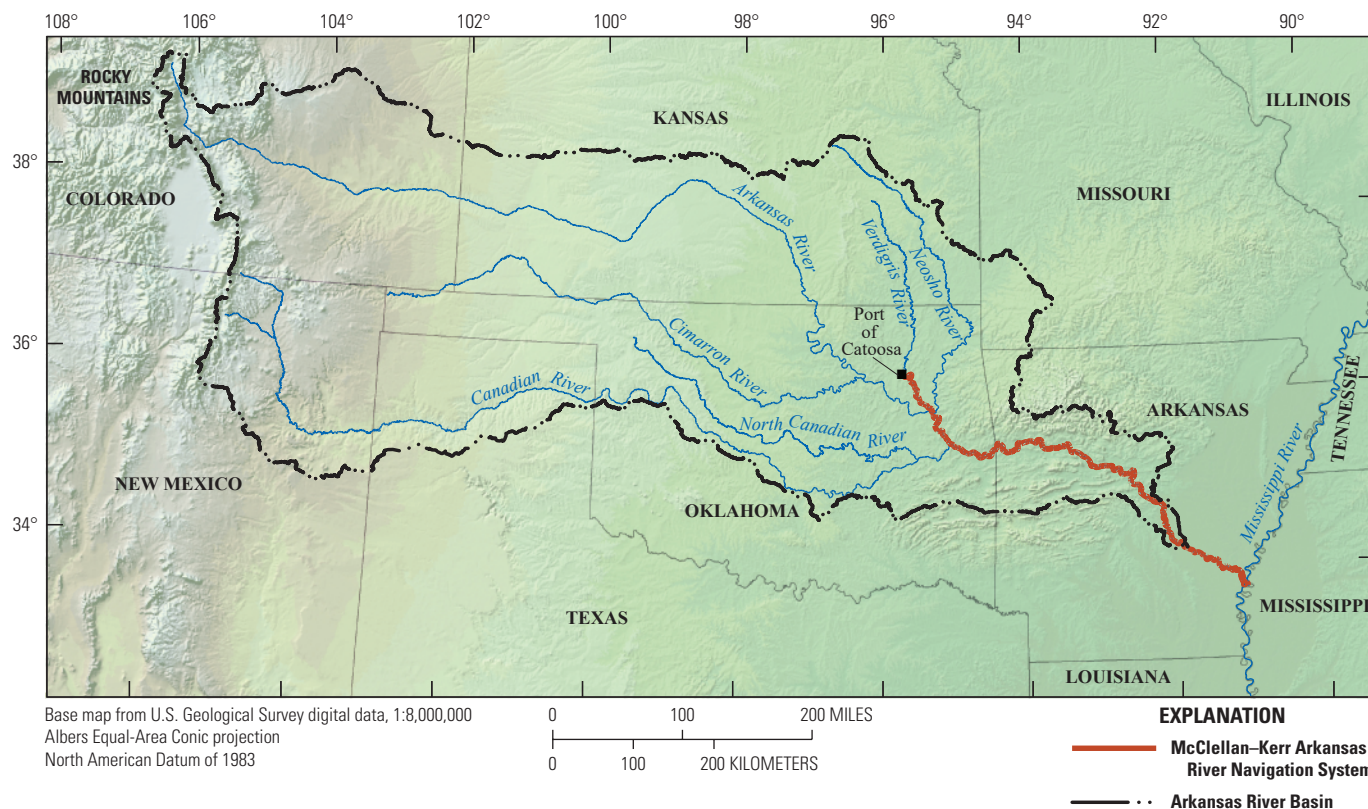


Figure 3. The Arkansas River Basin, which includes the McClellan-Kerr Arkansas River Navigation System.

General Weather Conditions and Rainfall During May 2019

In late May 2019, changes in the jet stream caused wind patterns to shift, drawing warm, moist air masses northward from the Gulf of Mexico. These warm, moist air masses combined with cooler-than-average air masses throughout Oklahoma and Kansas to produce historic rainfall for the month (National Oceanic and Atmospheric Administration [NOAA], 2019a). This pattern of repeated heavy rain culminated in an extreme rainfall event over a 24-hour period on May 21, 2019, when more than 6 inches of rain fell in parts of Tulsa and Stillwater, Okla. (NOAA, 2019b). After rains saturated much of Oklahoma and Kansas in the early part of the month, the additional heavy rainfall on May 21 spurred flooding along much of the Arkansas River. Smaller rainfall events following May 21 kept streams in flood stage through the end of May and early June (NOAA, 2019c). By the end of May 2019, parts of Oklahoma had received more than 25 inches of rain for the month (PRISM Climate Group, 2019). May rainfall totals were the highest on record for Kansas and Missouri, the second highest for Oklahoma, and the ninth highest for Arkansas, producing rainfall anomalies above the means of 6.66 inches, 5.65 inches, 6.78 inches, and 4.11 inches, respectively (NOAA, 2019c).

Methods

In this report, the term streamflow data refers to stage and volumetric streamflow (streamflow). Streamflow data were collected either systematically at streamgages or from periodic/intermittent field observations of streamflow at locations where no streamgage is present.

USGS streamgages operate autonomously by collecting data at set frequencies (typically either 15 or 30 minutes) dependent on basin size and concomitant flashiness of the stream. The typical streamgage automatically records stage data. Stage data are collected by using a variety of methods (float, submersible pressure transducer, nonsubmersible pressure transducer, or noncontact radar). Stage at each USGS streamgage was recorded every 15 minutes and transmitted hourly by the Geostationary Operational Environmental Satellite transmitter to the USGS National Water Information System database (USGS, 2019b). Although stage data are important, streamflow data are often more important for such purposes as streamflow forecasting, water-quality loading, flood-frequency analysis, and flood-mitigation planning. Derivation of streamflow from stage data at a streamgage requires periodic measurements of streamflow for the construction of a relation that will convert the stage data to streamflow data. In most cases, the relation is a simple stage-streamflow rating curve (rating curve)

(fig. 4). USGS personnel make onsite direct measurements of stream velocity and stream depth that are used to create the rating curve (fig. 5; Turnipseed and Sauer, 2010). After construction of the rating curve, continued periodic measurements of streamflow are required at various gage heights to calibrate the rating curve. The rating curve for the Arkansas River near Haskell, Okla. (07165570) streamgage was updated and extended based on data from the historic May 2019 streamflow (fig. 4). The rating curve allows for the determination of streamflow from the stage data when USGS personnel are not physically present at the streamgage to make a streamflow measurement.

In addition to the USGS, the USACE also collects streamflow data in the study area. Data collected by the USACE were obtained by using methods and standards similar to those used by USGS (USACE, Little Rock District, written commun., 2019). Any questions regarding methods of data collection for non-USGS data should be referred to the collecting agency. The USACE provided gage height records for the following sites: Arkansas River at James W. Trimble L&D near Van Buren, Arkansas (07250550), Arkansas River at Dardanelle, Arkansas (07258000), and Arkansas River at Murray Dam near Little Rock, Arkansas (07263450) (USGS, 2019b). The USGS quality assured these data and determined a maximum peak stage and streamflow for each site for the flood event of 2019.

Peak Streamflows and Stages

Peaks of record were measured at 12 USGS streamgages on various streams in eastern and northeastern Oklahoma (USGS, 2019a). Peak streamflow and stage during the May to June 2019 floods for seven streamgages on the Arkansas River are provided (table 1; fig. 1). The streamgages included in table 1 were chosen because (1) the 2019 peak streamflow for that location ranked first or second among all peak flows at that station for the period of record, (2) the site was a periodic/intermittent location where the peak streamflow was determined, or (3) the USACE determined this to be a site of interest. The data in table 1 are from both the USGS and USACE.

The peak stage and streamflow are not always coincident in time for the locations in this report, particularly for lower gradient sinuous streams and rivers characterized by complicated hydraulics that only form in low-gradient environments (Holmes and others, 2013).

Most of the flood peaks were recorded near the end of May 2019, with flood peaks occurring later with distance downstream. One exception was USGS streamgage Arkansas River near Muskogee, Okla. (07194500) (fig. 1) where the flood peaked earlier than at the upstream Tulsa (07164500) and Haskell (07165570) streamgages because of inflow from the Neosho and Verdigris Rivers.

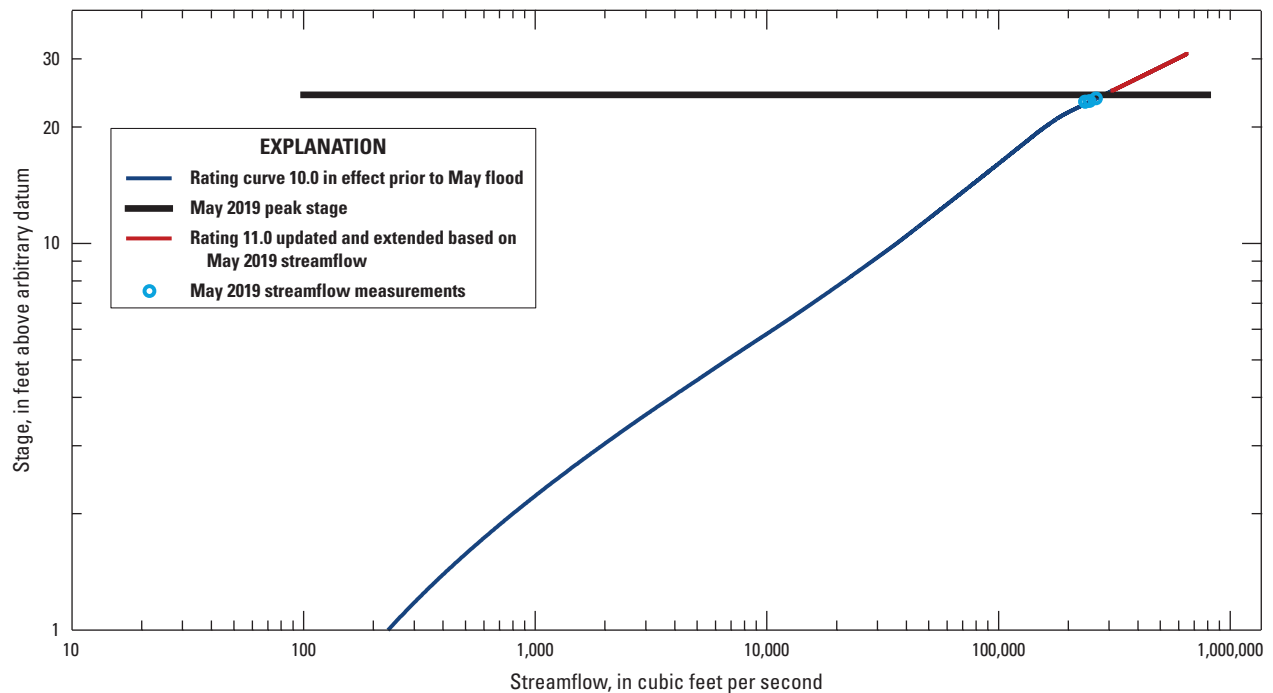


Figure 4. Rating curve for the U.S. Geological Survey streamgage 07165570, Arkansas River near Haskell, Oklahoma.



Figure 5. A direct streamflow measurement from the 11th Street bridge, looking downstream on the Arkansas River at Tulsa, Oklahoma, near U.S. Geological Survey streamgage 07164500.

Flood Exceedance Probabilities of Peak Streamflows

After a flood event, personnel from different agencies and groups commonly need to know the expected frequency and magnitude of peak streamflows observed. Peak-flow frequency data are determined from a series of the highest instantaneous annual peak discharges for the period of record at a streamgage. The probability that a peak will occur at a given location in a given year is determined from the annual peak streamflow data and is known as annual exceedance probability (AEP) (Holmes and others, 2013).

Each peak streamflow value listed in [table 1](#) is an instantaneous peak flow that can be expected to be equaled or exceeded on the average once every “y” years, where “y” is the recurrence interval. Similarly, each instantaneous peak flow has an “x”-percent probability of exceedance in any given year, where “x” is the exceedance probability, in percent. For example, the instantaneous peak flow corresponding to the 100-year recurrence interval can be expected to be equaled or exceeded on average once every 100 years; similarly, an instantaneous peak flow corresponding to a 1-percent AEP will have a 1-percent chance of being equaled or exceeded in any given year ([table 2](#)). Changes in land use, construction of new dams, and changes in long-term precipitation patterns can cause the designated AEPs and recurrence intervals for floods of a given magnitude to change over time (USGS, 2019c).

The flood-frequency estimates for this report were made by using the expected moments algorithm (Cohn and others, 1997, 2001) in the USGS software package PeakFQ, version 7.2 (Flynn and others, 2006; Veilleux and others, 2014) ([table 3](#)).

6 Peak Streamflow and Stages at Selected Streamgages on the Arkansas River in Oklahoma and Arkansas

Table 1. Site information for selected streamgages along the Arkansas River and peak streamflow values for the May to June 2019 flood event.

[USGS, U.S. Geological Survey; ft³/s, cubic foot per second; Ark., Arkansas; Okla., Oklahoma; >, greater than; <, less than; L&D, Lock and Dam]

USGS streamgage number ¹	USGS streamgage name	Latitude, in decimal degrees	Longitude, in decimal degrees	Peak streamflow (ft ³ /s)	Recurrence interval, in years
07152500	Arkansas River at Ralston, Okla.	36.504217	96.728367	185,000	<100
07164500	Arkansas River at Tulsa, Okla.	36.140648	96.006387	277,000	>100
07165570	Arkansas River near Haskell, Okla.	35.822778	95.637778	286,000	<200
07194500	Arkansas River near Muskogee, Okla.	35.769543	95.297187	600,000	<200
07250550	Arkansas River at James W. Trimble L&D near Van Buren, Ark. ²	35.348889	94.298333	570,000	200
07258000	Arkansas River at Dardanelle, Ark. ²	35.226111	93.149444	565,000	>200
07263450	Arkansas River at Murray Dam near Little Rock, Ark. ²	34.793056	92.358333	520,000	>100

¹Streamflow upstream from streamgage is regulated and, therefore, the estimated peak flows and confidence intervals were not weighted but represent the at-site flood-frequency analysis.

²Streamgage is operated by the U.S. Army Corps of Engineers, and data are quality assured and published by the USGS (2019b).

Table 2. Selected recurrence intervals and the associated annual exceedance probabilities.

Recurrence interval (years)	Annual exceedance probability (percent)
2	50
5	20
10	10
25	4
50	2
100	1
200	0.5
500	0.2

Table 3. Streamgage information related to calculation of annual exceedance probability for the May to June 2019 flood event along the Arkansas River in Oklahoma and Arkansas.

[AEP, annual exceedance probability; USGS, U.S. Geological Survey; ft, foot; ft³/s, cubic foot per second]

USGS streamgage number ¹	USGS streamgage name	Date of peak streamflow	Peak streamflow for May to June 2019 flood				Estimate, in percent	AEP for observed May to June 2019 flood	
			Peak gage height (ft)	Peak stream-flow (ft ³ /s)	Rank of peak streamflow in record	Number of annual peaks		66.7-percent confidence interval	
								Lower, in percent	Upper, in percent
07152500	Arkansas River at Ralston, Okla.	5/23/2019	22.14	185,000	1	43	1.5	0.4	3.9
07164500	Arkansas River at Tulsa, Okla.	5/29/2019	23.51	277,000	2	55	0.7	1.3	5.8
07165570	Arkansas River near Haskell, Okla.	5/29/2019	24.24	286,000	1	47	0.7	0.4	3.9
07194500	Arkansas River near Muskogee, Okla. ²	5/26/2019	46.39	600,000	1	33	0.6	0.5	5.0
07250550	Arkansas River at James W. Trimble L&D near Van Buren, Ark. ³	5/31/2019	406.96	570,000	1	50	0.5	0.4	3.5
07258000	Arkansas River at Dardanelle, Ark. ³	5/30/2019	45.91	565,000	1	50	0.4	0.4	3.5
07263450	Arkansas River at Murray Dam near Little Rock, Ark. ³	6/4/2019	259.75	520,000	1	50	0.8	0.4	3.5

USGS streamgage number ¹	2-percent AEP, 50-year recurrence			1-percent AEP, 100-year recurrence			0.5-percent AEP, 200-year recurrence			0.2-percent AEP, 500-year recurrence		
	Estimate	95-percent confidence interval		Estimate	95-percent confidence interval		Estimate	95-percent confidence interval		Estimate	95-percent confidence interval	
		Lower (ft ³ /s)	Upper (ft ³ /s)		Lower (ft ³ /s)	Upper (ft ³ /s)		Lower (ft ³ /s)	Upper (ft ³ /s)		Lower (ft ³ /s)	Upper (ft ³ /s)
07152500	172,000	128,000	287,000	198,000	138,000	361,000	244,000	147,000	448,000	259,000	155,000	591,000
07164500	206,000	149,000	387,000	252,000	173,000	544,000	302,000	196,000	755,000	377,000	226,000	1,150,000
07165570	217,000	159,000	424,000	261,000	183,000	601,000	310,000	207,000	847,000	382,000	237,000	1,320,000
07194500 ²	444,000	318,000	760,000	534,000	370,000	981,000	634,000	426,000	1,250,000	781,000	503,000	1,680,000
07250550	442,000	358,000	692,000	503,000	395,000	880,000	567,000	431,000	1,110,000	656,000	475,000	1,510,000
07258000	470,000	402,000	640,000	511,000	426,000	744,000	550,000	446,000	859,000	599,000	466,000	1,030,000
07263450	445,000	374,000	751,000	499,000	408,000	947,000	556,000	440,000	1,190,000	637,000	482,000	1,620,000

¹Streamflow upstream from streamgage is regulated; therefore, the estimated peak flows and confidence intervals were not weighted but represent the at-site flood-frequency analysis.

²Estimated peak flows and confidence intervals were weighted.

³Streamgage is operated by the U.S. Army Corps of Engineers, and data are quality assured and published by the USGS (2019b).

8 Peak Streamflow and Stages at Selected Streamgages on the Arkansas River in Oklahoma and Arkansas

The methods used for computing peak-streamflow frequency are from a published report referred to as Bulletin 17C (England and others, 2019). Bulletin 17C is an update to Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). Flood computation equations and algorithms in Bulletin 17C have been implemented into the PeakFQ program. The May 2019 peak streamflows were included in the PeakFQ analyses per guidance provided in USGS Office of Surface Water Technical Memorandum 2013.01 (USGS, 2012). Although Bulletin 17C states that guidelines do not apply to streamgages affected by reservoir regulation, with proper dataset handling, Bulletin 17C guidelines can be applied to produce reliable results at these streamgages (Advisory Committee on Water Information, 2002; USGS, 2012). Because the selected streamgages along the Arkansas River all have more than 80 percent of their drainage areas affected by reservoir regulation, the “at-site” skew was used to determine peak frequencies within PeakFQ. The only exception was the Arkansas River near Muskogee streamgage (07194500). The May 2019 flood produced an atypical

upper-tail peak-flow record that required a special handling of the dataset (Sando and McCarthy, 2018). A weighted skew was used to calculate the flood frequencies instead of the station skew.

Six of the seven selected USGS streamgages recorded new peak streamflows in 2019, with the seventh gage (Arkansas River at Tulsa, Okla., streamgage 07164500) recording the second highest peak streamflow since regulation began (table 3). Ranks for peak streamflows are based on water year.¹ The AEPs ranged from less than 1 to 1.5 percent for peak streamflows analyzed in this study. At the USGS streamgage Arkansas River near Muskogee, Okla. (07194500), a peak streamflow of 600,000 cubic feet per second was measured on May 26, 2019, corresponding to an AEP of 0.6 percent (fig. 6).

¹The water year is the annual period from October 1 through September 30 and is designated by the year in which the period ends. For example, the 2019 water year is from October 1, 2018, through September 30, 2019.

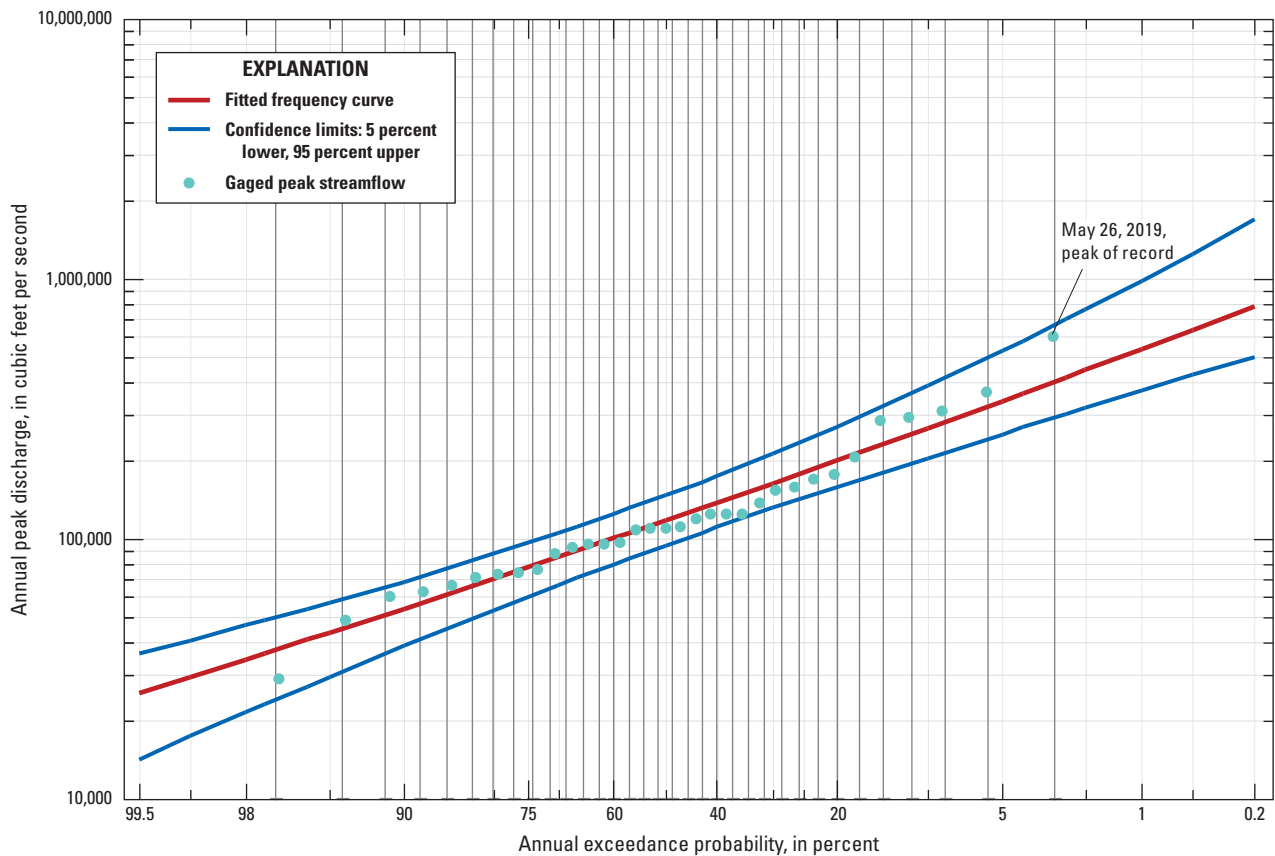


Figure 6. Flood-frequency curve for the annual peak streamflows at U.S. Geological Survey streamgage 07194500, Arkansas River near Muskogee, Oklahoma.

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