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

# Characterization of Peak Streamflow and Stages at Selected Streamgages in Eastern and Northeastern Oklahoma from the May to June 2019 Flood Event—With an Emphasis on Flood Peaks Downstream from Dams and on Tributaries to the Arkansas River

Open-File Report 2020–1090

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

**Cover.** Photograph showing USGS employees on State Highway 104 near the Arkansas River near Haskell, Oklahoma, streamgage (07165570). Photograph by Kevin Smith, U.S. Geological Survey.

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DAVID BERNHARDT, Secretary

**U.S. Geological Survey** James
F. Reilly II, Director

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## 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) |
| 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 |
| CADSWES | Center for Advanced Decision Support for Water and Environmental Systems (USACE) |
| FEMA | Federal Emergency Management Agency |
| HEC | Hydrologic Engineering Center (USACE) |
| HEC-SSP | Hydrologic Engineering Center statistical software package (USACE) |
| NOAA | National Oceanic and Atmospheric Administration |
| RMC-RFA | Risk Management Center-Reservoir Frequency Analysis Software (USACE) |
| USACE | U.S. Army Corps of Engineers |
| USGS | U.S. Geological Survey |

# Characterization of Peak Streamflow and Stages at Selected Streamgages in Eastern and Northeastern Oklahoma from the May to June 2019 Flood Event—With an Emphasis on Flood Peaks Downstream from Dams and on Tributaries to the Arkansas River

By Jason M. Lewis,[1] David J. Williams,[2] Sarah J. Harris,[2] and Adam R. Trevisan[1]

## Abstract

As much as 22 inches of rain fell in Oklahoma in May 2019, resulting in historic flooding along the Arkansas River and its tributaries in eastern and northeastern Oklahoma. The flooding along the Arkansas River and its tributaries that began in May continued into June 2019. Peaks of record were measured at nine U.S. Geological Survey (USGS) and U.S. Army Corps of Engineers (USACE) streamgages on various streams in eastern and northeastern Oklahoma. This report documents the peak streamflows and stages for 38 selected streamgages in eastern and northeastern Oklahoma and is a followup to a previous report by the USGS that documented flood peaks associated with the May 2019 flood event. Most of the flood peaks occurred from May 26 to June 4, 2019. This report includes data from streamgages on tributaries to the Arkansas River and uses modeling methods to extend the period of record for Arkansas River streamgages. 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. Several USGS and USACE streamgages along the Arkansas River and its tributaries recorded new peaks of record.

## Introduction[3]

Heavy rainfall resulted in major flooding across parts of eastern and northeastern Oklahoma 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. Thirteen flood-control reservoirs operated by the U.S. Army Corps of Engineers (USACE) in Kansas and Oklahoma reached new pools of record (USACE, 2019a). 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) and the USACE website (https://www.swt-wc.usace.army.mil/; USACE, 2020a).

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 businesses 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). Backwater conditions form when the water-level elevation in the main channel becomes higher than the water-level elevations in tributaries. In the absence of backwater conditions, water-level elevations in the main channel are usually lower than those in the tributaries, and in turn, the water-level elevations in the tributaries are usually lower than those in the floodplain.

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 and USACE streamgages along the Arkansas River and its tributaries recorded new peaks of record. As a result of the magnitude of the flooding in eastern and northeastern Oklahoma, the USGS, in cooperation with the Federal Emergency Management Agency (FEMA) and the USACE, assessed the meteorological and hydrological

[1]U.S. Geological Survey.

[2]U.S. Army Corps of Engineers.

[3]This section is modified from Lewis and Trevisan (2019).

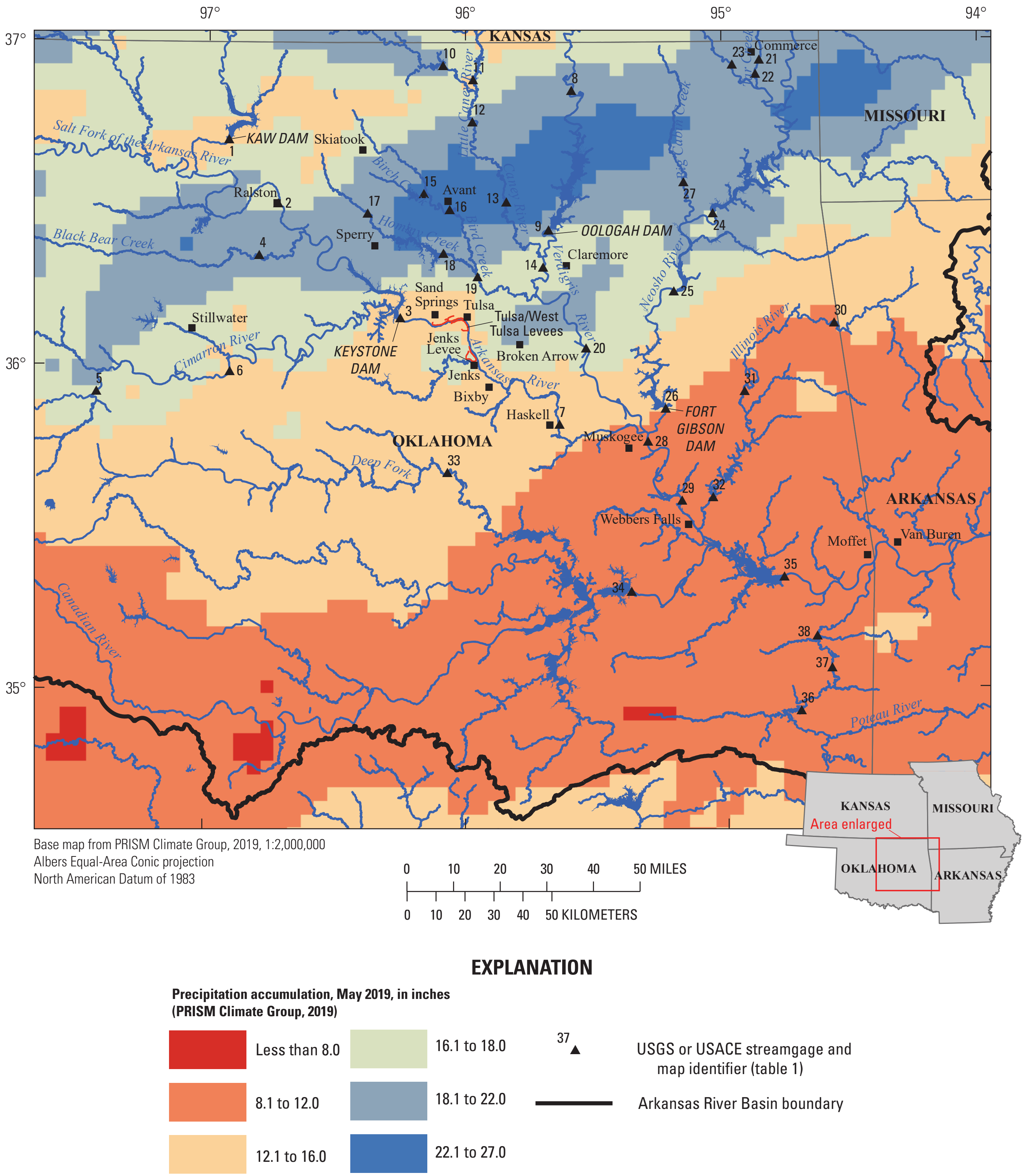


**Figure 1.** Location of selected U.S. Geological Survey (USGS) and U.S. Army Corps of Engineers (USACE) streamgages in eastern and northeastern Oklahoma and the total rainfall accumulation that occurred during May 2019.

conditions prior to and during the flood and determined flood peak streamflows and flood exceedance probabilities at USGS and USACE streamgages.

On May 27, 2019, a release of 275,000 cubic feet per second ($ft^3/s$) from Keystone Dam (fig. 1) into the Arkansas River was the second largest release from this dam since 1986 (USACE, 2019a). During the same time as the large release from Keystone Dam, large releases from the Kaw Dam on the Arkansas River and the Oologah Dam on a tributary to the Arkansas River were also necessitated by the flood event (fig. 1). Although flooding from the Arkansas River within Tulsa, Oklahoma, and its suburbs was largely confined to open public spaces (with the notable exception of the River Spirit Casino, which was closed for several weeks), people living in the neighborhoods in unincorporated Tulsa County to the west of Sand Springs experienced extensive flooding of their homes. The unregulated streamflow of the Arkansas River through Tulsa County, with neither Keystone Dam nor Kaw Dam in place, would have been 375,000 $ft^3/s$, which would have been catastrophic in parts of Sand Springs, Tulsa, Jenks, Bixby, and Broken Arrow, Oklahoma (USACE, 2019a). An estimated $6.8 billion of flood damages were prevented by USACE Tulsa District projects for water year[4] 2019, including Keystone Dam and the Tulsa/West Tulsa and Jenks Levees (USACE, 2020b). Oologah Dam reached a peak release of 64,500 $ft^3/s$ on May 25, 2019 (USACE, 2019a). The unregulated streamflow downstream from the Oologah Dam would have been 225,000 $ft^3/s$ if the dam had not been in place (USACE, 2019a). Severe flooding occurred downstream along the Verdigris River near Claremore, Okla. Bird Creek was also subjected to major flooding, particularly in and around the towns of Avant, Skiatook, and Sperry, Okla. On May 22, 2019, the peak stage at Sperry of 31.29 feet (ft) was the fourth highest in the period of record (USGS, 2019a). The Neosho River system was similarly subjected to major flooding. A stage of 25.51 ft measured at Commerce on May 24, 2019, was the fifth highest on record at that location, and downstream, a peak release of 228,300 $ft^3/s$ was made from Fort Gibson Dam on May 25 (USACE, 2019a). The unregulated streamflow along the Neosho River downstream from Fort Gibson Dam would have been an estimated 275,000 $ft^3/s$ without the dam (USACE, 2019a).

The lower reach of the Arkansas River was most affected by the flood, which was catastrophic in many locations. A peak stage of 46.39 ft, the second highest on record, was observed at Muskogee, Okla., on May 26, 2019 (USGS, 2019a, b). The streamflow along the Arkansas River at Muskogee was an estimated 600,000 $ft^3/s$. Extensive flooding occurred in and around the Port of Muskogee. Farther downstream, the towns of Webbers Falls and Moffett, Okla., were completely inundated. A flood of record occurred at Van Buren, Arkansas, with a streamflow of 570,000 $ft^3/s$ and a peak stage of 40.79 ft observed on June 1, 2019 (USGS, 2019a, b). This peak stage,

[4]The 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 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.

which resulted in flooding and levee breaches in Arkansas, exceeded the previous record by nearly 3 ft, and reached the Mississippi River by the second week of June. Without upstream flood-control reservoirs, the unregulated streamflows would have been an estimated 830,000 $ft^3/s$ at Muskogee and an estimated 930,000 $ft^3/s$ at Van Buren (USACE, 2019a).

Previously, FEMA Region VI developed a mission assignment in conjunction with the USACE Little Rock District and the USGS to document the peak streamflows and stages for seven streamgages along the Arkansas River in Oklahoma and Arkansas. This previous study was completed by Lewis and Trevisan (2019). For the current study by the USGS in cooperation with FEMA and USACE Tulsa District, a comprehensive characterization of streamflow frequencies along the Arkansas River and its tributaries in eastern and northeastern Oklahoma was completed.

## Purpose and Scope

This report documents peak streamflows and flood frequencies for selected USGS and USACE streamgages in eastern and northeastern Oklahoma that recorded the May–June 2019 flood event. This report includes data from streamgages on the Arkansas River and tributaries to the Arkansas River. Modeling methods were used to extend the regulated period of record for some of streamgages. Whereas Lewis and Trevisan (2019) documented the peak streamflows and stages for selected streamgages along the Arkansas River in Oklahoma and Arkansas, the primary purpose of this report is to document streamflow and flood frequencies for the Arkansas River downstream from selected dams and for tributaries to the Arkansas River in eastern and northeastern Oklahoma.

## Study Area[5]

The streamflow data (peak streamflow) documented in this report were obtained from USGS and USACE streamgages in the Arkansas River Basin, which drains large parts of Colorado, Kansas, Oklahoma, and Arkansas (U.S. Geological Survey, 2019a, b; USACE, 2020a). 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

[5]This section is modified from Lewis and Trevisan (2019).

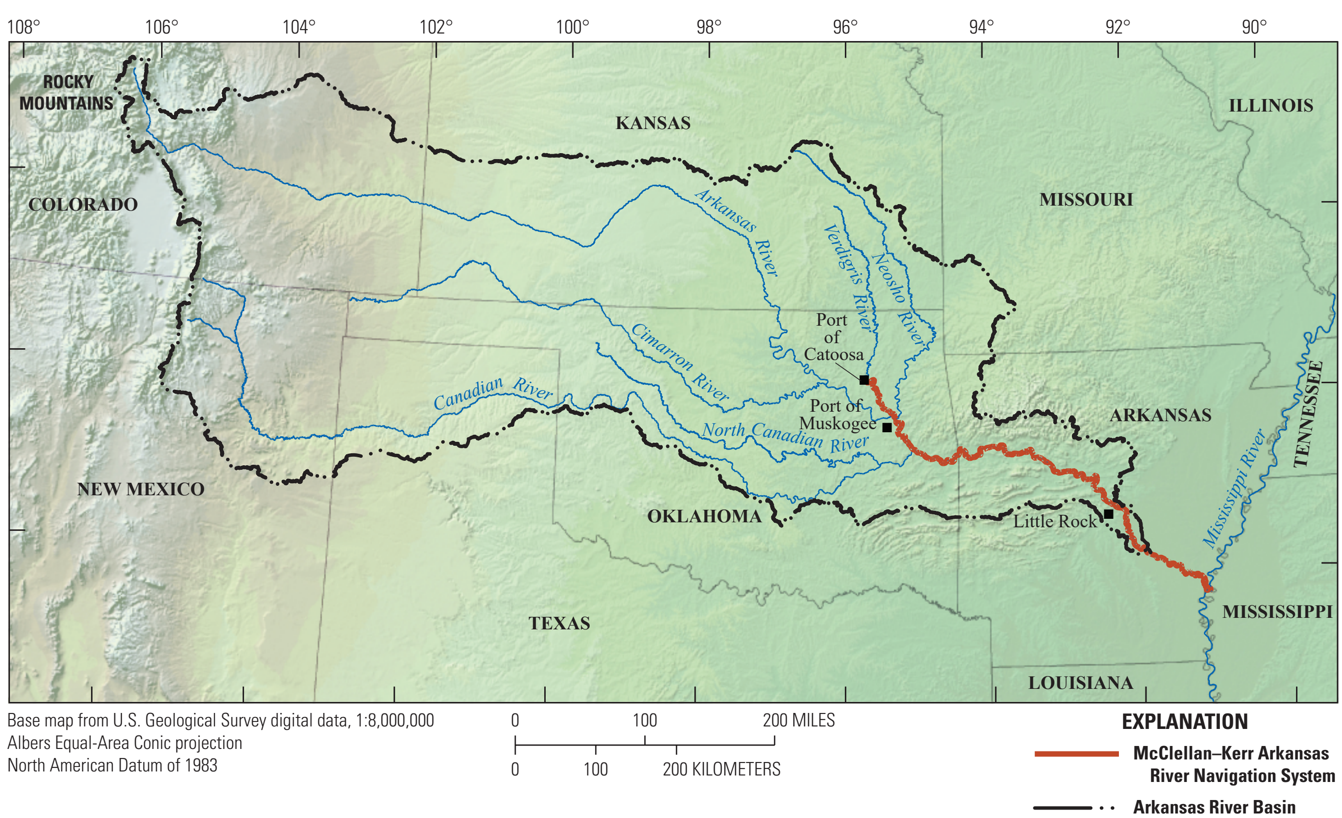


**Figure 3.** The Arkansas River Basin, which includes the McClellan-Kerr Arkansas River Navigation System.

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 (fig. 3).

## General Weather Conditions and Rainfall During May 2019

Widespread rainfall that saturated much of Oklahoma and Kansas in the early part of May 2019 was followed by changes in the jet stream in late May that spawned massive storms. Just before May 21, 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, generating repeated episodes of heavy rain that set numerous rainfall records 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 had 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 large rainfall anomalies compared to the normal monthly averages of 6.66 inches of rainfall for Kansas, 5.65 inches for Missouri, 6.78 inches for Oklahoma, and 4.11 inches for Arkansas (NOAA, 2019c).

## Methods

USGS and USACE streamgages operate autonomously by collecting streamflow data at set frequencies (typically either 15 or 30 minutes) dependent on basin size and concomitant "flashiness" of the stream (how rapidly streamflow increases and decreases in response to a storm event). The typical streamgage automatically records stage data (Turnipseed and Sauer, 2010). Stage data are collected by using a variety of methods (float, submersible pressure transducer, nonsubmersible pressure transducer, or noncontact radar). For USGS streamgages, stage was recorded every 15–30 minutes and transmitted hourly by the Geostationary Operational Environmental Satellite transmitter to the USGS National Water Information System database (USGS, 2019a, b). For the USACE streamgages discussed in this report, stage was also recorded every 15–30 minutes, and the data were transmitted by satellite to the USACE Tulsa District Water Control Data System (USACE, 2020a). 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, stream width, and stream depth (fig. 5) that are used to create the rating curve (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 (Rantz and others, 1982; Turnipseed and Sauer, 2010). The rating curve for the USGS streamgage 07165570, Arkansas River near Haskell, Okla., 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.

The Arkansas River and many of its tributaries are heavily regulated by USACE flood-control dams in Kansas and Oklahoma. In many cases, the effects of regulation are substantial enough that the distribution of observed annual maximum streamflows no longer maintain a curve shape similar to that of unregulated or "natural" conditions. Analytical methods used for calculating annual exceedance probabilities (AEPs) for unregulated streams are therefore not usually appropriate for highly regulated streams. The Interagency Advisory Committee on Water Data (1982), Bulletin 17B, explicitly excluded watersheds that were "…appreciably altered by reservoir regulation." Bulletin 17C, which is a major revision to Bulletin 17B, states that other methods such as "…simulated floods, graphical frequency analyses, and total probability concepts must be used for regulated streams" (Kubik, 1990; Sanders and others, 1990; USACE, 1997; as cited in England and others, 2019). All three of these methods were used in calculating AEPs for regulated stations.

Calculating AEPs for streamgages on regulated streams was based on simulated period-of-record streamflow from a comprehensive RiverWare model that was developed and maintained by the USACE Tulsa District (Center for Advanced Decision Support for Water and Environmental Systems [CADSWES], 2020). RiverWare is a robust stream and reservoir period-of-record modeling tool developed by the CADSWES at the University of Colorado in collaboration with the Tennessee Valley Authority, Bureau of Reclamation, and USACE. RiverWare provides a stream basin modeling environment for operations and planning that allows a high

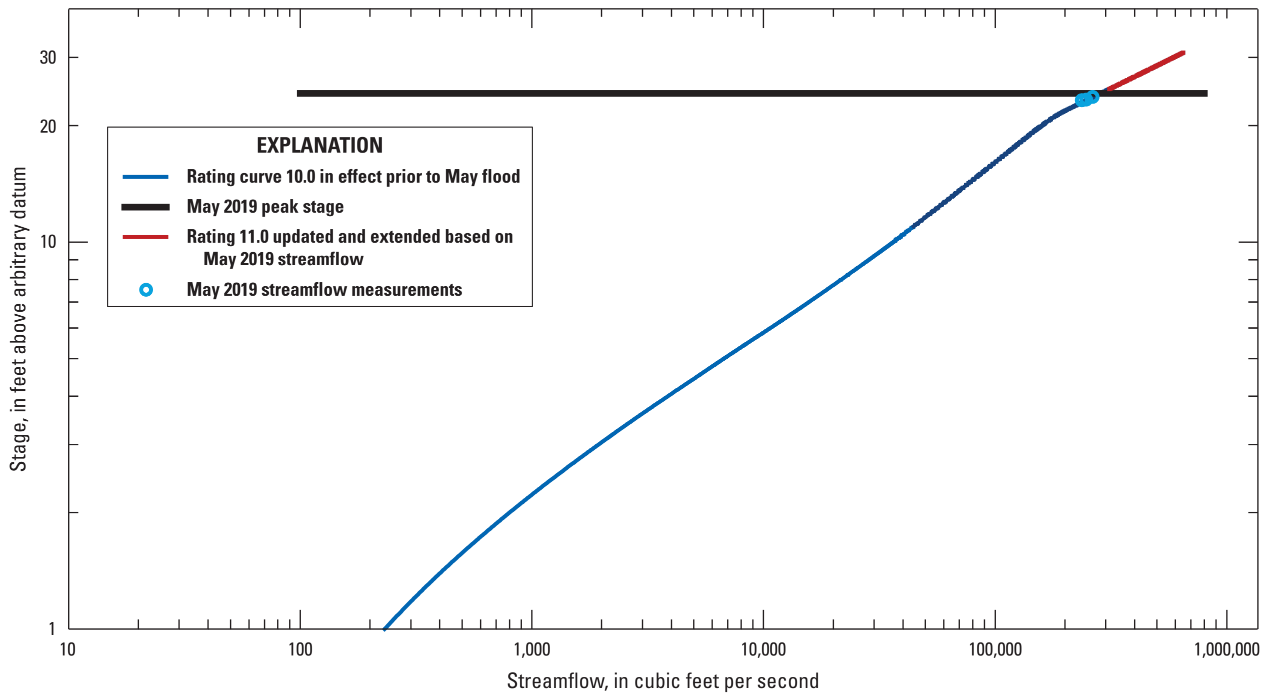


**Figure 4.** Rating curve for the U.S. Geological Survey streamgage 07165570, Arkansas River near Haskell, Oklahoma.

**Figure 5.** A direct streamflow measurement from the State Highway 20 bridge, looking downstream on the Verdigris River near Claremore, Oklahoma, near U.S. Geological Survey streamgage 07176000.

degree of flexibility for users to model any stream basin, manage data input and output efficiently enough for near real-time operations, and provide a selection of solution algorithms (CADSWES, 2020). The RiverWare model can be used to simulate regulated and unregulated conditions. The regulated simulation assumes that all reservoirs are in place for the entire specified period of record, with current operational criteria used for the entire period. Period-of-record headwater streamflows and intervening area streamflows are developed based on historical data, through preprocessing techniques, before any rule-based simulation is done. Preprocessing to generate intervening area streamflows includes running a local RiverWare model that uses observed headwater streamflows and observed releases from reservoirs, which are then routed downstream and subtracted from observed streamflow data at downstream streamgages. The local streamflows are incorporated into the rules-based simulation model. The unregulated simulation assumes that no reservoirs are in place for the specified period of record.

In the RiverWare model, each reach of a given stream is simulated individually. The model for the Arkansas River consists of reservoirs, control points, confluence objects, routing reaches, and data objects, and it extends from the headwater reservoirs on the Arkansas River and its tributaries in Kansas and Oklahoma downstream to Little Rock, Arkansas. The Arkansas River model includes reservoirs along the Arkansas River and major tributaries, including the Salt Fork of the Arkansas River and Caney, Verdigris, Neosho, Illinois, Canadian, and Poteau Rivers. The Arkansas River model is a daily time-step model with a period of record beginning in 1940 that has been updated through 2019.

The Arkansas River model contains physical and operational input data, including spillway and outlet works rating curves, established pool limits, and regulation criteria, to model system operational constraints; hydropower, water-supply, and water-quality criteria are also incorporated as applicable. When the model is run, preprocessed hydrologic data are routed through the river system beginning at the headwater reservoirs, based on the input data and operational rules. Subsequent releases are determined based on real-time and future forecast downstream conditions. Simulated releases are routed downstream and combined with intervening area streamflows until all hydrologic streamflows for the period of record are routed through the model extent. Mandatory releases, which initially use rule functions, are required to maintain structural integrity at each reservoir. These releases are made from each reservoir and routed to downstream control points. By rule directives, each downstream control point is evaluated for regulation criteria or limitations; the control points are used to determine how much channel space is projected to be filled based on incoming intervening area streamflow as well as known upstream mandatory releases. This sets the reach storage parameters for actual simulated releases for flood control and conservation purposes. Initial flood-control releases from the reservoirs are then simulated. The goal of the rules-based simulation is to maximize use of system channel storage space and minimize flooding so that flood-control releases are given priority. The simulated flood-control releases are then routed downstream. Next, conservation pool releases (such as low-flow or environmental releases) and diversions for water supply are simulated for each reservoir. Finally, for hydropower projects, daily load requirements are analyzed, and any additional releases required to meet the load are made. The required mandatory releases (flood control and low flow) are made through hydropower when possible. Water-supply diversions are taken directly from the reservoirs and typically not returned to the model. Depending on hydropower requirements, system excess or dump energy as well as thermal purchase energy required to meet system loads are simulated. In addition to the previously described requirements, through several iterations of the rule-based simulation, the Arkansas River model attempts to achieve a target uniform balance between competing reservoirs during the evacuation of system flood storage (USACE, 2020c).

The streamgages on regulated streams that were included in this study were also analyzed in conjunction with their corresponding unregulated period-of-record annual maximum streamflow datasets. This part of the analysis used an analytical curve that was developed in accordance with the methodology described in Bulletin 17C (England and others, 2019). A benefit of evaluating unregulated streamflow probabilities is the ability to show the effects that flood-control dams have on downstream reaches, which are most evident immediately downstream from a dam.

Stochastic methods were used to define the upper ends of the probabilistic curves at most locations. This was achieved by incorporating the relation between the stage of a reservoir and its corresponding outflow. In the case of dams with uncontrolled spillways, a straightforward approach was used where the outflow was computed for any given stage in conjunction with the geometry of the spillway itself by using the following weir equation:

$$Q = C \times L \times H^{3/2} \tag{1}$$

where

- $Q$ is the outflow from the dam, in cubic feet per second;
- $C$ is a coefficient based on the geometric characteristics of the spillway crest;
- $L$ is the length of the spillway crest, in feet; and
- $H$ is the depth of streamflow above the elevation of the spillway crest, in feet.

Dams with controlled spillways, which are most typically Tainter gates at USACE Tulsa District flood-control projects, have more complex operational rules (USACE, 2020c). For controlled spillways, a relation between inflow, outflow, and reservoir stage is defined based on the authorized operation of the flood-control project. If the probability of a reservoir stage is known and the inflow into the reservoir has the same probability, then the corresponding probabilistic outflow from the reservoir can be estimated.

For this study, probabilistic reservoir stages were estimated by using the USACE Risk Management Center-Reservoir Frequency Analysis Software (RMC-RFA) (USACE, 2018a, 2019d). RMC-RFA software was designed to facilitate hydrologic hazard assessments within the USACE Dam Safety Program; RMC-RFA can be used to produce a reservoir stage-frequency curve with uncertainty bounds by utilizing a deterministic flood routing model while treating the inflow volume, the inflow flood hydrograph shape, the seasonal occurrence of the flood event, and the antecedent reservoir stage as uncertain variables rather than fixed values (Smith and others, 2018). In order to quantify both the natural variability and knowledge uncertainty in reservoir stage-frequency estimates, RMC-RFA employs a two-looped, nested Monte Carlo methodology (USACE, 2018a). The natural variability of the reservoir stage is simulated in the inner loop, which is defined as a realization and which comprises thousands of simulated flood events. Knowledge uncertainty in the inflow volume frequency distribution is simulated in the outer loop, which comprises many realizations (USACE, 2018a).

Once the probabilities of reservoir stages had been estimated, those corresponding to the 1-percent, 0.5-percent, and 0.2-percent AEPs were then identified on the spillway rating curve for each respective project. The spillway rating curve is referred to in the model as the "spillway gate regulation schedule inflow parameter" curve for controlled spillways. For uncontrolled spillways, the intersection of the probabilistic stage and the spillway rating curve corresponded to the outflow with the same AEP based on the weir equation. This method also required knowledge of the probabilistic inflow if a controlled spillway was being analyzed, in which case, the probabilistic inflow and the reservoir stage with the same probability were identified on the spillway gate regulation schedule inflow parameter curve. The corresponding outflow with the same AEP was then estimated. The spillway rating curve was obtained from the water control manual for each respective reservoir project (USACE, 2020c).

Digital data for the model and output files for the RiverWare model used to simulate regulated and unregulated conditions and the physical and operational input data, including spillway and outlet works, rating curves, established pool limits, and regulation criteria for modeling system operational constraints, are available for download in a companion data release (Williams and Lewis, 2020).

# Peak Streamflows and Stages

Peaks of record were measured at nine USGS and USACE streamgages on various streams in eastern and northeastern Oklahoma (USGS, 2019a, b). Peak streamflows during the May to June 2019 floods for 38 streamgages are provided (table 1; fig. 1). The streamgages listed in table 1 were chosen for this study because they recorded flooding during the May–June 2019 flood event. 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 streams described in this report, particularly for the numerous sinuous streams (fig. 1) 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 increasing distance downstream. One exception was the USGS streamgage 07194500, Arkansas River near Muskogee, Okla. (number 28, fig. 1) where the flood peaked earlier than at the Haskell streamgage (number 7, fig. 1) because of inflow from the Neosho and Verdigris Rivers.

**Table 1.** Site information for selected streamgages in eastern and northeastern Oklahoma and peak streamflow values for the May to June 2019 flood event.

[USGS, U.S. Geological Survey; USACE, U.S. Army Corps of Engineers; $ft^3/s$, cubic feet per second; --, not applicable; Okla., Oklahoma; >, greater than; <, less than]

| Map identifier (fig. 1) | USGS station number | USACE station identifier | Station name | Latitude, in decimal degrees | Longitude, in decimal degrees | Peak streamflow, in $ft^3/s$ | Recurrence interval, in years |
|---|---|---|---|---|---|---|---|
| 1 | -- | KAWL | Arkansas River below Kaw Dam, Okla.[1] | 36.699444 | 96.921667 | 105,000 | <100 |
| 2 | 07152500 | RALS | Arkansas River near Ralston, Okla.[2] | 36.504217 | 96.728367 | 185,000 | >100 |
| 3 | -- | KEYS | Arkansas River below Keystone Dam, Okla.[1] | 36.151389 | 96.251389 | 274,600 | >100 |
| 4 | 07153000 | PAWN | Black Bear Creek at Pawnee, Okla.[2] | 36.343665 | 96.799479 | 19,500 | >50 |
| 5 | 07160000 | GUTH | Cimarron River near Guthrie, Okla.[2] | 35.920602 | 97.425875 | 62,300 | <10 |
| 6 | 07161450 | RIPL | Cimarron River near Ripley, Okla.[2] | 35.985893 | 96.912250 | 99,400 | >10 |
| 7 | 07165570 | HASK | Arkansas River near Haskell, Okla.[2] | 35.822778 | 95.637778 | 286,000 | >100 |
| 8 | 07171000 | LENA | Verdigris River near Lenapah, Okla.[2] | 36.851196 | 95.586088 | 83,300 | >25 |
| 9 | -- | OOLO | Verdigris River below Oologah Dam, Okla.[1] | 36.421667 | 95.678333 | 64,200 | >50 |
| 10 | -- | HULA | Caney River below Hulah Dam, Okla.[1] | 36.928889 | 96.088333 | 12,400 | <10 |
| 11 | -- | COPA | Little Caney River below Copan Dam, Okla.[1] | 36.885278 | 95.971389 | 7,300 | <25 |
| 12 | 07174400 | BART | Caney River at Bartlesville, Okla.[2] | 36.755644 | 95.972206 | 19,300 | <10 |
| 13 | 07175500 | RAMO | Caney River near Ramona, Okla.[2] | 36.508982 | 95.841931 | 42,600 | >10 |
| 14 | 07176000 | CLAR | Verdigris River near Claremore, Okla.[2] | 36.307500 | 95.699722 | 92,500 | >25 |
| 15 | -- | BIRC | Birch Creek below Birch Dam, Okla.[1] | 36.534444 | 96.162222 | 1,400 | >2 |
| 16 | 07176500 | AVAN | Bird Creek near Avant, Okla.[2] | 36.485088 | 96.060274 | 36,400 | <100 |
| 17 | 07176950 | HOMI | Hominy Creek near Hominy, Okla.[2] | 36.473679 | 96.378906 | 27,200 | <25 |
| 18 | -- | SKIA | Hominy Creek below Skiatook Dam, Okla.[1] | 36.350556 | 96.086667 | 5,900 | >100 |
| 19 | 07177500 | SPER | Bird Creek near Sperry, Okla.[2] | 36.278425 | 95.954162 | 42,100 | <50 |
| 20 | -- | INOL | Verdigris River near Inola, Okla.[1] | 36.057778 | 95.534722 | 101,000 | >25 |
| 21 | 07185000 | COMM | Neosho River near Commerce, Okla.[2] | 36.928681 | 94.957457 | 91,400 | <25 |
| 22 | 07185090 | -- | Tar Creek near Commerce, Okla.[2] | 36.943680 | 94.853286 | 6,660 | >10 |
| 23 | 07185095 | MIAT | Tar Creek at 22nd Street Bridge at Miami, Okla.[2] | 36.900070 | 94.868288 | 6,410 | <10 |
| 24 | -- | PENS | Grand River below Pensacola Dam, Okla.[1] | 36.471111 | 95.038333 | 189,500 | <50 |
| 25 | -- | HUDS | Grand River below Markham Ferry Dam, Okla.[1] | 36.231667 | 95.193056 | 226,700 | >50 |
| 26 | -- | FGIB | Grand River below Fort Gibson Dam, Okla.[1] | 35.871111 | 95.228333 | 228,300 | >50 |
| 27 | 07191000 | BCAB | Big Cabin Creek near Big Cabin, Okla.[2] | 36.568418 | 95.152189 | 42,500 | >10 |
| 28 | 07194500 | MUSK | Arkansas River at Muskogee, Okla.[2] | 35.769543 | 95.297187 | 600,000 | <100 |
| 29 | -- | WEBB | Arkansas River below Webbers Falls Lock and Dam, Okla.[1] | 35.586389 | 95.168333 | 611,000 | <100 |
| 30 | 07195500 | WATT | Illinois River near Watts, Okla.2 | 36.130082 | 94.572165 | 24,600 | >2 |
| 31 | 07196500 | TAHL | Illinois River near Tahlequah, Okla.[2] | 35.922869 | 94.923566 | 26,500 | >2 |
| 32 | -- | TENK | Illinois River below Tenkiller Dam, Okla.[1] | 35.596389 | 95.048889 | 11,000 | <2 |

**Table 1.** Site information for selected streamgages in eastern and northeastern Oklahoma and peak streamflow values for the May to June 2019 flood event.—Continued

[USGS, U.S. Geological Survey; USACE, U.S. Army Corps of Engineers; $ft^3/s$, cubic feet per second; --, not applicable; Okla., Oklahoma; >, greater than; <, less than]

| Map identifier (fig. 1) | USGS station number | USACE station identifier | Station name | Latitude, in decimal degrees | Longitude, in decimal degrees | Peak streamflow, in $ft^3/s$ | Recurrence interval, in years |
|---|---|---|---|---|---|---|---|
| 33 | 07243500 | BEGG | Deep Fork near Beggs, Okla.[2] | 35.673988 | 96.068608 | 20,000 | >5 |
| 34 | -- | EUFA | Canadian River below Eufaula Dam, Okla.[1] | 35.306944 | 95.362222 | 36,500 | <2 |
| 35 | -- | ROBE | Arkansas River below Robert S. Kerr Lock and Dam, Okla.1 | 35.349167 | 94.778333 | 546,000 | <50 |
| 36 | -- | WIST | Poteau River below Wister Dam, Okla.[1] | 34.935833 | 94.719444 | 5,100 | <2 |
| 37 | -- | POTE | Poteau River near Poteau, Okla.[1] | 35.066667 | 94.599722 | 6,500 | <2 |
| 38 | 07249413 | PANA | Poteau River near Panama, Okla.[2] | 35.165653 | 94.653002 | 21,500 | >2 |

[1]Station operated by the U.S. Army Corps of Engineers.

[2]Station operated by the U.S. Geological Survey.

# 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-streamflow frequency data are determined from a series of the highest instantaneous annual peak streamflows 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 the AEP (Holmes and others, 2013).

Each peak streamflow value listed in table 1 is an instantaneous peak streamflow that can be expected to be equaled or exceeded on average once every "y" years, where "y" is the recurrence interval. Similarly, each instantaneous peak streamflow has an "x"-percent probability of exceedance in any given year, where "x" is the exceedance probability, in percent. For example, the instantaneous peak streamflow 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 streamflow 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 calculated by the USGS for the unregulated streams in 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). 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

**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 |

Data, 1982). Flood computation equations and algorithms in Bulletin 17C have been implemented into PeakFQ, version 7.2. The May and June 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).

All the streamgages operated by the USGS discussed in this report monitored unregulated streamflows with two exceptions: more than 80 percent of the drainage areas upstream from USGS streamgages 07153000, Black Bear Creek at Pawnee, Okla., and 07243500, Deep Fork near Beggs, Okla., were affected by reservoir regulation. Therefore, the “at-site” skew function in PeakFQ was used to determine peak-streamflow frequencies for these streamgages.

The flood-frequency estimates calculated by the USACE for the regulated streams in this report were made by using the USACE Hydrologic Engineering Center’s (HEC) statistical software package (HEC-SSP) (USACE, 2019b). This is a statistical software tool developed by the USACE HEC that can perform flood analyses in accordance with Bulletin 17C procedures and graphical techniques (USACE, 2019b). Unregulated period-of-record annual maximum streamflow was analyzed by using Bulletin 17C methodology. Because most of the regulated period-of-record annual maximum streamflow datasets were so heavily affected by upstream dams that the application of Bulletin 17C was inappropriate, graphical frequency analysis was used. The estimation of confidence intervals has historically been problematic for nonanalytical curves (Goldman, 2001). Fortunately, HEC-SSP incorporates order statistics, which allows for an estimation of the 5-percent and 95-percent confidence intervals. The order statistic approach was limited to calculating uncertainty in the estimated frequency curve for the range of observed data (which was a 79-year equivalent length of record for the RiverWare simulated datasets) (USACE, 1997). Asymptotic approximation was used to extrapolate the estimates beyond the equivalent length of record. The order statistic and asymptotic estimates were matched at the limits of the simulated data.

A peak transform method described by Ergish (2010) was evaluated for possible widespread use in this study. The premise behind the peak transform method is that unregulated streamflows can be converted to regulated streamflows while maintaining the probabilistic distribution of the unregulated dataset by using linear regression (Ergish, 2010). A previous study by the USACE Tulsa District used the peak transform method in an assessment of streamflow frequency of the Red River at Shreveport, Louisiana, and found that the method worked well (USACE, 2018b). In the Red River at Shreveport study, the magnitude of the 1-percent AEP streamflow that was calculated by using the peak transform method differed from a graphical frequency analysis by less than 5 percent. In this study, however, the peak transform method generally performed poorly. This was attributed to the substantial amount of downstream regulation along many of the streams that were analyzed. Therefore, the peak transform method was only used for streamgages on Bird Creek, where the effects of regulation were not as pronounced.

Because the RiverWare model uses a daily time step, the same duration was also used for this analysis. Comparisons between average daily streamflows and instantaneous peak streamflows were made at a few downstream streamgages on the Arkansas River and its tributaries. Given the duration of releases from flood-control dams during major floods, very little difference (typically less than 5 percent) was observed between the two. Therefore, no peaking factor was applied. For streams that were either completely or largely unregulated, the application of a peaking factor became an important consideration. Bird Creek Basin was most affected by instantaneous streamflows in this study. Because USGS instantaneous peak and daily streamflow averages span the entire 80-year history of the RiverWare simulated period-of-record dataset, a ratio of observed streamflows showed that the instantaneous peaks were typically 20 percent higher than daily averages. Therefore, a peaking factor was applied to the instantaneous peak streamflows measured at USGS streamgages 07177500, Bird Creek near Sperry, Okla., and 07176500, Bird Creek near Avant, Okla. Otherwise, no adjustment was made for instantaneous peak streamflows.

Of the 38 streamgages in this study, 9 recorded new peak streamflows in 2019 (table 3). Ranks for peak streamflows are determined by water year. The AEPs ranged from less than 1 percent to 50 percent for peak streamflows analyzed in this study. At USGS streamgage 07153000, Black Bear Creek at Pawnee, Okla., a peak streamflow of record of 19,500 $ft^3/s$ was measured on May 21, 2019 (table 3; fig. 6). Peak streamflows of record were also measured at the following streamgages in Oklahoma: Arkansas River below Kaw Dam; 07165570, Arkansas River near Haskell; Verdigris River below Oologah Dam; 07176500, Bird Creek near Avant; 07176950, Hominy Creek near Hominy; Hominy Creek below Skiatook Dam, Okla.; Verdigris River near Inola; and 07185090, Tar Creek near Commerce.

**Table 3.** Peak-streamflow frequency estimates for selected streamgages in eastern and northeastern Oklahoma for the May to June 2019 flood event.

[USGS, U.S. Geological Survey; USACE, U.S. Army Corps of Engineers; ft, feet; $ft^3/s$, cubic feet per second; --, not applicable; %, percent; Y, yes; N, no]

| | | | | Analysis information | | Flood data | | | |
|---|---|---|---|---|---|---|---|---|---|
| Map identifier (fig. 1) | USGS station number | USACE station identifier | Station name | Water years for peak streamflows (systematic and historical) | Regulated | Date of peak streamflow | Peak stage (ft) | Peak streamflow, in $ft^3/s$ | Rank of peak streamflow in record |
| 1 | -- | KAWL | Arkansas River below Kaw Dam, Okla.[1] | 1940–2019 | Y | 5/25/2019 | -- | 105,000 | 1 |
| 2 | 07152500 | RALS | Arkansas River near Ralston, Okla.[1] | 1940–2019 | Y | 5/23/2019 | 22.14 | 185,000 | 2 |
| 3 | -- | KEYS | Arkansas River below Keystone Dam, Okla.[1] | 1940–2019 | Y | 5/29/2019 | -- | 275,000 | 2 |
| 4 | 07153000 | PAWN | Black Bear Creek at Pawnee, Okla.[3] | 1968–2019 | Y | 5/21/2019 | 26.18 | 19,500 | 1 |
| 5 | 07160000 | GUTH | Cimarron River near Guthrie, Okla.[2] | 1938–2019 | N | 5/21/2019 | 21.79 | 62,300 | 9 |
| 6 | 07161450 | RIPL | Cimarron River near Ripley, Okla.[2] | 1988–2019 | N | 5/26/2019 | 26.39 | 99,400 | 3 |
| 7 | 07165570 | HASK | Arkansas River near Haskell, Okla.[1] | 1940–2019 | Y | 5/29/2019 | 24.24 | 286,000 | 1 |
| 8 | 07171000 | LENA | Verdigris River near Lenapah, Okla.[1] | 1940–2019 | Y | 5/28/2019 | 37.50 | 83,300 | 6 |
| 9 | -- | OOLO | Verdigris River below Oologah Dam, Okla.[1] | 1940–2019 | Y | 5/25/2019 | -- | 64,500 | 1 |
| 10 | -- | HULA | Caney River below Hulah Dam, Okla.[1] | 1940–2019 | Y | 5/26/2019 | -- | 12,400 | 3 |
| 11 | -- | COPA | Little Caney River below Copan Dam, Okla.[1] | 1940–2019 | Y | 5/26/2019 | -- | 7,320 | 5 |
| 12 | 07174400 | BART | Caney River at Bartlesville, Okla.[1] | 1940–2019 | Y | 5/21/2019 | 18.21 | 19,300 | 4 |
| 13 | 07175500 | RAMO | Caney River near Ramona, Okla.[1] | 1940–2019 | Y | 5/23/2019 | 29.59 | 42,600 | 3 |
| 14 | 07176000 | CLAR | Verdigris River near Claremore, Okla.[1] | 1940–2019 | Y | 5/27/2019 | 45.75 | 92,500 | 3 |
| 15 | -- | BIRC | Birch Creek below Birch Dam, Okla.[1] | 1940–2019 | Y | 5/26/2019 | -- | 1,420 | 30 |
| 16 | 07176500 | AVAN | Bird Creek near Avant, Okla.[1] | 1940–2019 | Y | 5/21/2019 | 36.31 | 36,400 | 1 |
| 17 | 07176950 | HOMI | Hominy Creek near Hominy, Okla.[2] | 2004–2019 | N | 5/21/2019 | 43.06 | 27,200 | 1 |
| 18 | -- | SKIA | Hominy Creek below Skiatook Dam, Okla.[1] | 1940–2019 | Y | 5/21/2019 | -- | 5,900 | 1 |
| 19 | 07177500 | SPER | Bird Creek near Sperry, Okla.[1] | 1940–2019 | Y | 5/22/2019 | 31.55 | 42,100 | 5 |
| 20 | -- | INOL | Verdigris River near Inola, Okla.[1] | 1940–2019 | Y | 5/26/2019 | -- | 177,000 | 1 |
| 21 | 07185000 | COMM | Neosho River near Commerce, Okla.[1] | 1940–2019 | Y | 5/24/2019 | 25.53 | 91,400 | 7 |

| Map identifier (fig. 1) | Peak-streamflow frequency estimates | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Peak streamflow (ft³/s) for indicated annual exceedance probability (%) | | | | | | | |
| | 50% | 20% | 10% | 4% | 2% | 1% | 0.5% | 0.2% |
| 1 | 26,000 | 37,000 | 40,000 | 45,000 | 70,000 | 130,000 | 167,000 | 185,000 |
| 2 | 47,200 | 82,500 | 107,000 | 130,000 | 159,000 | 180,000 | 200,000 | 225,000 |
| 3 | 60,000 | 90,000 | 110,000 | 140,000 | 210,000 | 270,000 | 310,000 | 350,000 |
| 4 | 5,620 | 9,700 | 12,600 | 16,300 | 19,000 | 21,700 | 24,400 | 27,900 |
| 5 | 28,300 | 51,200 | 70,500 | 99,600 | 125,000 | 154,000 | 186,000 | 235,000 |
| 6 | 32,800 | 65,800 | 95,100 | 142,000 | 183,000 | 232,000 | 288,000 | 374,000 |
| 7 | 52,000 | 70,000 | 110,000 | 140,000 | 210,000 | 270,000 | 310,000 | 350,000 |
| 8 | 30,000 | 42,000 | 55,000 | 80,000 | 110,000 | 145,000 | 175,000 | 210,000 |
| 9 | 30,000 | 30,000 | 30,000 | 30,500 | 52,000 | 80,000 | 115,000 | 135,000 |
| 10 | 5,000 | 6,700 | 19,000 | 35,000 | 50,000 | 57,000 | 65,000 | 75,000 |
| 11 | 2,000 | 3,500 | 3,500 | 9,100 | 17,000 | 25,000 | 35,000 | 44,000 |
| 12 | 6,700 | 10,000 | 20,000 | 40,000 | 60,000 | 75,000 | 90,000 | 105,000 |
| 13 | 12,000 | 20,000 | 30,000 | 60,000 | 85,000 | 95,000 | 105,000 | 115,000 |
| 14 | 34,100 | 39,700 | 45,000 | 80,000 | 110,000 | 130,000 | 150,000 | 170,000 |
| 15 | 1,200 | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 |
| 16 | 10,000 | 16,900 | 21,800 | 26,800 | 33,300 | 38,400 | 43,500 | 50,400 |
| 17 | 8,700 | 15,100 | 20,100 | 27,300 | 33,200 | 39,500 | 46,400 | 56,300 |
| 18 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,900 | 6,000 |
| 19 | 11,200 | 20,500 | 27,200 | 34,000 | 43,100 | 49,900 | 56,900 | 66,100 |
| 20 | 44,000 | 60,200 | 80,000 | 100,000 | 140,000 | 180,000 | 210,000 | 240,000 |
| 21 | 33,500 | 58,400 | 74,700 | 102,000 | 120,000 | 140,000 | 160,000 | 190,000 |

**Table 3.** Peak-streamflow frequency estimates for selected streamgages in eastern and northeastern Oklahoma for the May to June 2019 flood event.—Continued

[USGS, U.S. Geological Survey; USACE, U.S. Army Corps of Engineers; ft, feet; ft³/s, cubic feet per second; --, not applicable; %, percent; Y, yes; N, no]

| | | | | Analysis information | | Flood data | | | |
|---|---|---|---|---|---|---|---|---|---|
| Map identifier (fig. 1) | USGS station number | USACE station identifier | Station name | Water years for peak streamflows (systematic and historical) | Regulated | Date of peak streamflow | Peak stage (ft) | Peak streamflow, in ft³/s | Rank of peak streamflow in record |
| 22 | 07185090 | -- | Tar Creek near Commerce, Okla.[2] | 2005–2019 | N | 5/21/2019 | 18.44 | 6,660 | 1 |
| 23 | 07185095 | MIAT | Tar Creek at 22nd Street Bridge at Miami, Okla.[2] | 1984–2019 | N | 5/21/2019 | 14.73 | 6,410 | 3 |
| 24 | -- | PENS | Grand River below Pensacola Dam, Okla.[1] | 1940–2019 | Y | 5/23/2019 | -- | 190,000 | 2 |
| 25 | -- | HUDS | Grand River below Markham Ferry Dam, Okla.[1] | 1940–2019 | Y | 5/24/2019 | -- | 227,000 | 2 |
| 26 | -- | FGIB | Grand River below Fort Gibson Dam, Okla.[1] | 1940–2019 | Y | 5/25/2019 | -- | 228,000 | 2 |
| 27 | 07191000 | BCAB | Big Cabin Creek near Big Cabin, Okla.[2] | 1941–2019 | N | 5/21/2019 | 47.42 | 42,500 | 5 |
| 28 | 07194500 | MUSK | Arkansas River at Muskogee, Okla.[1] | 1940–2019 | Y | 5/26/2019 | 46.39 | 600,000 | 2 |
| 29 | -- | WEBB | Arkansas River below Webbers Falls Lock and Dam, Okla.[1] | 1940–2019 | Y | 5/27/2019 | -- | 611,000 | 2 |
| 30 | 07195500 | WATT | Illinois River near Watts, Okla.[2] | 1956–2019 | N | 6/24/2019 | 19.99 | 24,600 | 24 |
| 31 | 07196500 | TAHL | Illinois River near Tahlequah, Okla.[2] | 1937–2019 | N | 6/25/2019 | 16.71 | 26,500 | 29 |
| 32 | -- | TENK | Illinois River below Tenkiller Dam, Okla.[1] | 1940–2019 | Y | 7/1/2019 | -- | 12,900 | 5 |
| 33 | 07243500 | BEGG | Deep Fork near Beggs, Okla.[3] | 1968–2019 | Y | 5/26/2019 | 26.01 | 20,000 | 19 |
| 34 | -- | EUFA | Canadian River below Eufaula Dam, Okla.[1] | 1940–2019 | Y | 6/2/2019 | -- | 36,600 | 9 |
| 35 | -- | ROBE | Arkansas River below Robert S. Kerr Lock and Dam, Okla.[1] | 1940–2019 | Y | 5/28/2019 | -- | 613,000 | 2 |
| 36 | -- | WIST | Poteau River below Wister Dam, Okla.[1] | 1940–2019 | Y | 5/5/2019 | -- | 5,080 | 7 |
| 37 | -- | POTE | Poteau River near Poteau, Okla.[1] | 1940–2019 | Y | 5/8/2019 | -- | 6,470 | 8 |
| 38 | 07249413 | PANA | Poteau River near Panama, Okla.[1] | 1940–2019 | Y | 6/25/2019 | 36.74 | 21,500 | 14 |

[1]Peak-streamflow frequency estimates were calculated by using the USACE Hydrologic Engineering Center's (HEC) statistical software package (HEC-SSP) (USACE, 2019b).

[2]Peak-streamflow frequency estimates were calculated by using PeakFQ (Veilleux and others, 2014).

[3]Peak-streamflow frequency estimates were calculated by using PeakFQ; the estimated peak flows were not weighted (England and others, 2019) but represent the at-site flood-frequency analysis.

| Map identifier (fig. 1) | Peak-streamflow frequency estimates | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Peak streamflow (ft³/s) for indicated annual exceedance probability (%) | | | | | | | |
| | 50% | 20% | 10% | 4% | 2% | 1% | 0.5% | 0.2% |
| 22 | 2,560 | 4,460 | 5,980 | 8,180 | 10,000 | 12,000 | 14,300 | 17,500 |
| 23 | 3,060 | 5,150 | 6,780 | 9,100 | 11,000 | 13,100 | 15,400 | 18,700 |
| 24 | 65,000 | 90,200 | 102,000 | 117,900 | 195,000 | 280,000 | 330,000 | 360,000 |
| 25 | 70,000 | 100,000 | 108,000 | 130,000 | 225,000 | 330,000 | 375,000 | 415,000 |
| 26 | 68,000 | 95,000 | 100,000 | 100,100 | 195,000 | 295,000 | 340,000 | 380,000 |
| 27 | 16,600 | 28,600 | 38,000 | 51,200 | 62,000 | 73,500 | 85,800 | 103,000 |
| 28 | 120,000 | 145,000 | 205,000 | 320,000 | 495,000 | 625,000 | 705,000 | 745,000 |
| 29 | 120,000 | 145,000 | 205,000 | 320,000 | 495,000 | 625,000 | 705,000 | 745,000 |
| 30 | 19,700 | 37,900 | 53,400 | 76,800 | 97,200 | 120,000 | 146,000 | 184,000 |
| 31 | 20,900 | 41,900 | 59,600 | 86,200 | 109,000 | 134,000 | 162,000 | 202,000 |
| 32 | 14,000 | 14,000 | 14,000 | 14,400 | 35,000 | 80,000 | 110,000 | 140,000 |
| 33 | 9,890 | 18,500 | 24,900 | 33,500 | 40,000 | 46,700 | 53,500 | 62,500 |
| 34 | 40,000 | 40,000 | 43,000 | 55,000 | 145,000 | 270,000 | 320,000 | 370,000 |
| 35 | 138,000 | 171,000 | 311,000 | 379,000 | 585,000 | 775,000 | 835,000 | 845,000 |
| 36 | 7,800 | 7,800 | 7,800 | 14,500 | 21,000 | 30,000 | 44,000 | 60,000 |
| 37 | 8,000 | 11,400 | 16,700 | 21,600 | 30,000 | 42,000 | 56,000 | 72,000 |
| 38 | 19,000 | 30,000 | 48,000 | 60,000 | 73,000 | 85,000 | 95,000 | 105,000 |

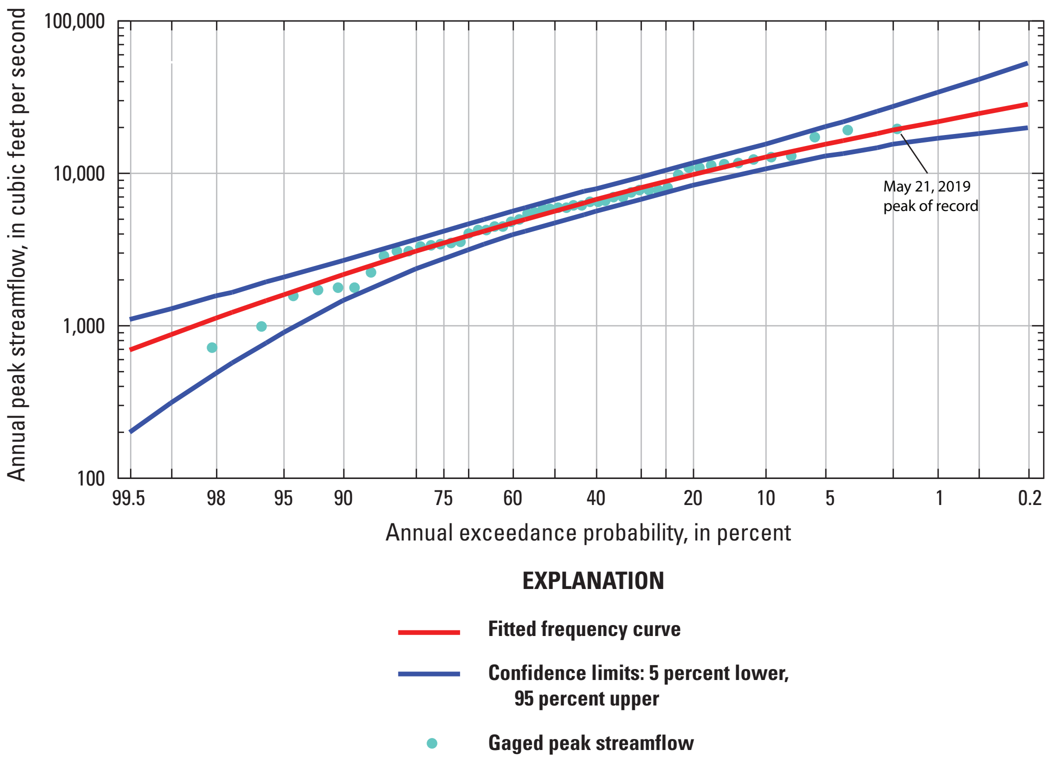


**Figure 6.** Flood-frequency curve for the annual peak streamflows during the regulated period of record at U.S. Geological Survey streamgage 07153000, Black Bear Creek at Pawnee, Oklahoma.

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