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Historical Hydrologic and Geomorphic Conditions on the Black River and Selected Tributaries, Arkansas and Missouri

Scientific Investigations Report 2021–5067

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

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By Jessica Z. LeRoy, Richard J. Huizinga, David C. Heimann, Evan M. Lindroth, and Henry F. Doyle

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter (mm)
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in)
centimeter (cm)	0.3937	inch (in)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre
square kilometer (km^2)	247.1	acre
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Flow rate	
meter per year (m/yr)	3.281	foot per year (ft/yr)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Datum

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29) or the North American Vertical Datum of 1988 (NAVD 88).

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

Abbreviations

ADCP	Acoustic Doppler Current Profiler
AEP	annual exceedance probability
DDBR WMA	Dave Donaldson Black River Wildlife Management Area
MAP	Mississippi alluvial plain
MK	Mann-Kendall
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NGVD 29	National Geodetic Vertical Datum of 1929
NWS	National Weather Service
NWIS	National Water Information System
SD	standard deviation
SIMS	Site Information Management System
TS	Theil-Sen
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WY	water year

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Abstract

The Black River flows through southeast Missouri and northeast Arkansas to its confluence with the White River in Arkansas. The U.S. Army Corps of Engineers operates Clearwater Dam on the Black River and a series of dams in the White River Basin primarily for flood control. In this study, the hydrology and geomorphology of the Black River are examined through an analysis of annual mean and peak discharges at streamgages, a specific stage analysis of stage and discharge at streamgages, and an examination of bathymetric data and aerial imagery. Five streamgages on the Black River were analyzed, in addition to four streamgages on Black River tributaries and one streamgage on the White River, located just downstream from the Black River confluence. The analyses indicated that regulation of discharges at the flood-control dams caused a decrease in the magnitude and variability of the peak discharges at several of the analyzed gages on the Black and White Rivers. Conversely, peak discharges on the Black River have been increasing since water year 2000, though this is not matched by an increase in peak discharges on the White River for the same time period. The specific stage analyses and the available morphologic data generally did not indicate pronounced changes in stage-discharge relations at streamgages on the Black River, with the exception of the gages nearest to Clearwater Dam.

Introduction

The Black River originates in the uplands of the Ozark Plateau and flows into the lowlands of the Mississippi alluvial plain (fig. 1). The lowland portion of the Black River meanders through heavily agricultural parts of southeast Missouri and northeast Arkansas and is therefore carefully managed for flood-control purposes. The U.S. Army Corps of Engineers (USACE) constructed Clearwater Dam on the Black River in 1948, creating a flood-control reservoir that is also used for recreational activities. A network of levees also was constructed on the Black River in the 1940s and 1950s to mitigate flooding. Recently, concerns have been raised regarding a perceived increase in the magnitude and frequency of flooding on the lowland reach of the Black River (J. Funkhouser, USACE, oral commun., 2020).

The Black River is a major tributary to the White River, constituting about 42 percent of the White River drainage area at their confluence near Newport, Arkansas (fig. 1). The White River drains a large portion of northern Arkansas and southern Missouri. The USACE manages water levels in the White River by controlling outflows from a system of reservoirs that includes Clearwater Lake on the Black River, as well as Beaver Lake, Table Rock Lake, and Bull Shoals Lake on the White River; Norfork Lake on the North Fork River; and Greers Ferry Lake on the Little Red River (not shown). These reservoirs are primarily operated for flood control and, with the exception of Clearwater Lake, include additional storage for hydroelectric power generation and water supply (USACE, 2020a). Bull Shoals and Norfork Lakes also are used to provide minimum discharges downstream during dry periods (USACE, 2020a). Managing this system of reservoirs is challenging and requires accurate stage and discharge data for the main stem White River and its tributaries, including the Black River.

In cooperation with the USACE, the U.S. Geological Survey (USGS) has operated and maintained streamgages at several sites in the Black River Basin since the 1920s and 1930s. At these streamgages, river stage is recorded at defined time intervals and converted to a discharge value by means of a stage-discharge relation referred to as a “rating” or “rating curve” (Carter and Davidian, 1968; Rantz and others, 1982; Sauer and Turnipseed, 2010). With time, it is possible for changes in the condition or morphology of the channel and flood plain at or near the streamgage to result in changes to the stage-discharge relation at that site, which can necessitate the development of a new rating curve. The magnitude and frequency of flood events also may change over time owing to changes in climate, land cover, or the conveyance capacity of the channel. Changes in the geomorphic and hydrologic conditions on the Black River and its tributaries may have implications for how Clearwater Lake and the other reservoirs in the White River Basin are managed. Therefore, this study aims to determine if the Black River and its tributaries have experienced increased flooding or changes in channel morphology.

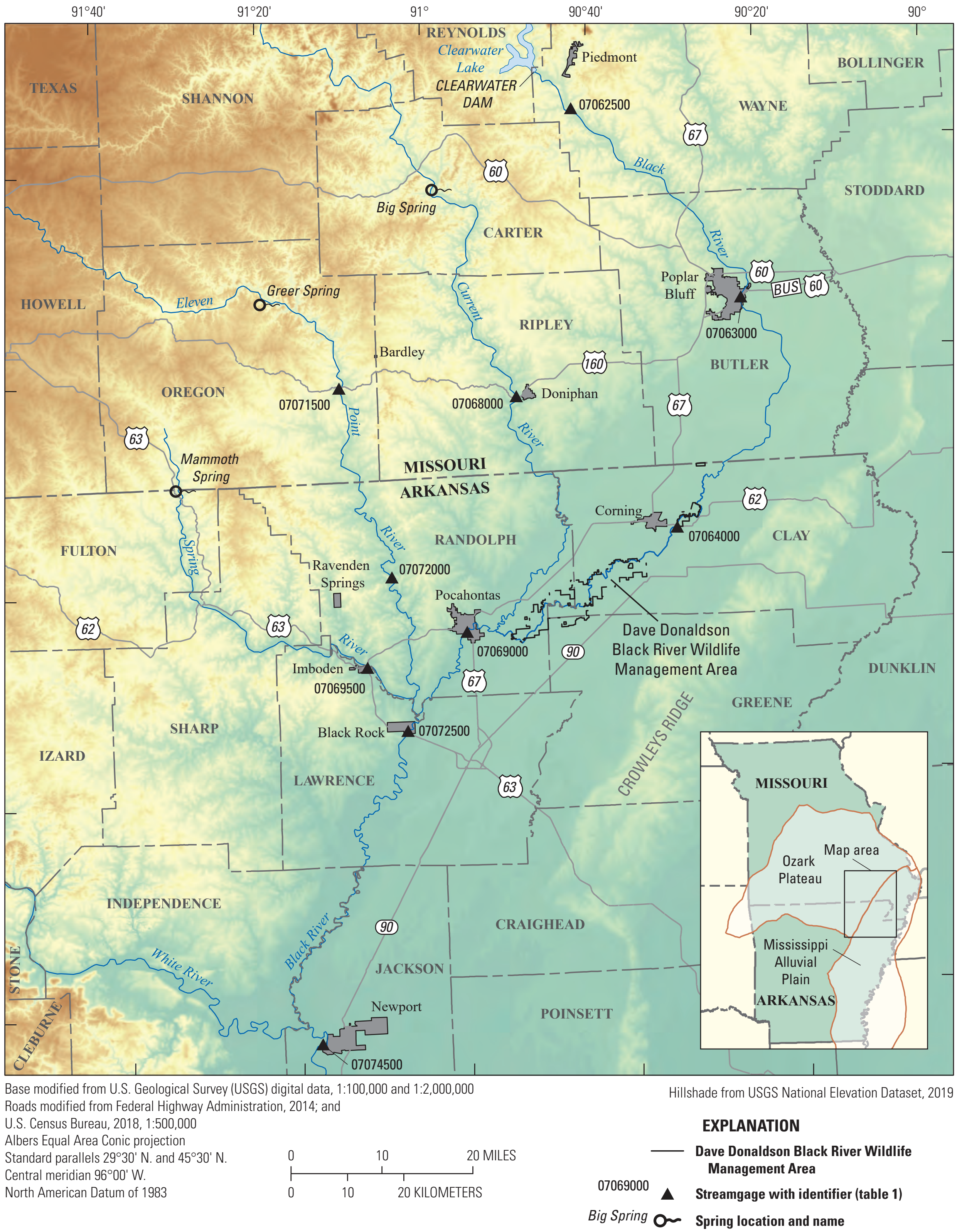

Figure 1. Locations of U.S. Geological Survey streamgages used in this study, major springs, and other points and areas of interest in the study area.

Purpose and Scope

The purpose of this report is to present results of an analysis of long-term streamgage records and historical discharge measurements made at five gages on the Black River, four gages on three of tributaries to the Black River, and a streamgage on the White River at Newport, Ark. Four approaches were used in examining the streamgage records and the historical discharge measurements at the gages. First, the record of annual mean discharge and annual peak discharge at each streamgage were examined to determine if the magnitudes of these annual statistics have changed over time. Second, flow-duration curves were developed over decadal periods using the record of daily mean discharges for each streamgage and analyzed for temporal changes in the exceedance probability of discharges. Third, specific-streamgage data (the stage associated with a particular discharge or narrow discharge range) from discharge measurements and rating curves were examined for changes in the relationship between stage and discharge over the period of record. Finally, the channel cross-sectional geometry data that is reported with some discharge measurements were examined for changes over time for four of the main stem Black River gages.

In addition to the analysis of the streamgage records, historical bathymetric datasets were used to construct longitudinal profiles of the bed of the Black River. This analysis is limited in scope and utility by the uncertainty associated with some of the historical bathymetric data, the limited time periods for which data are available, and the fact that the data were not specifically collected for the purposes of this study. Historical bathymetric cross-sections were extracted from a USACE hydraulic model that was based on a 1981 survey of the reach between Clearwater Dam and Poplar Bluff, Mo. Cross-sections were also extracted from a different USACE hydraulic model that was based on a 2004 survey of the reach between Poplar Bluff, Mo., and Pocahontas, Ark. The reach from Clearwater Dam to Poplar Bluff also was surveyed in 2020 (Rivers and others, 2020) and the reach from Poplar Bluff to Pocahontas was surveyed in 2018 (Richards and others, 2018). The longitudinal water-surface profile was also constructed from streamgage data to provide some context for the bathymetric data. The results presented in this report could inform how USACE manages outflows from reservoirs in the White River Basin, particularly Clearwater Lake on the Black River.

Description of Study Area

The study area is the Black River between Clearwater Dam and the confluence with the White River at Newport, Ark. (fig. 1). The Black River flows southeast from Clearwater Lake to Poplar Bluff, Mo., located roughly at the boundary between the Ozark Plateau and the Mississippi alluvial plain (MAP). Downstream from Poplar Bluff, the Black River curves toward the south, then toward the southwest as it crosses the border from Missouri into Arkansas. From Pocahontas, Ark., the Black River flows southwest to the confluence with the White River. The study area also includes three of the major tributaries to the Black River: the Current River, Eleven Point River, and Spring River (fig. 1). These tributaries flow south-southeast from their headwaters in the Ozark Plateau, joining the Black River along the reach between Corning and Black Rock, Ark. The Köppen-Geiger climate classification of the study area is warm temperate, the precipitation classification is fully humid, and the temperature classification is hot summer (Kottek and others, 2006). Mean annual precipitation in the Black River Basin (period of record 1901–2020) ranges from 42.5 to 50 inches, with precipitation increasing from the northwest to the southeast (Midwestern Regional Climate Center, 2021).

The main-stem Black River gages examined in this report are the Black River at Leeper, Mo. (07062500, hereafter referred to as “the BR-Leeper streamgage”); Black River at Poplar Bluff, Mo. (07063000, hereafter referred to as “the BR-Poplar Bluff streamgage”); Black River near Corning, Ark. (07064000, hereafter referred to as “the BR-Corning streamgage”); Black River at Pocahontas, Ark. (07069000, hereafter referred to as “the BR-Pocahontas streamgage”); and Black River at Black Rock, Ark. (07072500, hereafter referred to as “the BR-Black Rock streamgage). The Black River above Williamsville, Mo. (07062575) and Black River at Elgin Ferry, Ark. (07074420) are not included because the periods of record at those gages are somewhat short with less than 25 years of record as compared to the other streamgages that have greater than 80 years of record. The tributary gages examined in this report are the Current River at Doniphan, Mo. (07068000, hereafter referred to as “the CR-Doniphan streamgage”), Eleven Point River near Bardley, Mo. (07071500, hereafter referred to as “the EPR-Bardley streamgage”), Eleven Point River near Ravenden Springs, Ark. (07072000, hereafter referred to as “the EPR-Ravenden Springs streamgage”), and Spring River at Imboden, Ark. (07069500, hereafter referred to as “the SR-Imboden streamgage”). The White River at Newport, Ark. (07074500, hereafter referred to as “the WR-Newport streamgage”), located just downstream from the confluence of the Black River and White River, was also included. Information about these gages is given in table 1. Further detail on the data used from these gages is provided in the “Methods” section.

The geomorphology of the Black River Basin is dominated by the contrast between the highly dissected uplands of the Ozark Plateau and the broad, flat MAP (fig. 1). The Black River exits the Ozark Plateau flowing toward the southeast and takes a wide arcing path through the MAP between the Ozark Plateau to the west and Crowley’s Ridge to the east. The upland reach of the study area, between Clearwater Lake and Poplar Bluff, Mo., is a meandering, gravel-bedded stream with a narrower valley compared to the reaches downstream from Poplar Bluff (Cieslewicz, 2004). From Poplar Bluff, Mo., to about 10 miles (mi) downstream, the Black River is

Table 1. Streamgages used in this study.

[MO, Missouri; AR, Arkansas; USGS, U.S. Geological Survey; NAD 83, North American Datum of 1983; NAD 27: North American Datum of 1927; NGVD 29, National Geodetic Vertical Datum of 1929; NAVD 88, National American Vertical Datum of 1988; NWS, National Weather Service]

Streamgage name	USGS streamgage number	Latitude, in decimal degrees	Longitude, in decimal degrees	Drainage area, in square miles	Datum as of December 2020[1]	Date of first discharge measurement	Flood stage[2]	Flood discharge[3]
Black River at Leeper, MO	07062500	37.058722 (NAD 83)	90.687000 (NAD 83)	987	416.54 (NGVD 29)	6/4/1921	No data	No data
Black River at Poplar Bluff, MO	07063000	36.759583 (NAD 83)	90.388111 (NAD 83)	1,245	317.48 (NGVD 29)	2/11/1936	16	7,057
Black River near Corning, AR	07064000	36.401944 (NAD 83)	90.541389 (NAD 83)	1,750	272.90 (NGVD 29)	8/15/1938	15	20,040
Current River at Doniphan, MO	07068000	36.621944 (NAD 27)	90.847500 (NAD 27)	2,038	321.42 (NAVD 88)	6/14/1921	13	30,000
Black River at Pocahontas, AR	07069000	36.254167 (NAD 83)	90.970278 (NAD 83)	4,840	241.81 (NGVD 29)	7/15/1937	17	14,720
Eleven Point River near Bardley, MO	07071500	36.648694 (NAD 83)	91.200833 (NAD 83)	793	411.25 (NAVD 88)	9/14/1921	10	10,040
Eleven Point River near Ravenden Springs, AR	07072000	36.346389 (NAD 83)	91.114167 (NAD 83)	1,130	291.98 (NGVD 29)	11/1/1929	15	13,670
Spring River at Imboden, AR	07069500	36.205556 (NAD 83)	91.171667 (NAD 83)	1,180	254.07 (NGVD 29)	7/26/1923	18	17,170
Black River at Black Rock, AR	07072500	36.102500 (NAD 83)	91.097778 (NAD 83)	7,370	229.56 (NGVD 29)	6/25/1929	14	15,620
White River at Newport, AR	07074500	35.605278 (NAD 83)	91.288889 (NAD 83)	19,900	194.36 (NAVD 88)	8/1/1927	26	61,900

[1]Datums may be changed or resurveyed after December 2020, resulting in different values published in the National Water Information System (USGS, 2019). As of June 2021, the datums at the Black River near Corning, AR; Black River at Pocahontas, AR; and the Spring River at Imboden, AR had been updated to NAVD 88.

[2]National Weather Service flood stage, in feet above the current datum.

[3]Discharge corresponding to the NWS flood stage on the current rating curve, in cubic feet per second.

mildly sinuous and is flanked by a narrow, forested border with levees that are generally less than 0.25 mi from both sides of the channel (Cieslewicz, 2004; USACE, 2020h). Moving farther downstream, the channel becomes more sinuous and the forested border widens to approximately 0.5 mi (Cieslewicz, 2004).

The planform of the Black River changes substantially in the Dave Donaldson Black River Wildlife Management Area (DDBR WMA), located about 5.5 mi downstream from the BR-Corning streamgage (fig. 1). In the DDBR WMA, the Black River splits into a series of interconnected meandering channels and sloughs, the largest of which is the Little River (shown as the section of the Black River within the DDBR WMA in fig. 1). The Black River resumes its single-thread planform near the boundary between Clay and Randolph Counties (Arkansas). The forested area on either side of the channel narrows and, in some locations, the river directly borders agricultural fields with no riparian buffer. At Pocahontas, Ark., the Black River curves farther southward and meanders along the edge of the Ozark uplands until its confluence with the White River near Newport, Ark.

Several unregulated spring-fed tributaries contribute to the Black River downstream from Corning, Ark. The tributaries examined in this study—the Current River, the Eleven Point River, and the Spring River—are all mixed bedrock-gravel bed streams within the Ozark Plateau. These three tributaries are fed by the three largest springs in the Ozark Plateau (Adamski and others, 1995) and each represents a substantial portion of the drainage area at their nearest downstream Black River streamgages. The Current River is fed by Big Spring, the largest spring in the Ozark Plateau, and joins the Black River about 6.4 mi upstream from the BR-Pocahontas streamgage. The Current River at the confluence with the Black River has a drainage area of about 2,620 square miles (mi^2), corresponding to about 54 percent of the drainage area at the BR-Pocahontas streamgage (4,830 mi^2), and about 36 percent of the drainage area at the BR-Black Rock streamgage (7,370 mi^2). Greer Spring feeds the Eleven Point River, which joins the Spring River about 18 mi (straight line distance) upstream from its confluence with the Black River. The Spring River is also fed by Mammoth Spring and joins the Black River about 2.8 mi upstream from the BR-Black Rock streamgage. The drainage area of the Spring River (inclusive of the Eleven Point River) at the Black River confluence is about 2,420 mi^2, representing about 33 percent of the drainage area at the BR-Black Rock streamgage.

The hydrology of the Black River Basin has been affected by the construction and management of Clearwater Lake and Dam. Clearwater Dam is an earthen embankment dam and was completed in June 1948 (USACE, 2004). The drainage area that contributes to Clearwater Lake is 898 mi^2 and the lake is about 1,500 acres in surface area at the October–April conservation pool level of 494 feet (ft) above the North American Vertical Datum of 1988 (NAVD 88; Richards and Huizinga, 2018). The flood pool level is 567 ft and the maximum design pool level is 607.7 ft (USACE, 2004). The USACE maintains a minimum continuous discharge released from Clearwater Dam of 150 cubic feet per second (ft^3/s) for the municipal water supply of Poplar Bluff and Piedmont, Mo. (Edwards and others, 2011). Gated conduits are used for controlled flood releases and there is a side-saddle uncontrolled emergency spillway on the right dam abutment (USACE, 2004). The reservoir also provides a variety of recreational opportunities. In addition to Clearwater Dam on the Black River, there are five other major reservoirs in the White River Basin (Beaver Lake, Table Rock Lake, Bull Shoals Lake, Norfork Lake, and Greers Ferry Lake [not shown on fig. 1]), all of which were constructed in the 1940s to 1960s (USACE, 2020b, 2020c, 2020d, 2020e, 2020f, 2020g).

Agriculture and the timber industry in the MAP also had a major effect on the Black River. Beginning with the Swamp Land Act in the mid-1800s and continuing through the 1900s, much of the MAP was cleared, leveled, and ditched to improve drainage. The clearing and draining of the MAP for agriculture and the timber industry was responsible for the loss of 75 to 80 percent of the bottomland hardwood forest in the MAP (MacDonald and others, 1979; Oswalt, 2013). Bottomland hardwood forests act as natural sponges in the MAP, storing and slowing the movement of precipitation and floodwater and therefore reducing the magnitude of flood events (Smith and Klimas, 2002). As such, the removal of bottomland hardwood forest from a watershed is expected to result in higher flood peaks owing to increased runoff efficiency.

To protect agricultural land from flooding, levees were constructed on the Black River originally in the 1940s and 1950s (USACE, 2020h). Much of the levee system along the Black River is federally authorized but nonfederally operated and maintained. In addition to federally authorized levees, landowners sometimes construct earthen levees to protect their land from flooding. Of particular note is a nonfederally authorized levee that closely borders the east bank of the Black River directly north of Knobel, Ark. At this location, the Western Clay Drainage District levee (a federally authorized levee) also is quite close to the west bank of the Black River, which creates a constriction point where the river channel is confined between levees that are as close as 400 ft apart (Z. Yancey, Arkansas Game and Fish Commission, oral commun., 2020). There also is a network of smaller levees, raised roadways, artificial lakes, and water control structures in the DDBR WMA used by the Arkansas Game and Fish Commission to manage nearly 5,500 acres of green tree reservoirs (Arkansas Game and Fish Commission, undated). The structures are left open continuously with the exception of waterfowl season (mid-November to early February). During waterfowl season, the structure gates are kept closed unless the stage at the BR-Corning streamgage reaches about 9 to 10 ft, at which point the gates are opened to protect infrastructure from flooding.

The upland reach of the study area and the Black River tributaries have also been affected by gravel mining. Gravel mining can have negative geomorphic and ecologic effects by driving channel incision, increasing bank erosion and channel migration rates, causing loss of spawning habitat, increasing turbidity, and causing downstream sedimentation (Kondolf, 1994; Roell, 1999). Two pools in the reach of the Black River between Clearwater Lake and Poplar Bluff were created by instream gravel extraction, which is no longer occurring (Cieslewicz, 2004). The pools are near Keener Springs and Hendrickson, Mo. (not shown on fig. 1). Observations from local residents and Google Earth aerial imagery indicate that the pool near Keener Springs is filling with gravel (Cieslewicz, 2004). According to the Missouri Department of Conservation, gravel mining also is an ongoing issue in the Current, Eleven Point, and Spring River Basins (Wilkerson, 2003; Miller and Wilkerson, 2000; Kiner and others, undated).

Recent Large Floods on the Black River

Floods are a natural component of river hydrology, yet floods can endanger human lives and have costly impacts to infrastructure. The geomorphic effects of flood events are difficult to predict owing to the variety and complexity of the factors that affect fluvial erosion and deposition. Whether a flood causes widening or an increase or decrease in bed elevation in a given reach depends on the sediment transport capacity and erosivity of the flood, the amount of sediment supplied from upstream and the erodibility of the channel and flood-plain material, as well as the duration of the flood (Costa and O'Connor, 1995; Sholtes and others, 2018). Four of the largest flood peaks recorded on the Black River were in December 1982, March 2008, April 2011 (May 2011 for the WR-Newport streamgage), and April–May 2017 (table 2). The Black River experienced annual peaks at the BR-Poplar Bluff, BR-Corning, BR-Pocahontas, and BR-Black Rock streamgages during each of these four events. Moreover, these four floods are within the top five highest annual peak discharges at the BR-Black Rock and BR-Pocahontas streamgages. Large floods on the Current, Eleven Point, and Spring Rivers contributed substantially to the flooding on the Black River during these four recent events (table 2).

For all four events, the peak discharge at a given streamgage generally does not equal the combined peak discharges in the upstream contributing tributaries. This variation in peak discharge may be due in part to the natural attenuation of a flood peak with distance downstream caused by flood-plain storage, the low conveyance of the flood plain compared to the channel, and the arrival of flood peaks from different tributaries at different times. Another contributing factor may be uncertainty in the peak discharge. Peak discharges are typically difficult or impossible to measure and are instead determined indirectly (Benson and Dalrymple, 1967).

Above-normal rainfall in November 1982, followed by intense storms in early December 1982 caused widespread and record-breaking flooding throughout Illinois, Missouri, and Arkansas (Stone and Bingham, 1991). The BR-Black Rock streamgage peaked at 190,000 ft^3/s on December 4, 1982 (table 2). The December 1982 flood is the flood of record for water year (WY) 1983 at the BR-Black Rock streamgage as well as at the EPR-Ravenden Springs and the SR-Imboden streamgages. The WY refers to the 12-month period from October 1 of any given year through September 30 of the following year. The annual exceedance probability (AEP) of the December 1982 flood peak at BR-Black Rock, CR-Doniphan, EPR-Ravenden Springs, and SR-Imboden is less than 1 percent (greater than 100-year recurrence; Stone and Bingham, 1991). The December 1982 flood also falls within the top five annual peak discharges for all other gages in the study area except the BR-Corning streamgage (though it was the annual peak discharge for WY 1983 at the BR-Corning streamgage).

The March 2008 flood occurred during a period of springtime flooding throughout the State of Arkansas (Funkhouser and Eng, 2009). The Black River peaked at 135,000 ft^3/s on March 20, 2008, at the BR-Black Rock streamgage (table 2). The annual exceedance probability for this flood was between 4 and 2 percent (25- to 50-year recurrence) at the BR-Black Rock and BR-Pocahontas streamgages and between 10 and 4 percent (10- to 25-year recurrence) at the BR-Corning streamgage (Funkhouser and Eng, 2009). The AEPs for the tributaries were not reported, but the March 2008 flood was in the top five highest annual peak discharges on the Current, Eleven Point, and Spring Rivers.

A combination of record snowmelt and heavy storms in spring 2011 caused another widespread flood event in Arkansas and southern Missouri (Westerman and others, 2013). The peak discharge at the BR-Black Rock streamgage during this flood was 172,000 ft^3/s on April 26, 2011 (table 2), corresponding to an AEP between 1 and 2 percent (100- to 50-year recurrence; Westerman and others, 2013). The AEP of the flood peak was between 1 and 2 percent (100- to 50-year recurrence) at the BR-Pocahontas streamgage, between 0.5 and 1 percent (200- to 100-year recurrence) at the BR-Corning streamgage, and between 4 and 10 percent (25- to 10-year recurrence) at the BR-Poplar Bluff streamgage (Westerman and others, 2013). The AEPs for the tributary gages were not reported for the spring 2011 flood.

Continuous and heavy storms in late April–May 2017 resulted in flooding in eastern Oklahoma, much of Arkansas and Missouri, southern Illinois, and the southernmost tip of Indiana (Heimann and others, 2018). The April–May 2017 flood is the flood of record at the BR-Pocahontas streamgage, where it peaked at 105,000 ft^3/s on May 2, 2017 (table 2). Reported estimated AEPs for the April–May 2017 are 37.1 percent (3-year recurrence) for the BR-Poplar Bluff streamgage, 0.37 percent (274-year recurrence) for the CR-Doniphan streamgage, 1 percent (100-year recurrence) for the BR-Pocahontas streamgage, and less than 0.2 percent (greater than 500-year recurrence) for the EPR-Bardley and EPR-Ravenden Springs streamgages (Heimann and others, 2018).

The levee just east of Pocahontas, Ark., was breached multiple times during these recent large floods. During the 2008 flooding, this levee breached in two locations, along with other damage. Repairs were still underway during flooding in 2011. The 2011 flood breached the Pocahontas levee in 13

Table 2. Peak discharges during four recent large floods on the Black River as recorded in the National Water Information System (USGS, 2019).

[ft³/s, cubic foot per second; MO, Missouri, AR, Arkansas]

Streamgage name and number	December 1982		March 2008		April-May 2011		April–May 2017	
	Date of peak	Peak discharge (ft³/s)	Date of peak	Peak discharge (ft³/s)	Date of peak	Peak discharge (ft³/s)	Date of peak	Peak discharge (ft³/s)
Black River at Leeper, MO (07062500)	12/3/1982	40,900	No data	No data	4/24/2011	11,700	4/30/2017	13,200
Black River at Poplar Bluff, MO (07063000)	12/4/1982	65,600	3/19/2008	37,200	4/26/2011	24,400	5/1/2017	29,700
Black River near Corning, AR (07064000)	12/7/1982	23,400	3/22/2008	27,100	4/28/2011	40,700	5/4/2017	24,500
Current River at Doniphan, MO (07068000)	12/3/1982	122,000	3/19/2008	95,200	4/26/2011	90,100	5/1/2017	183,000
Black River at Pocahontas, AR (07069000)	12/7/1982	66,300	3/23/2008	72,200	4/28/2011	86,600	5/2/2017	105,000
Eleven Point River near Bardley, MO (07071500)	12/3/1982	49,800	3/19/2008	49,400	4/26/2011	33,400	4/30/2017	122,000
Eleven Point River near Ravenden Springs, AR (07072000)	12/3/1982	162,000	3/19/2008	69,700	4/26/2011	66,900	4/30/2017	164,000
Spring River at Imboden, AR (07069500)	12/3/1982	244,000	3/19/2008	97,300	4/26/2011	122,000	4/30/2017	54,800
Black River at Black Rock, AR (07072500)	12/4/1982	190,000	3/20/2008	135,000	4/26/2011	172,000	5/1/2017	158,000
White River at Newport, AR (07074500)	12/5/1982	330,000	3/21/2008	266,000	5/4/2011	292,000	5/5/2017	253,000

locations, and local property taxes were increased in an effort to cover approximately 1.1 million dollars in repairs (Arkansas Levee Task Force, 2019). Levee repairs from the 2011 flood were completed in February 2013 and the levee was restored to an active status by the USACE. However, the levee was overtopped by the 2017 flood, resulting in eight new breaches, which were repaired with funding and assistance from the USACE (Arkansas Levee Task Force, 2019).

Methods

This section describes the data sources and methods of analysis used in this study. Data sources include hydrologic records of annual discharge statistics, daily mean discharge, and discharge measurements at streamgages; aerial orthophotographs; and a limited bathymetric dataset derived from field surveys and hydraulic models. The data were analyzed for temporal trends in hydrology and channel morphology. Additionally, a longitudinal profile of the channel thalweg and the water surface of the main-stem Black River was constructed.

Discharge Measurements and Streamgage Data

At USGS streamgages, river stage is recorded at defined time intervals and converted to a discharge value by means of a rating curve (Carter and Davidian, 1968; Rantz and others, 1982; Sauer and Turnipseed, 2010). Rating curves are developed for a streamgage by relating the stage of the river to discharge values computed from direct measurements of channel velocity and area at or near the station throughout the range of stages observed at a site (hereafter referred to as “discharge measurements”; Carter and Davidian, 1968; Rantz and others, 1982; Turnipseed and Sauer, 2010). Discharge was measured routinely at each USGS streamgage. Most of these routine discharge measurements are made in nonflood or high AEP discharge conditions, so additional attempts are made to determine discharge during flood conditions to better define the rating at high stages. Typically, USGS rating curves are extended about 1.5 times the highest discharge measurement.

When determining discharge under wadable conditions, the channel is divided into multiple sections of roughly equal discharge conveyance for which the depth, width, and mean velocity are determined (Turnipseed and Sauer, 2010). The width and depth of each section are multiplied to obtain the incremental area of the section, which is further multiplied by the mean velocity of the section to obtain the incremental discharge for the section. These incremental values of discharge, area, and width are summed to compute the total discharge, cross-sectional area, and top width of the channel. This method of determining discharge is referred to as the “midsection method” or the “equal conveyance method.” During wadable discharge conditions, mean velocity was historically measured with a mechanical current meter, such as a Price Current AA meter or a Price Pygmy meter. Beginning in the early 2000s, it became more common to measure velocity using an Acoustic Doppler Velocimeter attached to a wading rod.

During nonwadable conditions, discharge measurements can either be made from a bridge or a boat. Historically, a crane on a rolling chassis would be used to deploy a mechanical current meter and move it to each measurement location using the midsection measurement method (Turnipseed and Sauer, 2010). If a bridge measurement was not possible, a mechanical current meter could also be deployed from a manned boat. However, any unintentional movements of the boat increase the error in the velocity measurements and can result in erroneous discharges. In the early 2000s, Acoustic Doppler Current Profilers (ADCPs) became the standard method for discharge measurements in nonwadable conditions (Mueller and others, 2013). Some ADCP models can be used in shallow, wadable conditions as well. ADCPs can be deployed from manned boats or small tethered boats deployed from a bridge, tagline, or cableway. As an ADCP is moved laterally across the channel, it continuously records velocity profiles and measures depth, corrects the velocity for the movement of the boat, and computes discharge. Some limitations of ADCPs include poor performance in highly turbulent flows or flows with a high suspended-sediment load. Additionally, ADCPs leave unmeasured areas around the perimeter of the channel cross-section where the discharge needs to be estimated. Despite these limitations, ADCPs substantially improved the ease and accuracy of discharge measurements (Mueller and others, 2013).

It is not always possible to measure discharge during flood events owing to safety concerns, difficulty accessing a site, or the timing of the flood. In such cases, indirect methods are used to estimate the peak discharge of the flood based on the elevation of high-water marks and hydraulic equations (Benson and Dalrymple, 1967). There are several indirect methods for estimating discharge, including slope area, contracted opening, flow over dam, and flow through culvert. All of these methods require a field survey of the elevation of high-water marks to construct a water-surface profile after the flood, as well as surveys of the channel geometry and estimates of hydraulic parameters such as the roughness coefficient.

USGS hydrologic technicians assign a quality code to each discharge measurement based on an estimation of the percent error of the measurement. Measurements coded as excellent, good, fair, or poor are estimated to be within 2, 5, 8, or greater than 8 percent of the actual discharge, respectively. “Excellent” measurements tend to be extremely rare; most measurements are coded as “good” or “fair.” Some of the oldest measurements in this study are coded as “unspecified” (it was likely not required to specify a quality code at the time these measurements were made). Historically, quality codes were estimated by technicians based on their expertise and knowledge of a particular site. On March 31, 2017, USGS hydrologic technicians began using QRev software (Mueller, 2016) to process discharge measurements in the field. The

QRev software provides an uncertainty estimate to guide technicians in assigning a quality code to their measurement, though it remains a somewhat subjective assessment.

In some cases, differences between the measured and rated discharge values can be attributed to measurement error and rating uncertainty. However, differences between a discharge measurement and the associated rated discharge can also reflect changes in the condition of the channel and flood plain at or near the streamgage since the rating was developed. Since about 1980, minor differences are accounted for with temporary "shifts" that are applied to a particular measurement so the measurement can be plotted on the current rating. These shifts are highly scrutinized to ensure a valid reason, such as accumulation of debris or scour of the channel control at low discharge. A persistent shift likely will result in an altered rating. Before 1980, "shifts" were handled with a different rating, some of which were used for less than a year before being changed. Each streamgage therefore has a record of historical ratings in addition to the rating that is currently in use. More recent ratings, with assigned numbers, are documented in a digital data management platform that is internal to USGS. Older ratings, identified by dates used, can be found for some streamgages in paper archives, but there are sometimes gaps between the paper archives and the digital records.

Historical discharge measurement records through December 31, 2019, were downloaded from the public National Water Information System (NWIS) web page for five streamgages on the Black River (07062500, 07063000, 07064000, 07069000, and 07072500), four streamgages on tributaries to the Black River (07068000, 07071500, 07072000, and 07069500), and one streamgage on the White River (07074500) (table 1; U.S. Geological Survey, 2019). Annual discharge statistics (annual mean and peak discharges), determined on a WY basis, were downloaded from NWIS for each streamgage through WY 2019 (U.S. Geological Survey, 2019). The daily mean discharges for WY 1950 through WY 2019 were also downloaded from NWIS for each streamgage (U.S. Geological Survey, 2019). Ratings were obtained from the digital and paper archives maintained by USGS and organized into chronological order as best as possible. Ratings named with letters (rather than numbers) in this report are older ratings from paper records for which a number was not assigned. Information about changes in the vertical datum of the streamgage and measurement locations were obtained from the internal USGS Site Information Management System (SIMS). Prior to analysis and visualization of the data, historical stages associated with measurements or calculated from ratings were adjusted to be referenced to the current datum of the streamgage.

Methods for Annual Discharge Statistics

Records of annual mean discharges and annual peak discharges were compared among the streamgages in the study area and examined for temporal trends. Descriptive statistics of the annual mean discharges and the annual peak discharges were calculated for the period of record for each streamgage. In some cases, there were a small number of peak discharges reported for very early floods (hereafter referred to as "early peak discharges") prior to consistent reporting of annual peak discharges. There is often a large gap in time between the early peak discharges, which were typically estimates made in the early 1900s, and the rest of the record. Therefore, the early peak discharges were excluded from the descriptive statistics and the trend analysis.

The annual mean discharges and the annual peak discharges were assessed for trends using the Mann-Kendall (MK) test for monotonic trends (Mann, 1945; Kendall, 1975; Helsel and others, 2020). The null hypothesis of the MK test is that there is no monotonic trend and the alternate hypothesis is that there is either an upward or a downward monotonic trend. Unlike linear regression, the MK test is nonparametric and therefore does not require an assumption of normality (Mann, 1945; Kendall, 1975; Helsel and others, 2020). Additionally, the MK test is robust for analyzing time series with missing or irregularly spaced data. At least four data points are required for the MK test and the statistical confidence of the MK test increases as the number of data points increases. It is harder for the MK test to reject the null hypothesis for a small dataset than a large dataset, even if the trend in the data is the same. The null hypothesis was rejected for trends with a confidence level of at least 95 percent (corresponding to a *p*-value less than 0.05). The choice of a 95-percent confidence level is subjective and failure to meet that criterion does not necessarily indicate that there is no trend in the data. A MK test with a *p*-value greater than the selected threshold (0.05 in this study) simply means that there is not enough evidence to reject the null hypothesis with that level of confidence, which is more likely to be the case with small datasets.

Unlike a regression, the MK test does not calculate a slope or intercept. The slope and intercept of the trends in this report were calculated using the Theil-Sen (TS) estimator, which is a nonparametric alternative to least-squares regression (Theil, 1950; Sen, 1968; Conover, 1999; Helsel and others, 2020). The TS estimator is less sensitive to outliers than least-squares regression. To compare trends among the streamgages in the study area, the TS slope was divided by the median value of the parameter of interest and reported as a percentage. For example, the TS slope of the annual mean discharge time-series would be divided by the median value of the annual mean discharges.

Methods for Flow-Duration Curves

Flow-duration curves show the percentage of time a given discharge was equaled or exceeded in a specified period of time, which can also be considered an exceedance probability (Searcy, 1959). Flow-duration curves were developed for the study area gages using daily mean discharges for periods of time spanning 10 WYs, beginning with WY 1940–49 and ending with WY 2010–19. The flow-duration curves for each streamgage in the study area were used to track how the exceedance probability of the discharge corresponding to the National Weather Service (NWS) flood stage (referred to herein as a flood discharge) at each streamgage has varied from decade to decade. The following section provides more details regarding the NWS flood stage. The NWS does not indicate a flood stage at the BR-Leeper streamgage, so the median peak discharge after the construction of Clearwater Dam was used for that site. The exceedance probability of the flood discharge in each of the eight decadal periods from WY 1940–49 to WY 2010–19 was determined from the flow-duration curves. Additionally, the seven decadal periods from WY 1950–59 to WY 2010–19 were examined for temporal trends in the flood discharge exceedance probability using MK tests. WY 1940–49 was excluded from the trend analysis to keep the focus on conditions following the construction of Clearwater Dam.

Methods for Morphologic Change Assessment

This section describes the methods used to assess morphologic change of the river channel near the streamgages in the study area. Specific stage analysis is used to infer possible changes in channel-bed elevation based on how the relation between stage and discharge at a streamgage has (or has not) changed over time. Channel cross-section data derived from discharge measurements at the gages are also examined for temporal changes. Additionally, aerial orthophotographs were used to assess changes in channel top width near the gages.

Specific Stage Analysis

Specific stage analysis refers to the method of examining temporal changes in the stage associated with a particular discharge at a streamgage (hereafter referred to as “specific stage”). Specific stage analysis can provide insight into geomorphic change at streamgages, particularly where there are limited historical bathymetric data (Juracek and Fitzpatrick, 2009). Changes in specific stage over time can imply similar changes in channel-bed elevation, though variations in specific stage can also be caused by changes in channel roughness or changes in the relevant hydraulic controls under those discharge conditions (for example, channel slope, channel width, riffles at low discharges). A common approach to specific stage analysis is to use a reference discharge that is below bankfull but still completely covers the bed, such as the mean annual discharge (Juracek, 2007; Bowen and Juracek, 2011). The hydraulics of a reference discharge that covers the bed but is below bankfull are controlled by the channel cross-sectional geometry, rather than low-discharge section controls, such as bars and riffles, or the physical characteristics of the flood plain. Another approach to specific stage analysis is to examine multiple reference discharges ranging from low discharges to floods, which may show different temporal trends (for example, see Huizinga, 2009).

Specific stage analysis is a useful tool for studying river morphodynamics but there are several important limitations. Distinguishing the possible underlying causes of changes in specific stage can be difficult without additional information about the channel or basin, such as the timing of major changes in land cover/use or construction of dams or river training structures. Additionally, site selection guidelines for streamgages prioritize channel stability and accessibility, which means that the channel near a streamgage may not be representative of the surrounding reach. Streamgages on the Black River and its tributaries tend to be near bridge crossings. Bridge abutments and piers can constrict the width of a channel, resulting in locally increased velocities. Therefore, the bed may scour near bridge crossings, even in the absence of reach-scale degradation, and likewise, deposition may be locally reduced or absent even under conditions of reach-scale aggradation (Federal Highway Administration, 2012). The local geomorphic conditions near a streamgage may differ from the surrounding reach, even in cases where the streamgage is not near a bridge crossing.

In this study, rather than selecting a single reference discharge, specific stage analysis was applied to a selection of discharges spanning the whole range of the historical measurements and ratings at each streamgage. The discharge values selected for the specific stage analysis span the range observed at each streamgage. For the analysis of specific stages from historical rating curves, the stage associated with a particular discharge was directly calculated using each historical rating. For the measured discharge data, it is unlikely to have multiple measurements at the exact same specified discharge. Therefore, the specific stage analysis and trend tests were computed for specific stages corresponding to discharges within plus or minus (±) 2.5 percent of the same discharges examined for the rating curves. The range of ±2.5 percent was selected to balance the need to keep the discharge ranges somewhat narrow with the need to have enough measurements within the discharge ranges to identify temporal trends. Even so, some of the discharge ranges had fewer measurements than needed for robust trend testing, particularly at the highest discharges. The time series of specific stages were assessed for temporal trends using MK tests with a 95-percent confidence level. The TS slope and intercept also were calculated. The MK tests were applied during the period of record for all gages except the BR-Leeper, BR-Poplar Bluff, and BR-Corning streamgages. For these three gages, the MK tests were applied from October 1948 through December 2019 to reflect conditions after the construction of Clearwater Dam. This trend analysis does not account for uncertainty in the measurements or rated discharges. Detailed results of the MK tests, including the number of data points used in the analysis, the MK *p*-value, the TS slope, and the TS intercept, are provided in tables 1.1–1.10. In addition to the MK tests, the specific stages from both measurements and ratings were plotted over time for a selection of the analyzed discharges.

Bankfull stage is noted in the specific stage and rating curve analyses because the relation between stage and discharge at a streamgage often differs for discharges below bankfull stage compared to above bankfull. Above bankfull stage, the flowing water is not confined by the channel banks, so an increase in stage corresponds to a substantially greater increase in discharge compared to discharges below bankfull. Therefore, for a site with well-defined banks and a flood plain, there is typically a break in slope of the rating curve just above bankfull stage. Stage-discharge relations may also be affected by variations in the roughness characteristics with stage caused by changes in vegetation type or substrate. However, identifying bankfull stage can be challenging and subjective, even when detailed field observations are available. In the absence of detailed field observations, the flood stage at each streamgage is referenced in the analyses of stage-discharge relations, as reported by the NWS Advanced Hydrologic Prediction Service (National Weather Service, 2020a). The NWS defines flood stage as "an established stage for a given location above which a rise in water-surface level begins to create a hazard to lives, property, or commerce… [and is] not necessarily the same as bankfull stage" (National Weather Service, 2020b). Although the NWS flood stage is not a perfect proxy for bankfull stage, it provides some context for understanding how the shape of the rating curve relates to channel geometry. Any known potential differences between NWS flood stage and bankfull stage are noted.

Cross-Section Data from Discharge Measurements

Most discharge measurements at USGS streamgages include notes on the cross-sectional area, top width, and mean velocity of the flowing water during the measurement. This information may also include the measurement type (that is, whether the measurement was made from a bridge, a manned boat, or by wading), the measurement method (for example, ADCP, midsection method, or a weir calculation), and occasionally the measurement location. Measurement notes tend to be mostly complete for recent measurements, but older measurements may be missing some or all of the aforementioned components. Nevertheless, measurement notes are typically the only source of historical cross-sectional data near streamgages. The measurement notes from four main-stem Black River streamgages (BR-Poplar Bluff, BR-Corning, BR-Pocahontas, and BR-Black Rock) were examined for evidence of multiple measurement cross-sections and for temporal trends in top width, depth, bed elevation, and mean velocity. The BR-Leeper streamgage was not included because the primary area of concern regarding increased flooding is in the lowland reach of the Black River. The cross-sectional data from tributary gages were not included in this analysis because preliminary analyses indicated they provide little additional information to the analysis of the main-stem gages.

The cross-sectional area, top width, mean velocity, measurement type, measurement method, and any information on measurement location were compiled from NWIS for four of the Black River streamgages in the study area (BR-Poplar Bluff, BR-Corning, BR-Pocahontas, and BR-Black Rock; U.S. Geological Survey, 2019). The mean depths for measurements below flood stage were estimated by dividing the cross-sectional area by the top width. The estimated mean depths were subtracted from the measured stage to estimate the mean bed elevation at the time of measurement. The mean depth and bed elevation were not estimated for measurements above flood stage owing to the discontinuity in the relation between width and stage when flow spills out on to the flood plain.

Discharge measurements generally are made near gages, yet the precise location of measurements may vary depending on stage and the type of measurement, or in response to changes in channel form or the infrastructure used to access the channel. At any particular streamgage, one measurement cross-section may be used for wading measurements at low discharge, another for moving-boat ADCP measurements at moderate discharge, and yet another for bridge measurements during flood discharges (see "Discharge Measurements and Streamgage Data" section). A measurement cross-section may also be temporarily or even permanently relocated for any number of reasons, such as construction of a new bridge or substantial channel migration. Measurement notes on the type and method of measurement can help with piecing together the shifting locations of measurement cross-sections but are often insufficient owing to unclear or missing descriptions. The SIMS station description also contains general information on measurement cross-section locations but is not definitive for any individual measurement and may not apply to historical measurements.

To aid in identification of distinct measurement cross-sections, "at-a-station" hydraulic geometry plots (Leopold and Maddock, 1953) were generated for each Black River streamgage using cross-section data in the measurement notes. Typically, the mean width, depth, and velocity at a cross-section are power functions of discharge and will plot as straight lines on logarithmic axes for discharges below bankfull. The slopes of these lines depend on the channel morphology and hydraulic control (including roughness) at a section. Sections with enough difference in morphology or hydraulic control are therefore distinguishable in hydraulic geometry plots. The hydraulic geometry plots for the Black River gages were cross-referenced with the SIMS station description and with notes on measurement type, method, and location. The number, and in some cases, locations of measurement cross-sections were inferred from this information. The results provide context for understanding temporal variations in the cross-sectional geometry and velocity of flows in the Black River.

In an approach similar to specific stage analysis, the cross-section morphometry data for a particular discharge range were plotted over time and assessed for temporal trends using MK tests. The cross-section data show a lot of variability and it can be difficult to discern whether variations in cross-sectional geometry over time are caused by actual changes in channel shape at a given section or the use of multiple, different measurement cross-sections. Therefore, this analysis was only done for measurements that were determined to be made at the same general location over time. Fewer discharge bands were analyzed for the cross-section data compared to the specific stage data, because fewer measurements had cross-section data recorded.

Aerial Orthophotographs

Historical aerial orthophotographs were used in a limited capacity to validate observations regarding temporal changes in channel top width for four main-stem Black River streamgages (BR-Poplar Bluff, BR-Corning, BR-Pocahontas, and BR-Black Rock). Detailed examination of the aerial photographs over the full length of the Black River was beyond the scope of this project. Two sets of aerial photographs were obtained: one from 1994 and one from either 2016 or 2017. Digital aerial orthophotographs (3.28-ft resolution) of the BR-Poplar Bluff, BR-Corning, BR-Pocahontas, and BR-Black Rock streamgages from 1994 were downloaded from the USGS National Aerial Photography Program through the EarthExplorer web page (U.S. Geological Survey, 2020a). Digital aerial orthophotographs acquired in 2017 (1-ft resolution) covering the entire Arkansas portion of the Black River (BR-Corning, BR-Pocahontas, and BR-Black Rock streamgages) were obtained from the State of Arkansas GIS office (State of Arkansas, 2017). A 2016 digital aerial orthophotograph of the BR-Poplar Bluff streamgage (2-ft resolution) was sourced from the U.S. Department of Agriculture National Agriculture Imagery Program (U.S. Department of Agriculture, 2016).

The aerial photographs were imported into Esri ArcMap version 10.6 (Esri, 2018) to compare the channel top width in the 1994 images to the 2016–17 images. The top width of the channel was measured at the best estimation of discharge measurement cross-sections. To minimize the effect of varying water levels on the top width measured from the aerial imagery, the top width was estimated as the distance between the line of perennial vegetation apparent on either side of the banks. Therefore, these top width measurements are an estimate of the top width during bankfull discharge. The accuracy of the channel top widths measured from aerial imagery is limited by the uncertainty in determining the top-of-bank position from a plan-view image. Assuming the error in determining the top-of-bank position is roughly the image resolution, the top width measurement error is estimated as $\sqrt{2 \times (\mathit{image\ resolution})^2}$, or 4.6 ft for the lowest-resolution images in this analysis (3.28-ft resolution). This value was rounded to 5 ft to give a conservative estimate for the error for the top width measurements.

Longitudinal Profile Data and Methods

To further assess changes in channel morphology along the Black River, the longitudinal profile was examined. Historical bathymetric data were identified for two reaches of the Black River. Cross-sections within the reach between Clearwater Dam and Poplar Bluff were extracted from a USACE hydraulic model that was developed using a bathymetric survey from 1981 and surveyed again in 2020 (Rivers and others, 2020). Cross-sections also were extracted from a USACE hydraulic model for the reach between Poplar Bluff and Pocahontas, though this model was developed using a bathymetric survey from 2004. The reach between Poplar Bluff and Pocahontas also was surveyed along cross-sections in 2018 (Richards and others, 2018).

A variety of factors complicate the direct comparison of the cross-sections extracted from the hydraulic models with the data surveyed in 2018 and 2020. First, the vertical datum of the hydraulic model data is unknown, so any differences between the hydraulic model and the recent surveys could be due to the use of a different datum. Second, most of the hydraulic model cross-sections between Poplar Bluff and Pocahontas (2004 data) were not co-located with the cross-sections surveyed in the same reach in 2018 and were not spaced at similar intervals; however, many, but not all, of the cross-sections between Clearwater Dam and Poplar Bluff (1981 data) were co-located with the cross-sections survey in 2020. Third, the cross-sections extracted from the hydraulic models are far less detailed than the 2018/2020 data, with only a few points describing the in-channel morphology. Finally, the elapsed time between the historical hydraulic model data and the 2018/2020 survey data is not particularly long and any possible changes in that time are likely to be small. There is no robust way to estimate the error associated with the historical datasets, which may be large compared to any potential channel change. Therefore, no attempt is made to quantify changes in channel morphology or directly compare cross-sections. Rather, the deepest point in each cross-section was extracted and plotted against the streamwise distance downstream from Clearwater Dam to give the longitudinal bed profile of the channel thalweg.

The longitudinal water-surface profile of the Black River was constructed from streamgage data for three discharge conditions to compare with the bed profile. The BR-Leeper, BR-Poplar Bluff, BR-Corning, BR-Pocahontas, and BR-Black Rock streamgages were included in the water-surface profile, as well as data from a stage-only streamgage in the Clearwater Dam tailwater (USGS 07062050, Clearwater Tailwater near Piedmont, Mo.). The three discharge conditions include points in time when the discharge at BR-Poplar Bluff is close to the annual mean discharge (1,420 ft^3/s; April 4, 2017; 00:00), when a flood is peaking at BR-Poplar Bluff (16,000 ft^3/s; May 1, 2017, 12:00), and when that same flood is peaking at BR-Corning (7,100 ft^3/s at BR-Poplar Bluff and 19,900 at BR-Corning; May 4, 2017, 08:00). Water-surface elevations in NAVD 88 were computed for each streamgage by adding the stage to the streamgage datum, and the mean water-surface slope between each consecutive pair of gages was computed as the difference between the water-surface elevations at the gages divided by the distance between the gages.

Annual Discharge Statistics

The median of the annual mean discharges for the period of record (hereafter referred to as the “median discharge”; table 3) of the Black River increases from 987 ft^3/s at the BR-Leeper streamgage to 8,377 ft^3/s at the BR-Black Rock streamgage (table 3). The median of the annual peak discharges on the Black River for the period of record (hereafter referred to as the “median peak discharge”; table 4), also increases with distance downstream from 6,510 ft^3/s at the BR-Leeper streamgage to 41,400 ft^3/s at the BR-Black Rock streamgage (excludes early peak discharges; table 4). The Current, Spring, and Eleven Point Rivers constitute a large part of the Black River Basin; therefore, these tributaries contribute substantially to the discharge of the Black River. The median discharge at the CR-Doniphan streamgage (2,783 ft^3/s) is about one-half the median discharge at the nearest downstream streamgage (BR-Pocahontas, 5,858 ft^3/s) (table 3). The median discharge at the EPR-Ravenden Springs (1,138 ft^3/s) and SR-Imboden (1,390 ft^3/s) streamgages, when combined, is about 30 percent of the median discharge at the nearest downstream streamgage (BR-Black Rock, 8,377 ft^3/s) (table 3). The WR-Newport streamgage has a median discharge of 21,790 ft^3/s (table 3) and a median peak discharge 82,950 ft^3/s (table 4).

Table 3. Descriptive statistics of the annual mean discharges for all study area gages for the period of record.

[POR, period of record, in water years; MO, Missouri; AR, Arkansas]

Streamgage name and number	Annual mean discharge POR	Annual mean discharge statistics (cubic feet per second)				
		Minimum	Maximum	Mean	Median	Standard deviation
Black River at Leeper, MO (07062500)	1949 to 2019	430	2,219	1,038	987	400
Black River at Poplar Bluff, MO (07063000)	1949 to 2019	564	2,858	1,426	1,395	508
Black River near Corning, AR (07064000)	1948 to 2019	662	4,014	1,944	1,958	754
Current River at Doniphan, MO (07068000)	1922 to 2019	1,326	5,856	2,852	2,783	930
Black River at Pocahontas, AR (07069000)	1937 to 2019	2,383	10,820	5,850	5,858	2,042
Eleven Point River near Bardley, MO (07071500)	1922 to 2019	303	1,782	795	746	329
Eleven Point River near Ravenden Springs, AR (07072000)	1930 to 2019	435	2,326	1,185	1,138	449
Spring River at Imboden, Arkansas (07069500)	1937 to 2019	466	2,793	1,438	1,390	545
Black River at Black Rock, AR (07072500)	1948 to 2019	3,552	17,330	9,031	8,377	3,274
White River at Newport, AR (07074500)	1943 to 2019	8,073	46,320	22,983	21,790	8,575

Table 4. Descriptive statistics of the annual peak discharge timeseries for the period of record (excluding early peak discharges) and the periods of time before and after water year 1948.

[POR, period of record used in this study, in water years; ft^3/s, cubic feet per second; WY, water year; MO, Missouri; AR, Arkansas]

Streamgage name and number	Annual peak discharge POR[1]	Mean peak discharge (ft^3/s)			Median peak discharge (ft^3/s)			Standard deviation (ft^3/s)		
		POR[1]	Before WY 1948[1]	After WY 1948	POR[1]	Before WY 1948[1]	Post-dam	POR[1]	Before WY 1948[1]	After WY 1948
Black River at Leeper, MO (07062500)	1922 to 2019	12,970	27,554	6,542	6,510	22,950	5,560	15,836	21,386	5,358
Black River at Poplar Bluff, MO (07063000)	1923 to 2019	12,870	20,700	10,151	7,920	23,900	7,465	11,770	15,060	9,032
Black River near Corning, AR (07064000)	1915 to 2019	13,960	14,870	13,559	12,300	13,000	12,250	8,380	10,153	7,398
Current River at Doniphan, MO (07068000)	1919 to 2019	35,156	29,968	37,246	27,900	25,500	29,300	27,907	21,958	29,856
Black River at Pocahontas, AR (07069000)	1937 to 2019	29,549	26,543	30,042	23,750	28,000	23,600	18,972	14,521	19,653
Eleven Point River near Bardley, MO (07071500)	1922 to 2019	13,634	11,690	14,335	8,890	7,780	9,030	15,398	10,905	16,738
Eleven Point River near Ravenden Springs, AR (07072000)	1930 to 2019	19,277	13,031	20,665	12,000	11,800	12,000	25,404	7,390	27,723
Spring River at Imboden, Arkansas (07069500)	1937 to 2019	35,381	29,306	36,309	27,800	31,800	27,150	32,465	16,941	34,209
Black River at Black Rock, AR (07072500)	1905 to 2019	51,913	47,730	54,411	41,400	42,000	40,650	34,135	30,011	36,348
White River at Newport, AR (07074500)	1886 to 2019	109,207	126,826	94,035	82,950	103,500	69,400	73,613	79,100	65,351

[1]Excludes early peak discharges from the following water years at the specified gages: 1904 (Black River at Leeper, MO; Black River at Poplar Bluff, MO; Current River at Doniphan, MO), 1915 (Black River at Leeper, MO; Current River at Doniphan, MO; Eleven Point River neat Bardley, MO; Spring River at Imboden, AR), and 1927 (Black River at Pocahontas, AR).

The annual mean discharges for all the streamgages were assessed for temporal trends using MK tests. The MK tests indicate there was a statistically significant increase in annual mean discharge during the period of record for the BR-Leeper, BR-Poplar Bluff, BR-Corning, CR-Doniphan, and EPR-Ravenden Springs streamgages (table 5; fig. 2). However, the TS slope of these trends is small (3.9 to 6.7 ft^3/s per year, corresponding to less than 1 percent of the median discharge at the associated streamgages). The other gages did not show statistically significant trends in annual mean discharge over time and similarly had small TS slopes (1.7 to 23.9 ft^3/s per year, corresponding to less than 1 percent of the median discharge at the associated streamgages). The annual peak discharges also were analyzed with MK tests. The BR-Leeper and WR-Newport showed a statistically significant decrease in annual peak discharge during the period of record (excluding early peak discharges; table 6). The CR-Doniphan and BR-Pocahontas had statistically significant increases in annual peak discharge during the period of record. However, the TS slopes for the downward and upward trends were quite small, with absolute values less than 1 ft^3/s per year (corresponding to less than 0.01 percent of the median peak discharge per year), indicating minimal long-term change in peak discharges over time. None of the other streamgages in the study area had a statistically significant monotonic trend in annual peak discharge during the period of record (table 6, fig. 3).

The annual peak discharges also were tested for temporal trends during WY 2000 to WY 2019 (19 WYs) to determine if there had been a recent increase in peak discharge magnitude. Four of the main-stem Black River streamgages (BR-Poplar Bluff, BR-Corning, BR-Pocahontas, and BR-Black Rock) and the CR-Doniphan, EPR-Bardley, and EPR-Ravenden Springs streamgages showed significant increases in annual peak discharge from WY 2000 to WY 2019, though the TS slopes are small (1.0 to 6.9 ft^3/s per year, corresponding to less than 0.1 percent of the median peak discharge per year at the associated streamgages; table 6). Heimann and others (2018) completed a similar analysis of temporal changes in annual peak discharges and annual precipitation for 49 streamgages in southern parts of the Midwestern United States. None of the main-stem Black River gages analyzed in the present study were examined for trends by Heimann and others (2018), but their results provide some regional context. Heimann and others (2018) concluded that recent (1989–2017) increases in peak discharges within the Ozark Plateau may be related to a concurrent increase in the frequency of large-magnitude rain events (defined as daily precipitation greater than 2 inches). They also noted that land-use changes may have contributed to trends in peak discharges but did not examine this possibility in detail.

To directly examine the effect of Clearwater Dam on the Black River peak discharges, box and whisker plots were used to show the distribution of peak discharges before and

Table 5. Mann-Kendall trend test results for the period of record of annual mean discharges.

[POR, period of record, in water years; ft^3/s, cubic feet per second; MO, Missouri; AR, Arkansas]

Streamgage name and number	Annual mean discharge POR	Annual mean discharge trend test results				
		Mann-Kendall result[1]	Mann-Kendall *p*-value	Theil-Sen Slope (ft^3/s per year)	Theil-Sen Slope (percent)[2]	Theil-Sen Intercept (ft^3/s)
Black River at Leeper, MO (07062500)	1949 to 2019	Upward	0.0143	4.8	0.49	−8,478.8
Black River at Poplar Bluff, MO (07063000)	1949 to 2019	Upward	0.0040	6.7	0.48	−11,874.7
Black River near Corning, AR (07064000)	1948 to 2019	Upward	0.0225	6.7	0.34	−11,379.9
Current River at Doniphan, MO (07068000)	1922 to 2019	Upward	0.0319	5.4	0.19	−7,768.7
Black River at Pocahontas, AR (07069000)	1937 to 2019	Cannot reject null	0.0802	14.1	0.24	−22,074.7
Eleven Point River near Bardley, MO (07071500)	1922 to 2019	Cannot reject null	0.0647	1.7	0.23	−2,458.4
Eleven Point River near Ravenden Springs, AR (07072000)	1930 to 2019	Upward	0.0171	3.9	0.34	−6,528.3
Spring River at Imboden, Arkansas (07069500)	1937 to 2019	Cannot reject null	0.0547	3.8	0.27	−6,045.9
Black River at Black Rock, AR (07072500)	1948 to 2019	Cannot reject null	0.0549	23.9	0.29	−38,465.0
White River at Newport, AR	1943 to 2019	Cannot reject null	0.1836	17.1	0.08	−10,939.8

[1]The null hypothesis is that there is no monotonic trend.

[2]Theil-Sen slope, in percent of the median annual mean discharge per year.

Table 6. Mann-Kendall trend test results for the annual peak discharges for the period of record (excluding early peak discharges) and for water year 2000 to the most-recent reported annual peak discharge.

[POR, period of record, in water years; ft^3/s, cubic feet per second]

Streamgage name and number	Annual peak discharge POR[1]	Median peak discharge (ft^3/s)[1]	Annual peak discharge trend test results POR[1]					Annual peak discharge trend test results water year 2000 to 2019				
			Mann-Kendall result[2]	Mann-Kendall *p*-value	Theil-Sen Slope (ft^3/s per year)	Theil-Sen Slope (percent)[3]	Theil-Sen Intercept (ft^3/s)	Mann-Kendall result[2]	Mann-Kendall *p*-value	Theil-Sen Slope (ft^3/s per year)	Theil-Sen Slope (percent)[3]	Theil-Sen Intercept (ft^3/s)
Black River at Leeper, MO (07062500)	1922 to 2019	6,510	Downward	0.0004	−0.64	−0.0098	27,473.3	Cannot reject null	0.1457	0.07	0.0011	5,110.6
Black River at Poplar Bluff, MO (07063000)	1923 to 2019	7,920	Cannot reject null	0.1287	−0.23	−0.0029	18,477.8	Upward	0.0231	1.0	0.013	−26,380.9
Black River near Corning, AR (07064000)	1915 to 2019	12,300	Cannot reject null	0.1663	−0.0078	−0.0001	14,107.1	Upward	0.0078	1.2	0.010	−26,743.0
Current River at Doniphan, MO (07068000)	1919 to 2019	27,900	Upward	0.0340	0.58	0.0021	21,345.7	Upward	0.0215	6.2	0.022	−196,439.0
Black River at Pocahontas, AR (07069000)	1937 to 2019	23,750	Upward	0.0494	0.46	0.0019	19,171.8	Upward	0.0051	4.2	0.018	−110,509.0
Eleven Point River near Bardley, MO (07071500)	1922 to 2019	8,890	Cannot reject null	0.0946	0.23	0.0026	8,967.4	Upward	0.0309	3.1	0.035	−87,499.7
Eleven Point River near Ravenden Springs, AR (07072000)	1930 to 2019	12,000	Cannot reject null	0.0803	0.55	0.0046	9,882.4	Upward	0.0435	4.3	0.036	−96,720.8
Spring River at Imboden, Arkansas (07069500)	1937 to 2019	27,800	Cannot reject null	0.0940	0.34	0.0012	27,470.1	Cannot reject null	0.1315	1.7	0.006	−15,854.3

Table 6. Mann-Kendall trend test results for the annual peak discharges for the period of record (excluding early peak discharges) and for water year 2000 to the most-recent reported annual peak discharge.—Continued

[POR, period of record, in water years; ft³/s, cubic feet per second]

Streamgage name and number	Annual peak discharge POR[1]	Median peak discharge (ft³/s)[1]	Annual peak discharge trend test results POR[1]					Annual peak discharge trend test results water year 2000 to 2019				
			Mann-Kendall result[2]	Mann-Kendall *p*-value	Theil-Sen Slope (ft³/s per year)	Theil-Sen Slope (percent)[3]	Theil-Sen Intercept (ft³/s)	Mann-Kendall result[2]	Mann-Kendall *p*-value	Theil-Sen Slope (ft³/s per year)	Theil-Sen Slope (percent)[3]	Theil-Sen Intercept (ft³/s)
Black River at Black Rock, AR (07072500)	1905 to 2019	41,400	Cannot reject null	0.0502	0.37	0.0009	44,299.2	Upward	0.0100	6.9	0.017	−199,730.0
White River at Newport, AR (07074500)	1886 to 2019	82,950	Downward	0.0070	−0.68	−0.0008	125,458.6	Cannot reject null	0.0726	6.0	0.0072	−168,991.0

[1]Excludes early peak discharges from the following water years at the specified gages: 1904 (Black River at Leeper, MO; Black River at Poplar Bluff, MO; Current River at Doniphan, MO), 1915 (Black River at Leeper, MO; Current River at Doniphan, MO; Eleven Point River near Bardley, MO; Spring River at Imboden, AR), and 1927 (Black River at Pocahontas, AR).

[2]The null hypothesis is that there is no monotonic trend.

[3]Theil-Sen slope, in percent of the median peak discharge per year.

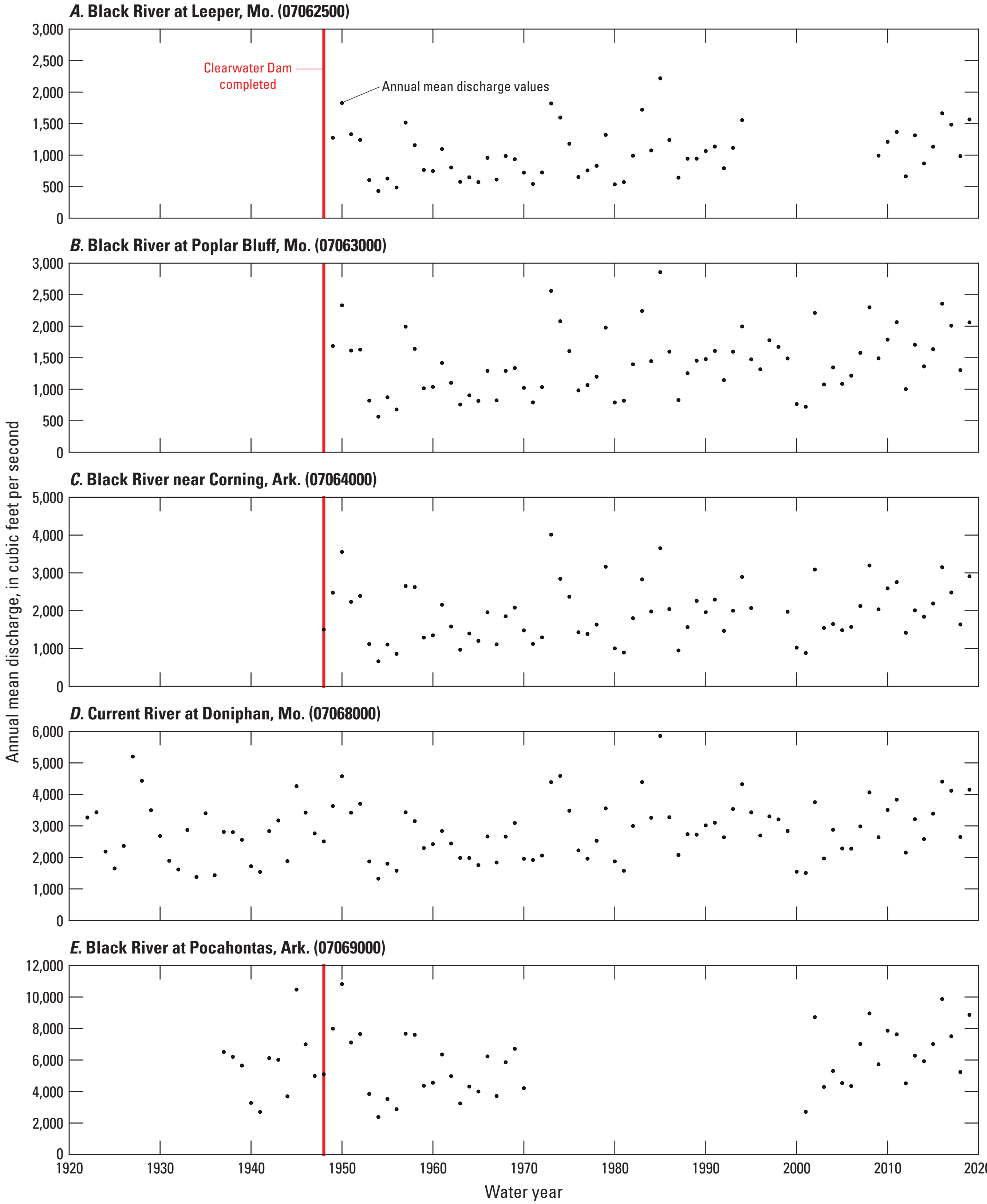

Figure 2. Annual mean discharges for streamgages in the study area. *A*, Black River at Leeper, Missouri (07062500). *B*, Black River at Poplar Bluff, Missouri (07063000). *C*, Black River near Corning, Arkansas (07064000). *D*, Current River at Doniphan, Missouri (07068000). *E*, Black River at Pocahontas, Arkansas (07069000). *F*, Eleven Point River near Bardley, Missouri (07071500). *G*, Eleven River near Ravenden Springs, Arkansas (07072000). *H*, Spring River at Imboden, Arkansas (07069500). *I*, Black River at Black Rock, Arkansas (07072500). *J*, White River at Newport, Arkansas (07074500).

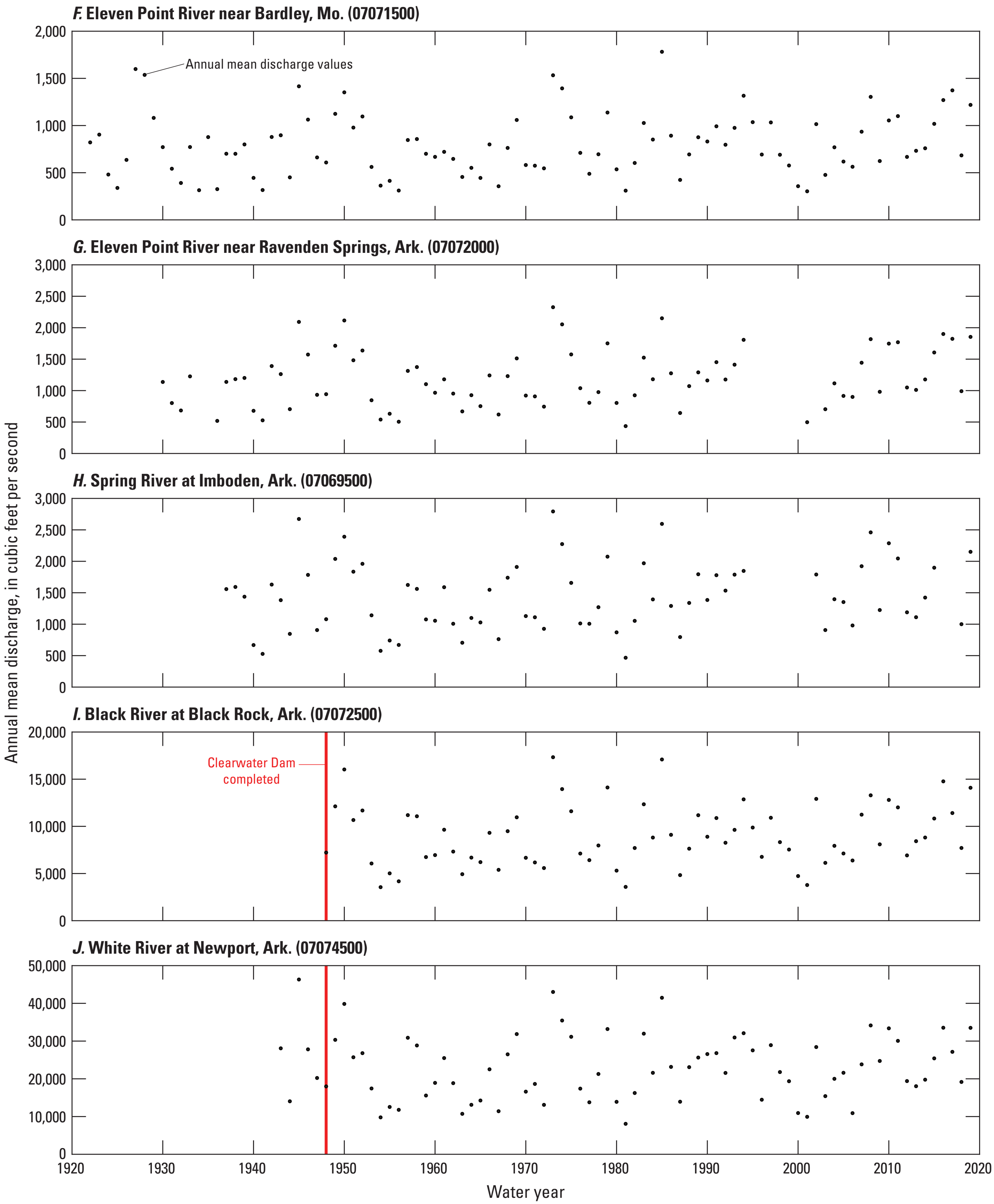

Figure 2. Annual mean discharges for streamgages in the study area. *A*, Black River at Leeper, Missouri (07062500). *B*, Black River at Poplar Bluff, Missouri (07063000). *C*, Black River near Corning, Arkansas (07064000). *D*, Current River at Doniphan, Missouri (07068000). *E*, Black River at Pocahontas, Arkansas (07069000). *F*, Eleven Point River near Bardley, Missouri (07071500). *G*, Eleven River near Ravenden Springs, Arkansas (07072000). *H*, Spring River at Imboden, Arkansas (07069500). *I*, Black River at Black Rock, Arkansas (07072500). *J*, White River at Newport, Arkansas (07074500).—Continued

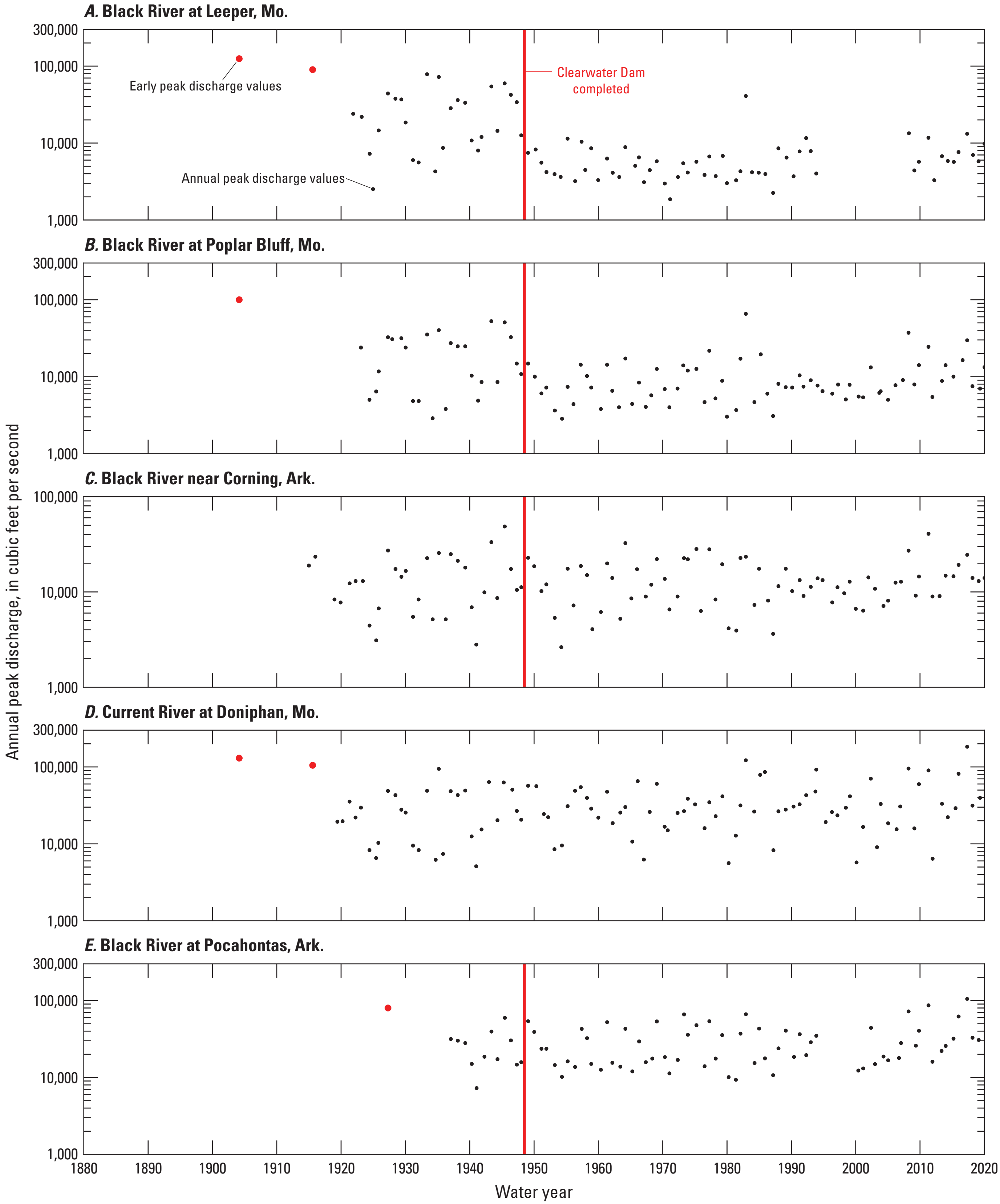

Figure 3. Annual peak discharges for streamgages in the study area. The scale of the y-axis varies among these plots. *A*, Black River at Leeper, Missouri (07062500). *B*, Black River at Poplar Bluff, Missouri (07063000). *C*, Black River near Corning, Arkansas (07064000). *D*, Current River at Doniphan, Missouri (07068000). *E*, Black River at Pocahontas, Arkansas (07069000). *F*, Eleven Point River near Bardley, Missouri (07071500). *G*, Eleven River near Ravenden Springs, Arkansas (07072000). *H*, Spring River at Imboden, Arkansas (07069500). *I*, Black River at Black Rock, Arkansas (07072500). *J*, White River at Newport, Arkansas (07074500).

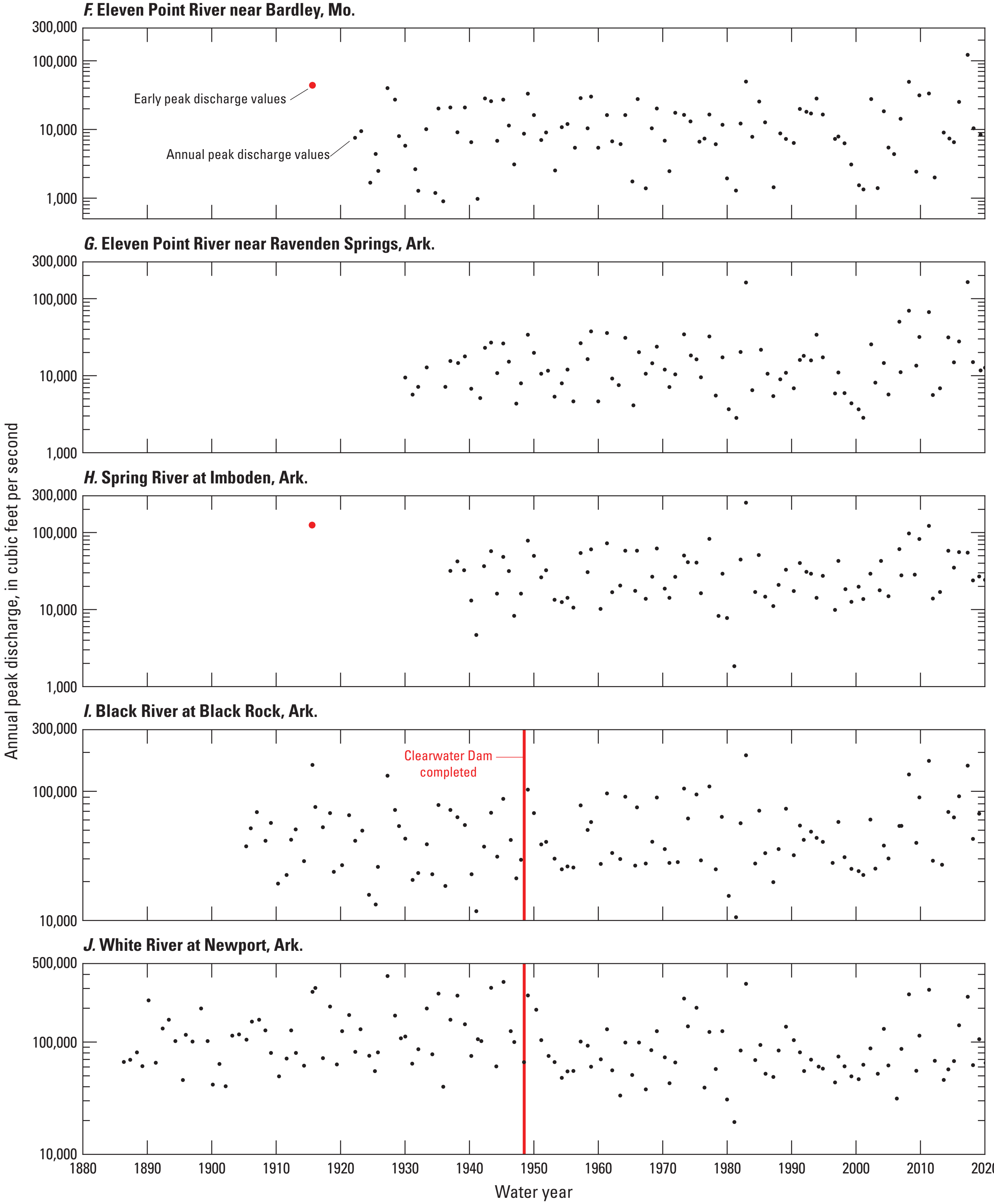

Figure 3. Annual peak discharges for streamgages in the study area. The scale of the y-axis varies among these plots. *A*, Black River at Leeper, Missouri (07062500). *B*, Black River at Poplar Bluff, Missouri (07063000). C, Black River near Corning, Arkansas (07064000). *D*, Current River at Doniphan, Missouri (07068000). *E*, Black River at Pocahontas, Arkansas (07069000). *F*, Eleven Point River near Bardley, Missouri (07071500). *G*, Eleven River near Ravenden Springs, Arkansas (07072000). *H*, Spring River at Imboden, Arkansas (07069500). *I*, Black River at Black Rock, Arkansas (07072500). J, White River at Newport, Arkansas (07074500).—Continued

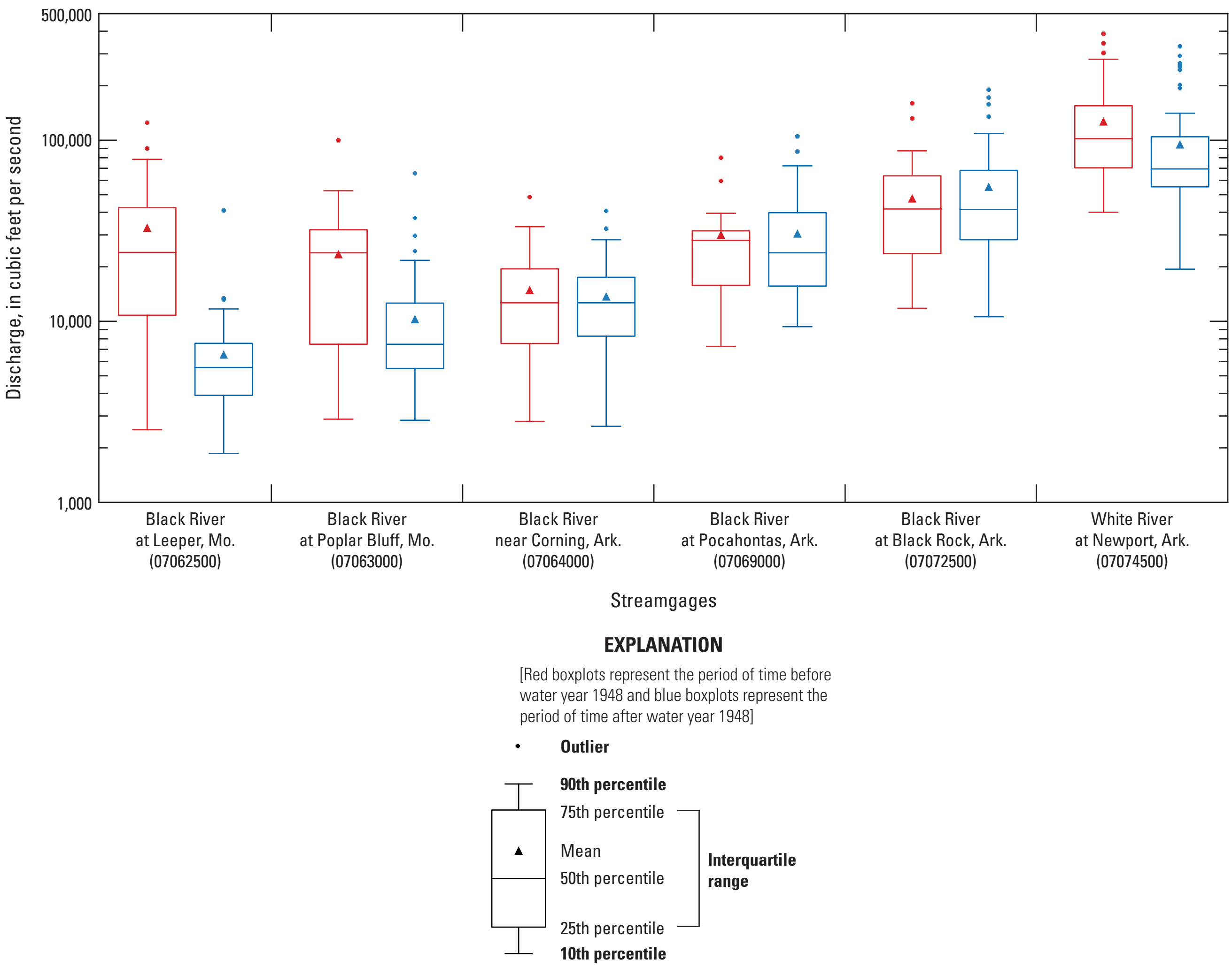

Figure 4. Distributions of annual peak discharges for Black River and White River streamgages before and after Clearwater Dam was constructed in water year 1948. The pre-1948 data include early peak discharges. The time periods used to create this plot for each streamgage are as follows, though there are multiyear gaps between early peak discharges and the main period of record for some streamgages: Black River at Leeper, Mo. (07062500), WY 1904 to 2019; Black River at Poplar Bluff, Mo. (07063000), WY 1904 to 2019; Black River near Corning, Ark. (07064000), WY 1915 to 2019; Black River at Pocahontas, Ark. (07069000), WY 1927 to 2019; Black River at Black Rock, Ark. (07072500), WY 1905 to 2019; White River at Newport, Ark. (07074500), WY 1886 to 2019.

after WY 1948 (fig. 4). Following construction of the dam in 1948, the median peak discharge at the BR-Leeper streamgage decreased from 22,950 to 5,560 ft^3/s and the standard deviation of the annual peak discharges decreased from 21,386 to 5,358 ft^3/s (table 4, fig. 4). Similarly, the median peak discharge at the BR-Poplar Bluff streamgage decreased from 23,900 to 7,465 ft^3/s and the standard deviation of the annual peak discharges decreased from 15,060 to 9,032 ft^3/s (table 4, fig. 4). The effect of Clearwater Dam farther downstream at the BR-Corning, BR-Pocahontas, and BR-Black Rock streamgages is not as pronounced (table 4, fig. 4). However, the pre-dam records for these gages are short compared to the post-dam records, particularly for the BR-Pocahontas streamgage. The peak discharges before and after WY 1948 also are shown for the WR-Newport streamgage to be consistent with the analyses at the other gages, though multiple reservoirs were constructed in the White River Basin in the 1940s to 1960s. The median peak discharge at the WR-Newport streamgage decreased from 103,500 ft^3/s (before WY 1948) to 69,400 (after WY 1948), which likely reflects the combined effects of those reservoirs. The standard deviation of the annual peak discharges at WR-Newport decreased only slightly from 79,100 to 65,351 ft^3/s.

Flow-Duration Curves

Flow-duration curves were used to examine temporal variability in the exceedance probability of the discharge corresponding to the NWS flood stage (the "flood discharge") at each streamgage in the study area (the median peak discharge was used at the Leeper streamgage). Variations in the exceedance probability of the flood discharges indicate variations in the frequency of flood events. An example of the flow-duration curves developed for the BR-Poplar Bluff streamgage, using daily mean discharge for 10 WY periods following the construction of Clearwater Dam, beginning with WYs 1940–49 and ending with WYs 2010–19, is shown in figure 5. The completion of Clearwater Dam in 1948 resulted in reduced exceedance probabilities for discharges greater than about 4,000 ft^3/s and, in general, increased exceedance probabilities for discharges less than 4,000 ft^3/s. Additionally, the exceedance probability of the flood discharge decreased substantially at the BR-Leeper, BR-Poplar Bluff, and BR-Corning streamgages after Clearwater Dam was constructed (fig. 6). This is consistent with the use of the dam for flood control. The BR-Pocahontas and BR-Black Rock streamgages are downstream from major unregulated tributaries and therefore do not show as much effect from Clearwater Dam. The WR-Newport streamgage generally shows a decline in the exceedance probability of the flood discharge that likely results from the construction of flood-control dams throughout the basin in the 1940s through 1960s.

Long-term trends in the exceedance probability for a given discharge would indicate a long-term trend in how often the daily mean discharge equaled or exceeded that discharge. Note that the trend analysis begins after Clearwater Dam was constructed and therefore does not provide a comparison to pre-dam conditions. The only streamgage with a significant temporal trend in the post-dam exceedance probability of the flood discharge was the BR-Leeper streamgage (table 7). The flood discharge at the BR-Leeper streamgage was the post-dam median peak discharge because there is no NWS flood stage for this streamgage. The exceedance probability of the median peak discharge at the BR-Leeper streamgage roughly quadrupled between 1980 and 2019, but these high discharges were still far less likely than in the pre-dam period. Although not a long-term trend, the exceedance probability of the flood discharges at nearly all of the study area gages was higher in WYs 2010–19 than in the previous two decades (with the exception of the SR-Imboden streamgage; fig. 6). Although the decadal patterns in the flood discharge exceedance probability may not be indicative of any significant long-term trends, they may contribute to how stakeholders and managers perceive changes in flood frequency.

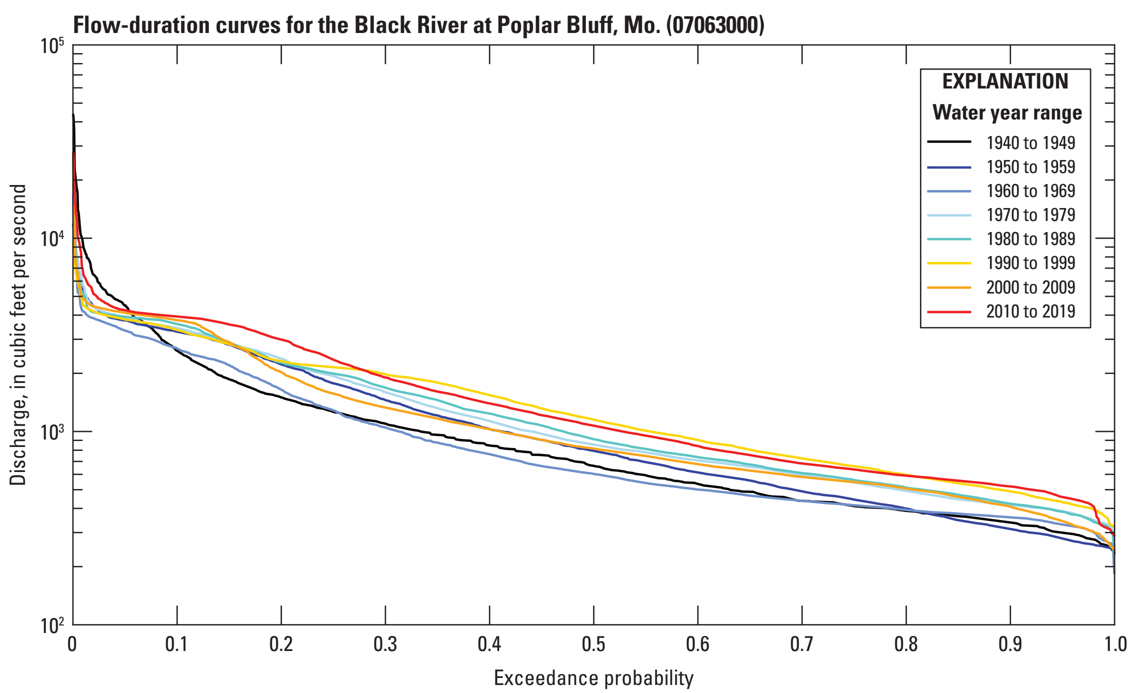

Figure 5. Flow-duration curves for the Black River at Poplar Bluff, Missouri (07063000), streamgage.

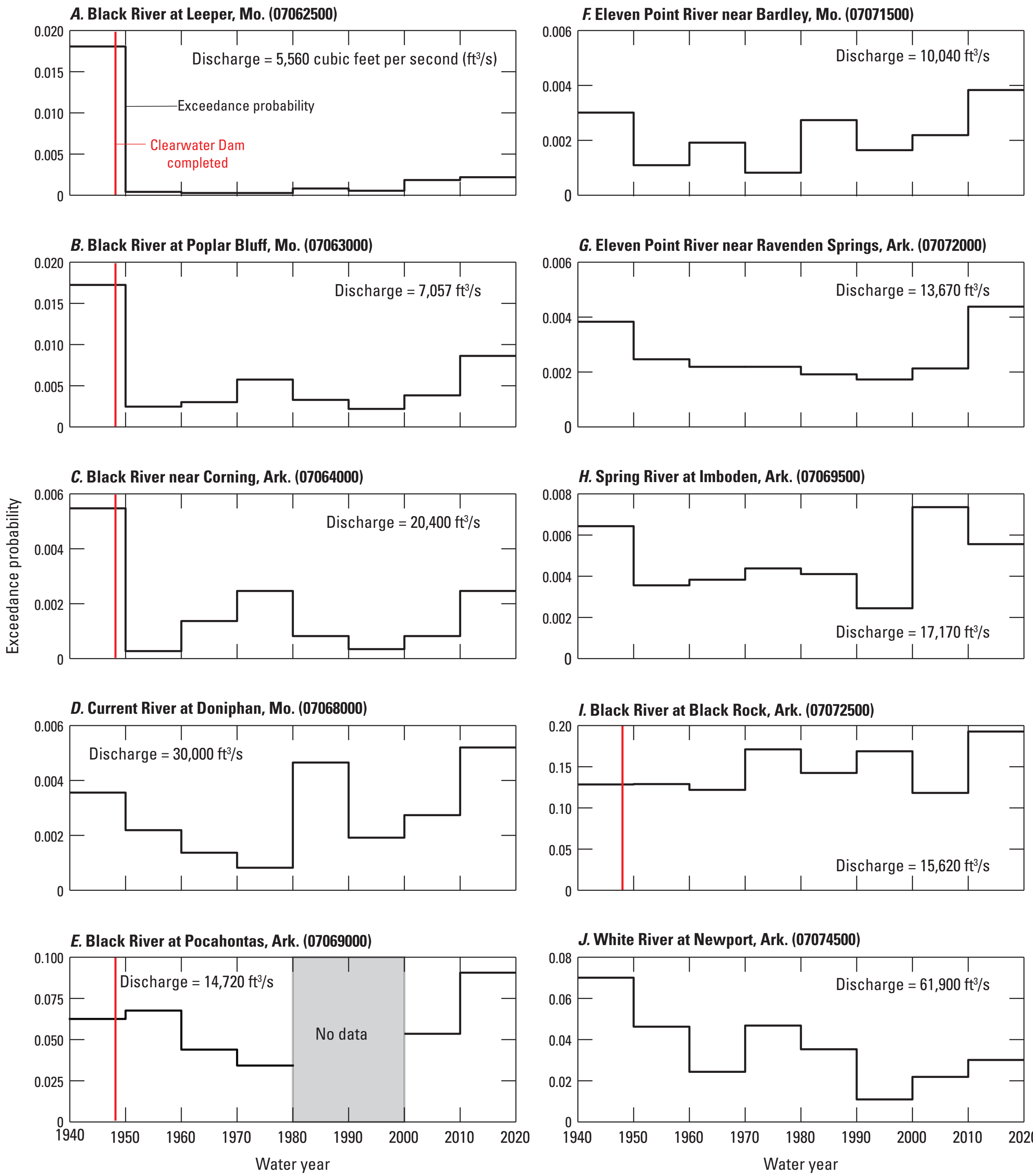

Figure 6. Exceedance probabilities for the discharge corresponding to the National Weather Service flood stage at each streamgage plotted versus time. The scale of the y-axis varies among these plots. *A*, Black River at Leeper, Missouri (07062500). *B*, Black River at Poplar Bluff, Missouri (07063000). *C*, Black River near Corning, Arkansas (07064000). *D*, Current River at Doniphan, Missouri (07068000). *E*, Black River at Pocahontas, Arkansas (07069000). *F*, Eleven Point River near Bardley, Missouri (07071500). *G*, Eleven River near Ravenden Springs, Arkansas (07072000). *H*, Spring River at Imboden, Arkansas (07069500). *I*, Black River at Black Rock, Arkansas (07072500). *J*, White River at Newport, Arkansas (07074500).

Table 7. Statistics related to the exceedance probability of the discharge corresponding to the National Weather Service flood stage at each study area streamgage.

[ft³/s, cubic foot per second; EP, exceedance probability; MO, Missouri; AR, Arkansas; ID, insufficient data for Mann-Kendall test]

Streamgage name and number	Flood discharge (ft³/s)	Mean EP	Standard deviation of EP	Mann-Kendall result	Mann-Kendall *p*-value	Theil-Sen slope	Theil-Sen intercept
Black River at Leeper, MO (07062500)	5,560	9.09E-04	7.29E-04	Upward	0.0355	2.97E-05	−5.83E-02
Black River at Poplar Bluff, MO (07063000)	7,057	4.16E-03	2.12E-03	Cannot reject null	0.2296	2.74E-05	−5.10E-02
Black River near Corning, AR (07064000)	20,400	1.22E-03	8.53E-04	Cannot reject null	0.5568	1.09E-05	−2.09E-02
Current River at Doniphan, MO (07068000)	30,000	2.70E-03	1.52E-03	Cannot reject null	0.2296	5.02E-05	−9.74E-02
Black River at Pocahontas, AR (07069000)	14,720	5.80E-02	1.97E-02	ID	ID	ID	ID
Eleven Point River near Bardley, MO (07071500)	16,600	8.21E-04	6.21E-04	Cannot reject null	0.1023	1.82E-05	−3.57E-02
Eleven Point River near Ravenden Springs, AR (07072000)	15,890	1.73E-03	8.66E-04	Cannot reject null	0.7639	−5.24E-08	1.63E-03
Spring River at Imboden, Arkansas (07069500)	17,170	4.46E-03	1.46E-03	Cannot reject null	0.2296	3.33E-05	−6.21E-02
Black River at Black Rock, AR (07072500)	15,620	1.49E-01	2.65E-02	Cannot reject null	0.5480	9.96E-04	−1.83E+00
White River at Newport, AR (07074500)	61,900	3.08E-02	1.21E-02	Cannot reject null	0.3675	−3.65E-04	7.55E-01

Assessment of Morphologic Change at Streamgages

This section describes the results of the specific stage analysis for all gages addressed in this study. This section also includes the results of the analysis of channel cross-section data and aerial photographs for four main-stem Black River gages (BR-Poplar Bluff, BR-Corning, BR-Pocahontas, and BR-Black Rock).

Black River at Leeper, Missouri

The Black River at Leeper, Mo., streamgage (07062500) is at river mile 249 on the downstream side of the Missouri State Highway 34 (MO–34) bridge crossing. The drainage area upstream from the BR-Leeper streamgage is 987 mi^2 (table 1). According to the SIMS station description, the streambed near the BR-Leeper streamgage consists of coarse gravel, sand, and silt. Google Earth™ imagery from November 2015 shows a large bar that is attached to the left-descending bank about 700 ft upstream from the MO–34 bridge and extends downstream toward the center of the channel about 100 ft downstream from the bridge. The 2015 Google Earth™ imagery also shows that the channel banks are forested in the vicinity of the BR-Leeper streamgage and some large woody debris is visible in the center of the channel, about 280 ft downstream from the streamgage. Flow at the BR-Leeper streamgage has been regulated by Clearwater Dam (8 mi upstream) since June 1948. The current streamgage datum is 416.54 ft above the National Geodetic Vertical Datum of 1929 (NGVD 29), though two other datums have been used during the history of the streamgage. All ratings and measurements examined herein have been adjusted to the current streamgage datum.

The USGS began making discharge measurements at the BR-Leeper streamgage in June 1921 (U.S. Geological Survey, 2019). The SIMS station description indicates that wading discharge can be measured 250 ft upstream from the streamgage. Discharge measurements at higher discharges are made from the deck of the MO–34 bridge. A total of 782 discharge measurements have been made at the BR-Leeper streamgage through December 2019, of which 759 were coded as fair, good, or unspecified. The discharge measurements ranged from 109 to 53,300 ft^3/s, but most (90 percent) measurements were made at discharges less than 3,300 ft^3/s and the median measured discharge was 591 ft^3/s (fig. 7*A*; standard deviation [SD]=3,730 ft^3/s).

A number of ratings have been used at the BR-Leeper streamgage. Ratings 8–17 (1981–2019) are available from digital archives. Ratings prior to 1981 were unavailable. The rating curves for the BR-Leeper streamgage (fig. 7*B*) do not show any distinct break in slope and the NWS does not specify a flood stage for the BR-Leeper streamgage. It is therefore difficult to estimate the bankfull stage for this site with the available information. In general, the current rating curve (rating 17) plots above the historical measurements and ratings at discharge below 5,000 ft^3/s and above 10,000 ft^3/s (fig. 7*B*). The current rating plots in the middle of the rating curves between 5,000 and 10,000 ft^3/s, though it still plots above most of the discharge measurements (fig. 7*B*). This plot indicates that the stage for a given discharge is higher now than it was historically. Three discharge measurements in particular have been important in affecting how ratings 13–17 (April 2008 to present) compare to ratings 9–11 (October 1982 to September 1992) at stages above 7.5 ft. These are the discharge measurements made on January 4, 1993 (discharge=7,790 ft^3/s, stage=11.53 ft); April 10, 2008 (discharge=12,200 ft^3/s, stage=13.19 ft); and May 3, 2011 (discharge=5,110 ft^3/s, stage=8.12 ft).

The specific stage plots for the measurements visually show an increase in specific stage over time since the 1920s (fig. 8*A*). MK tests were used to assess the measurement data for trends for the period of time after the construction of Clearwater Dam. Discharges greater than 4,000 ft^3/s did not have a sufficient number of measurements for an MK test (table 1.1). The MK tests for the measurements indicate a statistically significant increase in specific stage for 1,000 and 2,000 ft^3/s since WY 1949 (table 1.1). These discharges are close to the period of record mean of the annual mean discharges (hereafter referred to as the mean discharge; 1,038 ft^3/s), which is a common reference discharge used in specific stage analysis. Therefore, this result indicates that the channel-bed elevation near the streamgage may have increased since 1949. Other possible explanations include channel narrowing or a decrease in flow velocity. Given the limited number of discharge measurements in the 1,000 and 2,000 ft^3/s ranges, it is not clear whether this increase in stage over time was steady and gradual or intermittent in response to flood events.

The specific stage plots derived from the rating curves seem to show slightly elevated stages for discharges between 4,000 and 10,000 ft^3/s between the early 1990s and middle 2000s (fig. 8*B*). In general, the specific stage plots derived from the rating curves do not have statistically significant monotonic trends according to MK tests, with the exception of upward trends since the 1980s for 15,000 and 20,000 ft^3/s. However, these trends should be viewed with caution because the rating curves are based on a limited number of measurements at these high discharges (table 1.1).

Black River at Poplar Bluff, Missouri

The Black River at Poplar Bluff, Mo., streamgage (07063000) is at river mile 211.2, 1,500 ft upstream from the Business Route U.S. Highway 60 (BR US–60) bridge. The drainage area upstream from the BR-Poplar Bluff streamgage is 1,245 mi^2 (table 1). Discharge measurement notes indicate that the streambed near the streamgage consists of gravel, though a few notes also describe the bed as sand or silt. The surrounding area near the BR-Poplar Bluff streamgage is

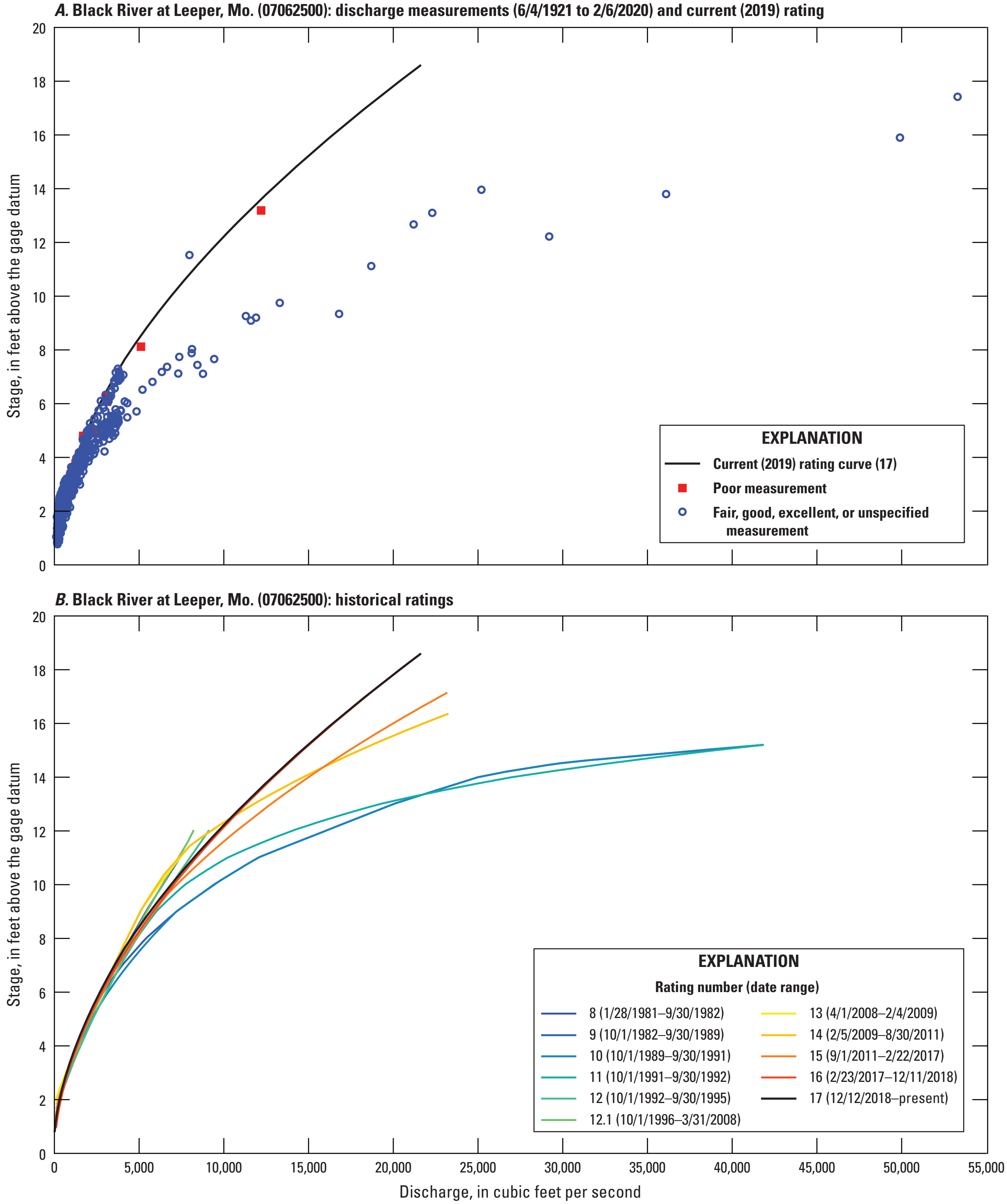

Figure 7. Discharge measurements and historical ratings from the Black River at Leeper, Missouri (07062500), streamgage. *A*, Current (2019) rating and discharge measurements. *B*, Historical (1981–2019) ratings.

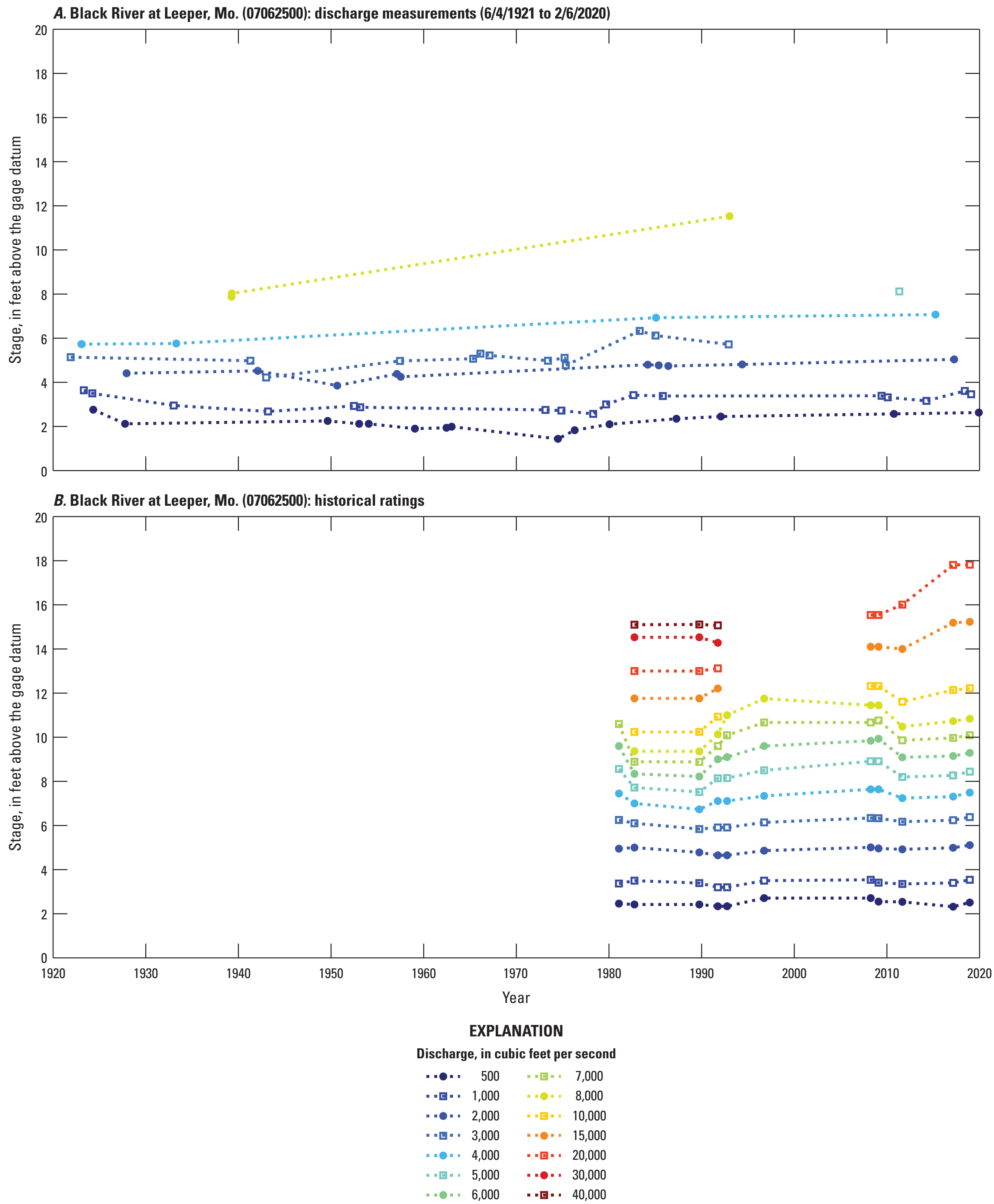

Figure 8. Results of specific stage analysis for the Black River at Leeper, Missouri (07062500), streamgage. *A*, Specific stage from discharge measurements. *B*, Specific stage from ratings.

urban, with a thin line of trees or brush on the channel banks. Flow at the BR-Poplar Bluff streamgage has been regulated by Clearwater Dam (47 mi upstream) since June 1948. The current streamgage datum is 317.48 ft above the NGVD 29, though several different datums have been used during the history of the streamgage. All ratings and measurements examined herein have been adjusted to the current streamgage datum.

Prior to October 1, 1939, a stage streamgage was operated at locations near the present-day streamgage by the NWS. The USGS began making discharge measurements at the BR-Poplar Bluff streamgage in February 1936 and assumed operation of the stage streamgage in October 1939 (U.S. Geological Survey, 2019). The SIMS station description recommends one of three measurement cross-sections depending on discharge conditions. Wading measurements can be made 0.5 mi downstream from the streamgage at discharges less than 400 ft^3/s. For discharges greater than 400 ft^3/s, measurements can be made at the Vine Street bridge. Overflow measurements may be needed in Palmer slough (0.75 mi to east of the streamgage) above a stage of 9 ft and are needed in a ditch 3 mi east of the streamgage above a stage of 13 ft. Above 17 ft, all overflow can be measured from four overflow bridges on BR US–60, located about 0.6 mi, 1.4 mi, 1.9 mi, and 2.2 mi northeast of the streamgage. The SIMS station description also notes that the US–60 bridge, located about 4.5 mi upstream from the streamgage, should be considered for flood measurements. Between February 1936 and December 2019, 768 discharge measurements have been made at the BR-Poplar Bluff streamgage, ranging from 226 to 65,600 ft^3/s (fig. 9*A*; median=893 ft^3/s, SD=4,780 ft^3/s;). Most of the measurements (nearly 90 percent) were made at discharges less than 4,000 ft^3/s. The measurements were mostly coded as fair, good, or unspecified (684 measurements). There were 83 poor measurements ranging from 264 to 31,000 ft^3/s.

A number of ratings have been used at the BR-Poplar Bluff streamgage; ratings A–P (1936–61) and ratings 10–15 (1999–present) are available from paper and digital archives. Ratings between 1961 and 1999 were unavailable. The current rating curve at the BR-Poplar Bluff streamgage (rating 15) shows a break in slope at approximately 17 ft (fig. 9*A*). This break in slope indicates that the NWS flood stage of 16 ft (7,057 ft^3/s on the current rating curve) is a good approximation of the bankfull stage. Even so, according to the SIMS station description, there is some overflow in nearby sloughs and ditches at stages as low as 9 ft. For discharges less than about 7,000 ft^3/s (roughly corresponding to bankfull stage), the current rating curve generally plots below the historical measurements and historical rating curves (fig. 9), indicating that the stage for a given measured discharge was historically higher than it is now for discharges less than about 7,000 ft^3/s. In contrast, for discharges greater than 7,000 ft^3/s, the current rating plots near the top of the range of measured stages and historical rating curves (fig. 9). There is a long gap in the record of ratings between the 1960s and early 2000s and it is unknown if the rating curves from that time period would match these observations.

New ratings for the BR-Poplar Bluff streamgage were developed following the March 2008 and April 2011 flood events. Rating 13 took effect March 17, 2008, though it only differs from the previous rating (12) above a stage of 18 ft. Similarly, rating 14.1 took effect April 10, 2011, and only differs from rating 14 above a stage of 17 ft; that is, the rating curves before and after the March 2008 and April 2011 flood events were identical below 18 and 17 ft, respectively (fig. 9*B*). The lack of change in the rating curves below the flood stage indicates that these two individual flood events did not substantially affect the in-channel morphology or roughness.

The measured specific stage data reflect the temporal trends identified from the historical rating curves (fig. 10*A*; table 1.2). The MK tests and TS slopes indicate downward trends in specific stage for most discharges less than or equal to 4,400 ft^3/s (table 1.2). The downward trends were statistically significant for most of the tested discharge values, though in some cases the null hypothesis could not be rejected. In particular, a discharge of 1,400 ft^3/s (close to the mean discharge of 1,426 ft^3/s) had a statistically significant downward trend with a TS slope of −0.032 feet per year (ft/yr). The tested discharges greater than 4,400 ft^3/s did not include enough measurements to compute the MK test.

The temporal trends in the rating curves from the BR-Poplar Bluff streamgage generally reflect the trends identified in the measured specific stage data (fig. 10). Most discharges less than 6,000 ft^3/s show a statistically significant decrease in stage of about −0.03 ft/yr since WY 1949 for a given rated discharge (table 1.2). The discharges from 7,000 to 9,000 ft^3/s (close to the NWS flood stage) show no trend according to a strict interpretation of the 95-percent confidence level; however, they all have a negative TS slope. The rating curves are closely clustered around 10,000 ft^3/s, indicating minimal change in the specific stage for this discharge over time, which is reflected by a zero TS slope. In contrast, discharges 15,000 to 30,000 ft^3/s show a statistically significant increase in the stage ranging from 0.0076 to 0.037 ft/yr associated with a rated discharge (table 1.2). However, these trends are questionable given that the ratings are based on very few measurements at such high discharges (fig. 9*A*).

Overall, the specific stage analysis results for the BR-Poplar Bluff streamgage indicate a decrease in specific stage for discharges less than the discharge corresponding to the NWS flood stage. This result is consistent between the analysis done for the measurements and the ratings and may indicate a decrease in the channel-bed elevation near the BR-Poplar Bluff streamgage.

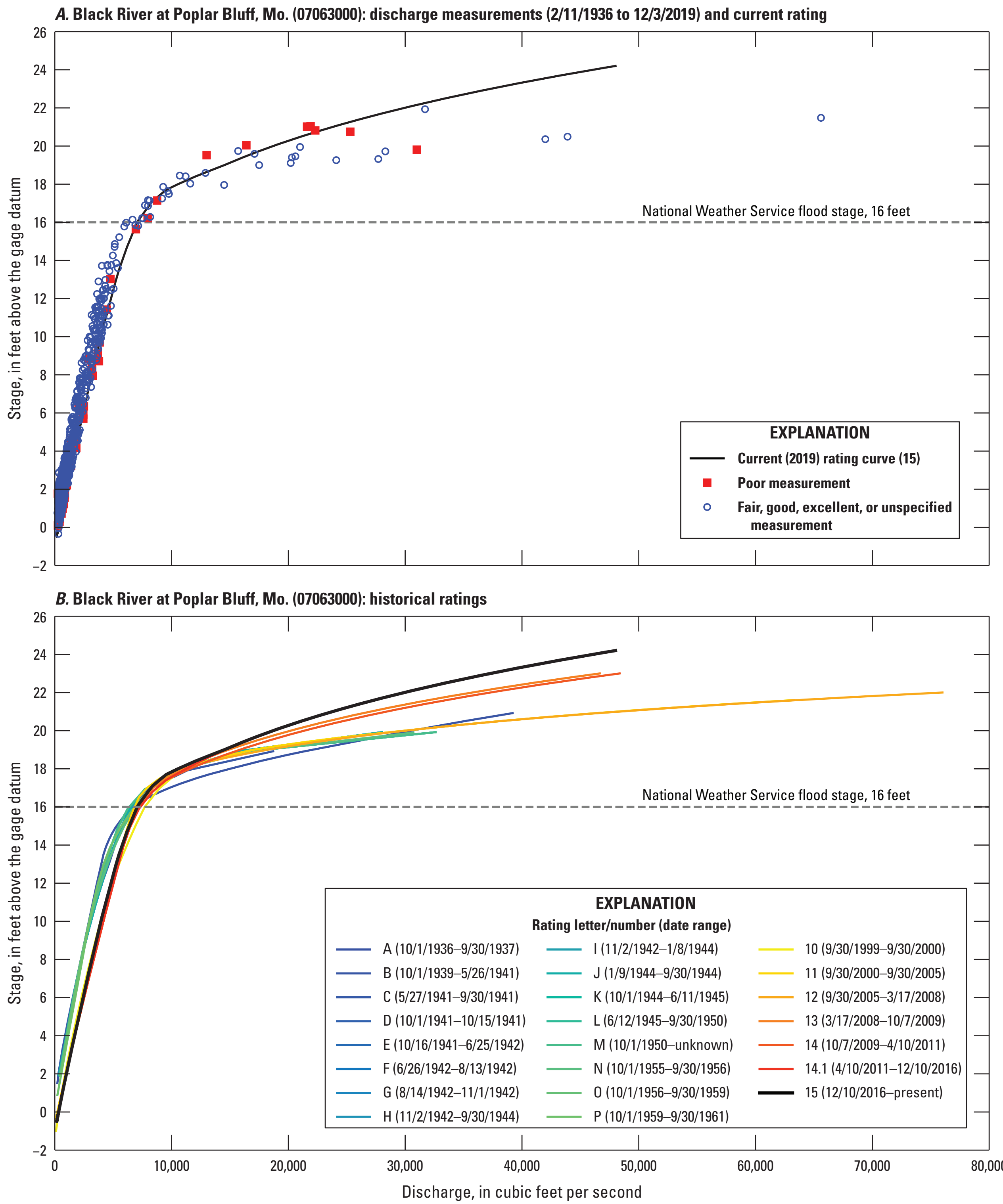

Figure 9. Discharge measurements and historical ratings from the Black River at Poplar Bluff, Missouri (07063000), streamgage. *A*, Current (2019) rating and discharge measurements. *B*, Historical (1936-2019) ratings.

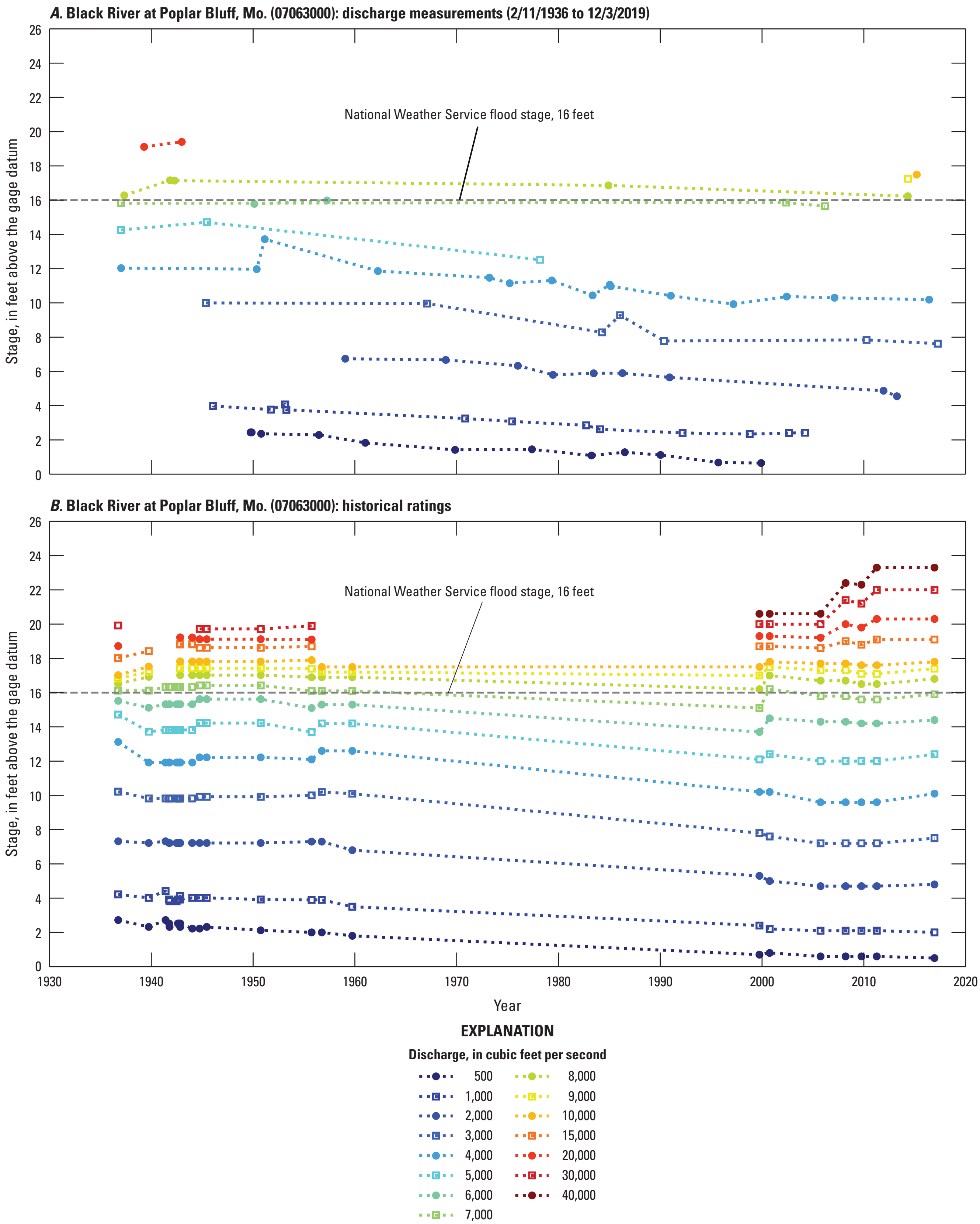

Figure 10. Results of specific stage analysis for the Black River at Poplar Bluff, Missouri (07063000), streamgage. *A*, Specific stage from discharge measurements. *B*, Specific stage from ratings.

BR-Poplar Bluff Cross-Section Data

The Black River at Poplar Bluff, Mo., had around 300 measurements with at least partial notes on cross-sectional geometry, velocity, measurement method, and measurement type. No cross-sectional data are available between September 1965 and August 1984. The hydraulic geometry plots (fig. 11) and measurement notes indicated the use of at least three sections, which is consistent with the SIMS station description. Low-discharge measurements generally were tagged as wading measurements in the notes with no method specified. Older wading measurements were most likely made with a mechanical current meter, like the Price AA or Price pygmy meters, whereas more recent wading measurements were most likely made with an acoustic velocity meter. The wading measurements are a distinct group in the hydraulic geometry plots (fig. 11) and likely correspond to the wading section noted in the SIMS station description, located 0.5 mi downstream from the streamgage.

Most of the BR-Poplar Bluff measurements were bridge measurements. Prior to 2004, nearly all bridge measurements at the BR-Poplar Bluff streamgage were crane measurements. Based on the time period these were made (mostly prior to 2004), the crane measurements were most likely

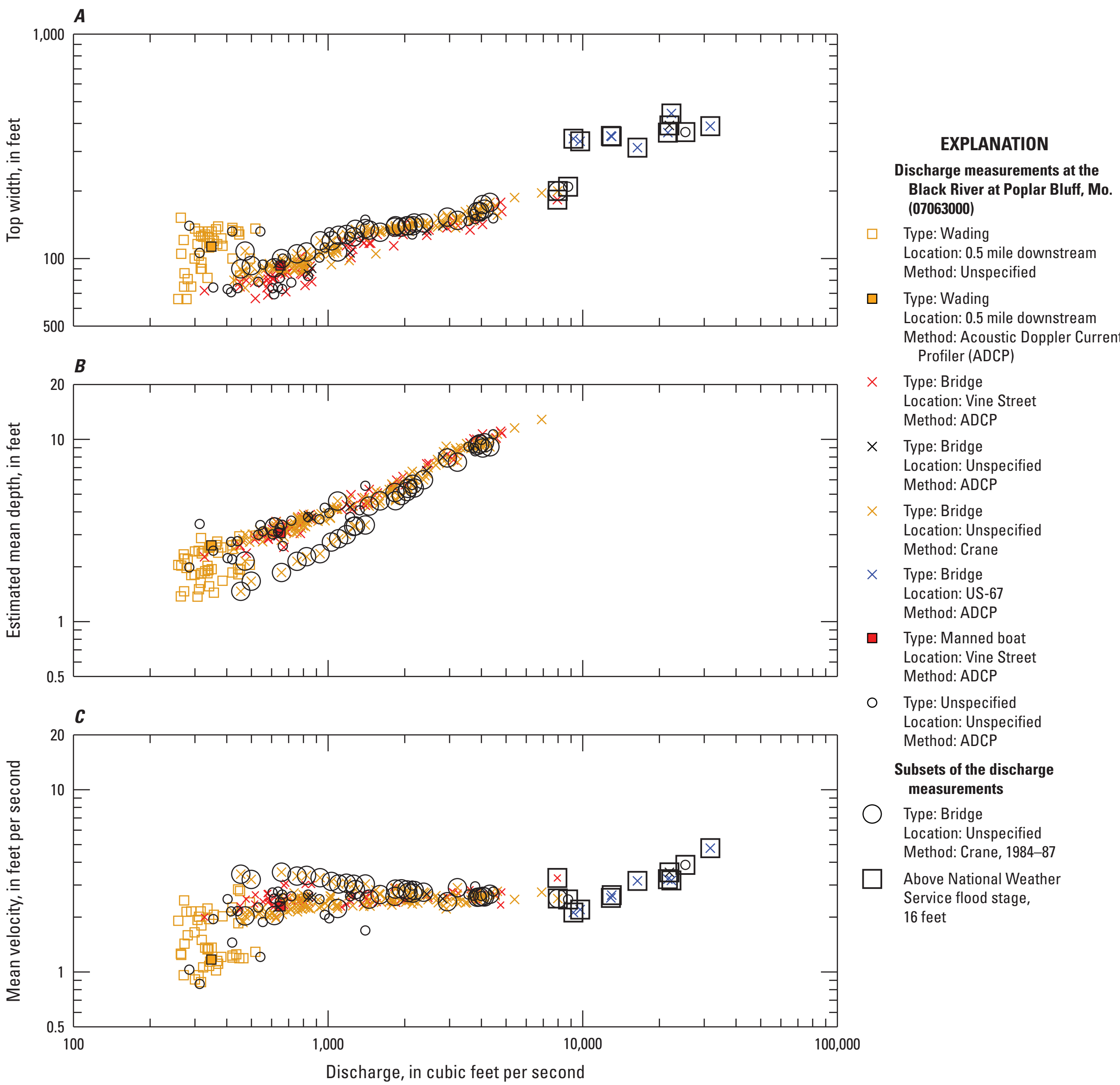

Figure 11. Hydraulic geometry plots for the Black River at Poplar Bluff, Missouri (07063000), streamgage. *A*, Top width vs. discharge. *B*, estimated mean depth vs. discharge. *C*, Mean velocity vs. discharge.

made using a mechanical current meter, such as a Price AA meter. Beginning in 2004, nearly all bridge measurements at the BR-Poplar Bluff streamgage were made using ADCPs. Additionally, in October 2008, technicians began regularly noting whether the measurement was made upstream or downstream from the streamgage. The moderate-discharge bridge measurements were mostly made downstream from the streamgage and are therefore interpreted to be at the Vine Street bridge, as described in the SIMS station description. Based on the hydraulic geometry plots, the Vine Street bridge section generally appears to be narrower and faster than the wading section for discharges around 500 ft^3/s owing to the constriction created by the bridge (fig. 11). Although locations were not noted for the crane measurements, the hydraulic geometry relations for the crane measurements roughly align with those for moderate-discharge ADCP measurements, so the crane measurements are also interpreted as at the Vine Street bridge (fig. 11). However, the plots of depth and velocity with discharge for crane measurements made between 1984 and 1987 deviate from the Vine Street bridge relations and may have been made at a different section or under conditions with different hydraulic control. These measurements are therefore excluded from the temporal trend analysis. Thirteen measurements were made at discharges above the NWS flood stage (17 ft), all of which were bridge measurements made after 2008 with an ADCP. Eight of these were noted as made upstream from the streamgage and were most likely made at the US–60 bridge, as indicated in the SIMS station description.

The measurements at Vine Street bridge span a long time period and wide discharge range compared to the other measurement cross-sections. Therefore, only the Vine Street bridge cross-sectional data were analyzed for temporal trends for discharges ranging from 500 to 4,000 ft^3/s. The selection of discharges was based on the number of measurements with cross-section data available. The discharges also were chosen to be below the NWS flood stage on the current rating curve (16 ft; 7,057 ft^3/s). The top width of flows at Vine Street bridge visually appear to decrease over time by about 10 ft during the previous two decades for discharges ranging from 500 to 4,000 ft^3/s (fig. 12). The trend was statistically significant (according to an MK test) for only 3 out of the 9 discharges plotted (800; 1,800; and 3,500 ft^3/s). Comparison of the 1994 aerial imagery to the 2016 imagery did not reveal a major change in channel top width at the Vine Street bridge (fig. 13). However, the channel widened by nearly 40 ft about a quarter mile downstream from the Vine Street bridge. The extent to which the March 2008 and April 2011 floods (or other individual high-discharge events) were responsible for this widening is unknown.

The estimated mean bed elevation also appears to decrease over time since the late 1980s (fig. 12), but this trend was only significant for 2 of the 9 analyzed discharges (1,400 and 1,800 ft^3/s). The estimated mean depth did not show much change over time since the late 1980s (this plot is not shown). Additionally, the mean velocity visually appears to be increasing over time (fig. 12), which would be consistent with flows becoming narrower but not deeper, though this trend was only significant for the two lowest discharges (500 and 800 ft^3/s). These results are consistent with the specific stage analysis, which also indicated a decrease in bed elevation near the BR-Poplar Bluff streamgage.

Black River near Corning, Arkansas

The Black River near Corning, Ark., streamgage (07064000) is at river mile 152.2, on the downstream side of the U.S. Route 62 (US–62) bridge. The drainage area upstream from the BR-Corning streamgage is 1,750 mi^2 and the current streamgage datum is 272.90 ft above NGVD 29; all streamgage records are relative to the current datum. According to the SIMS station description, the banks of the channel are clay and covered with scattered timber. Discharge measurement notes describe the channel bed as sand or silt. The banks of the channel near the BR-Corning streamgage are forested; the width of the forested area varies from a single line of trees in some areas to a wide swath of forest in others. Similar to the BR-Poplar Bluff streamgage, discharge at the BR-Corning streamgage has been regulated by Clearwater Dam (106 mi upstream) since June 1948. The USACE established a nonrecording streamgage 30 ft downstream from the present streamgage beginning July 27, 1918. The USGS later installed a recording streamgage 30 ft downstream from the present streamgage on November 5, 1953. On October 10, 1957, the recording streamgage was moved to its present location on the US–62 bridge.

The USGS has made discharge measurements at the BR-Corning streamgage since August 1938 (U.S. Geological Survey, 2019). The SIMS station description indicates that moving-boat ADCP measurements can be made just upstream from the streamgage at low and medium stages. However, according to measurement notes, moving-boat ADCP measurements have been made upstream and downstream from the streamgage, mostly within 500 ft of the streamgage. The SIMS station description also states that a good low-water section is about 2.0 mi upstream from the streamgage and that bridge measurements are made from the downstream side of the US–62 bridge, which is the only bridge in the area (excepting a railroad bridge several miles downstream). According to the SIMS station description, overflow measurements are made from a relief bridge about a half mile east of the main bridge, when stage is above 10.7 ft. A total of 746 discharge measurements have been made at the BR-Corning streamgage through December 2019. These measurements ranged from 225 to 36,200 ft^3/s (fig. 14*A*; median=1,095 ft^3/s; SD=4,260 ft^3/s;). Most of the measurements (nearly 90 percent) were made at discharges less than 5,000 ft^3/s. Of the 746 measurements, only 28 were rated as poor and these ranged from 314 to 36,200 ft^3/s.

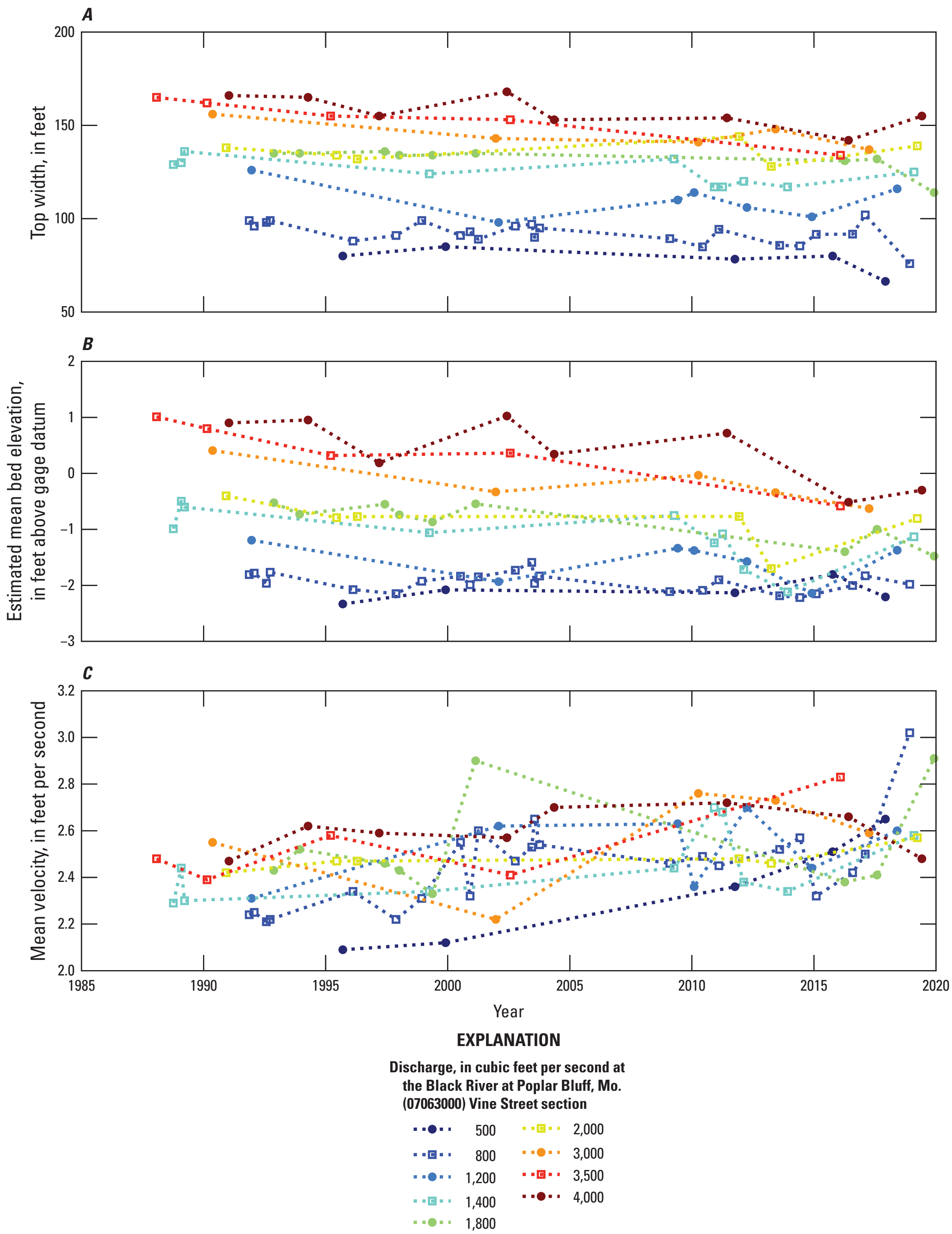

Figure 12. Temporal variations from measurements made at Vine Street bridge downstream from the Black River at Poplar Bluff, Missouri (07063000), streamgage. *A*, Top width. *B*, Estimated mean bed elevation. *C*, Mean velocity for selected discharges.

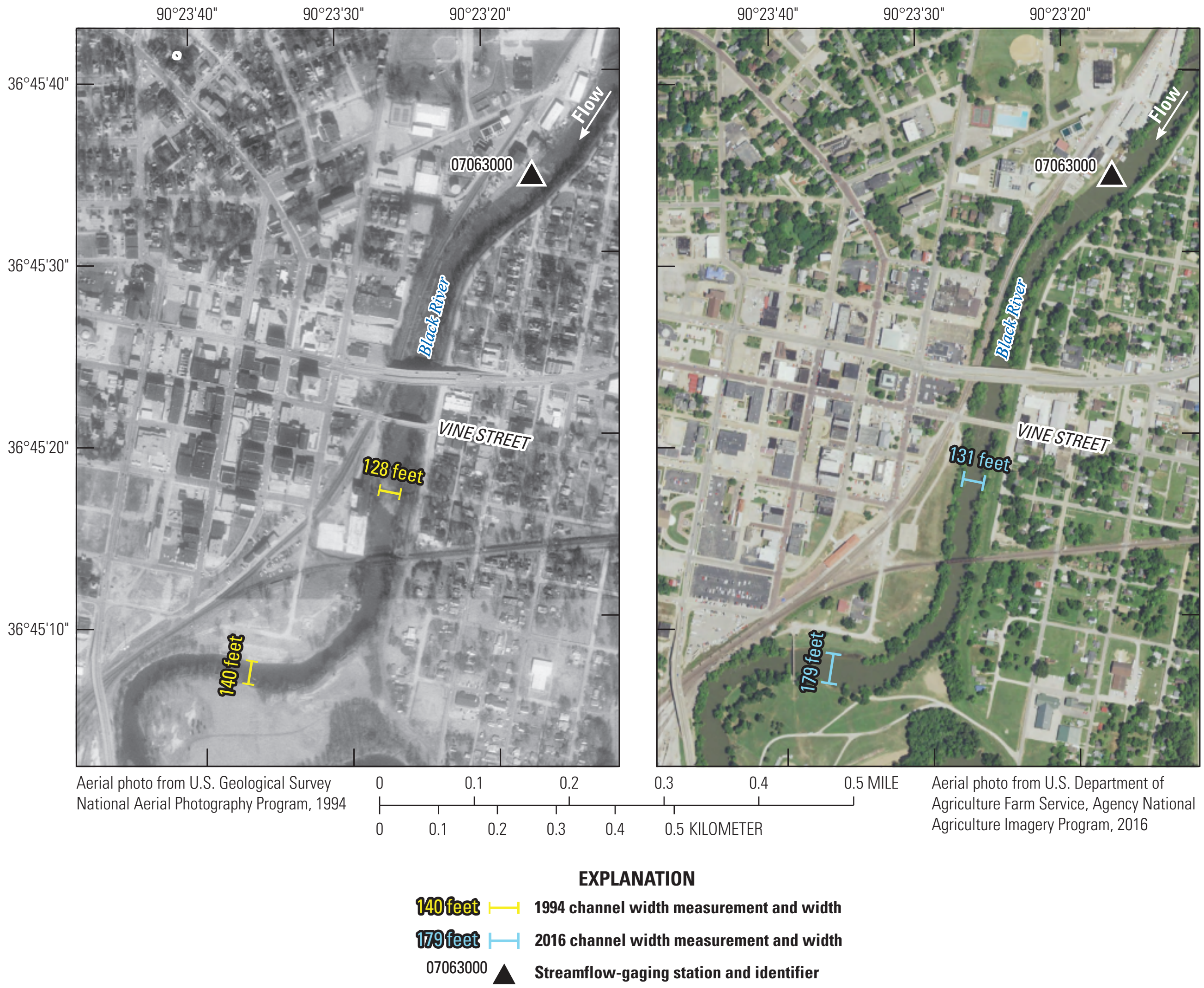

Figure 13. Digital aerial orthophotographs of the area around the Black River at Poplar Bluff, Missouri (07063000), streamgage in 1994 and 2016.

Ratings 6–11 (1973–2019) at the BR-Corning streamgage were found in digital archives; there is no archive data of previous ratings. The current rating curve (rating 11) has two distinct breaks in slope, the first at a stage of about 11 ft and the second at a stage of about 13 ft. The NWS flood stage of 15 ft (20,400 ft^3/s on the current rating curve; fig. 14*A*) corresponds closely with the second break in slope on the current rating curve. According to the SIMS station description, overflow measurements are needed at a stage of 10.7 ft (4,018 ft^3/s on the current rating curve), which is likely a better estimate of bankfull stage than the NWS flood stage of 15 ft. It is possible that the NWS flood stage was chosen to be higher than the bankfull stage because the stream is not located immediately within Corning and the only infrastructure in its immediate vicinity is the US–62 bridge crossing.

The current rating curve is similar to the historical rating curves below a stage of about 10 ft (fig. 14*B*). Above 10 ft, the current rating curve differs substantially from the historical ratings, which all have a single break in slope at a stage of about 10 to 11 ft, compared to the two breaks in slope in the current rating. At high stages, rating 11 is based on discharge measurements made during the March 2008 and April 2011 floods. These include two discharge measurements made on March 22, 2008 (discharge=26,300, stage=15,88 ft; discharge=26,600 ft^3/s, stage=15.87, respectively), one on April 28, 2011 (discharge=36,200 ft^3/s, stage=18.11 ft), and two discharge measurements made on May 4 and May 5, 2011 (discharge=23,000 ft^3/s, stage=15.13 ft; discharge=22,800 ft^3/s, stage=15.22 ft, respectively). Although it is typical for USGS ratings to extend 1.5 times the highest discharge measurement, ratings 10 and 11 extend beyond this

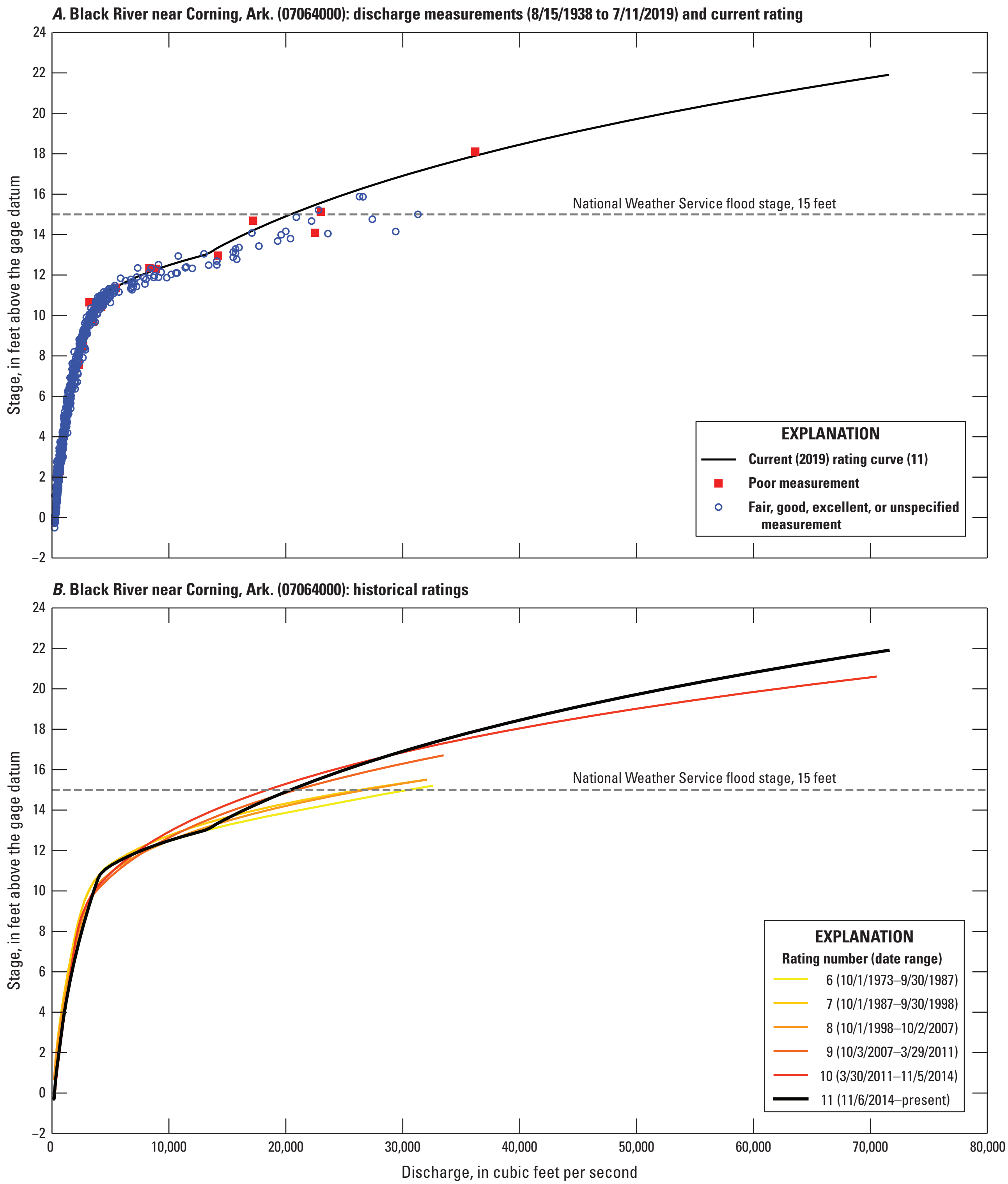

Figure 14. Discharge measurements and historical ratings from the Black River near Corning, Arkansas (07064000), streamgage. *A*, Current (2019) rating and discharge measurements. *B*, Historical (1973–2019) ratings.

point. The reason for this is unknown, but the stage-discharge relation described by ratings 10 and 11 at these very high discharges should be viewed cautiously.

The measured specific stage data at the BR-Corning streamgage do not indicate much change during the period of record since the 1940s (fig. 15*A*). There is a statistically significant upward trend for a few of the tested discharges (400; 500; 900; and 1,100 ft^3/s), though the TS slope for these discharges is only between 0.01 and 0.02 ft/yr (table 1.3). The specific stage data derived from the rating curves do not extend as far back in time as the measurements. The analysis of temporal trends in the rating curves at the BR-Corning streamgage only extends back to 1973 because of the limited number of ratings recovered from the archives. The specific stages derived from the rating curves had a negative TS slope (decreasing over time) for discharges less than or equal to 7,000 ft^3/s (stage=about 12 ft), zero slope for discharges between 7,000 and 10,000 ft^3/s, and a positive TS slope (increasing over time) for discharges charges greater than or equal to 15,000 ft^3/s (fig. 15*B*, table 1.3). However, these trends were not statistically significant, with a few exceptions. The exceptions are the significant downward trend for 1,300 to 1,700 ft^3/s (about −0.024 to −0.028 ft/yr) and the significant upward trend for 30,000 ft^3/s (about 0.053 ft/yr), which is such a high discharge that the ratings are based on very few measurements and may be unreliable (table 1.3). Overall, the specific stage analysis for the BR-Corning streamgage shows minimal change over time in the stage for a given discharge.

BR-Corning Cross-Section Data

The Black River near Corning, Ark., had 654 measurements with at least partial notes on the geometry, velocity, and location of the cross-section where the measurement was made. Based on the SIMS station description, the relief bridge east of the main channel begins to flow above 10.7 ft (4,018 ft^3/s on the current rating curve), so 10.7 ft is used to identify flood flows rather than the NWS flood stage of 15 ft. The measurement notes indicate that prior to 2003, boat measurements were most common, followed by bridge measurements with a crane (fig. 16). The location and method for the pre-2003 boat measurements were not specified, though boat measurements during that time period were most likely made using a mechanical current meter. Only six wading measurements were noted, one of which did not have any cross-sectional data. Beginning in 2003, ADCPs became the standard measurement method at BR-Corning for moving-boat and bridge measurements.

Many of the pre-2003 boat measurements (largely those made at discharges less than 2,000 ft^3/s) were made at a comparatively narrow, shallow, and fast-flowing section (fig. 16). The remaining pre-2003 boat measurements (largely those made at discharges greater than 2,000 ft^3/s) were comparatively wide, deep, and slow-flowing for a given discharge. The locations of the manned-boat ADCP measurements were noted in some cases and were made upstream and downstream from the streamgage, typically within about 500 ft. The upstream manned-boat ADCP measurements generally align with the pre-2003 boat measurements made at discharges greater than 2,000 ft^3/s. The downstream manned-boat ADCP measurements were slightly narrower and deeper for a given discharge than the upstream manned-boat ADCP measurements. Therefore, at least three measurement cross-sections have been used for manned-boat measurements at low to moderate discharges—one used for pre-2003 measurements less than 2,000 ft^3/s (unknown location), one used for pre-2003 measurements greater than 2,000 and some manned-boat ADCP measurements (located within 500 ft upstream from the streamgage), and one used for some manned-boat ADCP measurements (located within 500 ft downstream from the streamgage). The SIMS station description indicates a “low-water” cross-section about 2 mi upstream from the streamgage and a “medium stage” cross-section about 200 ft upstream from the streamgage, but, in contrast to the measurement notes, does not mention any cross-sections downstream from the streamgage.

The crane measurements, which must have been made at the US–62 bridge, align with the manned-boat ADCP measurements at discharges below about 2,500 ft^3/s. Therefore, the channel geometry and hydraulic control likely does not vary substantially near the streamgage at discharges less than about 2,500 ft^3/s. Between 2,500 and 10,000 ft^3/s, the crane measurements show substantial variability in width (about 200 to 600 ft) and estimated mean depth (about 6 to 11 ft), but less variability in mean velocity. The reason for this variability is unknown but may be related to many of these measurements being made at close to the current bankfull stage of 10.7 ft, wherein some measurements were made just above and some just below the overtopping stage, resulting in large differences in top width with small changes in depth.

Forty-two measurements have been made at discharges greater than 10,000 ft^3/s, of which nine have top widths and seven have mean velocities in the measurement notes. At such high discharges, the water level is well above the estimated bankfull stage of 10.7 ft and requires overflow measurements. Some of these measurements, namely those made using a tethered ADCP deployed from a bridge (red x’s in fig. 16), appear narrower than other measurements above 10,000 ft^3/s because the relief and overbank discharges were entered as separate measurements, rather than being included in the main channel measurement width.

The estimated mean bed elevation during all the measurements is shown over time in figure 17. The marked decrease in bed elevation since the early 2000s is more likely due to the use of multiple measurement cross-sections than channel incision. At least two cross-sections were used for boat measurements prior to 2003 and manned-boat ADCP measurements have been made both upstream and downstream from the streamgage (fig. 17). There were no clear temporal trends in top width, estimated mean depth, or mean velocity based on the measurements at the BR-Corning streamgage (not shown). Variations in these parameters are either associated with

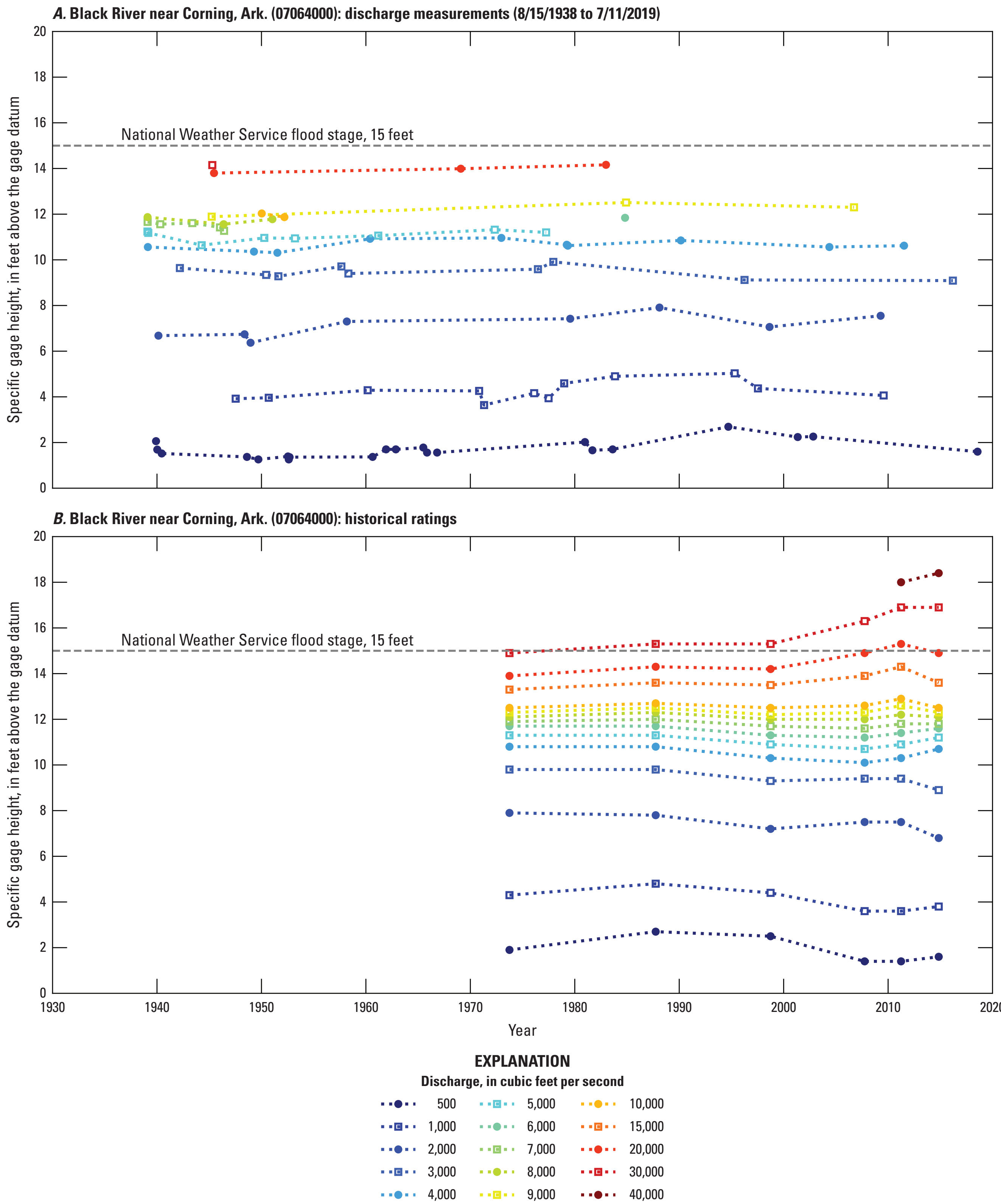

Figure 15. Results of specific stage analysis for the Black River near Corning, Arkansas (07064000), streamgage. *A*, Specific stage from discharge measurements. *B*, Specific stage from ratings.

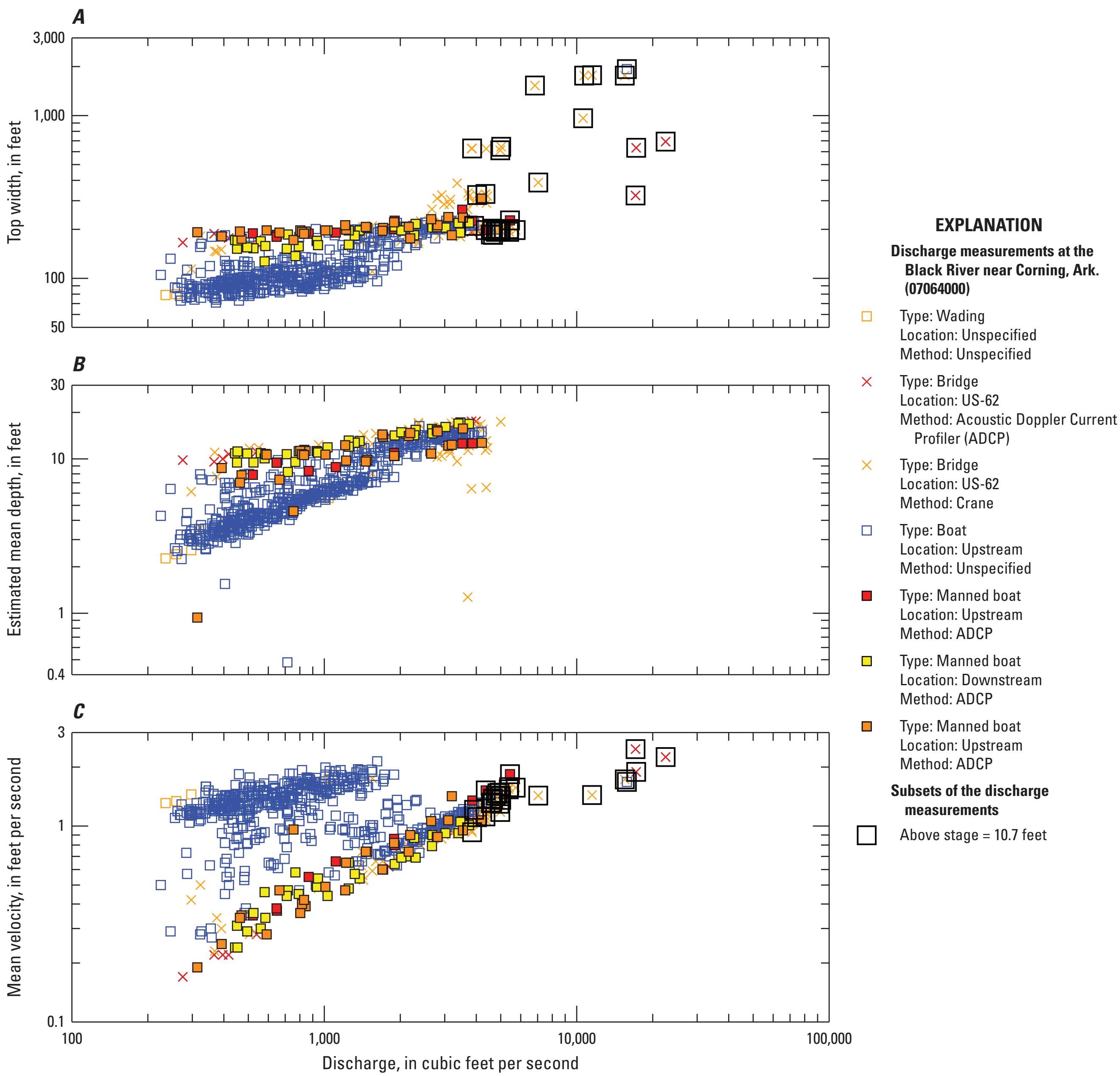

Figure 16. Hydraulic geometry plots for the Black River near Corning, Arkansas (07064000), streamgage. *A*, Top width vs. discharge. *B*, Estimated depth vs. discharge. *C*, Mean velocity vs. discharge.

different measurement locations or were too noisy to interpret. However, the aerial imagery indicates a slight increase in channel width of about 16 ft at a section 250 ft upstream from the streamgage, from about 176 ft in 1994 to about 192 ft in 2017 (fig. 18). A similar increase in width (about 14 ft) is observed 250 ft downstream from the streamgage, from about 157 ft in 1994 to about 171ft in 2017 (fig. 18). It is possible that the widening observed from 1994 to 2017 near the BR-Corning streamgage was driven by the March 2008 and April 2011 floods. The extent to which these floods (or other individual high-discharge events) were responsible for this widening cannot be directly verified with the available imagery. Additionally, it is possible that the channel width changed prior to 1994, but this has not been examined with aerial imagery.

The widening of the channel near the BR-Corning streamgage provides some context for the specific stage analysis results described in the "Black River near Corning, Arkansas" section. An increase in channel width results in an increase in the cross-sectional area of the flow and, therefore, should result in a decrease in the specific stage (assuming no changes in bed elevation, roughness, or hydraulic control). However, changes in bed elevation, roughness, or hydraulic control may serve to either enhance or diminish the effect

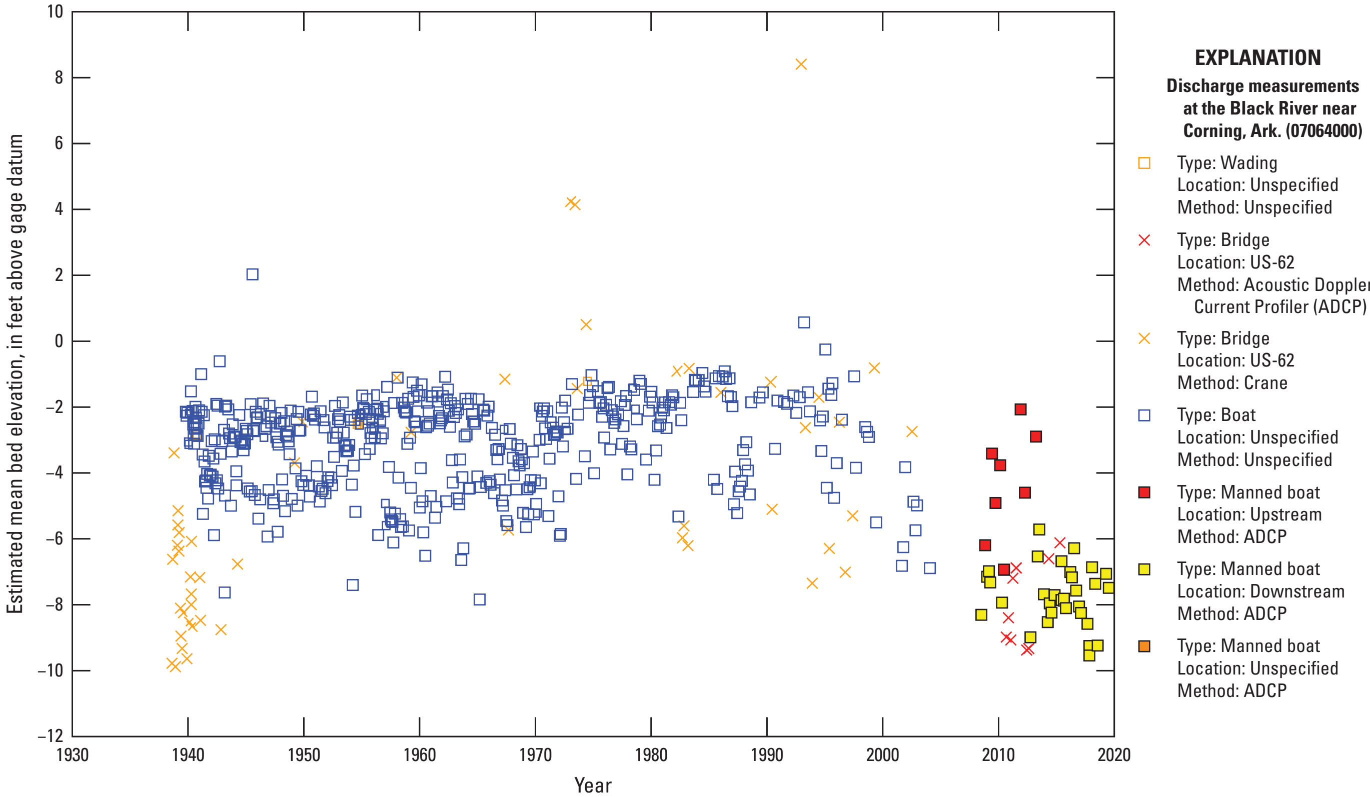

Figure 17. Estimated mean bed elevation for measurements made near the Black River near Corning, Arkansas (07064000), streamgage, plotted over time.

of widening on specific stage. Specific stages derived from the BR-Corning rating curves show a decrease during the period from 1994 to 2017 (when widening was observed) for discharges less than or equal to 3,000 ft^3/s (fig. 15*B*). This decrease in specific stage is consistent with widening, but it is unknown if this decrease was enhanced (or counteracted) by a concurrent decrease (or increase) in bed elevation or roughness. For discharges that exceed the bankfull discharge (about 4,000 ft^3/s), specific stages are roughly constant or increase during 1994 to 2017 (fig. 15*B*). The increases in specific stage observed for discharges that exceed the bankfull discharge are more likely to reflect changes in the conveyance capacity of the flood plain or uncertainty in the rating curve (particularly at very high discharges) than changes in channel morphology. Overall, the specific stage analysis for the BR-Corning streamgage is consistent with the widening observed from 1994 to 2017.

Current River at Doniphan, Missouri

The Current River at Doniphan, Mo., streamgage (07068000) is at river mile 51.3, about 0.5 mi upstream from U.S. Route 160 (US–160). The drainage area upstream from the CR-Doniphan streamgage is 2,038 mi^2 and the current streamgage datum is 321.42 ft above NAVD 88 (table 1). The streambed near the CR-Doniphan streamgage consists mainly of gravel, and a coarse gravel bar is about 250 ft downstream from the streamgage according to the SIMS station description and discharge measurement notes. The Current River is unregulated and fed by the largest spring in the Ozark Plateau (Big Spring). The confluence of the Current River with the Black River is about 6.4 mi upstream from the BR-Pocahontas streamgage. From August 1, 1918, to February 28, 1992, the USACE obtained stage readings at a nearby location; the USGS began operation of the streamgage on June 14, 1921. The streamgage has been at several locations and several datums during its history. Owing to some uncertainty in the early datum corrections, ratings and measurements prior to July 1936 are not included in this analysis. Stages for ratings and measurements between July 1936 and September 1971 were adjusted upward by 1 ft to correct for a datum change on November 1, 1971.

Discharge measurements have been made at the CR-Doniphan streamgage since June 1921 (U.S. Geological Survey, 2019), but the analysis in this study is limited to measurements made beginning July 11, 1936. Wading measurements can be made at the streamgage at discharges less than about 1,200 ft^3/s. Otherwise, discharge is measured from the downstream side of the US–160 bridge. A total of 724 discharge measurements have been made at the CR-Doniphan streamgage between July 1936 and December 2019, ranging from 821 to 174,000 ft^3/s (fig. 19*A*; median=2,015 ft^3/s;

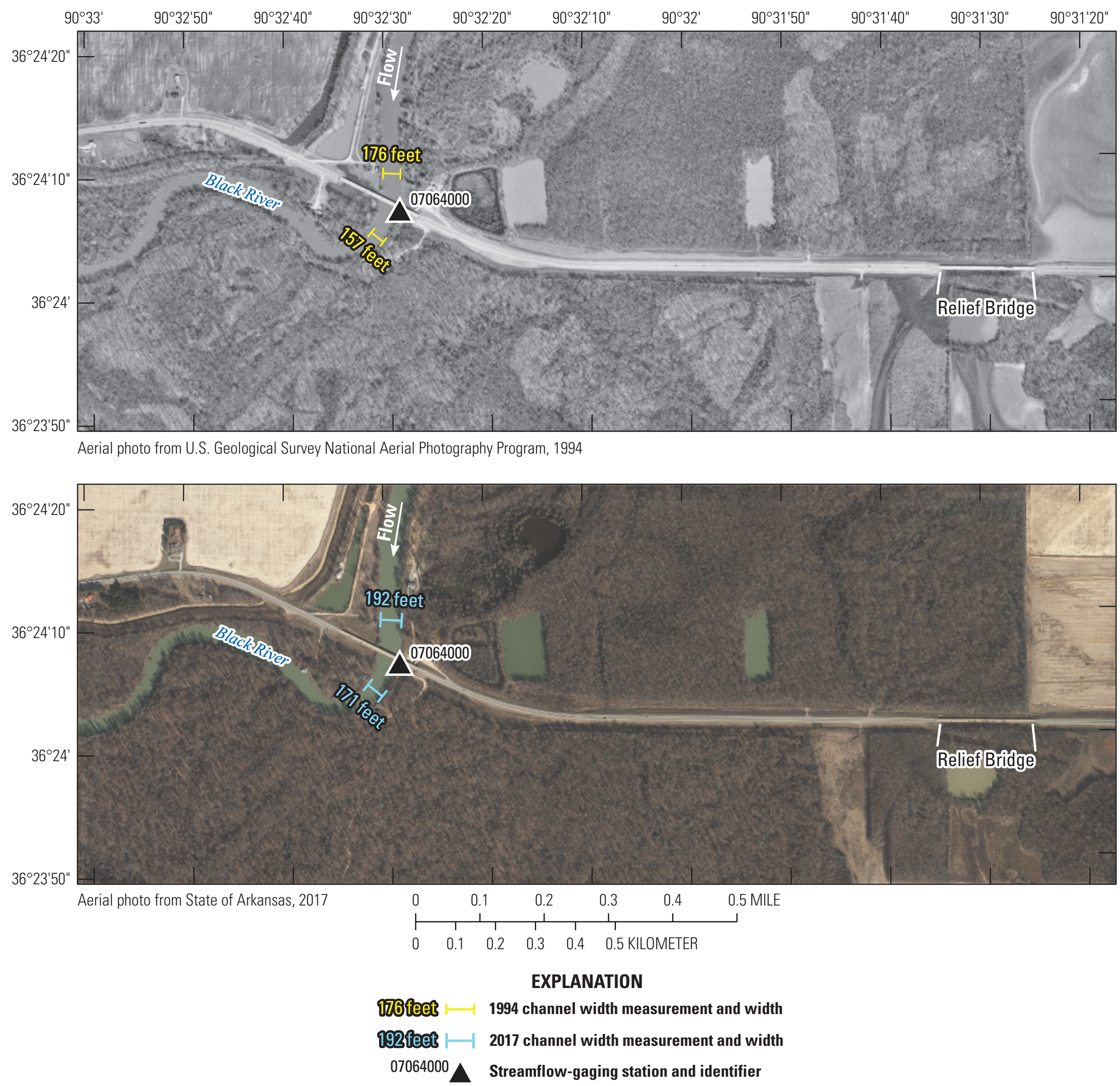

Figure 18. Digital aerial orthophotographs of the area around the Black River near Corning, Arkansas (07064000), streamgage in 1994 and 2017.

SD=11,990 ft^3/s). Most of the measurements (nearly 90 percent) were made at discharges less than 6,000 ft^3/s. Of the 724 measurements, 23 were rated as poor, ranging from 1,160 to 86,700 ft^3/s.

Ratings A–AA (1918–49) and ratings 1–8 (1957–71) at the CR-Doniphan streamgage are available from paper archives, and ratings 15–21 (1997–2019) are available from digital archives. Ratings between 8 and 15 (between October 1, 1971, and September 30, 1997) were unavailable and it is unknown whether any ratings existed between rating AA and rating 1. The current rating curve (rating 21) shows a broad curve with no distinct break in slope (fig. 19*A*), which is consistent with field observations that indicate that channel at this site is somewhat poorly defined. The NWS flood stage is 13 ft (30,000 ft^3/s on the current rating curve), though bankfull stage is probably closer to the NWS action stage of 10 ft (21,140 ft^3/s on the current rating curve).

The historical ratings are clustered in two groups, with ratings P–AA (July 1936 to January 1949) and ratings 1–8 (October 1957 to September 1971) in one group, indicating a higher stage for a given discharge than the second group of ratings 15–21 (September 1997 to present; fig. 19*B*). The gap in the available historical ratings between September 1971 and September 1997 may account for the two distinct groups of rating curves, rather than a more gradual change from the older ratings to the more recent ratings. The current rating

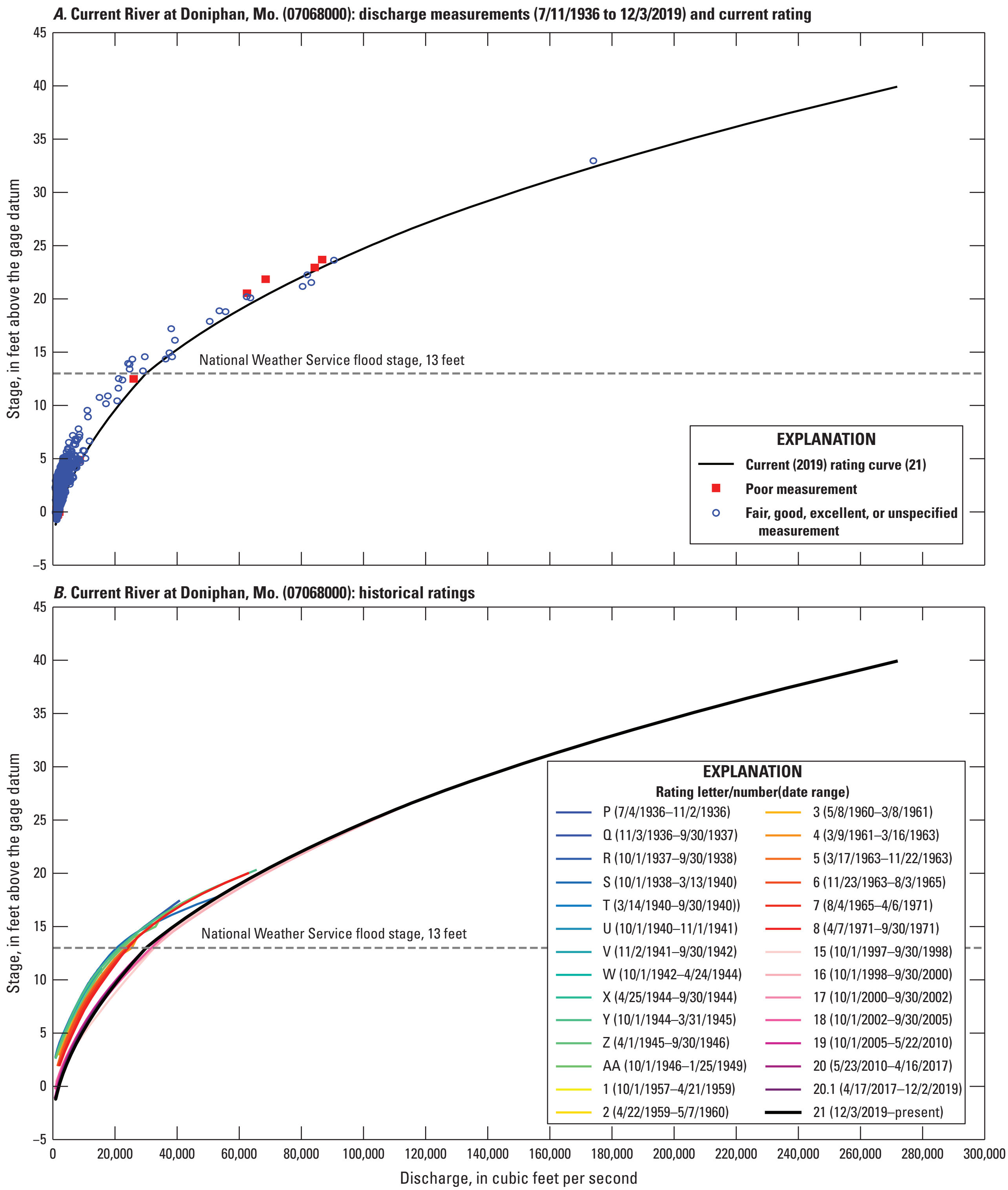

Figure 19. Discharge measurements and historical ratings from the Current River at Doniphan, Missouri (07068000), streamgage. *A*, Current (2019) rating and discharge measurements. *B*, Historical (1936–2019) ratings.

plots with the second group of ratings developed after 1997 and is on the low end of the range of the discharge measurements, which show considerable variability. The upper end of the current rating is based on a discharge measurement made during the April–May 2017 flood on May 1, 2017 (discharge=174,000 ft^3/s, stage=32.97 ft).

The measured specific stages show a significant downward trend since the 1940s for nearly all of the tested discharges ranging from 900 to 8,700 ft^3/s (fig. 20*A*; table 1.4), including 2,900 ft^3/s (close to the mean discharge of 2,852 ft^3/s), which had a TS slope of about −0.043 ft/yr. The exceptions were 900; 4,100; 6,600; and 8,700 ft^3/s, all of which had MK test *p*-values above 0.05. There were not enough measurements to compute an MK test for discharges greater than 8,700 ft^3/s. The historical ratings also show a statistically significant decrease in specific stage with a mean TS slope of −0.044 ft/yr since 1936 for 900 to 60,000 ft^3/s (fig. 20*B*; table 1.4). The downward trend in specific stage may indicate a decrease in the channel-bed elevation near the CR-Doniphan streamgage.

Black River at Pocahontas, Arkansas

The Black River at Pocahontas, Ark., streamgage (07069000) is at river mile 90.1, on the downstream side of the U.S. Route 67 (US–67) bridge. The drainage area upstream from the BR-Pocahontas streamgage is 4,840 mi^2 and the current streamgage datum is 241.81 ft above NGVD 29 (table 1). Discharge measurement notes indicate that bed consists of sand and silt in the vicinity of the BR-Pocahontas streamgage. The surrounding area is a mix of urban and agricultural land with a thin forested riparian border. Although the BR-Pocahontas streamgage is downstream from Clearwater Dam, it is also downstream from the confluence with the Current River, an unregulated tributary (with approximately 54 percent of the contributing drainage area) that reduces the discharge-regulating effect of Clearwater Dam at the BR-Pocahontas streamgage. The USACE operated nonrecording gages near the present streamgage between July 18, 1918, and July 15, 1937, when the USGS installed a nonrecording streamgage on the upstream side of the US–67 highway bridge. The USGS later installed a recording streamgage and moved the nonrecording streamgage to the downstream side of the bridge on July 24, 1940.

The USGS has made discharge measurements at the BR-Pocahontas streamgage since July 1937, excepting September 1970 to September 1981 and August 1994 to January 2000 (U.S. Geological Survey, 2019). According to the SIMS station description, extreme low-stage measurements can be made at a riffle about 1.75 mi (9,240 ft) downstream from the streamgage, which is the control during low water. The SIMS station description recommends that low- to moderate-stage manned-boat measurements (up to about 17–18 ft stage) be made 500–800 ft downstream from the streamgage. Measurement notes indicate the measurement location for only 38 of 43 manned-boat measurements made since November 2008, and these range from 100 to 3,500 ft downstream from the streamgage. At flood stages and some moderate discharges, discharge has been measured from the downstream side of the US–67 bridge. A total of 623 discharge measurements have been made at the BR-Pocahontas streamgage through December 2019, ranging from 1,140 to 99,100 ft^3/s (fig. 21*A*; median=4,020 ft^3/s; SD=11,320 ft^3/s). Nearly 90 percent of the measurements were made at discharges less than 15,000 ft^3/s. There were 36 measurements rated as poor that ranged from 1,960 to 99,100 ft^3/s and included the nine highest measurements on record.

Ratings 6–9 (1988–2019) at the BR-Pocahontas streamgage are available in digital archives, and paper copies of rating 5 (started 1967) and rating O (started 1956) were found and included in this analysis. Ratings 7 and 7.1 appear to be identical and have been combined for simplicity. No archive data were found of other previous ratings, and ratings between O and 5, if they existed, were unavailable. The current rating curve (rating 9) has a break in slope at a stage of about 20 ft (fig. 21*A*). The NWS flood stage is 17 ft, corresponding to 14,720 ft^3/s on the current rating curve. The NWS flood stage is consistent with the SIMS station description, which indicates that the left bank overflows at stages above 17–18 ft.

The current rating curve, which took effect November 8, 2017, is similar to the historical rating curves, except at very high stages (fig. 21*B*). Above 24 ft, the current rating plots lower than ratings 7, 8, and 8.1 owing to the effect of a small number of flood measurements on the upper ends of the rating curves. All of the measurements that equal or exceed 58,700 ft^3/s were made during either the 2008, 2011, or 2017 floods and all are rated as “poor.” The two measurements with the greatest discharges were measured during the May 2017 flood (discharges=99,100 and 95,600 ft^3/s, stages=28.10 and 27.81 ft) and clearly had a big effect on the shape of the current rating (rating 9). The two high-discharge measurements that plot above the current rating (discharges=68,900 and 78,800 ft^3/s, stages=26.63 and 28.39 ft) were measured during the April 2011 flood. These two April 2011 measurements were used in the development of ratings 8 and 8.1 but were superseded by the May 2017 measurements in the development of rating 9.

The measured specific stages for discharges between 2,000 and 27,000 ft^3/s have generally not significantly increased or decreased since the late 1930s (fig. 22*A*; table 1.5). The exception is for measurements within 2.5 percent of 3,000 and 4,000 ft^3/s, which showed significant downward trends of 0.019 and 0.011 ft/yr, respectively. However, 3,000–4,000 ft^3/s is less than the mean discharge (5,850 ft^3/s) and may be affected by changes in the low-discharge section control. There are not enough measurements at discharges greater than 27,000 ft^3/s for trend analysis. The trend analysis for the rating curves shows no significant change over time for discharges ranging from 2,000 to 110,000 ft^3/s (fig. 22*B*; table 1.5).

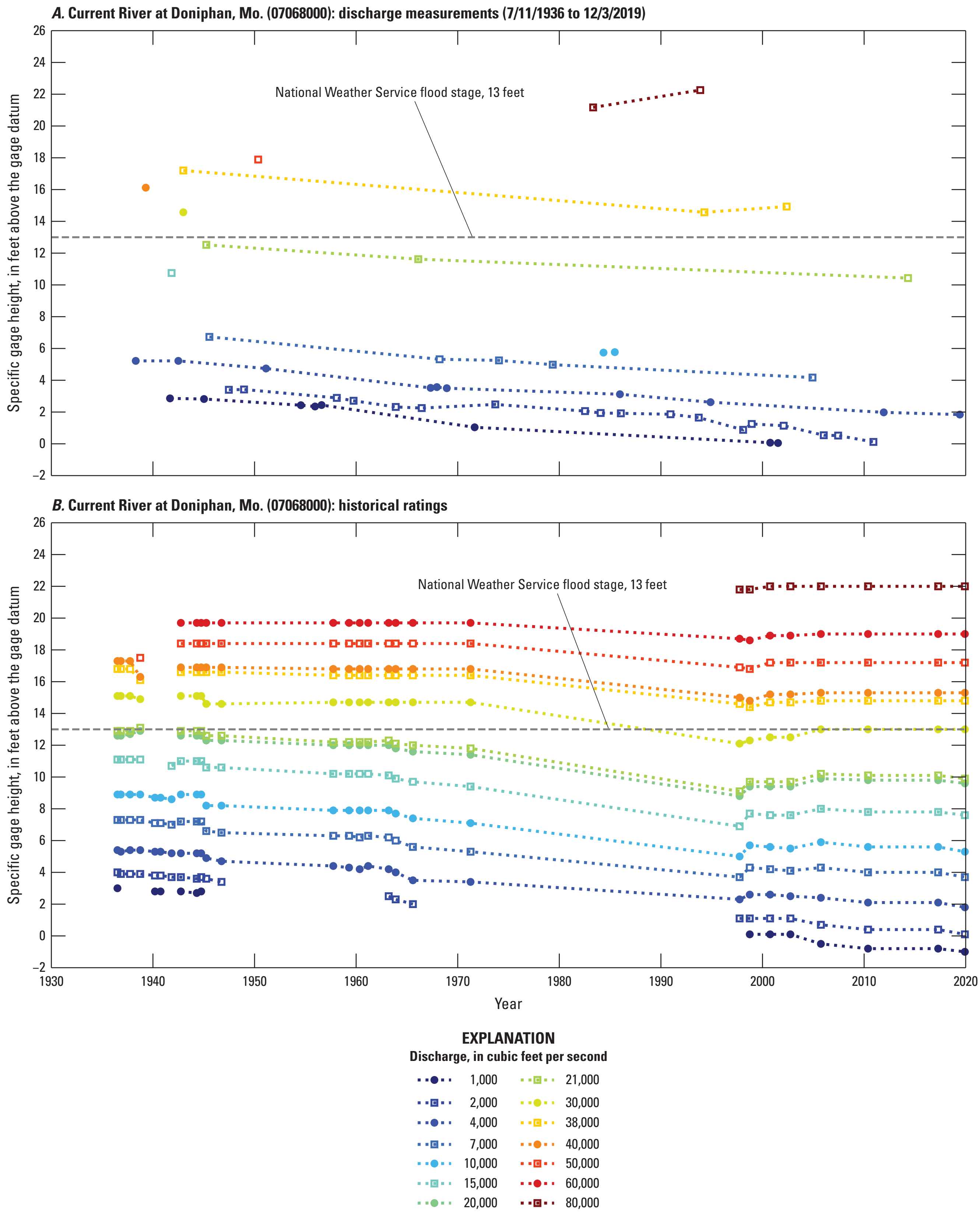

Figure 20. Results of specific stage analysis for the Current River at Doniphan, Missouri (07068000), streamgage. *A*, Specific stage from discharge measurements. *B*, Specific stage from ratings.

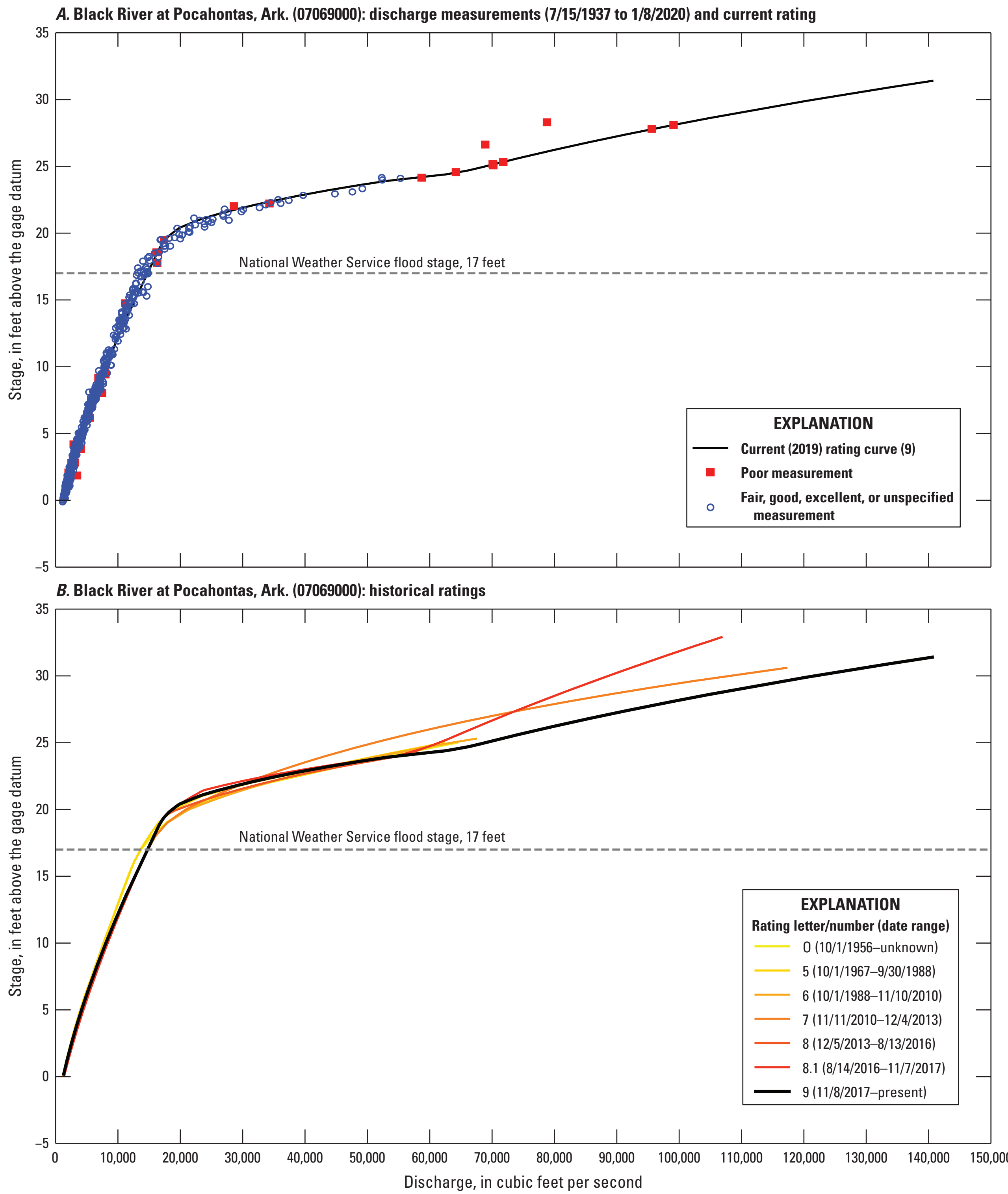

Figure 21. Discharge measurements and historical ratings from the Black River at Pocahontas, Arkansas (07069000), streamgage. *A*, Current (2019) rating and discharge measurements. *B*, Historical (1956-2019) ratings.

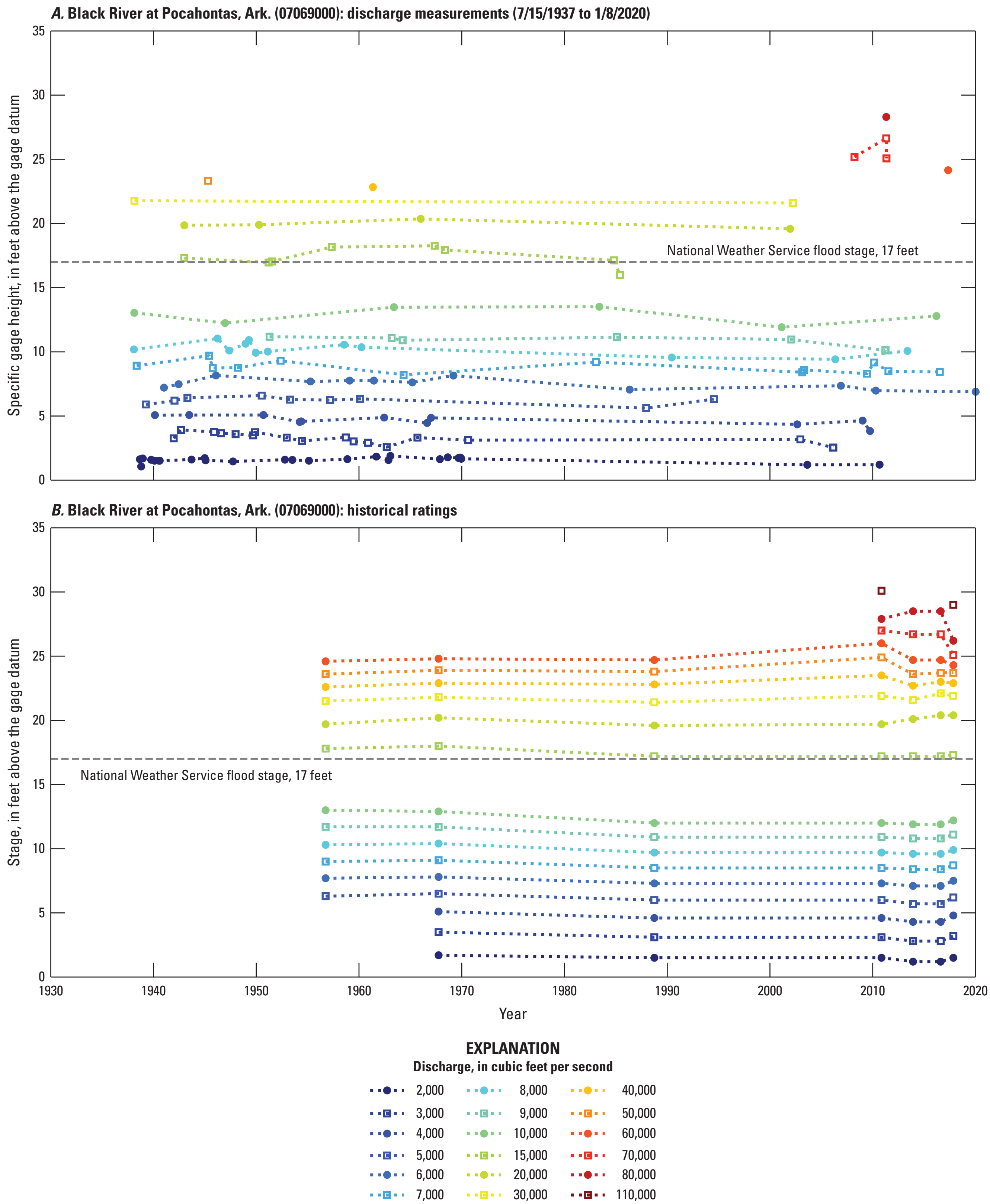

Figure 22. Results of specific stage analysis for the Black River at Pocahontas, Arkansas (07069000), streamgage. *A*, Specific stage from discharge measurements. *B*, Specific stage from ratings.

BR-Pocahontas Cross-Section Data

The Black River at Pocahontas, Ark., had 546 measurements with at least partial notes on the geometry, velocity, and location of the cross-section where the measurement was made. The NWS flood stage of 17 ft (14,720 ft³/s on the current rating curve) is used to identify overbank discharges because it is consistent with the SIMS station description. Similar to the BR-Corning streamgage, ADCPs became the primary measurement method in 2003. Prior to 2003, it is likely that a mechanical current meter was deployed from a boat during low to moderate discharges and from the US–67 bridge during high discharges. The hydraulic geometry plots show that the manned-boat ADCP measurements were slightly wider and slower than the pre-2003 moving-boat measurements for discharges less than about 20,000 ft³/s (fig. 23). Most of the discharge measurements above 20,000 ft³/s were made off the US–67 bridge.

The manned-boat measurements were examined for temporal trends in the cross-section data. The top width for a given discharge visually appears to have increased since 1940 for discharges less than or equal to 10,000 ft³/s, which corresponds to a stage of 12.1 ft on the current rating curve. This trend was statistically significant according to MK tests for

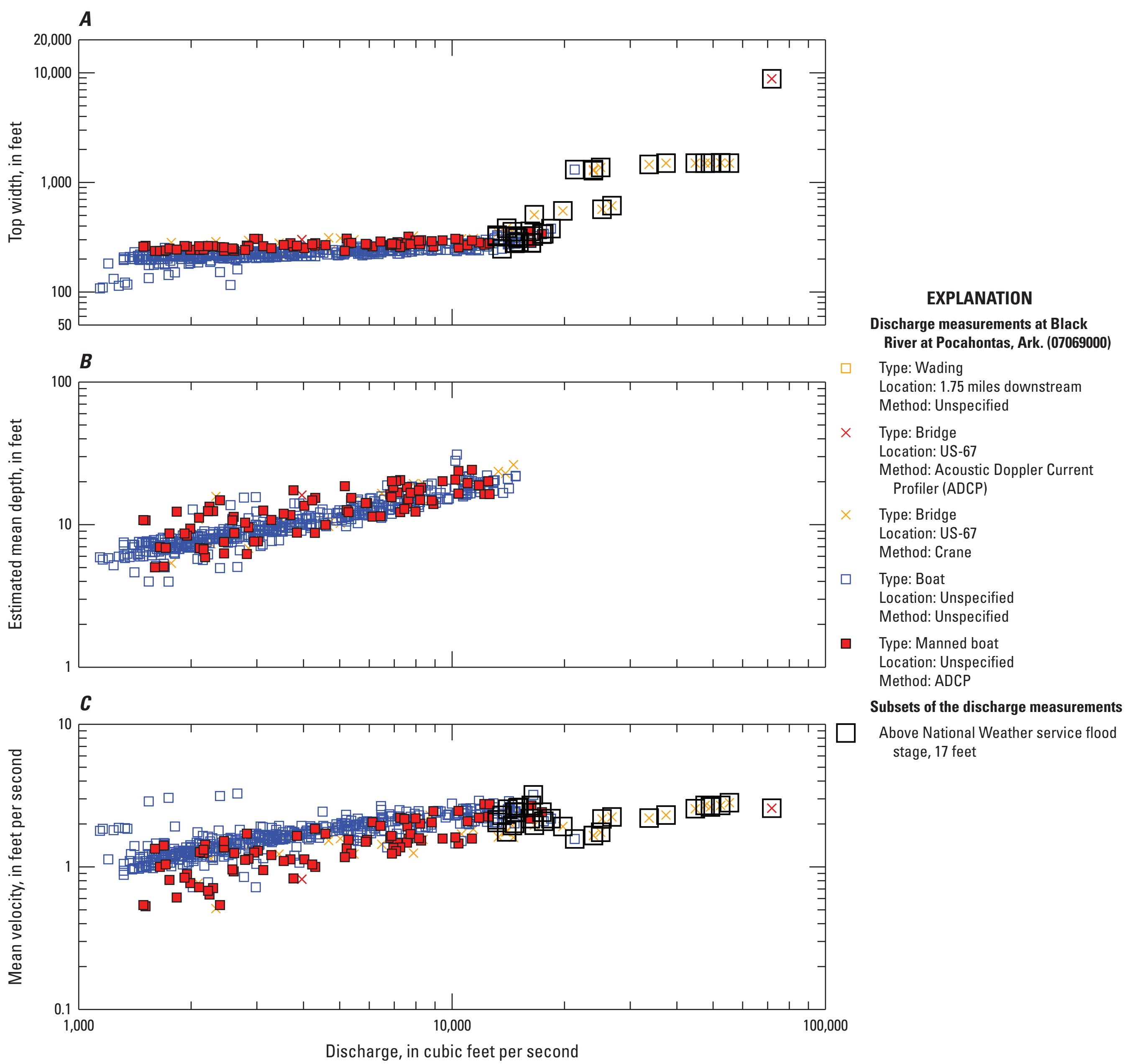

Figure 23. Hydraulic geometry plots for the Black River at Pocahontas, Arkansas (07069000), streamgage. *A*, Top width vs. discharge. *B*, Estimated mean depth vs. discharge. *C*, Mean velocity vs. discharge.

2,000; 6,000; 7,000; and 9,000 ft³/s (fig. 24*A*). There also was a statistically significant decrease in mean velocity over time for 2,000; 3,000; 4,000; and 7,000 ft³/s, as might be expected for a widening cross-section (fig. 24*B*). There was no consistent temporal trend in estimated mean depth or estimated mean bed elevation (not shown). The temporal change in top width and mean velocity may be due in part to the possibility that a variety of different measurement cross-sections were used prior to November 2008, when it became standard procedure to note the measurement cross-section. The change in mean velocity may also be due in part to the switch from mechanical current meters to ADCPs in 2003. However, the increase in channel top width is consistent with observations from historical aerial photographs. The historical aerial photographs show an increase in channel top width of about 35 ft (from about 260 ft in 1994 to about 295 ft in 2017; figs. 24*A*, 25), as measured 500 ft downstream from the streamgage. The extent to which the March 2008 and April 2011 floods (or other individual high-discharge events) were responsible for this widening is unknown.

Eleven Point River near Bardley, Missouri

The Eleven Point River near Bardley, Mo., streamgage (07071500) is at river mile 53.7, on the downstream side of the US–160 bridge. The Eleven Point River is unregulated and spring fed. According to the SIMS station description, the streambed near the EPR-Bardley streamgage consists of sand and gravel. Most of the surrounding area is forested, though there is also an open field on the left-descending side of the

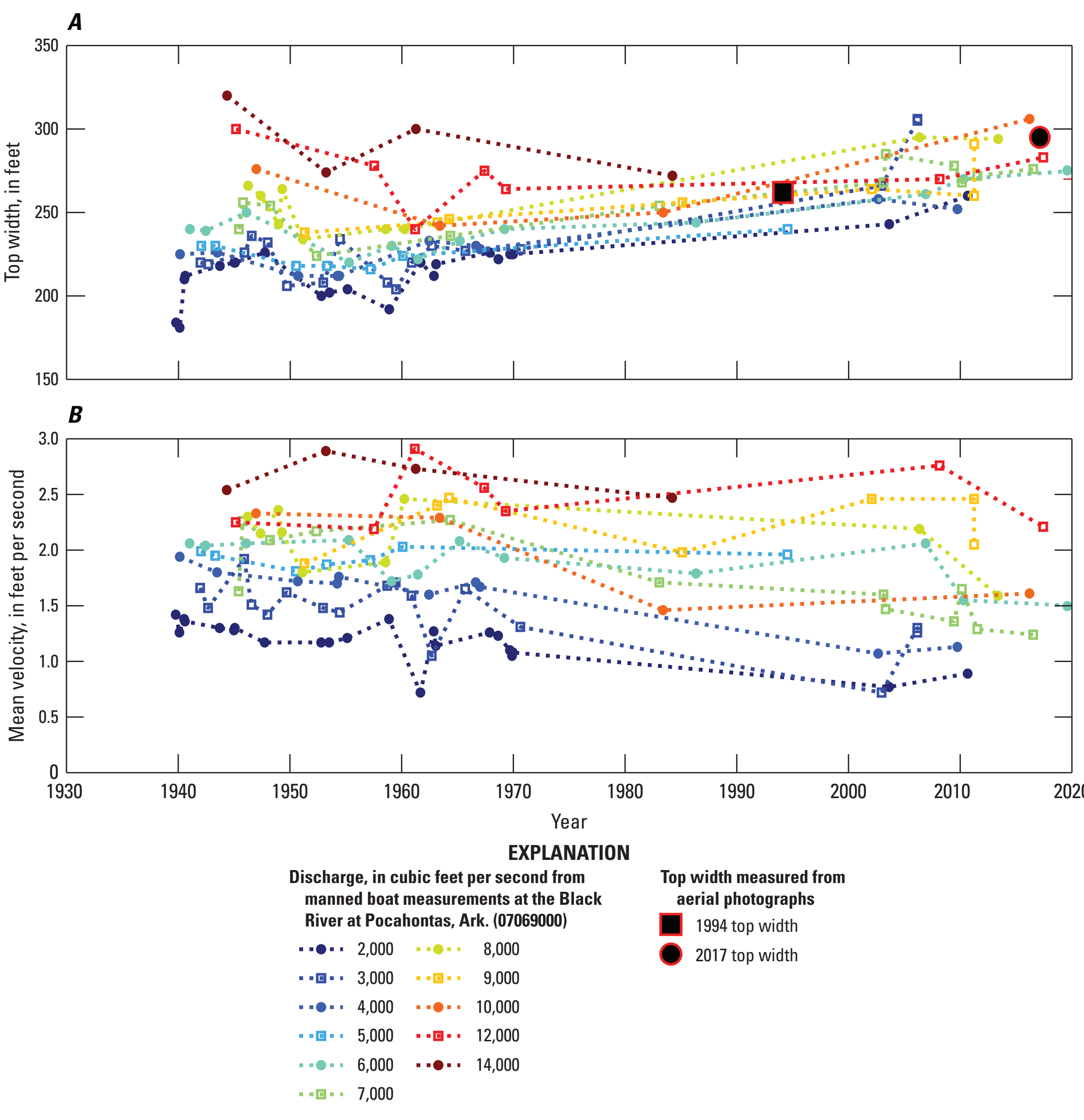

Figure 24. Temporal variations from manned-boat measurements made at the Black River at Pocahontas, Arkansas (07069000), streamgage. *A*, Top width. *B*, Mean velocity for selected discharges.

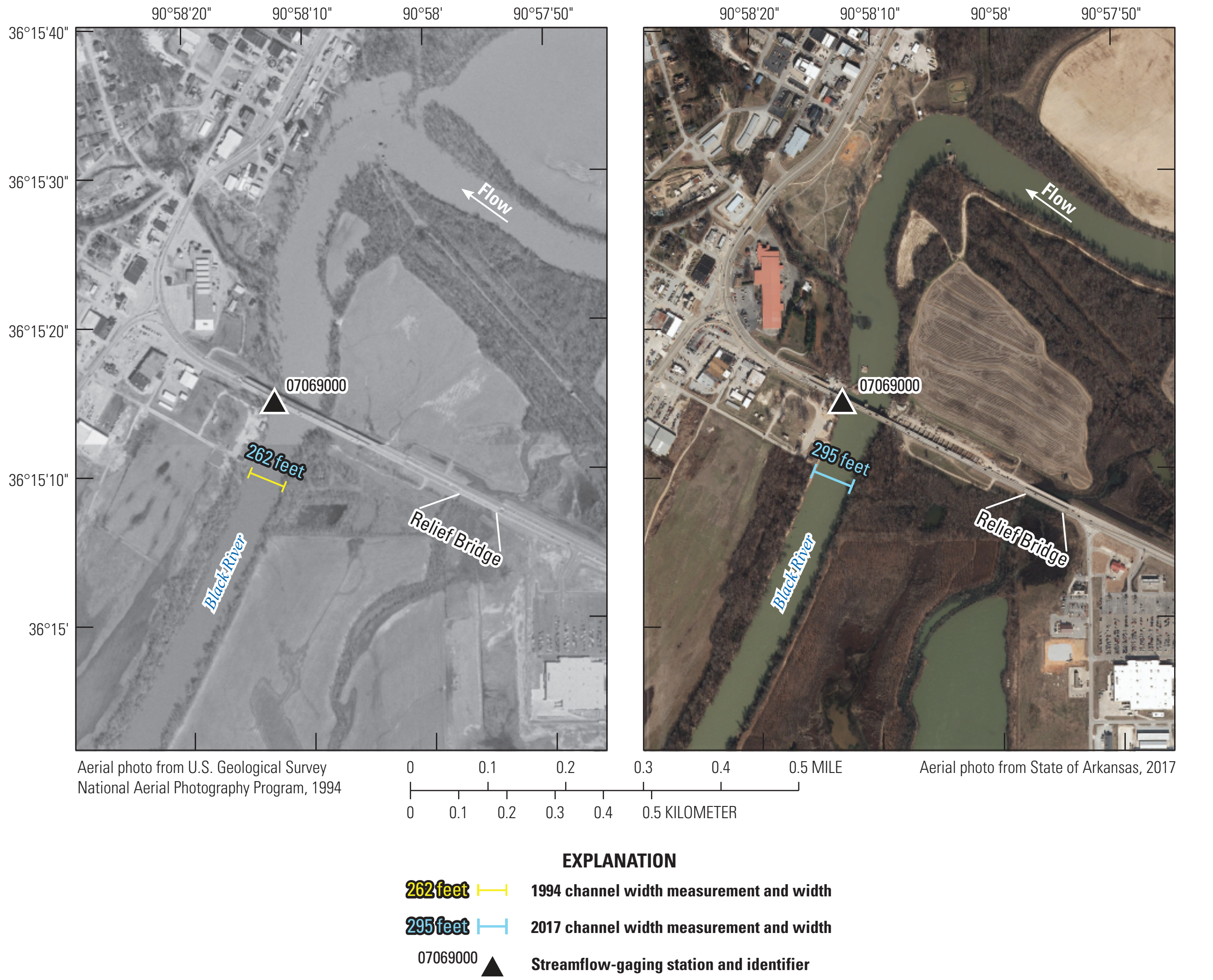

Figure 25. Digital aerial orthophotographs of the area around the Black River at Pocahontas, Arkansas (07069000), streamgage in 1994 and 2017.

channel downstream from the streamgage. The drainage area upstream from the EPR-Bardley streamgage is 793 mi^2 and the current streamgage datum is 411.25 ft above NAVD 88 (table 1). Prior to June 26, 1934, the streamgage was 100 ft upstream at a datum 0.06 ft higher. The EPR-Bardley streamgage was established as a USGS gaging station on October 22, 1921.

The first USGS discharge measurement at the EPR-Bardley streamgage was made on September 14, 1921 (U.S. Geological Survey, 2019). Measurements currently are made with an ADCP from the downstream side of the US–160 bridge, or by wading near the streamgage at low discharge. The SIMS station description indicates that the right bank is high and is not subject to overflow, whereas the left bank overflows at a stage of about 12 ft. Between September 1921 and December 2019, 825 discharge measurements were made at the EPR-Bardley streamgage. The measurements range from 158 to 124,000 ft^3/s (fig. 26*A*; median=567 ft^3/s; SD=5,020 ft^3/s), though about 90 percent were made at discharges less than 1,600 ft^3/s. The measurements were mostly coded as fair, good, or unspecified (789 measurements). There were 36 poor measurements ranging from 216 to 26,800 ft^3/s.

Ratings A–U (1922–48) at the EPR-Bardley streamgage are available from paper archives and ratings 8–14 (1997–2019) are available from digital archives. Ratings between U and 8 (1948–97) were unavailable. The current rating curve (rating 14) does not have a distinct break in slope, though a slight break is visible around 18 ft (fig. 26*B*). Field observations indicate that the channel has a poorly defined left bank with a riparian corridor and the right bank coincides with a bluff. The NWS flood stage at the EPR-Bardley streamgage is 10 ft (10,040 ft^3/s on the current rating curve). The SIMS station description indicates that the left bank of the channel will overflow at stages above 12 ft (14,270 ft^3/s on the current rating curve), which is 2 ft higher than the NWS flood stage.

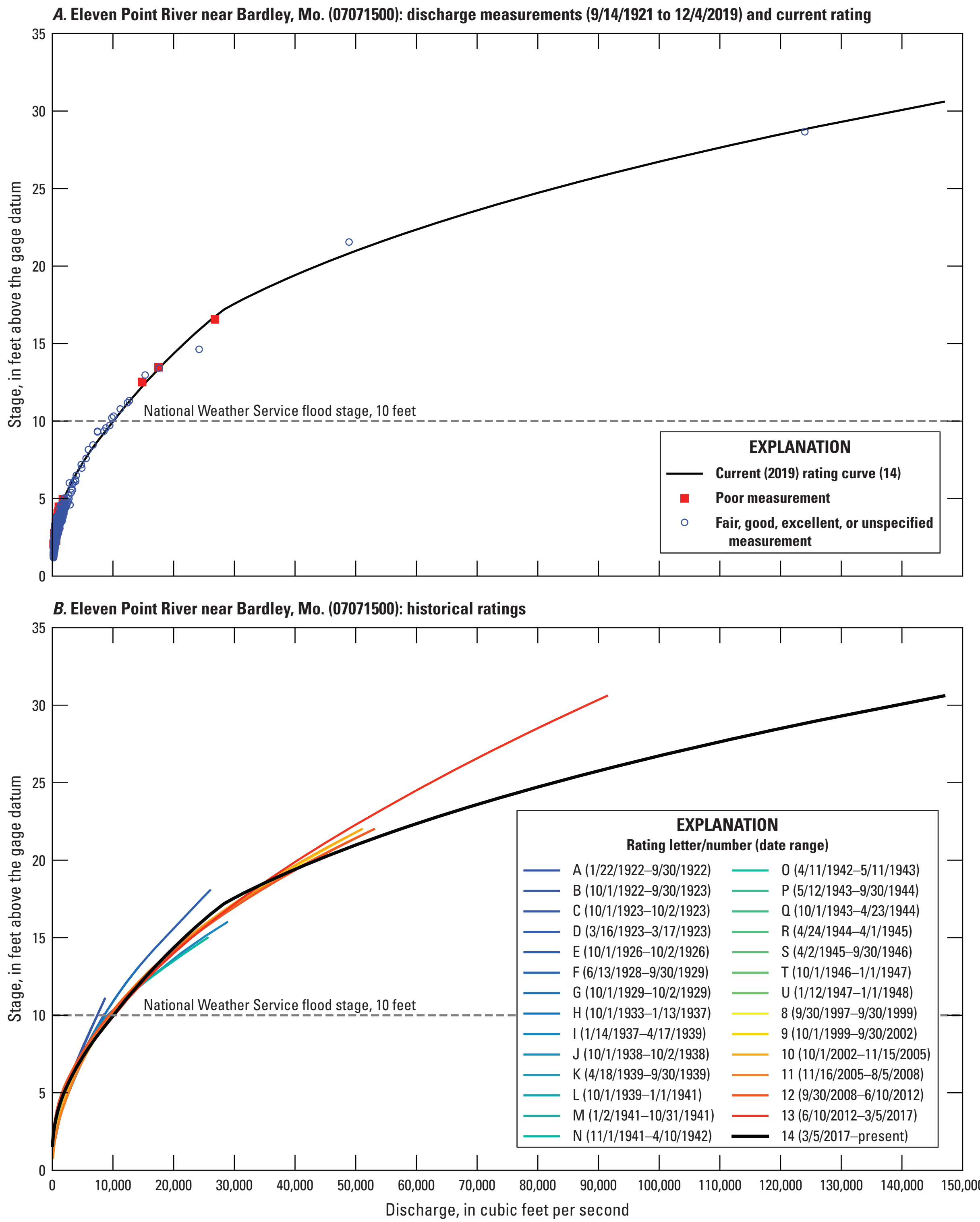

Figure 26. Discharge measurements and historical ratings from the Eleven Point River near Bardley, Missouri (07071500), streamgage. *A*, current (2019) rating. *B*, Historical ratings.

The ratings are clustered close together at stages less than 6 ft, but the current rating plots at the top of the range of ratings and measurements (fig. 26*B*). Between 6 and 12 ft, the older, lettered ratings (January 1922 to January 1948) plot above the numbered ratings (September 1997 to present), though above 12 ft the lettered ratings diverge to plot above and below the current rating. The numbered ratings also diverge from each other at high stages where the ratings are based on a small number of measurements. The upper end of the current rating (rating 14) is based on an indirect discharge determined for the April–May 2017 flood, which happens to be the highest discharge included in the measurements (discharge=124,000 ft^3/s, stage=28.66 ft). The second highest discharge included in the measurements is also an indirect discharge that was determined for the December 1982 flood (discharge=48,900 ft^3/s, stage=21.55 ft). The upper end of ratings 8 to 13 appear to be set according to that discharge.

The stage associated with a particular discharge visually appears to be slowly increasing over time since the 1920s for discharge less than about 2,000 ft^3/s (fig. 27). However, the trend is less than 0.01 ft/yr and generally is not statistically significant for both the measurements and the ratings, with a few exceptions (table 1.6). There were not enough measurements at discharges greater than 2,000 ft^3/s to test the trends in the specific stage data for statistical significance. The ratings show a significant downward trend for discharges from 6,000 to 10,000 ft^3/s, but the TS slope is less than 0.01 ft/yr. Above 10,000 ft^3/s, there is no significant trend in the specific stages derived from the ratings. These results indicate that the channel at the EPR-Bardley streamgage has been generally stable since the 1920s.

Eleven Point River near Ravenden Springs, Arkansas

The Eleven Point River near Ravenden Springs, Ark., streamgage (07072000) is at river mile 21.2, on the upstream side of the bridge on Arkansas State Highway 90 (AR–90). The drainage area upstream from the EPR-Ravenden Springs streamgage is 1,130 mi^2 and the current streamgage datum is 291.98 ft above NGVD 29 (table 1). The SIMS station description indicates that the streambed consists of sand and gravel at the EPR-Ravenden Springs streamgage. The surrounding area is a mix of forest and open fields and in some locations the bank vegetation is sparse. The USGS operated a nonrecording streamgage at the present location from November 1, 1929, to June 30, 1933, at a datum 292.02 ft above NGVD 29. The USACE assumed operation of that streamgage on February 24, 1936, but replaced it with a recording streamgage on December 11, 1938, on the downstream side of the bridge at the current datum. The USGS began operating that recording streamgage on July 1, 1939; however, it was removed August 9, 1983, owing to demolition of the AR–90 bridge. Daily stage readings were made by an observer between August 19 and October 13, 1983. On October 13, 1983, a recording streamgage on the new AR–90 bridge at the current datum began operation.

Discharge was measured by the USGS at the EPR-Ravenden Springs streamgage between November 1, 1929, and March 27, 1933, and from April 27, 1939, to the present (U.S. Geological Survey, 2019). Wading measurements can be made about one-third of a mile downstream from the streamgage when the stage is below 3 ft. At higher stages, measurements are made from the AR–90 bridge with an ADCP. Above 16 ft, there is flow over the road that must be measured by wading (stage less than 18.3 ft) or from a boat (stage greater than 18.3 ft). A total of 733 discharge measurements have been made at the EPR-Ravenden Springs streamgage through December 2019, ranging from 254 to 162,000 ft^3/s (fig. 28*A*; median=837 ft^3/s; SD=6,610 ft^3/s). Nearly 90 percent of the measurements were made at discharges less than 2,500 ft^3/s. There were 22 measurements rated as poor, ranging from 376 to 24,500 ft^3/s.

Ratings 1–6 (1943–2019) at the EPR-Ravenden Springs streamgage are available from digital archives; no prior ratings were found. The current rating curve (rating 6) shows a break in slope at approximately 19 ft, which is above the NWS flood stage of 15 ft (13,670 ft^3/s on the current rating curve; fig. 28). The NWS flood stage matches the bankfull stage identified in the SIMS station description. The measurements show minimal scatter and the historical ratings are tightly clustered, which indicates a generally stable measurement cross-section since the 1940s (fig. 28). Similarly, the specific stage plots for the measurements and the ratings do not show temporal trends in specific stage (fig. 29; table 1.7). There are a few minor exceptions with statistically significant upward trends at low discharges, but the TS slope of these trends is less than 0.005 ft/yr (table 1.7). The highest discharge included in the measurements at the EPR-Ravenden Springs streamgage is an indirect discharge from the December 1982 flood (discharge=162,000 ft^3/s, stage=29.06 ft). This indirect discharge sets the upper ends of ratings 2–6, which explains the minimal variation among the upper ends of those ratings. These results indicate that the channel near the EPR-Ravenden Springs streamgage has been generally stable since the 1930s, though a small amount of aggradation is possible.

Spring River at Imboden, Arkansas

The Spring River at Imboden, Ark., streamgage (07069500) is at river mile 12.1, on the downstream side of the US–62 bridge. Like the Current River and Eleven Point River, the Spring River is unregulated and spring fed. Discharge measurement notes for the SR-Imboden streamgage indicate that the streambed includes sand, gravel, and cobbles. SR-Imboden, a small urban area, is on the right-descending side of the channel; otherwise the surrounding area is a mix of open fields and forest, with a thin line of trees on the channel

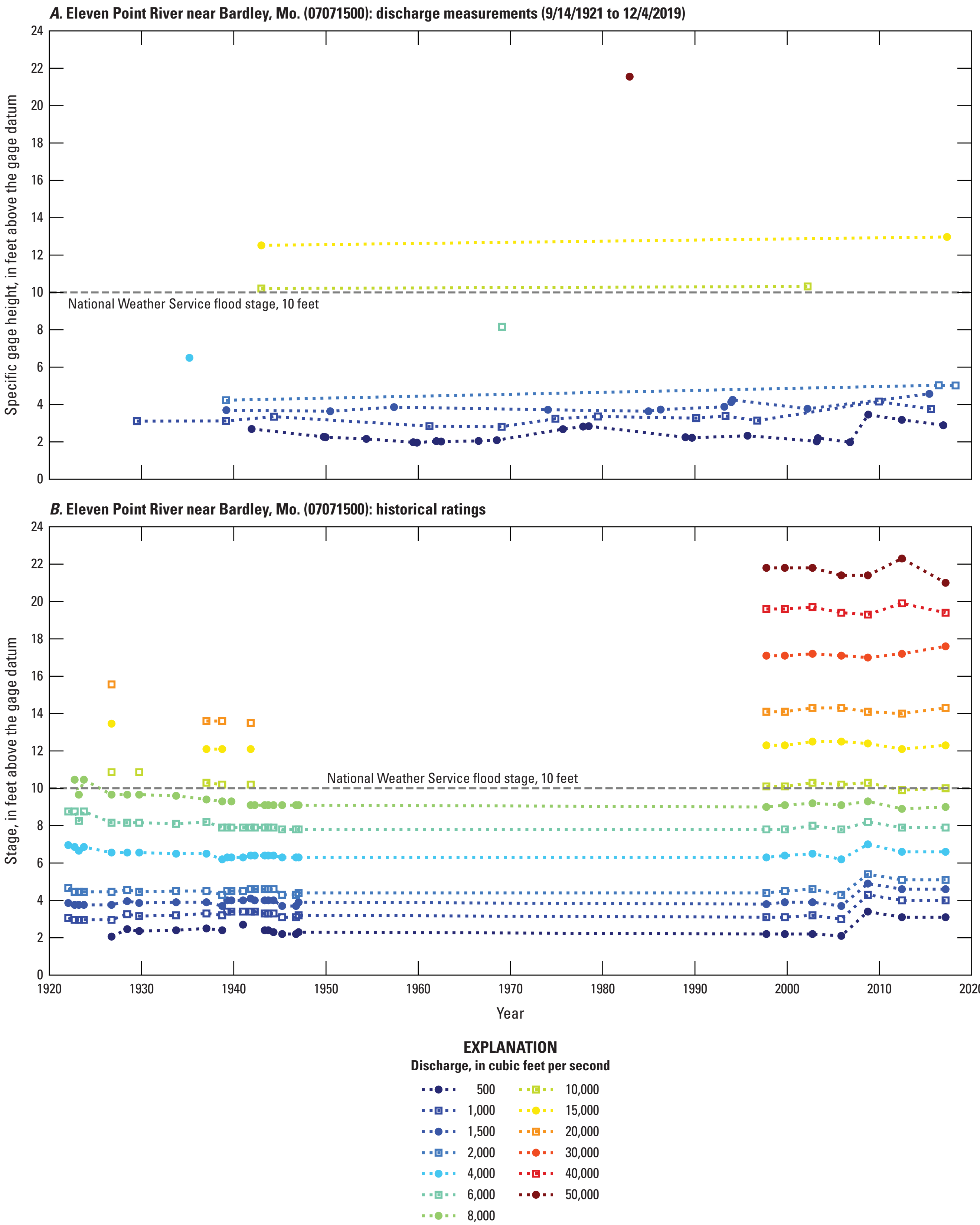

Figure 27. Results of specific stage analysis for the Eleven Point River near Bardley, Missouri (07071500), streamgage. *A*, Specific stage from discharge measurements. *B*, Specific stage from ratings.

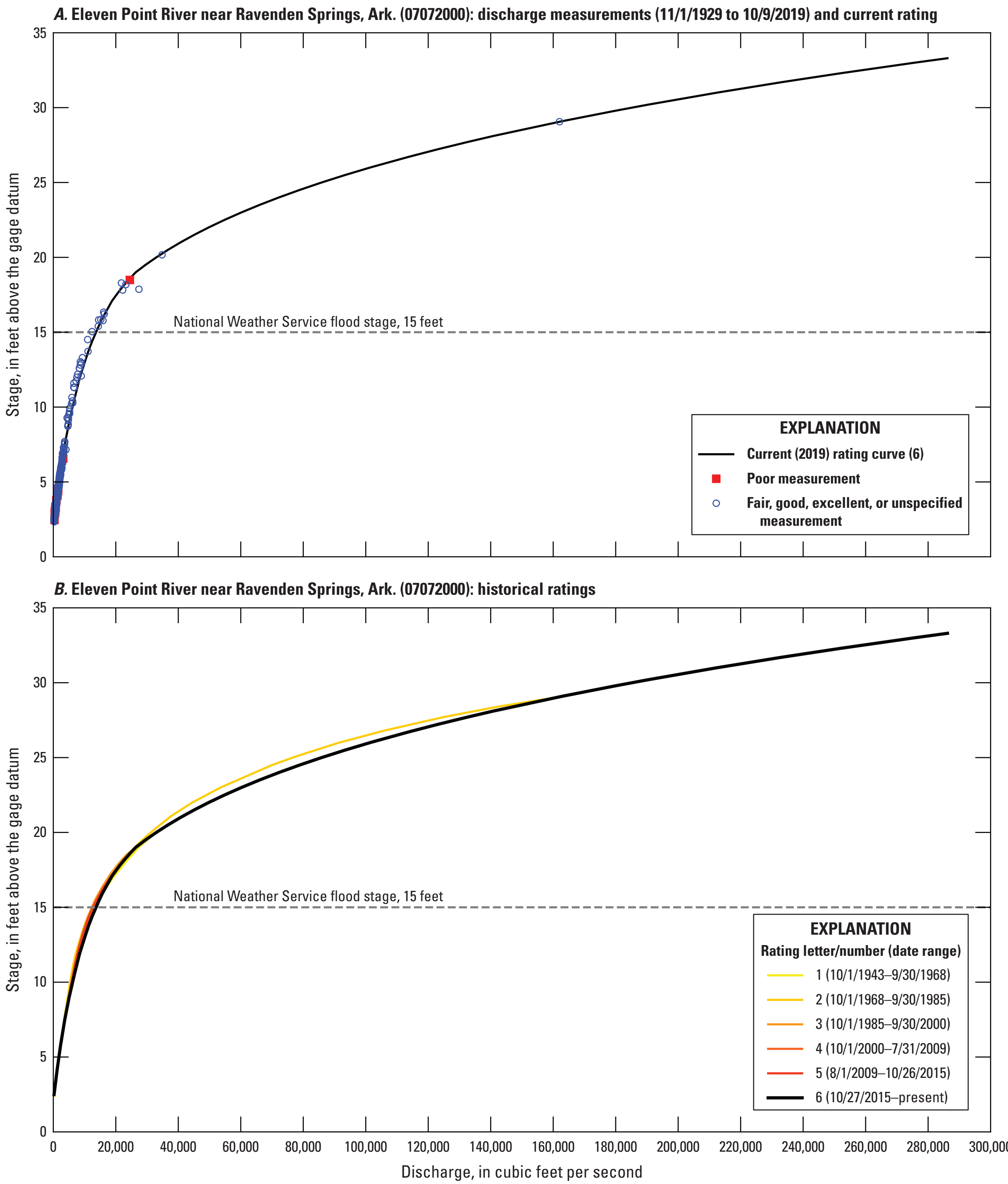

Figure 28. Discharge measurements and historical ratings from the Eleven Point River near Ravenden Springs, Arkansas (07072000), streamgage. *A*, Current (2019) rating and discharge measurements. *B*, Historical (1943-2019) ratings.

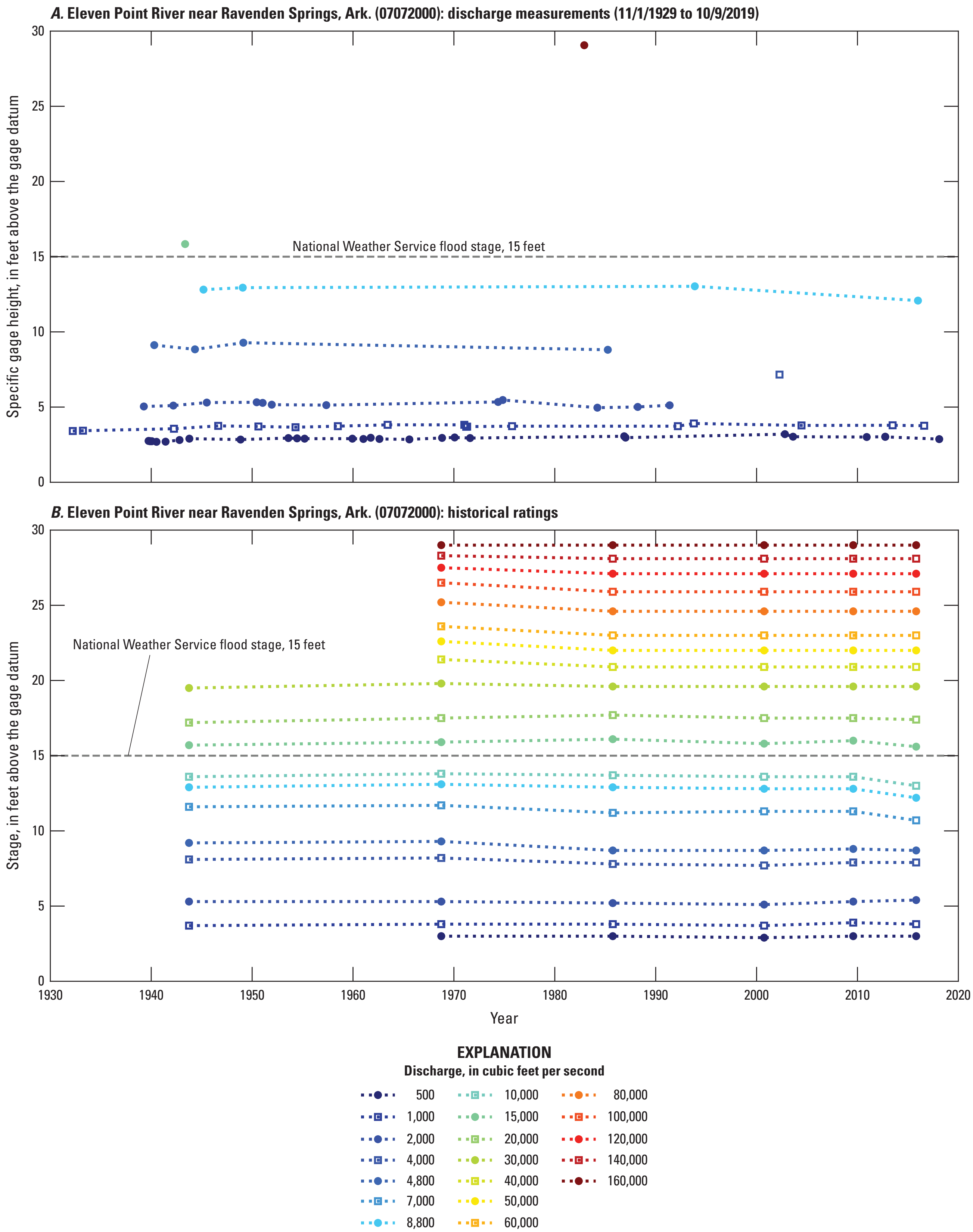

Figure 29. Results of specific stage analysis for the Eleven Point River near Ravenden Springs, Arkansas (07072000), streamgage. *A*, Specific stage from discharge measurements. *B*, Specific stage from ratings.

banks. The Eleven Point River feeds into the Spring River downstream from the SR-Imboden streamgage about 3.8 river miles upstream from the confluence of the Spring River with the Black River. The confluence of the Spring River with the Black River is about 2.8 mi upstream from the BR-Black Rock streamgage (07072500). The drainage area upstream from the SR-Imboden streamgage is 1,180 mi^2 and the current streamgage datum is 254.07 ft above NGVD 29 (table 1).

Discharge was measured by the USGS at the SR-Imboden streamgage since July 26, 1923 (U.S. Geological Survey, 2019). Wading measurements can be made about 0.5 mi upstream when stage is below 3.0 ft. Moderate discharges can be measured with an ADCP by boat about 200–500 ft upstream from the streamgage. High-stage measurements are made with an ADCP from the downstream side of the US–62 bridge. Between July 1923 and December 2019, 762 discharge measurements have been made at the SR-Imboden streamgage. The measurements range from 4.23 to 74,500 ft^3/s (fig. 30*A*, median=801 ft^3/s; SD=6,190 ft^3/s), though about 90 percent were made at discharges less than 4,000 ft^3/s. The measurements mostly were coded as fair, good, or unspecified (707 measurements). There were 55 poor measurements ranging from 355 to 73,700 ft^3/s.

Ratings 5–11 (1995–2019) at the SR-Imboden streamgage are available from digital archives; no prior ratings were found. The current rating (rating 11) has a break in slope around a stage of 20 ft, which is above the NWS flood stage of 18 ft (17,170 ft^3/s on the current rating curve; fig. 30). The SIMS station description does not note the overbank stage for this site and the USGS 3D Elevation Program Digital Elevation Model does not have sufficient resolution in this area to clearly identify a top-of-bank elevation (U.S. Geological Survey, 2020b). The current rating plots in the center of the range of measurements below a stage of 10 ft, at the bottom of the range of measurements for stages between 10 and 20 ft, and through the center of the range of measurements above 20 ft (fig. 30).

The historical ratings are very similar to each other below a stage of 10 ft but diverge at higher stages (fig. 30*B*). Variability in discharge measurements at stages from about 10 to 25 ft seem to be the dominant factor in determining the shape of the ratings. There are only three measurements above 25 ft, of which only two are shown in figure 30. The two discharge measurements above a stage of 25 ft that are listed on NWIS were made on March 28, 1977 (discharge=74,500 ft^3/s, stage=27.87 ft) and April 11, 2008 (discharge=73,700, stage=26.25 ft; U.S. Geological Survey, 2019). An indirect discharge measurement of 244,000 ft^3/s was calculated for the December 1982 flood and corresponds to the maximum known stage at the SR-Imboden streamgage (38.12 ft on December 3, 1982, according to the SIMS station description). This indirect flood measurement was not included in the measurements on NWIS for unknown reasons and is therefore not shown in figure 30 (U.S. Geological Survey, 2019). The extrapolation of the upper ends of ratings 5 and 6 to nearly 250,000 ft^3/s is based on this indirect measurement, though it was not used in ratings 7–11.

The specific stage analysis for both the measurements and the ratings do not show clear temporal trends in the stage associated with a particular discharge for most discharges (fig. 31). The exception to this is a downward trend in specific stage for measured discharges less than or equal to 800 ft^3/s (table 1.8). The mean TS slope for the stage corresponding to measured discharges ranging from 300 to 800 ft^3/s is −0.011 ft/yr. This trend is not reflected in the ratings or at higher discharges but may indicate that the low-discharge section control has changed since the 1940s. However, the channel near the SR-Imboden streamgage appears to be generally stable.

Black River at Black Rock, Arkansas

The Black River at Black Rock, Ark., streamgage (07072500) is at river mile 69.3, on the downstream side of the U.S. Route 63 (US–63) bridge. The drainage area upstream from the BR-Black Rock streamgage is 7,370 mi^2 and the current streamgage datum is 229.56 ft above NGVD 29 (table 1). The drainage area of the Black River upstream from Clearwater Dam (898 mi^2) represents only 12 percent of the drainage area at the BR-Black Rock streamgage. Moreover, the BR-Black Rock streamgage is downstream from the confluences of two major unregulated tributaries—the Current River and Spring River. Therefore, discharge regulation by Clearwater Dam likely has a minimal effect on discharges at the BR-Black Rock streamgage. According to the SIMS station description and discharge measurement notes, the streambed near the BR-Black Rock streamgage is sand with rock shelves and the banks are steep and covered with scattered timber. BR-Black Rock is on the right-descending side of the channel and is surrounded by a mix of agricultural fields and forest. The left-descending side of the channel is mostly agricultural fields, though there is a narrow border of trees along the channel bankline.

Prior to March 1978, the BR-Black Rock streamgage was operated intermittently at several locations near the present streamgage by the NWS, USGS, and USACE. The USGS resumed operation of the streamgage on March 1, 1978, and moved the streamgage to its present location on November 12, 1978. A small number of discharge measurements were made at the BR-Black Rock streamgage prior to October 1977, but the analysis herein is limited to measurements made after that date (U.S. Geological Survey, 2019). The SIMS station description indicates that boat measurements can be made 1,320 ft upstream and 200–500 ft downstream from the US–63 bridge at stages below 18.5 ft. Measurements are made from the downstream side of the US–63 bridge at stages above 18.5 ft, including measurements in two relief channels east of the main channel. Between October 1977 and December 2019, 277 discharge measurements have been made at the BR-Black Rock streamgage. This is fewer than the other Black River gages in the study area because the period of record used for this analysis is much shorter. These measurements range from 1,830 to 164,000 ft^3/s (fig. 32*A*; median=6,140 ft^3/s; SD=16,660 ft^3/s), though nearly 90 percent were made at discharges less than 18,000 ft^3/s. Thirty of the measurements

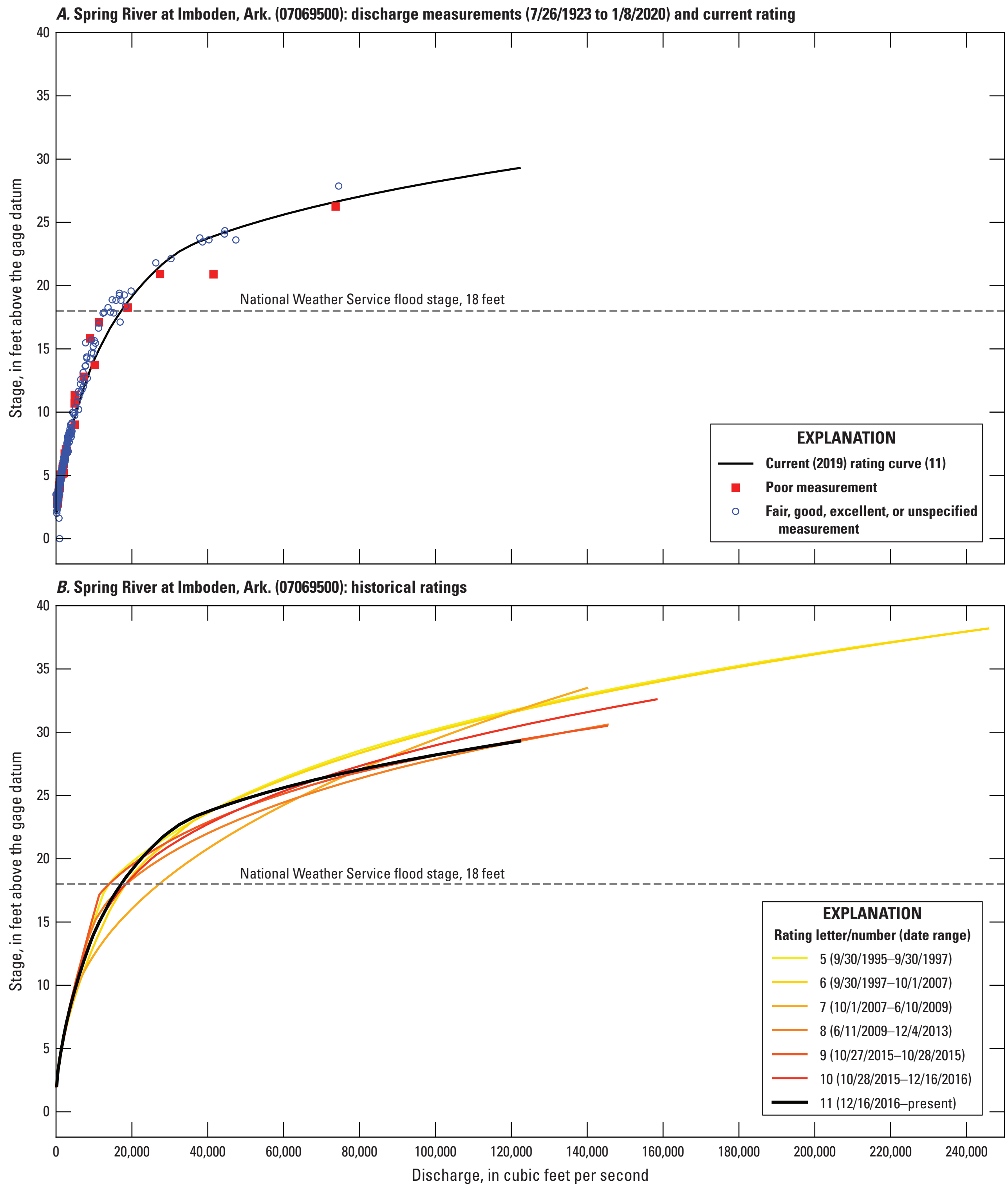

Figure 30. Discharge measurements and historical ratings from the Spring River at Imboden, Arkansas (07069500), streamgage. *A*, Current (2019) rating and discharge measurements. *B*, Historical (1995–2019) ratings.

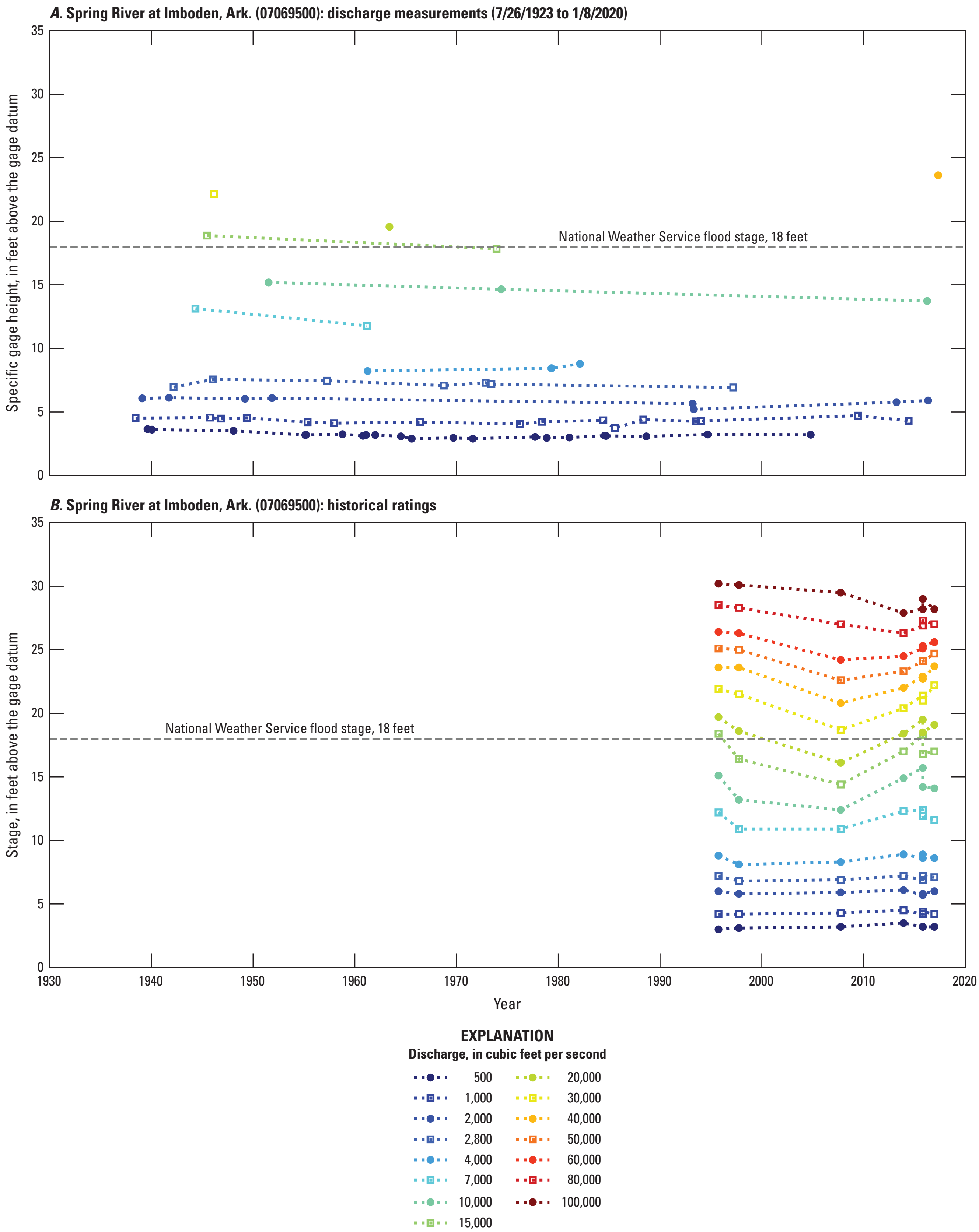

Figure 31. Results of specific stage analysis for the Spring River at Imboden, Arkansas (07069500), streamgage. *A*, Specific stage from discharge measurements. *B*, Specific stage from ratings.

at BR-Black Rock were rated as poor, ranging from 2,390 to 39,300 ft^3/s, and do not include any of the highest discharge measurements (fig. 32*A*).

Ratings 13–16 (1978–2019) at the BR-Black Rock streamgage are available in digital archives. No other previous ratings were found. The current rating (rating 16) is typical for a site with well-defined banks and a flood plain, with a break in slope around 22 ft, which roughly corresponds to the flood-plain elevation adjacent to the channel (fig. 32*A*). Additionally, the SIMS station description indicates that the relief channels for the US–63 bridge begin to flow at stages above approximately 18.5 ft (21,660 ft^3/s on the current rating curve). A stage of 18.5 ft is well above the NWS flood stage of 14 ft (15,620 ft^3/s on the current rating curve), which may be conservative to account for areas that are inundated before the relief channels begin to flow. The four highest discharge measurements were made during the April 2011 flood (discharge=164,000 ft^3/s, stage=30.14 ft; and discharge=111,000 ft^3/s, stage=28.20 ft), the April–May 2017 flood (discharge=125,000 ft^3/s, stage=28.89 ft), and the December 1982 flood (discharge=78,800 ft^3/s, stage=26.58 ft). There has not been much variation in the rating curves at the BR-Black Rock streamgage and the measurements are tightly clustered around the current rating (fig. 32*B*), which is potentially indicative of a stable measurement cross-section. Furthermore, there were no significant trends in the specific stage data for either the measurements or the ratings (fig. 33, table 1.9).

BR-Black Rock Cross-Section Data

The Black River at Black Rock, Ark., had 253 measurements with at least partial notes on the geometry, velocity, and location of the cross-section where the discharge was measured. Based on the SIMS station description, a stage of 18.5 ft (21,660 ft^3/s on the current rating curve) is used to identify overbank discharges. As with the other Black River gages in the study area, ADCPs became the primary measurement method in 2003. Prior to 2003, it is likely that a mechanical current meter was deployed from a moving boat during low to moderate discharges and from the US–63 bridge during high discharges. Most of the measurements at the BR-Black Rock streamgage have been made from a manned boat and only 10 have been made from the US–63 bridge (fig. 34). The pre-2003 boat measurements (blue squares in fig. 34) were mostly narrower, shallower, and faster for a given discharge than the post-2003 manned-boat ADCP measurements. This difference in the width, estimated mean depth, and mean velocity for a given discharge suggests that a different measurement cross-section was used for the pre-2003 boat measurements than was used for the post-2003 manned-boat ADCP measurements. The pre-2003 boat measurements also generally align with the bridge measurements in the hydraulic geometry plots (fig. 34). The locations of the post-2003 manned-boat ADCP measurements were sometimes noted and include sections upstream and downstream from the streamgage. However, the hydraulic geometry relations of the upstream and downstream manned-boat ADCP measurements are similar to each other while being notably different from the pre-2003 boat measurements.

There were no clear temporal trends in top width, estimated mean depth, estimated mean bed elevation, or mean velocity at the BR-Black Rock streamgage. Comparison of the 2017 aerial photographs to the 1994 imagery did not reveal substantial variations in channel width, though the meander bends upstream and downstream from the bridge did migrate laterally during that time period (fig. 35). The top width of the Black River was about 235 ft at the US–63 bridge crossing in 2017, based on the aerial photograph of the site, which is in the range of the pre-2003 boat measurements (185 to 300 ft; fig. 34). The channel widens with distance upstream and downstream from the bridge. At a distance of 0.25 mi upstream and downstream from the bridge, the channel top width in 2017 was about 335 ft and 320 ft, respectively, which indicates the pre-2003 manned-boat measurements were made closer to the bridge than the post-2003 manned-boat ADCP measurements.

White River at Newport, Arkansas

The White River at Newport, Ark., streamgage (07074500) is a short distance downstream from the confluence of the White River and the Black River, about 60 ft downstream from the Arkansas State Highway 367 (AR–367) bridge. The drainage area upstream from the WR-Newport streamgage is 19,900 mi^2 and the current streamgage datum is 194.36 ft above NAVD 88 (table 1). The Black River constitutes about 42 percent of the drainage area at the WR-Newport streamgage; the remaining drainage area of the White River is heavily regulated by the dams that form Beaver Lake, Table Rock Lake, and Bull Shoals Lake on the White River, and Norfork Lake on the North Fork River. The SIMS station description for the WR-Newport streamgage states that the streambed consists of sand and gravel, the right-descending bank is covered with brush and trees, and the left-descending bank is covered with riprap. The city of Newport is on the left-descending side of the channel and the surrounding area is largely agricultural fields.

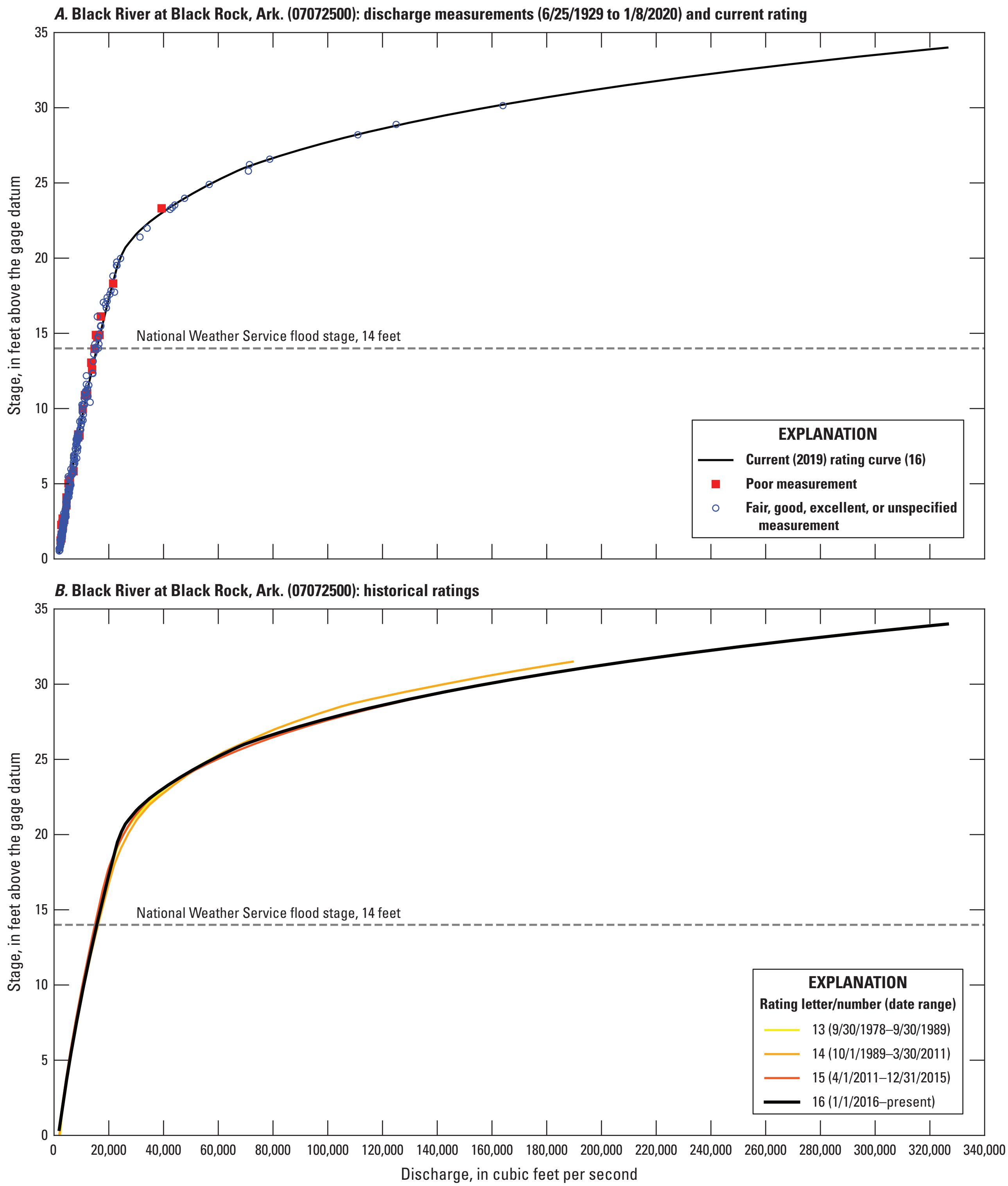

Figure 32. Discharge measurements and historical ratings from the Black River at Black Rock, Arkansas (07072500), streamgage. *A*, Current (2019) rating and discharge measurements. *B*, Historical (1978-2019) ratings.

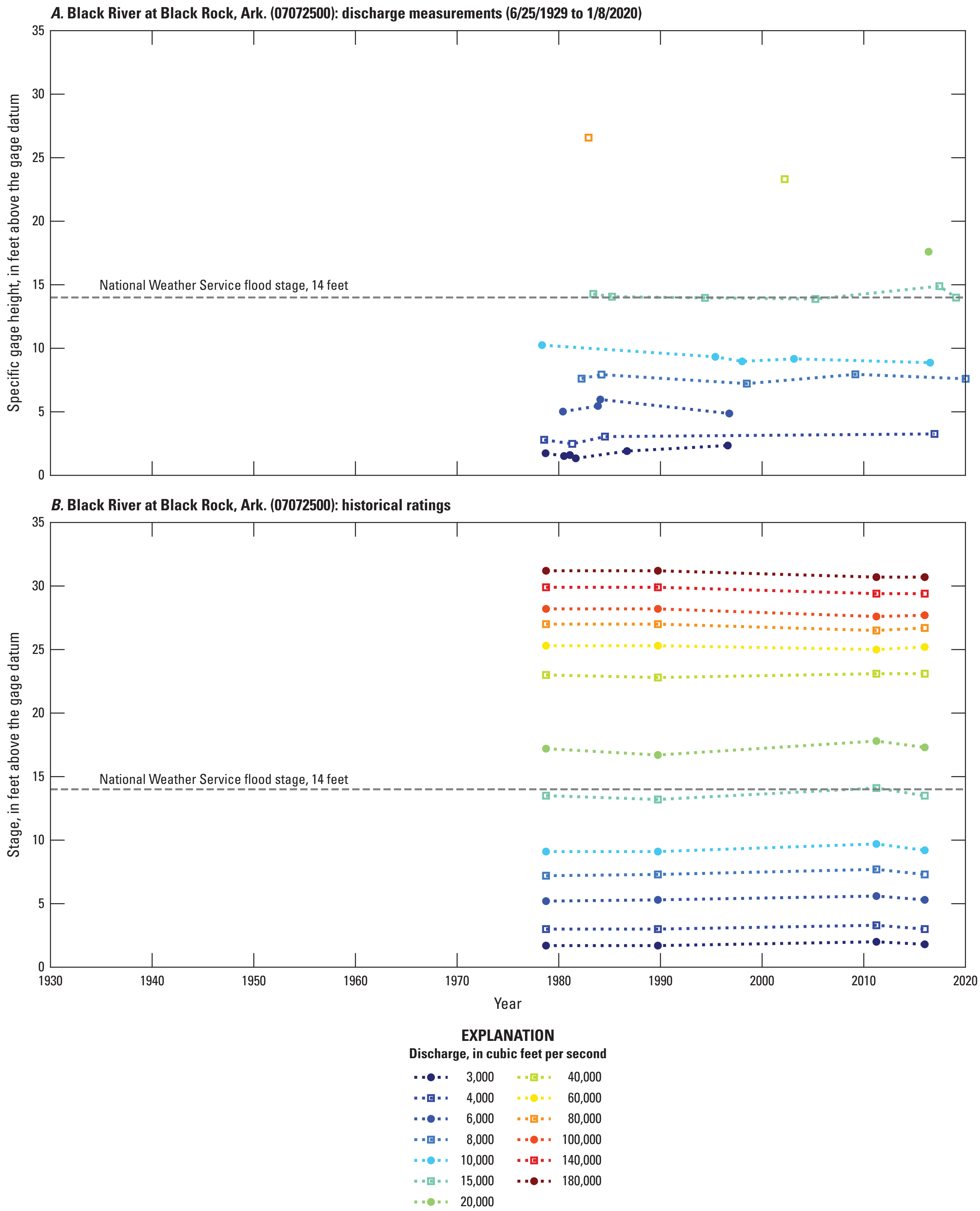

Figure 33. Results of specific stage analysis for the Black River at Black Rock, Arkansas (07072500), streamgage. *A*, Specific stage from discharge measurements. *B*, Specific stage from ratings.

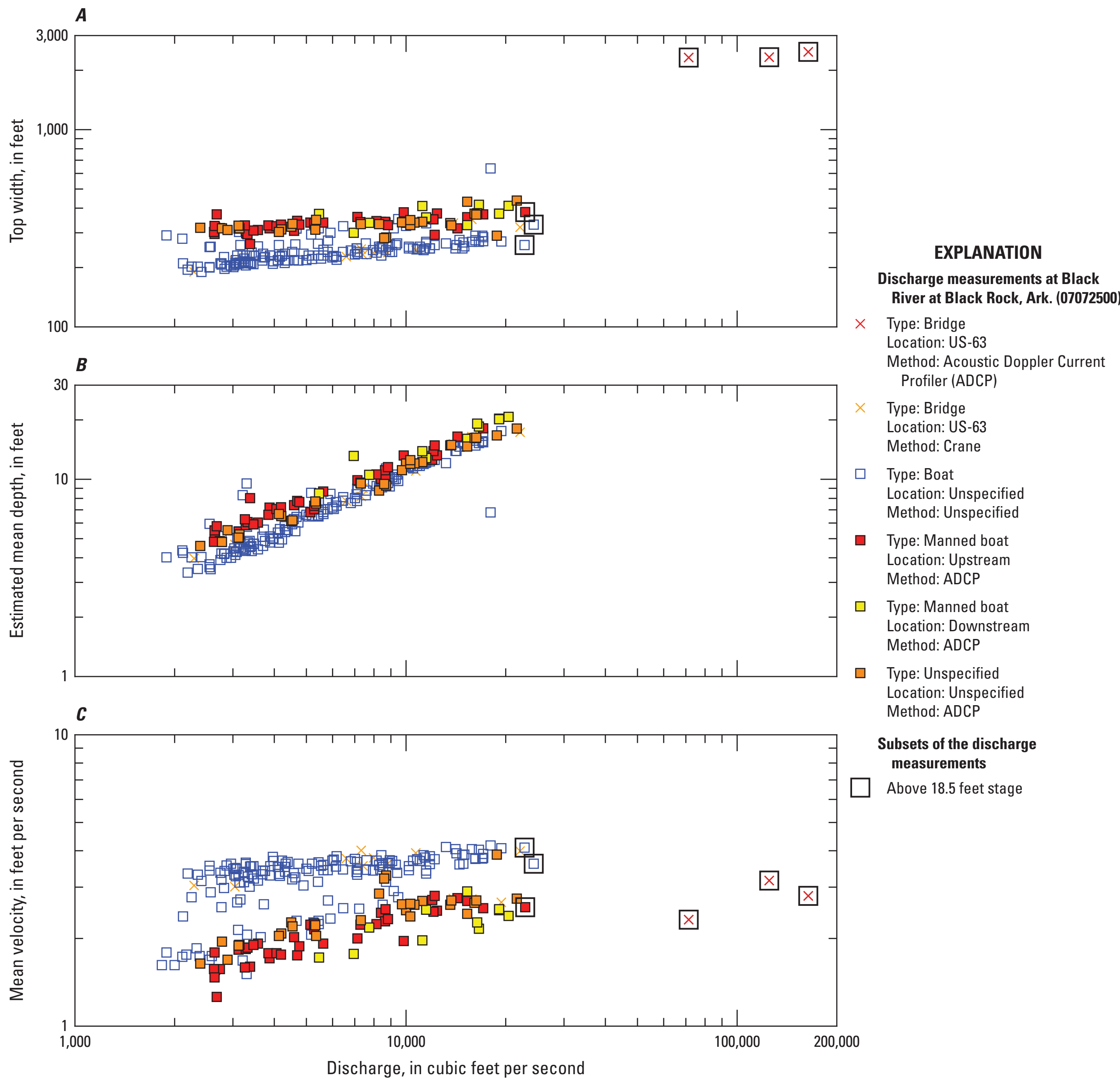

Figure 34. Hydraulic geometry plots for the Black River at Black Rock, Arkansas (07072500), streamgage. *A*, Top width vs. discharge. *B*, Estimated depth vs. discharge. *C*, Mean velocity vs. discharge.

Prior to March 1, 1978, the WR-Newport streamgage was operated intermittently at several locations near the present streamgage by the NWS, USGS, and USACE. The USGS assumed operation of the streamgage at the present location and datum on March 1, 1978 (U.S. Geological Survey, 2019). A limited number of discharge measurements were made prior to March 1, 1978, but the datum for the stage associated with these measurements is unclear, so they are not considered in this study. The SIMS station description indicates that discharge can be measured with a boat-mounted ADCP near the streamgage for stages below 24 ft. At stages above 24 ft, discharge is measured using an ADCP deployed from the US–67 bridge, which is 18.1 mi downstream from the streamgage. Measurements must also be made at three relief openings on the US–67 bridge to the east of the main channel. There have been 337 discharge measurements made at the WR-Newport streamgage between March 1978 and December 2019. These measurements range from 2,900 to 296,000 ft^3/s (fig. 36*A*; median=19,500 ft^3/s; SD=41,840 ft^3/s). About 90 percent of the measurements were made at discharges less than 60,000 ft^3/s. There were 27 measurements at the WR-Newport streamgage that were rated as poor, ranging from 6,850 to 290,000 ft^3/s, including several of the highest measurements (fig. 36*A*).

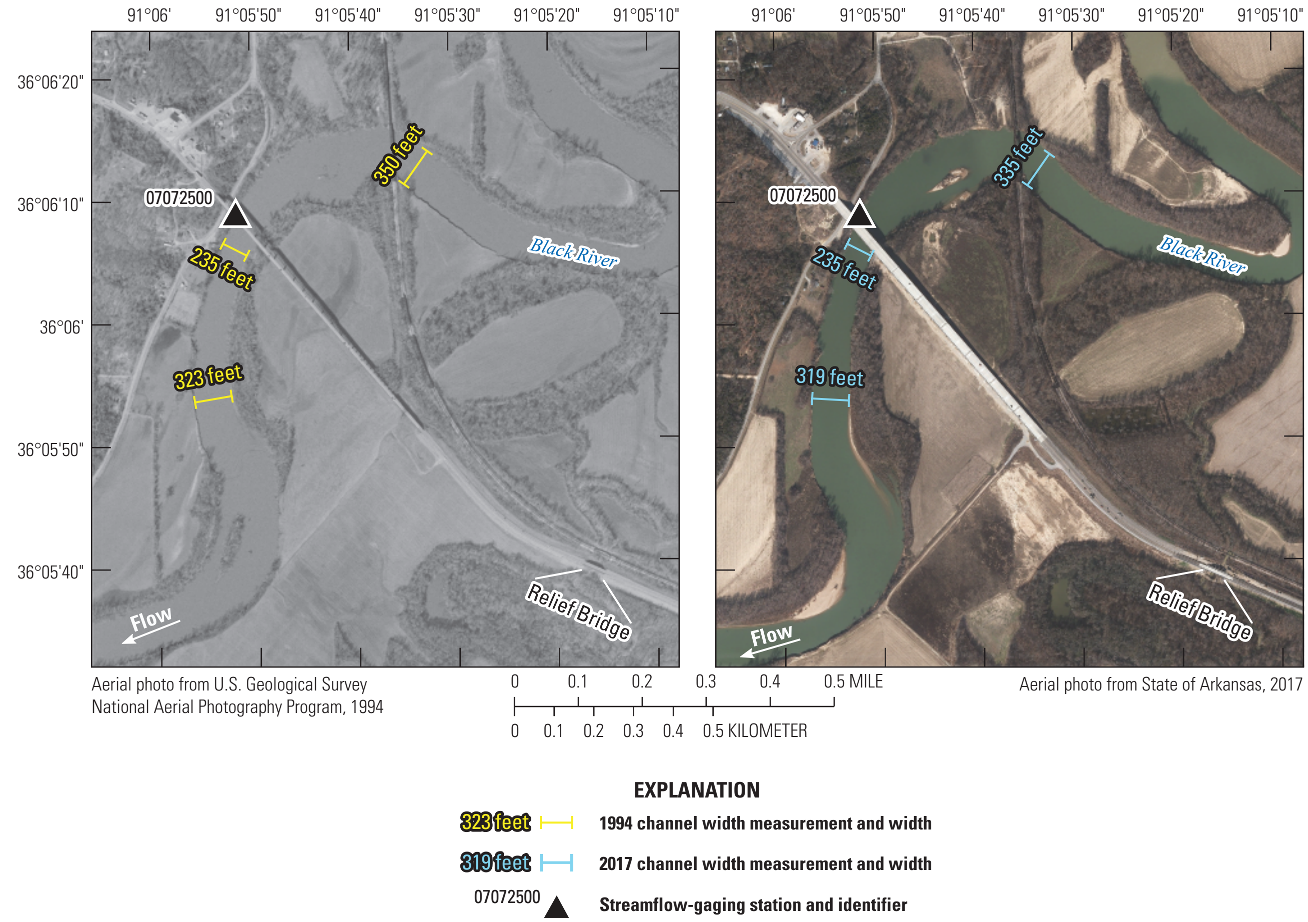

Figure 35. Digital aerial orthophotographs of the area around the Black River at Black Rock, Arkansas (07072500), streamgage in 1994 and 2017.

Ratings 10–15 (1979–2019) at the WR-Newport streamgage are available in digital archives. No other previous ratings were found. Similar to several of the previously discussed gages, the current rating (rating 15) is typical for a site with well-defined banks and a flood plain, with a break in slope around 28 ft (fig. 36*A*). The break in the rating slope at 28 ft is generally consistent with the NWS flood stage of 26 ft (61,900 ft^3/s on the current rating curve). Below a stage of about 22 ft, there has not been much variation in the rating curves at the BR-Black Rock streamgage since 1979 and the measurements are tightly clustered around the current rating (fig. 36). The current rating deviates from the historical ratings above 22 ft, showing a smaller discharge for a given stage between 22 and about 32 ft, and a higher discharge for a given stage above about 32 ft. There were no significant trends in the specific stage data for the measurements or the ratings (fig. 37, table 1.10). However, the specific stages for the measurements visually appear to be increasing over time. The lack of a statistically significant trend in these data may be related to the small number of data points for many of the tested discharges.

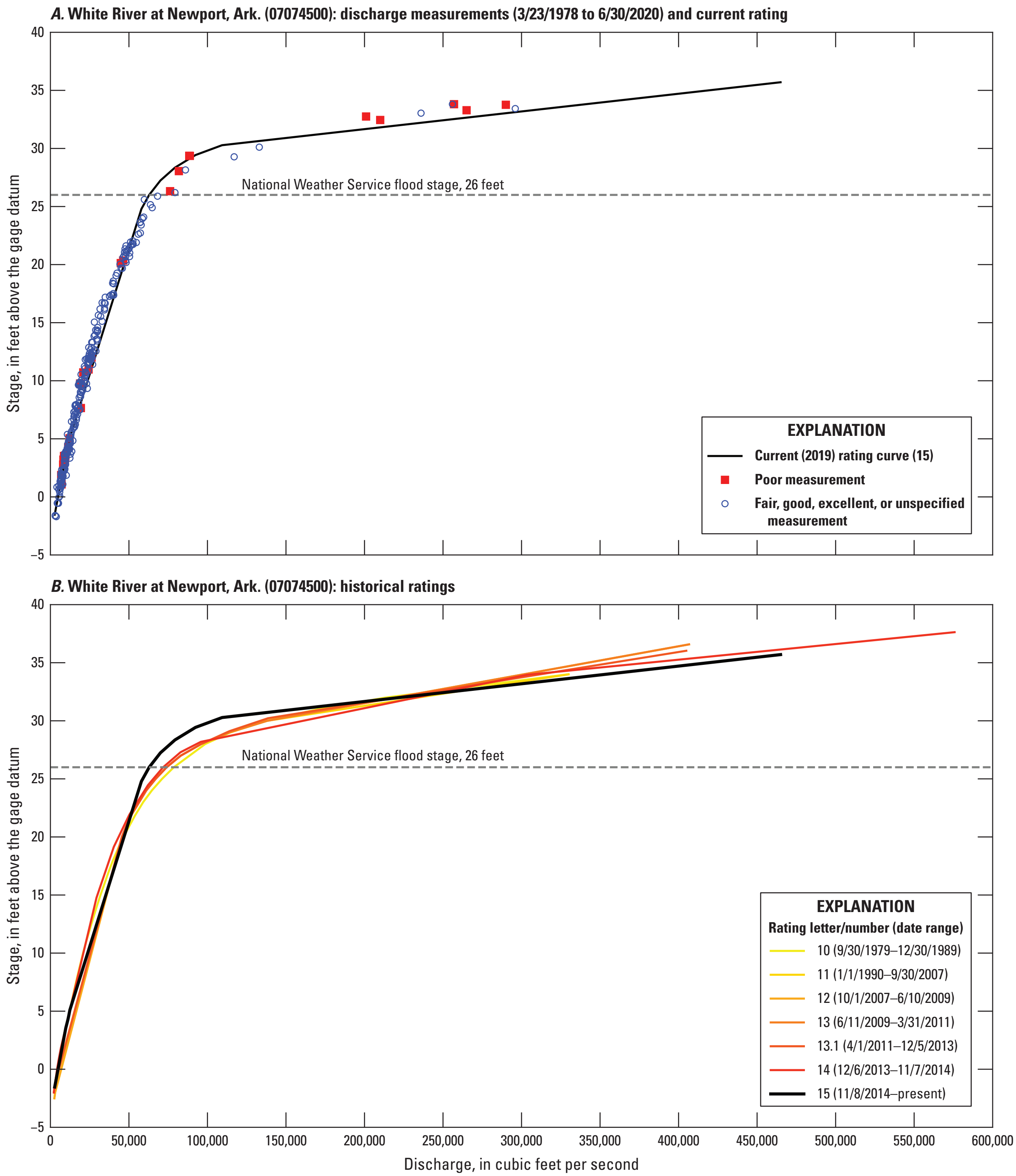

Figure 36. Discharge measurements and historical ratings from the White River at Newport, Arkansas (07074500), streamgage. *A*, Current (2019) rating and discharge measurements. *B*, Historical (1979-2019) ratings.

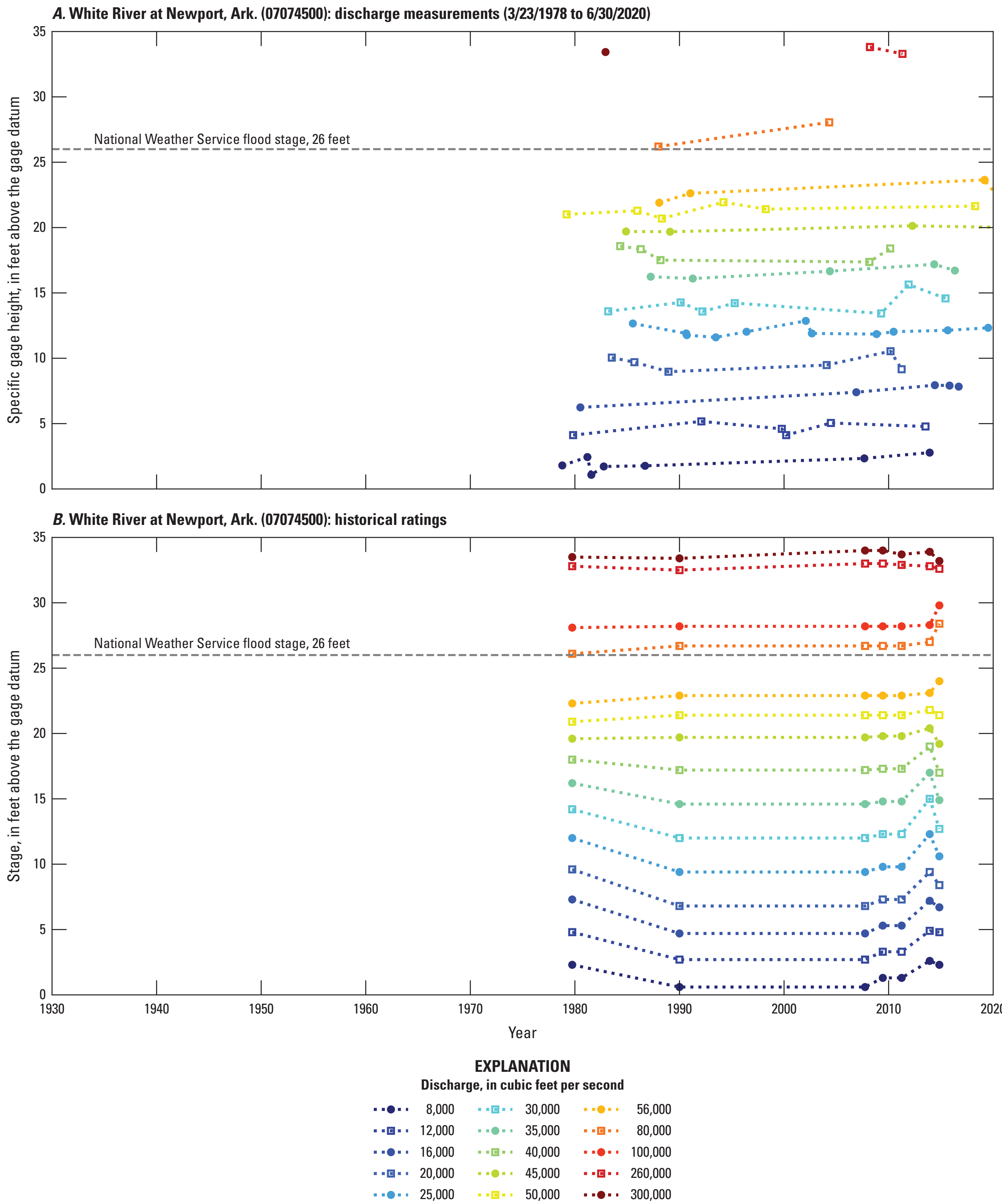

Figure 37. Results of specific stage analysis for the White River at Newport, Arkansas (07074500), streamgage. *A*, Specific stage from discharge measurements. *B*, Specific stage from ratings.

Longitudinal Profile of the Black River

The longitudinal profile of the Black River thalweg indicated that the bed slope decreases with distance downstream from Clearwater Dam (fig. 38). The greatest break in slope is between Leeper and Poplar Bluff, Mo., which is consistent with the general boundary between the Ozark Plateau and the MAP (fig. 1). The increase in bed elevation at about 122 river miles downstream from Clearwater Dam corresponds to the location of the DDBR WMA, where the channel becomes multithreaded and water levels are managed with multiple control structures. There is no definitive change apparent between the data extracted from the USACE hydraulic models and the 2018/2020 surveys, given the potentially large error in comparing the two datasets.

The water-surface profile shows a similar pattern as the longitudinal profile of the bed, with steeper slopes upstream from BR-Poplar Bluff and gentler slopes downstream from BR-Poplar Bluff (fig. 39). There is some variation in the water-surface profile among the three discharge conditions, though all three discharge conditions show the same general pattern. A comparison of May 1 to May 4, 2017, shows the subtle difference in the water-surface profile caused by the passage of a flood wave through the river. Though it is a subtle difference, the water-surface slope between BR-Poplar Bluff and BR-Corning is higher when the flood peak is at BR-Poplar Bluff and decreases as the flood wave moves downstream to BR-Corning.

According to seminal work by Lane (1955), alluvial rivers will tend toward an equilibrium between the sediment supply and the sediment transport capacity. This principle is often referred to as "Lane's relationship." The equation form of Lane's relationship states that the product of the sediment discharge and grain size is proportional to the product of the water discharge and the slope. If Lane's relationship is imbalanced, one or more of the parameters will adjust to bring the stream to equilibrium. For example, the bed could aggrade with a decrease in slope if the sediment delivered to the gentler reach by the steeper reach exceeds the transport capacity of the gentler reach. It is difficult to apply Lane's Relationship to the Black River owing to the effect of Clearwater Dam and the lack of data regarding the sediment supply. The downstream effects of dams are complex and depend not only on how the dam affects the sediment supply but also on how the dam affects the magnitude and frequency of sediment-transporting discharges (Grant and others, 2003). Although not directly quantified, it is likely that Clearwater Dam has substantially reduced the supply of sediment to the reach downstream. Additionally, Clearwater Dam also roughly quartered the mean annual peak discharge at the BR-Leeper streamgage and halved the mean annual peak discharge at the BR-Poplar Bluff streamgage (table 4). Moreover, at the BR-Poplar Bluff streamgage, Clearwater Dam reduced the exceedance probability of discharges greater than about 3,000 ft^3/s (fig. 5); however, extreme high discharges downstream from Clearwater Dam are still possible, as evidenced by the major floods in December 1982, March 2008, April 2011, and April–May 2017 (table 2).

The specific stage analysis indicated possible aggradation at the BR-Leeper streamgage (fig. 8) and possible degradation at the BR-Poplar Bluff streamgage (fig. 10). The channel bed near the BR-Leeper streamgage is aggrading despite the likelihood that Clearwater Dam reduced the sediment supply,

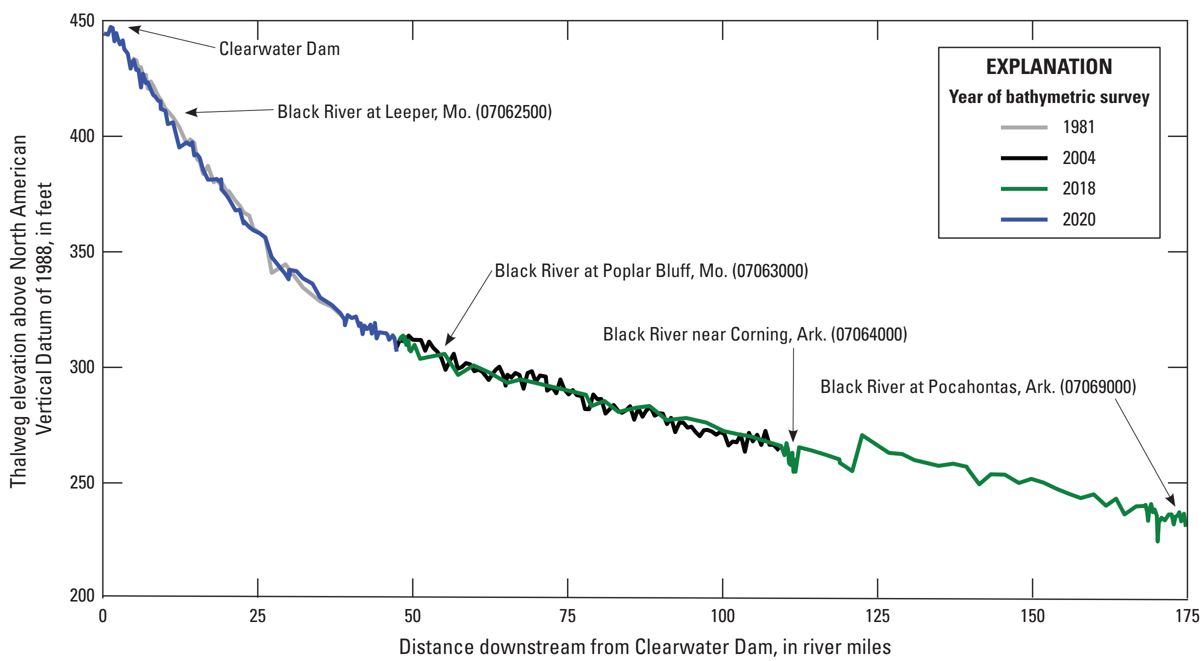

Figure 38. Longitudinal profile of the thalweg of the Black River from Clearwater Dam to Pocahontas, Arkansas.

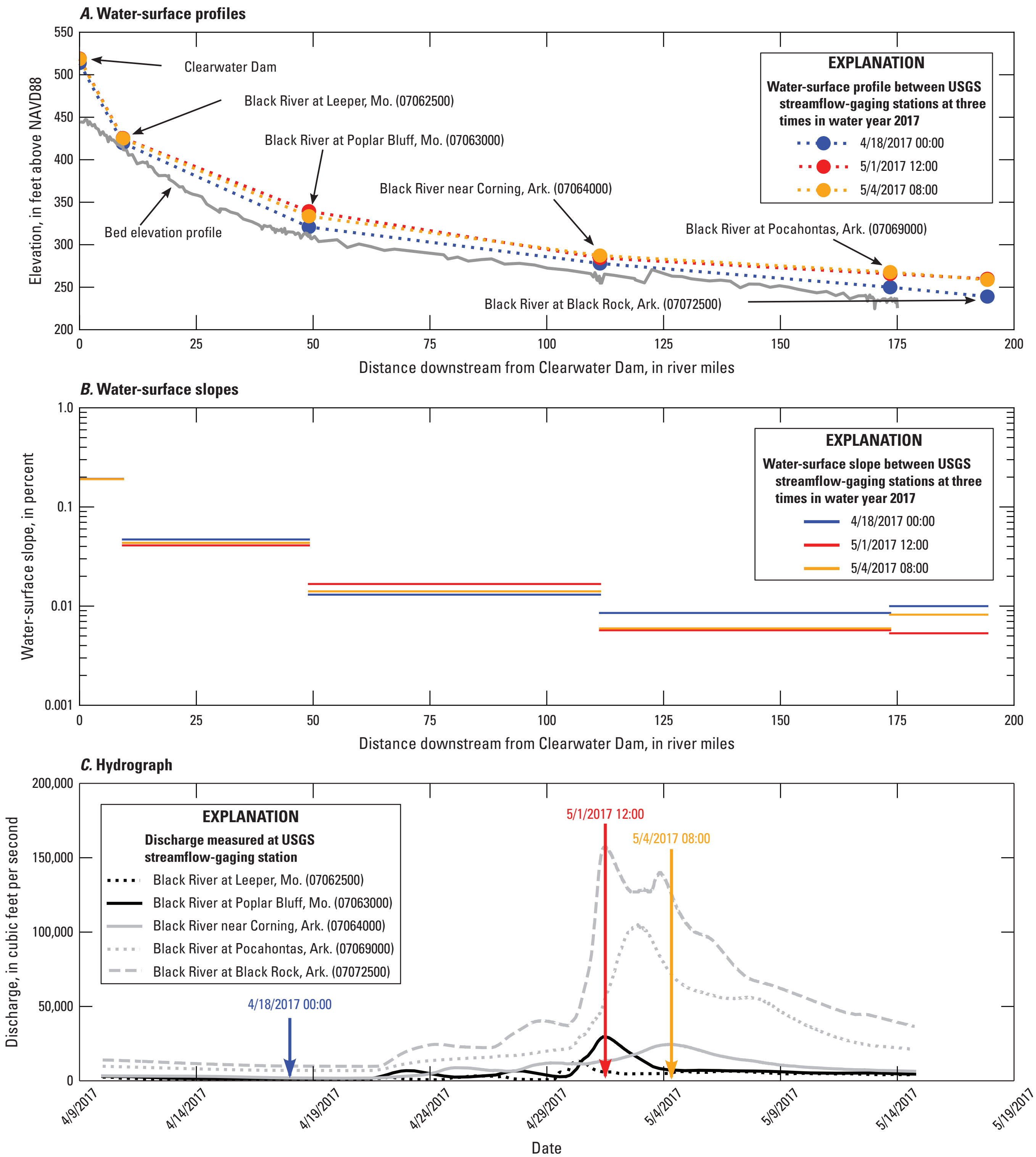

Figure 39. Longitudinal profiles of the water surface elevation and water surface slopes of the Black River for three points in time. *A*, Water surface elevations of the Black River from Leeper, Missouri, to Pocahontas, Arkansas, based on stage measurements at streamgages. *B*, Mean water-surface slopes between streamgages. *C*, Hydrographs from the study area streamgages, indicating the three points in time shown in panels *A* and *B*.

which indicates the altered discharge regime is insufficient to transport the remaining sediment supply. There is also the possibility that additional sediment is being mobilized from the channel bed or banks between the dam and the BR-Leeper streamgage to drive aggradation near BR-Leeper. Degradation at the BR-Poplar Bluff streamgage indicates the opposite—that the post-dam discharge regime has excess sediment transport capacity compared to the post-dam sediment supply. Therefore, the balance of sediment supply and sediment transport capacity must change between the BR-Leeper and BR-Poplar Bluff streamgages. The slope decreases but the discharge increases with distance downstream, and peak discharges were not as strongly affected by Clearwater Dam at BR-Poplar Bluff compared to BR-Leeper (table 4). It is also likely that sediment supply at BR-Leeper differs from BR-Poplar Bluff, but it is not possible to describe this with the available data, even qualitatively. Finally, it is possible that the local morphodynamic conditions at the BR-Leeper and BR-Poplar Bluff gages are not representative of the surrounding reaches.

Summary and Conclusions

The Black River flows through southeast Missouri and northeast Arkansas to its confluence with the White River. The U.S. Army Corps of Engineers operates Clearwater Dam on the Black River and a series of dams in the White River Basin primarily for flood control. This study investigated whether or not flood magnitude and frequency, stage-discharge relations, or channel morphology have changed over time at U.S. Geological Survey streamgages along the Black River and its tributaries downstream from Clearwater Dam. Annual discharge records, flow-duration curves, discharge measurements, historical rating curves, a limited bathymetric dataset, and multidate aerial imagery were examined.

The main-stem Black River gages analyzed in this report are the Black River at Leeper, Missouri (07062500; BR-Leeper); Black River at Poplar Bluff, Missouri (07063000; BR-Poplar Bluff); Black River near Corning, Arkansas (07064000; BR-Corning); Black River at Pocahontas, Arkansas (07069000; BR-Pocahontas); and Black River at Black Rock, Arkansas (07072500; BR-Black Rock). The tributary gages examined in this report are the Current River at Doniphan, Missouri (07068000; CR-Doniphan), Eleven Point River near Bardley, Missouri (07071500; EPR-Bardley), Eleven Point River near Ravenden Springs, Arkansas (07072000; EPR-Ravenden Springs), and Spring River at Imboden, Arkansas (07069500; SR-Imboden). The White River at Newport, Ark. (07074500; WR-Newport), located just downstream from the confluence of the Black River and White River, was also included.

The Mann-Kendall trend analysis of annual discharge records indicated a statistically significant upward trend in the annual mean discharge over the period of record (since the 1920s–50s) for the BR-Leeper, BR-Poplar Bluff, BR-Corning, CR-Doniphan, and EPR-Ravenden Springs streamgages. However, the slope of these trends is small (less than 1 percent of the median discharge at the associated streamgages). Similarly, the slopes of observed statistically significant long-term trends in annual peak discharges (downward trends at BR-Leeper and WR-Newport; upward trends at CR-Doniphan and BR-Pocahontas) were small (less than 0.01 percent of the median peak discharge at the associated streamgages). The annual peak discharges also were tested for temporal trends during water years 2000–19 to determine if there had been a recent increase in peak discharge magnitude. Four of the main-stream Black River streamgages (BR-Poplar Bluff, BR-Corning, BR-Pocahontas, BR-Black Rock) and the CR-Doniphan, EPR-Bardley, and EPR-Ravenden Springs streamgages showed significant increases in annual peak discharge from water years 2000–19, though again, the slopes were small (less than 0.1 percent of the median peak discharge per year at the associated streamgages).

To directly examine the effect of Clearwater Dam on the Black River peak discharges, box and whisker plots were used to show the distribution of peak discharges before and after 1948. The regulation of discharges in the Black River at Clearwater Dam resulted in a decrease in the median and standard deviation of annual peak discharges at the BR-Leeper and the BR-Poplar Bluff streamgages compared to pre-dam conditions. However, the effect of Clearwater Dam decreased with distance downstream, particularly at streamgages downstream from unregulated tributaries. The WR-Newport streamgage also showed a decrease in the median and standard deviation of annual peak discharges following the construction of multiple dams in its basin in the 1940s–1960s.

Flow-duration curves were used to examine temporal variability in the exceedance probability of the discharge corresponding to the National Weather Service flood stage (the “flood discharge”) at each streamgage in the study area (the median peak discharge was used at the BR-Leeper streamgage). The exceedance probability of the flood discharge was relatively high in water years 2010–19 compared to prior decades at nearly all the study area gages (excepting SR-Imboden), which is consistent with the upward trend in annual peak discharges observed during water years 2000–19 for the BR-Poplar Bluff, BR-Corning, BR-Pocahontas, BR-Black Rock, and CR-Doniphan streamgages. Moreover, three of the major floods of record on the Black River occurred during water years 2000–19 (March 2008, April 2011, and April–May 2017).This indicates that the last 10–20 years have been a period of relatively frequent flooding and high annual peak discharges along the Black River compared to previous years.

Specific stage analyses indicated generally stable channels at most of the streamgages on the Black River and its tributaries, as well as at the White River at Newport, Arkansas (07074500), streamgage. The lack of substantial geomorphic change is not necessarily unexpected because the study area streamgages are all at bridge crossings, which tend to be located in generally stable locations. Even so, system-wide degradation or aggradation might still be a detectable in the specific stage data. The most convincing trends in specific stage were the decreases observed at the BR-Poplar Bluff and the CR-Doniphan streamgages, which were indicative of bed degradation, and the possible aggradation at the BR-Leeper streamgage. The cross-sectional data derived from the discharge measurements similarly indicated bed degradation at the measurement cross-section near the BR-Poplar Bluff streamgage. The contrasting results of the specific stage analysis for the BR-Leeper and the BR-Poplar Bluff streamgages point toward a complex variation in sediment supply and sediment transport capacity downstream from Clearwater Dam. Further study could improve the understanding of the balance of sediment supply and sediment transport capacity in the Black River, including the effect of Clearwater Dam and the potential effects on channel morphology.

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Appendix

Tables 1.1–1.10 (available at https://doi.org/10.3133/sir20215067) contain the results of Mann-Kendall trend tests on specific stages from discharge measurements and rating curves at the study area streamgages.

For more information about this publication, contact:
Director, USGS Central Midwest Water Science Center
1400 Independence Road
Rolla, MO 65401
573–308–3667

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