Prepared in cooperation with the Arkansas Natural Resources Commission

Trends in Precipitation, Streamflow, Reservoir Pool Elevations, and Reservoir Releases in Arkansas and Selected Sites in Louisiana, Missouri, and Oklahoma, 1951–2011

Scientific Investigations Report 2013–5240

Cover background: White River at Calico Rock, Arkansas, during flood of March 19, 2008. Photograph by Daniel M. Wagner, U.S. Geological Survey.

Front cover: Water being released from floodgates at Beaver Dam on the White River during flood of April 2008. Photograph by U.S. Army Corps of Engineers, Little Rock District.

Back cover:

Top, NEXRAD radar image showing 24-hour precipitation totals for storm that occurred on June 10–11, 2010, in west-central Arkansas. Image provided by National Weather Service, Little Rock, Arkansas.

Bottom, Arkansas River at Dardanelle, Arkansas, during low-flow conditions on September 29, 2012. Photograph by Daniel M. Wagner, U.S. Geological Survey.

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By Daniel M. Wagner, Joshua D. Krieger, and Katherine R. Merriman

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi ²)	259.0	hectare (ha)
square mile (mi ²)	2.590	square kilometer (km ²)
Volume		
cubic foot (ft ³)	28.32	cubic decimeter (dm ³)
cubic foot (ft ³)	0.02832	cubic meter (m ³)
acre-foot (acre-ft)	1,233	cubic meter (m ³)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm ³)
Flow rate		
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)
cubic foot per second per square mile [(ft ³ /s)/mi ²]	0.01093	cubic meter per second per square kilometer [(m ³ /s)/km ²]

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

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

Trends in Precipitation, Streamflow, Reservoir Pool Elevations, and Reservoir Releases in Arkansas and Selected Sites in Louisiana, Missouri, and Oklahoma, 1951–2011

By Daniel M. Wagner,¹ Joshua D. Krieger,² and Katherine R. Merriman³

Abstract

The U.S. Geological Survey (USGS) and the U.S. Army Corps of Engineers (USACE) conducted a statistical analysis of trends in precipitation, streamflow, reservoir pool elevations, and reservoir releases in Arkansas and selected sites in Louisiana, Missouri, and Oklahoma for the period 1951–2011. The Mann-Kendall test was used to test for trends in annual and seasonal precipitation, annual and seasonal streamflows of 42 continuous-record USGS streamflow-gaging stations, annual pool elevations and releases from 16 USACE reservoirs, and annual releases from 11 dams on the Arkansas River. A statistically significant ($p \leq 0.10$) upward trend was observed in annual precipitation for the State, with a Sen slope of approximately 0.10 inch per year. Autumn and winter were the only seasons that had statistically significant trends in precipitation. Five of six physiographic sections and six of seven 4-digit hydrologic unit code (HUC) regions in Arkansas had statistically significant upward trends in autumn precipitation, with Sen slopes of approximately 0.06 to 0.10 inch per year. Sixteen sites had statistically significant upward trends in the annual mean daily streamflow and were located on streams that drained regions with statistically significant upward trends in annual precipitation. Expected annual rates of change corresponding to statistically significant trends in annual mean daily streamflows, which ranged from 0.32 to 0.88 percent, were greater than those corresponding to regions with statistically significant upward trends in annual precipitation, which ranged from 0.19 to 0.28 percent, suggesting that the observed trends in regional annual precipitation do not fully account for the observed trends in annual mean daily streamflows. Trends in annual maximum daily streamflows were similar to trends in the annual mean daily streamflows but were only statistically significant at seven sites. There were more statistically significant trends

(28 of 42 sites) in the annual minimum daily streamflows than in the annual means or maximums. Statistically significant trends in the annual minimum daily streamflows were upward at 18 sites and downward at 10 sites. Despite autumn being the only season that had statistically significant upward trends in seasonal precipitation, statistically significant upward trends in seasonal mean streamflows occurred in every season but spring. Trends in the annual mean, maximum, and minimum daily pool elevations of USACE reservoirs were consistent between metrics for reservoirs in the White, Arkansas, and Ouachita River watersheds, while trends varied between metrics at DeQueen Lake, Millwood Lake, and Lake Chicot. Most of the statistically significant trends in pool elevation metrics were upward and gradual—Sen slopes were less than 0.37 foot per year—and were likely the result of changes in reservoir regulation plans. Trends in the annual mean and maximum daily releases from USACE reservoirs were generally upward in all HUC regions. There were few statistically significant trends in the annual mean daily releases because the reservoirs are operated to maintain a regulation stage at a downstream site according to guidelines set forth in the regulation plans of the reservoirs. The annual number of low-flow days was both increasing and decreasing for reservoirs in northern Arkansas and southern Missouri and generally increasing for reservoirs in southern Arkansas.

Introduction

Surface water is an important resource that historically has been plentiful in Arkansas. In recent years, there have been increasing demands for freshwater for drinking in the northwestern and central parts of the State, irrigation in the eastern part of the State, and for industrial use statewide; between 1960 and 2010, water use in Arkansas increased over 700 percent (Stephens and Halberg, 1961; Terrance W. Holland, U.S. Geological Survey, written commun., 2013).

Arkansas' proximity to subtropical moisture derived from the Gulf of Mexico and the elevated topography of the Ouachita Mountains and the Ozark Plateaus make the State

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prone to flooding (O'Connor and Costa, 2003). Notable floods occurred in Arkansas in April 1927, July 1963, May 1968, December 1971, December 1982, December 1987, May 1990, March and April 2008, June 2010, and April and May 2011 (Gilstrap and Christensen, 1964; Gilstrap, 1972, 1973; Neely, 1985, 1989, 1991; Southard, 1992; O'Connor and Costa, 2004; Funkhouser and Eng, 2008; Holmes and others, 2010; Holmes and Wagner, 2011; Westerman and others, 2013). Conversely, Arkansas is also subject to periods of extreme drought, such as those experienced statewide from 1952–56, 1962–67, 1980–83, and in 2012 (Neely, 1991; National Oceanic and Atmospheric Administration, 2012).

To properly assess the State's water resources and risk of flood or drought, water managers need to understand trends in the occurrence and availability of surface water to facilitate proper resource management in the future. As part of updating the State Water Plan (Arkansas Natural Resources Commission, 2013), the U.S. Geological Survey (USGS) and the U.S. Army Corps of Engineers (USACE), in cooperation with the Arkansas Natural Resources Commission (ANRC), conducted a statistical analysis of trends in precipitation, streamflow, reservoir pool elevations, and reservoir releases in Arkansas and selected sites in Louisiana, Missouri, and Oklahoma, 1951–2011.

Purpose and Scope

The purpose of this report was to elucidate spatial patterns of temporal trends in various metrics of precipitation, streamflow, reservoir pool elevation, and reservoir releases in Arkansas and selected sites in Louisiana, Missouri, and Oklahoma during the 1951–2011 calendar years. The scope of the analysis included:

1. Annual and seasonal precipitation metrics computed from Parameter-elevation Regressions on Independent Slopes Model (PRISM) data (PRISM Climate Group, 2013) for the entire State of Arkansas, parts of six physiographic sections that contained part of the State of Arkansas, and parts of seven 4-digit hydrologic unit code (HUC) regions that contained part of the State of Arkansas (fig. 1),
2. Annual and seasonal streamflow metrics computed using the daily mean streamflow time-series data from 42 continuous-record streamflow-gaging stations operated by the USGS in Arkansas, Louisiana, Missouri, and Oklahoma;
3. Annual reservoir pool elevation and release metrics computed using daily time-series data from 14 USACE reservoirs in Arkansas and two USACE reservoirs in Missouri; and
4. Annual reservoir release metrics computed using daily time-series data from 11 USACE dams on the Arkansas River in Arkansas.

Several privately operated water-supply reservoirs in Arkansas lacked sufficient continuous record of pool elevations or releases during the analysis period of 1951–2011 and, therefore, were not used in the analysis.

Results of the statistical analyses of precipitation data are presented by physiographic and HUC regions. Results of the statistical analyses of streamflow, reservoir pool elevations, and reservoir releases are presented by metric. All results are discussed with particular attention to differences between physiographic and HUC regions, as the HUC regions correspond closely to planning regions used in the Arkansas State Water Plan. Site information and analytical results are presented in tables 1–13 at the end of the report. Analytical results are also presented graphically.

Descriptions of Physiographic Sections

Two major topographic regions exist in Arkansas: the Interior Highlands physiographic division and the Coastal Plain physiographic province (Fenneman, 1938). The Interior Highlands are underlain by bedrock of Paleozoic age, while the Coastal Plain is underlain by bedrock and unconsolidated sediments of Cretaceous, Tertiary, and Quaternary age (McFarland, 1998). The Interior Highlands physiographic division contains the Ouachita and Ozark Plateaus physiographic provinces. The Ouachita province is further divided into the Ouachita Mountains and Arkansas Valley physiographic sections; the Ozark Plateaus province is further divided into the Boston Mountains and Springfield-Salem plateaus physiographic sections (Fenneman, 1938). Two physiographic sections in the Coastal Plain physiographic province, the Mississippi Alluvial Plain and the West Gulf Coastal Plain, are present in Arkansas (Fenneman, 1938).

Ouachita Mountains

The Ouachita Mountains of southeastern Oklahoma and west-central Arkansas (fig. 1) are composed of ridges of complexly folded and faulted Paleozoic bedrock (McFarland, 1998; Woods and others, 2004). The ridges increase in height to the west, with the highest ridges having maximum elevations of slightly greater than 2,600 feet (ft) (Renken, 1998). The ridges are aligned east-west, which allows the southern slopes to receive more direct sunlight and creates a cooler climate on the northern slopes. As a result of the geologic structure of the Ouachita Mountains, streams in the region exhibit what is known as a trellis drainage pattern, meandering in valleys between the ridges and occasionally cutting across and through the ridges. Local relief in the valleys of the larger streams often exceeds 1,000 ft. The Ouachita River, a tributary of the Red River, drains the central and southeastern part of the mountains. Three tributaries of the Arkansas River—the Fourche LaFave, Petit Jean, and Poteau Rivers—drain most of the northern part of the mountains. The Little River, also a tributary of the Red River, drains most of the southwestern part of the mountains.

Figure 1. Locations of selected continuous-record U.S. Geological Survey (USGS) streamflow-gaging stations, U.S. Army Corps of Engineers (USACE) reservoirs, and USACE dams on the Arkansas River in Arkansas, Louisiana, Missouri, and Oklahoma.

Arkansas Valley

The Arkansas Valley surrounds the Arkansas River from eastern Oklahoma to near Conway, Ark., and marks the transition between the Boston Mountains to the north and the Ouachita Mountains to the south (fig. 1). The Arkansas Valley is underlain by bedrock of Pennsylvanian age that is extensively faulted north of the Arkansas River and broadly folded south of the Arkansas River; the flood plain of the Arkansas River is underlain by unconsolidated alluvial deposits of Quaternary age (McFarland, 1998). North of the Arkansas River, the Arkansas Valley is characterized by rolling, flat-topped ridges similar to those in the Ozark Plateaus; south of the Arkansas River, the section is characterized by east-west trending ridges similar to those in the Ouachita Mountains. Between these two areas is the wide, low-lying flood plain of the Arkansas River. Although the elevation of the Arkansas Valley is generally 300–600 ft, the elevation of the higher ridges occasionally exceeds 1,000 ft (Renken, 1998).

Boston Mountains and Springfield-Salem Plateaus

The Ozark Plateaus physiographic province contains two physiographic sections, the Boston Mountains and the Springfield-Salem plateaus (fig. 1). Both are deeply dissected plateaus characterized by rolling, flat-topped ridges having maximum elevations of slightly greater than 1,700 ft in the Springfield-Salem plateaus and 2,500 ft in the Boston Mountains. Streams in the region have downcut into the plateaus, forming V-shaped valleys with local relief of 300 to over 1,000 ft (Renken, 1998). Karst topography is prominent in the limestone and dolomite rocks of Paleozoic age that underlie the Springfield-Salem plateaus; springs and sinkholes impact the hydrology of this section, contributing or capturing streamflow (Vineyard and Feder, 1982). The St. Francois Mountains, a subsection within the Springfield-Salem plateaus in southeastern Missouri, is underlain by igneous rocks of Precambrian age that form the geologic core of the Ozark Plateaus. The Black and St. Francis Rivers (fig. 1), which have their headwaters in this region, may experience hydrologic effects that differ from those experienced by streams that have their watersheds entirely within the karst topography of the Springfield-Salem plateaus. The White River drains the northern and eastern parts of the Boston Mountains and the majority of the Springfield-Salem plateaus in southern Missouri and northern Arkansas before flowing into the Mississippi Alluvial Plain. The southwestern parts of the Boston Mountains and Springfield-Salem plateaus are drained by numerous tributaries of the Arkansas River.

Mississippi Alluvial Plain

The Mississippi Alluvial Plain is a relatively flat physiographic section with a low flood plain and little topographic relief (Renken, 1998). The section is underlain

by unconsolidated alluvial deposits of Quaternary age (McFarland, 1998). Major streams that drain the region include the St. Francis, Cache, White, Arkansas, and Mississippi Rivers (fig. 1); aside from the largest rivers, such as the White, Arkansas, and Mississippi, streams in this region generally have poorly defined channels that meander through wetlands (Woods and others, 2004). In many areas within the Mississippi Alluvial Plain, stream channels have been altered for flood control and irrigation. Water use for irrigation is intensive in this region, and most of the water use is from groundwater sources (Clark and others, 2011). Base flow of streams in the Mississippi Alluvial Plain has been shown to be affected by declining groundwater levels in the Mississippi River Valley alluvial aquifer. In a groundwater availability study of the Mississippi River Valley alluvial aquifer, predevelopment (prior to the year 1870) groundwater recharge to streams was shown to be approximately 727,000 acre-feet per year (acre-ft/yr), but by 2006, stream losses to groundwater were shown to be approximately 697,000 acre-ft/yr (Clark and others, 2011).

West Gulf Coastal Plain

The West Gulf Coastal Plain physiographic section in southern and southwestern Arkansas (fig. 1) consists of low, gently rolling hills interspersed by hardwood bottomlands (Renken, 1998). The section is underlain by sedimentary rocks of Cretaceous and Tertiary age, small areas of igneous rocks of Cretaceous age, and unconsolidated alluvial deposits of Quaternary age (McFarland, 1998). Many small streams in the region become ephemeral in the summer months (Woods and others, 2004). Manmade reservoirs, used for water supply, generation of hydroelectric power, and recreation, are common in the headwaters of streams in the West Gulf Coastal Plain. Major rivers that drain the region include the Red, Little, Ouachita, and Saline Rivers (fig. 1).

Descriptions of Hydrologic Unit Code (HUC) Regions

Hydrologic Unit Code Region 1107 Neosho–Verdigris River Watersheds

Hydrologic Unit Code region 1107 contains the watershed of the Neosho River, a tributary of the Arkansas River that drains parts of Kansas, Missouri, and Oklahoma; only the part of the region that intersects Arkansas was examined in this study. The region includes parts of two physiographic sections, the Springfield-Salem plateaus and the Osage Plains; the Neosho River flows along the western boundary of the plateaus, separating them from the plains to the west (fig. 2). A USGS streamflow-gaging station in the HUC region (site 19), located on the unregulated part of the Elk River upstream from Grand Lake O' The Cherokees (an impoundment of the Neosho River in Oklahoma), was used in the statistical analysis in this study (table 1).

Figure 2. Locations of selected continuous-record U.S. Geological Survey (USGS) streamflow-gaging stations, U.S. Army Corps of Engineers (USACE) reservoirs, and USACE dams on the Arkansas River in Hydrologic Unit Code regions 1107 and 1111.

Hydrologic Unit Code Region 1111—Lower Arkansas River Watershed

Hydrologic Unit Code region 1111 encompasses part of the watershed of the Arkansas River that extends upstream from the Robert S. Kerr Reservoir in Oklahoma to downstream from Little Rock, Ark. (fig. 2); only the part of the region that intersects Arkansas was examined in this study. The region includes parts of six physiographic sections present in Arkansas—11 USGS streamflow-gaging stations, 9 on unregulated streams (sites 20, 21, 23–27, 29, and 30) and 2 on regulated streams (sites 22 and 28); 2 USACE reservoirs (sites 56 and 57); and 9 USACE dams on the Arkansas River (sites 47–55) that were used in the statistical analysis in this study (tables 1 and 2).

Hydrologic Unit Code Region 1101—Upper White River Watershed

Hydrologic Unit Code region 1101 encompasses the watershed of the White River upstream from its confluence with the Little Red River (fig. 3). The region includes parts of four physiographic sections: the Springfield-Salem plateaus, the Boston Mountains, the Arkansas Valley, and the Mississippi Alluvial Plain; 13 USGS streamflow-gaging stations, 10 on unregulated streams (sites 5–7, 9, and 11–16) and 3 on regulated streams (sites 8, 10, and 17); and 6 USACE reservoirs (sites 44 and 65–69) were used in the statistical analysis in this study (tables 1 and 2). Big Spring, Mammoth Spring, Greer Spring, and Double Spring, the first, second, third, and fifth largest springs, respectively, in the Springfield-Salem plateaus (Vineyard and Feder, 1982), are located within the region. Big and Greer Springs (sites 11 and 14, respectively) are continuously monitored by USGS and were included in the statistical analysis. A USGS streamflow-gaging station on Mammoth Spring (USGS 07069190, Mammoth Spring at Mammoth Spring, Ark.) was not included in the analysis because continuous monitoring at the site did not begin until February 1981 (see “Methods” section for length of record requirements).

Hydrologic Unit Code Region 0802—Lower Mississippi – St. Francis River Watersheds

Hydrologic Unit Code region 0802 encompasses the watersheds of the Lower Arkansas, Mississippi, and White Rivers, the Cache River, and the St. Francis River (fig. 4). The region is located almost entirely within the Mississippi Alluvial Plain physiographic section, with the very northern part located in the Springfield-Salem plateaus section, including the St. Francois Mountains subsection. Six USGS streamflow-gaging stations, three on unregulated streams (sites 1, 18, and 31) and three on the regulated part of the St. Francis River (sites 2, 3, and 4), and two USACE dams

on the Arkansas River (sites 45 and 46) were used in the statistical analysis in this study (tables 1 and 2). Parts of the Cache River (site 18) and Bayou Meto (site 31) watersheds are located near the Cache and Grand Prairie critical groundwater areas (Arkansas Natural Resources Commission, 2006).

Hydrologic Unit Code Region 0804—Lower Red – Ouachita River Watersheds

Hydrologic Unit Code region 0804 encompasses the watershed of the Ouachita River upstream from the confluence of Bayous Bartholomew and D’Arbonne (fig. 5); only the part of the region that intersects Arkansas was examined in this study. The region includes parts of three physiographic sections: the Ouachita Mountains, the West Gulf Coastal Plain, and a small part of the Mississippi Alluvial Plain. Eight USGS streamflow-gaging stations, six on unregulated streams (sites 35, 37, and 39–42) and two on the regulated part of the Ouachita River (sites 36 and 38), and three USACE reservoirs (sites 58–60) were used in the statistical analysis in this study (table 1). Part of the watersheds of the Ouachita River (site 38), the Saline River (site 39), and Little Corney Bayou (site 42) are within the south Arkansas critical groundwater area (Arkansas Natural Resources Commission, 2006).

Hydrologic Unit Code Region 0805—Boeuf-Tensas River Watersheds

Hydrologic Unit Code region 0805 encompasses the watersheds of the Boeuf and Tensas Rivers to their confluence with the Ouachita River (fig. 5); only the part of the region that intersects Arkansas was examined in this study. The region is located almost entirely within the Mississippi Alluvial Plain physiographic section. One USACE reservoir, Lake Chicot (site 43), was used in the statistical analysis in this study (table 2).

Hydrologic Unit Code Region 1114—Red-Sulphur River Watersheds

Hydrologic Unit Code region 1114 encompasses part of the Red River watershed that includes the watershed of the Little River, the main tributary to Millwood Lake (fig. 5); only the part of the region that intersects Arkansas was used in the analysis. The region includes parts of two physiographic sections, the Ouachita Mountains and the West Gulf Coastal Plain. Three USGS streamflow-gaging stations, one on the unregulated part of Bayou Dorcheat (site 34) and two on regulated streams (sites 32 and 33), and four USACE reservoirs (sites 61–64) were used in the statistical analysis in this study (table 1). Part of the watershed of Bayou Dorcheat is located within the south Arkansas critical groundwater area (Arkansas Natural Resources Commission, 2006).

Figure 3. Locations of selected continuous-record U.S. Geological Survey (USGS) streamflow-gaging stations and U.S. Army Corps of Engineers (USACE) reservoirs in Hydrologic Unit Code region 1101.

Figure 4. Locations of selected continuous-record U.S. Geological Survey (USGS) streamflow-gaging stations, U.S. Army Corps of Engineers (USACE) reservoirs, and USACE dams on the Arkansas River in Hydrologic Unit Code region 0802.

Figure 5. Locations of selected continuous-record U.S. Geological Survey (USGS) streamflow-gaging stations and U.S. Army corps of Engineers (USACE) reservoirs in Hydrologic Unit Code regions 0804, 0805, and 1114.

Methods

Precipitation

The precipitation data used for this study were derived from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (PRISM Climate Group, 2013). PRISM precipitation data are derived from the National Climatic Data Center (NCDC) Global Historical Climate Network and has been corrected for orographic effects because of elevation (Daly and others, 1994, 2002). The precipitation data developed by PRISM are spatially gridded and available as an ACSII grid file at a 2.5-arc minute (4 kilometers) resolution. Monthly and annual precipitation data are available for the United States from 1895 to 2012 (PRISM Climate Group, 2013).

Scripts written in the Python programming language, version 2.7, were used to retrieve and process the PRISM data used in the analysis (Python, 2013). Precipitation data were obtained for the Nation and then extracted to the boundary of the State of Arkansas. A zonal average was extracted for each month or year for the spatial areas of interest (statewide, physiographic sections, and HUC regions). The zonal average was compiled chronologically into text files for the spatial areas of interest that were used as input to the Mann-Kendall test. Seasonal precipitation was computed by summing the monthly zonal average.

U.S. Geological Survey Streamflow-Gaging Stations

Daily mean streamflow (hereafter “daily streamflow”) and site information records for all continuous-record streamflow-gaging stations in the USGS Arkansas Water Science Center database were retrieved and placed in a Microsoft Access database for querying. The daily streamflow records were examined visually and numerically for missing data. For trends analysis, it is desirable to have 80 percent or more of the daily streamflow record present in any one-third of the analysis period (Helsel and Hirsch, 2002); however, to incorporate continuous-record USGS streamflow-gaging stations that went into service in the mid- to late 1950s, those having 60 percent or more of the daily streamflow record present in any one-third of the analysis period of 1951–2011 were used, yielding 28 streamflow-gaging stations in Arkansas that met the criteria. To further increase the size of the dataset, 14 continuous-record USGS streamflow-gaging stations in Louisiana, Missouri, and Oklahoma, which monitor inflows to or outflows from Arkansas and also meet the criteria for continuous daily streamflow record, were added to the dataset (fig. 1, table 1).

Regulation

The USGS considers a stream to be regulated if more than 10 percent of the drainage area at the streamflow-gaging station of interest is impounded or there is more than 103 acre-ft of reservoir storage capacity in the watershed upstream from the gage (Benson, 1963). Using these criteria, 12 of the 42 USGS streamflow-gaging stations used in the analysis were considered regulated (table 1). The White, St. Francis, Black, Petit Jean, Ouachita, and Red Rivers became regulated by large reservoirs prior to 1951; however, two streamflow-gaging stations in the dataset, USGS 07247000, Poteau River at Cauthron, Ark. (site 22), and USGS 07340000, Little River near Horatio, Ark. (site 33), had regulated periods beginning after 1951. For these two streamflow-gaging stations, the entire analysis period and the preregulation and postregulation periods were analyzed separately. All three trends are included in the tables, but only the trends for the entire analysis period are presented in the figures and discussed in the report. The postregulation periods for the two sites are as follows:

1. Regulation began on the Poteau River in September 1974 with the completion of 16 floodwater-detention reservoirs that impounded drainage from 92 square miles (mi²), or 45 percent, of the 203 mi² in the watershed upstream from the gage. For analytical purposes, the period of January 1951–December 1974 was considered the preregulation period, and January 1975–December 2011 was the postregulation period (table 1).
2. Regulation began on the Little River in October 1968 with the impoundment of the Mountain Fork by Broken Bow Reservoir (fig. 5). The main stem of the Little River upstream from the confluence with the Mountain Fork was impounded in 1969 by Pine Creek Reservoir. For analytical purposes, January 1951–December 1968 was considered the preregulation period, and January 1969–December 2011 was the postregulation period (table 1).

Metrics Used in Trends Analysis

Annual Streamflow Metrics

The annual mean daily streamflow was used as a metric of central tendency and is also useful as a proxy for total annual runoff; because total annual runoff is also computed from the daily streamflow dataset, a trend in the annual mean daily streamflow is the same as a trend in total annual runoff. The annual maximum daily streamflow was used as a metric of high-flow conditions. The annual minimum daily streamflow was used as a metric of low-flow conditions. Annual metrics for years with less than 300 daily streamflows were not used in the analysis.

Seasonal Streamflow Metrics

Seasonal mean daily streamflows of USGS streamflow-gaging stations on unregulated streams were computed from the daily streamflow dataset by first assigning a season to each daily streamflow and then computing the mean of the daily streamflows in each season. The Mann-Kendall test was used to compute the trend in the mean daily streamflow for each season using the analysis period of 1951–2011.

U.S. Army Corps of Engineers Reservoirs and Dams on the Arkansas River

Data from USACE reservoirs and dams on the Arkansas River used in the analysis were retrieved from the USACE database using the Hydrologic Engineering Center Data Storage System Visual Utility Engine (HEC–DSSVue; U.S. Army Corps of Engineers, 2009), a Java-based visual utilities program. Except for Lake Chicot and Clearwater Lake (sites 43 and 44), all of the reservoirs and the dams on the Arkansas River record reservoir pool elevations and releases on an hourly time step. The pool elevation of Lake Chicot is recorded daily at 6 a.m.; releases are not recorded. The pool elevation of Clearwater Lake is recorded daily at midnight. All datasets for the USACE reservoirs and dams on the Arkansas River were complete for the period used (table 2). Some of the reservoirs had a period of recorded data prior to the official start of their regulation period because of dam construction. These data were not used because the dams were not yet fully operational.

All 11 dams on the Arkansas River (sites 45–55) and many of the reservoirs, including 3 in the Ouachita River watershed (sites 58–60), 4 in the Little River watershed (sites 61–64), and 2 in the White River watershed (sites 65 and 69), were not in operation until after 1960 (table 2). As a result, these sites did not meet the criteria used to select USGS streamflow-gaging stations for this study (60 percent or more of the continuous daily record present in any one-third of the analysis period). Although there are no records present for these sites during all or part of the early one-third of the analysis period (1951–71), the sites were included in the analysis because their records were otherwise complete, and trends in pool elevation and release metrics for these sites were considered important for water-management purposes.

Annual Metrics Used in Trends Analysis

Various metrics of annual pool elevations and releases for the USACE reservoirs were computed using a combination of the computational functions of HEC–DSSVue and Microsoft Excel. Metrics computed in HEC–DSSVue were the annual mean, maximum, and minimum daily reservoir pool elevations and the annual mean and maximum daily reservoir releases.

Annual pool elevation metrics were not computed for dams on the Arkansas River because the dams are operated to maintain their navigational pools within a 1-ft range; therefore, changes in pool elevation do not necessarily indicate a change in available volume of water. In addition, 1-ft deviations from the operation plans of the dams are sometimes enacted to raise the navigational pools to prevent grounding of tow vessels. These temporary increases in pool elevation would skew trends without accurately representing hydraulic conditions.

Instead of using the annual minimum daily reservoir release as a metric of low-flow conditions, the annual number of days with a mean release equal to or below the 10th percentile daily release (hereafter referred to as the “number of low-flow days”) was computed for each reservoir using Microsoft Excel (for dams on the Arkansas River, the annual number of days with a mean release equal to or below 1,000 cubic feet per second [ft^3/s] was used). A year with a greater number of low-flow days indicates a year having more frequent low-flow conditions. The annual minimum daily release was not used as a metric of low-flow conditions because the dams tend to have at least one day per year where no water is released through the dam or hydroelectric plant; such days are not necessarily indicative of low-flow conditions. The annual 10th percentile daily release was not used because the value was similar from year to year for most sites.

Seasonal Metrics Used in Trends Analysis

Seasonal metrics of pool elevations and releases were not computed for the reservoirs because their regulation plans have their own unique seasonal stepping benchmarks. Although these benchmarks are called seasonal pools, they follow a planting and harvesting season rather than the calendric seasons. The durations of these seasonal benchmarks or pools range from 15 days to many months.

Trend Analysis

Mann-Kendall Test

The Mann-Kendall test for Kendall’s tau (Helsel and Hirsch, 2002) was used to test for monotonic (unidirectional, only increasing or decreasing with time) trends in precipitation, streamflow, reservoir pool elevation, and reservoir release time-series data. The test is a rank-based procedure that is typically used to determine whether the central value, such as the mean or median, of a dataset changes over time (Helsel and Hirsch, 2002). A normal distribution of the dataset is not required, making it useful for environmental data such as precipitation and streamflow, which are typically not normally distributed.

Kendall's tau correlation coefficient is computed by first ordering all (x,y) data pairs by increasing values of the independent variable x. For the purposes of this study, the dependent variable, y, represents precipitation, streamflows, reservoir pool elevations, or reservoir releases; the independent variable, x, represents time in years. Using an annual streamflow dataset as an example, data pairs (year, streamflow) are ordered by increasing time (in years). For the correlation to be positive, streamflow has to increase more often than it decreases as the year increases; conversely, for the correlation to be negative, streamflow has to decrease more often than it increases as the year increases. For the correlation to be zero, streamflow has to increase and decrease the same number of times (Helsel and Hirsch, 2002). The streamflow for each year in the dataset is compared with the streamflow from every other succeeding year in the dataset, for a total of $n(n-1)/2$ possible combinations to be made among the n (year, streamflow) data pairs (Helsel and Hirsch, 2002).

The test statistic, S, measures the dependence of y (streamflow) on x (year). S is computed as $S=P-M$, where P is the number of comparisons when y (streamflow) increases with x (year) and M is the number of comparisons when y (streamflow) decreases with x (year) (Helsel and Hirsch, 2002).

Kendall's tau correlation coefficient (τ) is then computed as $\tau=S/[n(n-1)/2]$, where $\tau = +1$ if all y (streamflow) values increase with increasing x (year) values and $\tau = -1$ if all y (streamflow) values decrease with increasing x (year) values (Helsel and Hirsch, 2002). Using the annual streamflow example, τ can be thought of as a percent likelihood of seeing an increase or a decrease in the dependent variable y (streamflow) for any given increase in the independent variable x (year). As an example, given the analysis period of 1951–2011 ($n=61$ years), there are $n(n-1)/2$, or 1,830, data pairs; if P (increases in streamflow)=1000 and M (decreases in streamflow)=830, then $S=170$ and $\tau=0.09$. It is, therefore, only 9 percent more likely that there would be an increase rather than a decrease in streamflow from one year to the next.

The Sen slope is a measure of the expected rate of change in y (streamflow) for a given time step (year) (Helsel and Hirsch, 2002). The Sen slope is the median of the slopes computed from the data pairs used in the computation of Kendall's tau. For this study, an expected annual percent rate of change was computed for each metric as the ratio of the Sen slope to the median value of the metric, expressed as a percentage.

The p-value assigned to the test result represents the probability of obtaining a value of τ at least as large in absolute value as the one actually observed. For any statistical test, a "null hypothesis" and "alternate hypothesis" are considered; in the case of the Mann-Kendall test and the annual streamflow example, the null hypothesis is that $\tau=0$ and there is no trend in streamflow over time; the alternate hypothesis is that $\tau \neq 0$ and streamflow varies monotonically

over time. The null hypothesis is rejected if the p-value is smaller than a predetermined level of significance. Given that the purpose of the study was to elucidate spatial patterns of trends in Arkansas and the surrounding region, results having a 10-percent level of significance ($p \leq 0.10$) were considered statistically significant. For this study, results having a level of significance less than 1 percent are reported as less than 0.01 ($p < 0.01$), regardless of the actual value.

A graphical user interface (GUI) for R, a software environment for statistical computing (<http://www.r-project.org/>; David L. Lorenz, U.S. Geological Survey, written commun., 2013), was used to determine data distribution, compute summary statistics (annual mean, minimum, maximum, and so forth) of precipitation and streamflow data, execute the Mann-Kendall test, and save test results. Kendall's tau (τ), the p-value, the Sen slope corresponding to the trend in each metric, the median value of the metric, and the expected annual rate of change are presented in tables 3–13 at the end of the report.

Analysis Period

The 1951 to 2011 calendar years were selected as the analysis period for several reasons:

1. Mean annual precipitation and runoff were previously mapped for the State of Arkansas for the period 1951–80 (Freiwald, 1984), and a similar beginning date was wanted for this statistical analysis;
2. More USGS streamflow-gaging stations could be included in the dataset than if a beginning date before 1951 had been chosen; and
3. An analysis period of at least 50 years was wanted so that short-term natural variations in climate and streamflow would not obscure or falsely indicate interdecadal trends (Lins and Slack, 1999; Hu and others, 1998).

For seasonal analysis, the year was divided into four seasons consisting of 3 months each:

1. Winter–January, February and March;
2. Spring–April, May and June;
3. Summer–July, August, and September; and
4. Autumn–October, November, and December.

The USGS streamflow-gaging stations, USACE reservoirs, and USACE dams on the Arkansas River that were used in the analysis had varied periods of record. For those having a period of record beginning on or before January 1, 1951 (table 1), only data for the 1951–2011 calendar years were used in the analysis. For those that went into service after 1951, the dataset used in the analysis began with the first complete calendar year of the period of record (table 1).

Trends in Precipitation, Streamflow, Reservoir Pool Elevations, and Reservoir Releases

Results of the Mann-Kendall test (Kendall's tau, p-value, Sen slope, and median) for monotonic trends in the various precipitation, streamflow, reservoir pool elevations, and reservoir release metrics, regardless of statistical significance, are presented in tables 3–13 and figures 6–14. For each trend, an expected annual rate of change was computed as the ratio of the Sen slope to the median value, expressed as a percent, and is included in the tables.

Precipitation Trends

Trends in Annual Precipitation

The long-term mean and median annual precipitation for Arkansas from 1951 to 2011 were 49.79 and 48.29 inches, respectively (table 3); the median occurred in 2006 (fig. 6). The wettest year during the analysis period was 1957, when the State received 71.40 inches of precipitation, or

approximately 23 inches more than the long-term median; the driest year was 1963, when the State received 32.59 inches, or approximately 16 inches less than the long-term median.

With respect to physiographic sections, the Ouachita Mountains had the greatest long-term mean annual precipitation, while the Springfield-Salem plateaus had the least (fig. 7). The greatest annual precipitation, 80.86 inches, occurred in the West Gulf Coastal Plain in 2009, while the least, 27.20 inches, occurred in the Boston Mountains in 1963 (table 3).

With respect to HUC regions, HUC 0804 had the greatest long-term mean annual precipitation, while HUC 1107 had the least (fig. 7). The greatest annual precipitation, 78.90 inches, occurred in HUC 0804 in 2009, while the least, 21.40 inches, occurred in HUC 1107 in 1963 (table 3).

Statistically significant ($p \leq 0.10$) upward trends in mean annual precipitation were observed statewide in the Springfield-Salem plateaus and Ouachita Mountains physiographic sections and in HUCs 1101, 1107, and 1111 (fig. 8, table 3). Sen slopes corresponding to statistically significant trends in mean annual precipitation ranged from approximately 0.10 to 0.12 inches per year (in/yr). Expected annual rates of change corresponding to statistically significant trends in mean annual precipitation ranged from 0.19 to 0.28 percent.

Figure 6. Annual departures from long-term median annual precipitation for the State of Arkansas and 5-year weighted average of departures from long-term median annual precipitation, 1951–2011.

Figure 7. Mean annual and seasonal precipitation for *A*, physiographic sections within Arkansas, and *B*, parts of Hydrologic Unit Code regions that intersect Arkansas, 1951–2011.

Trends in Seasonal Precipitation

When analyzed for the entire State of Arkansas, the long-term mean seasonal precipitation for the period 1951–2011 was greatest during spring (14.16 inches) and least during summer (10.52 inches) (table 3). The greatest seasonal precipitation, 25.73 inches, occurred in the spring of 1957, while the least, 4.13 inches, occurred in the autumn of 2000.

When analyzed by physiographic section, the long-term mean seasonal precipitation for the period 1951–2011 was greatest during spring in the Ouachita Mountains (15.38

inches) and least during summer in the Mississippi Alluvial Plain (9.92 inches) (fig. 7, table 3). The greatest seasonal precipitation, 30.90 inches, occurred in the spring of 1957 in the Boston Mountains, while the least, 2.19 inches, occurred in the Boston Mountains in the autumn of 1989 (table 3).

When analyzed by HUC region, the long-term mean seasonal precipitation for the period of 1951 to 2011 was greatest during winter in HUC 0805 (15.03 inches) and least during winter in HUC 1107 (7.49 inches) (fig. 7, table 3). The greatest seasonal precipitation, 31.72 inches, occurred in HUC 0805 in the autumn of 1982, while the least, 2.45 inches, occurred in HUC 1107 in the winter of 1972 (table 3).

Figure 8. Results of Mann-Kendall test for monotonic trends in the mean annual precipitation for *A*, the State of Arkansas; *B*, physiographic sections within Arkansas; and *C*, parts of Hydrologic Unit Code regions that intersect Arkansas, 1951–2011.

Both upward and downward trends were observed in seasonal mean precipitation, depending on the physiographic section, HUC region, and season (fig. 9, table 3). Statistically significant upward trends in autumn precipitation were observed statewide in all physiographic sections except the Boston Mountains (fig. 9A) and in all HUC regions except 1107 (fig. 9E). Sen slopes corresponding to statistically significant trends in autumn precipitation ranged from approximately 0.06 to 0.10 in/yr, and expected annual rates of change corresponding to statistically significant trends ranged from 0.53 to 0.73 percent. Statistically significant downward trends were observed in the winter precipitation in the Mississippi Alluvial Plain and HUC 0802 in eastern Arkansas (fig. 9B, F). For both the Mississippi Alluvial Plain and HUC 0802, Sen slopes were approximately -0.04 in/yr and expected annual rates of change were approximately -0.30 percent. No statistically significant trends were observed in spring or summer precipitation statewide or in any physiographic section or HUC region (fig. 9C, D, G, H).

Trends in Streamflows at U.S. Geological Survey Streamflow-Gaging Stations

Trends in Annual Streamflows

Of 42 streamflow-gaging stations analyzed for the entire analysis period (1951–2011), 39 had upward trends in the annual mean daily streamflow, while only 3 had downward trends (fig. 10A, table 4). Sixteen of these trends were statistically significant, and all statistically significant trends were upward. Fifteen of the 16 sites that had statistically significant trends were located on streams in parts of HUCs 0802, 1101, 1107, or 1111 that drain the Springfield-Salem plateaus or the Boston Mountains physiographic sections, while the remaining site (site 38) was located on the Ouachita River, in part of HUC 0804 that drains the southeastern Ouachita Mountains and the West Gulf Coastal Plain physiographic sections. Four sites that had statistically significant trends (sites 2, 10, 22, and 38) were located on regulated streams. Sen slopes corresponding to statistically significant trends in the annual mean daily streamflows ranged from 0.39 (ft³/s)/yr (site 21)

to 39.79 (ft³/s)/yr (site 16). Expected annual rates of change corresponding to statistically significant trends in the annual maximum daily streamflows ranged from 0.32 percent (site 11) to 0.88 percent (site 21).

Thirty-five of 42 streamflow-gaging stations analyzed had upward trends in the annual maximum daily streamflow, while only 7 had downward trends (fig. 10B, table 5). Seven sites had statistically significant trends that were upward at five and downward at two. Four of the five sites that had statistically significant upward trends were located on unregulated streams in HUC 1111 that drain the southern Boston Mountains or northern Ouachita Mountains physiographic sections (sites 24–26 and 30), while the fifth site, Greer Spring (site 14), was located in HUC 1101, in the Springfield-Salem plateaus physiographic section of southeastern Missouri. The two sites that had statistically significant downward trends were located on regulated streams—one on the St. Francis River (site 2) downstream from Lake Wappapello in HUC 0802 in southeastern Missouri and the other on the Little River (site 33) in HUC 1114 in southwestern Arkansas. Sen slopes corresponding to statistically significant trends in the annual maximum daily streamflows ranged from -314.26 (ft³/s)/yr (site 33) to 177.66 (ft³/s)/yr (site 24). Expected annual rates of change corresponding to statistically significant trends in the annual maximum daily streamflows ranged from -1.13 percent (site 33) to 1.41 percent (site 24).

Twenty-three of 42 streamflow-gaging stations analyzed had upward trends in the annual minimum daily streamflow and 19 had downward trends (fig. 10C, table 6). Twenty-eight sites had statistically significant trends that were upward at 18 sites and downward at 10. Sites that had statistically significant upward trends were located in most HUC regions, while sites that had statistically significant downward trends were located in all HUC regions except 0805 and 1107. Eight of the 28 sites that had statistically significant trends were located on regulated streams; five of these sites (2, 22, 33, 36, and 38) had upward trends and three (4, 8, and 28) had downward trends. Sen slopes corresponding to statistically significant trends in the annual minimum daily streamflows ranged from -8.89 (ft³/s)/yr (site 4) to 7.28 (ft³/s)/yr (site 16). Expected annual rates of change corresponding to statistically significant trends in the annual minimum daily streamflows ranged from -4.92 percent (site 31) to 4.91 percent (site 22).

A. Autumn **B. Winter** **C. Spring** **D. Summer**

Significant trends occur when p is 0.10 or less. A positive expected annual rate of change indicates an upward trend, while a negative value indicates a downward trend. The magnitude of expected annual rate of change indicates the strength of the trend.

Figure 9. Results of Mann-Kendall test for monotonic trends in seasonal mean precipitation for *A*, physiographic sections in autumn; *B*, physiographic sections in winter; *C*, physiographic sections in spring; *D*, physiographic sections in summer; *E*, Hydrologic Unit Code regions in autumn; *F*, Hydrologic Unit Code regions in winter; *G*, Hydrologic Unit Code regions in spring; and *H*, Hydrologic Unit Code regions in summer, 1951–2011.

E. Autumn

F. Winter

G. Spring

H. Summer

EXPLANATION

HUC-0805
HUC (Hydrologic Unit Code, level 4) region
Arkansas State boundary

Significant trends occur when p is 0.10 or less. A positive expected annual rate of change indicates an upward trend, while a negative value indicates a downward trend. The magnitude of expected annual rate of change indicates the strength of the trend.

Figure 9. Results of Mann-Kendall test for monotonic trends in seasonal mean precipitation for *A*, physiographic sections in autumn; *B*, physiographic sections in winter; *C*, physiographic sections in spring; *D*, physiographic sections in summer; *E*, Hydrologic Unit Code regions in autumn; *F*, Hydrologic Unit Code regions in winter; *G*, Hydrologic Unit Code regions in spring; and *H*, Hydrologic Unit Code regions in summer, 1951–2011.—Continued

Figure 10. Results of Mann-Kendall test for monotonic trends in *A*, annual mean daily streamflows; *B*, annual maximum daily streamflows; and *C*, annual minimum daily streamflows of selected continuous-record U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma, 1951–2011.

B. Annual maximum daily streamflows

Figure 10. Results of Mann-Kendall test for monotonic trends in *A*, annual mean daily streamflows; *B*, annual maximum daily streamflows; and *C*, annual minimum daily streamflows of selected continuous-record U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma, 1951–2011.—Continued

C. Annual minimum daily streamflows

Figure 10. Results of Mann-Kendall test for monotonic trends in *A*, annual mean daily streamflows; *B*, annual maximum daily streamflows; and *C*, annual minimum daily streamflows of selected continuous-record U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma, 1951–2011.—Continued

Trends in Seasonal Streamflows

Autumn

Twenty-eight of 30 streamflow-gaging stations analyzed had upward trends in the autumn mean daily streamflow, while only 2 (sites 34 and 41) had downward trends (fig. 11A, table 7). Trends were statistically significant at 10 sites, and all statistically significant trends were upward. Seven of the 10 sites that had statistically significant trends (sites 1 and 11–16) were located on streams or springs in parts of HUCs 0802 and 1101 that drain the eastern part of the Springfield-Salem plateaus, while the remaining three sites (30, 31, and 39) were located on streams in HUCs 1111, 0802, and 0804 that drain the northeastern Ouachita Mountains and parts of the West Gulf Coastal Plain and the Mississippi Alluvial Plain. Sen slopes corresponding to statistically significant trends in the autumn mean daily streamflow ranged from 1.56 (ft³/s)/yr (site 11) to 34.96 (ft³/s)/yr (site 16). Expected annual rates of change corresponding to statistically significant trends in the autumn mean daily streamflow ranged from 0.43 percent (site 11) to 1.61 percent (site 39).

Winter

Twenty-six of 30 streamflow-gaging stations analyzed had upward trends in the winter mean daily streamflow, while only four (sites 18, 27, 29, and 35) had downward trends (fig. 11B, table 7). Six sites had statistically significant trends that were upward at five (sites 5, 13, 14, 19, and 20) and downward at one (site 18). The five sites that had statistically significant upward trends were located on streams in HUCs 1101, 1107, or 1111 that drain the Springfield-Salem plateaus, while the one that had a statistically significant downward trend (site 18) was located in HUC 0802 in the Mississippi Alluvial Plain. Sen slopes corresponding to statistically significant trends in the winter mean daily streamflow ranged from -12.56 (ft³/s)/yr (site 18) to 10.48 (ft³/s)/yr (site 13). Expected annual rates of change corresponding to statistically significant trends in the winter mean daily streamflow ranged from -0.71 percent (site 18) to 0.99 percent (site 19).

Spring

Sixteen of 30 streamflow-gaging stations analyzed had upward trends in the spring mean daily streamflow and 14 had downward trends (fig. 11C, table 7); none of the trends were statistically significant. Spring mean daily streamflows generally trended upward in northern and western Arkansas and southern Missouri, and downward in central, southern, and eastern Arkansas.

Summer

Twenty-one of 30 streamflow-gaging stations analyzed had upward trends in the summer mean daily streamflow and 9

had downward trends (fig. 11D, table 7). Nine sites had statistically significant trends that were upward at eight sites and downward at one (site 29). The eight sites that had statistically significant upward trends were located on streams in HUCs 1101 or 0802 that drain the eastern part of the Springfield-Salem plateaus, or on streams in HUCs 0802 or 0804 that drain the Mississippi Alluvial Plain. The one site that had a statistically significant downward trend (site 29) was located in HUC 1111, in the Arkansas Valley. Sen slopes corresponding to statistically significant trends in the summer mean daily streamflow ranged from -0.57 (ft³/s)/yr (site 29) to 7.18 (ft³/s)/yr (site 18). Expected annual rates of change corresponding to statistically significant trends in the summer mean daily streamflow ranged from -2.99 percent (site 29) to 1.30 percent (site 18).

Trends in Annual Pool Elevations of U.S. Army Corps of Engineers Reservoirs

Of 16 reservoirs analyzed, 14 had upward trends in their annual mean daily pool elevations, while only 2 had downward trends (fig. 12A, table 8). Eleven of the 16 sites had statistically significant trends that were upward at 10 sites and downward at 1 site (site 60). Sites that had statistically significant upward trends included all six reservoirs in HUC 1101 (sites 44 and 65–69), two in HUC 1111 (sites 56 and 57), and two in HUC 0804 (sites 58 and 59). The one site that had a statistically significant downward trend was DeGray Lake (site 60) in HUC 0804. Sen slopes corresponding to statistically significant trends in annual mean daily pool elevations ranged from -0.06 ft/yr (site 60) to 0.25 ft/yr (site 65). Expected annual rates of change corresponding to statistically significant trends in annual mean daily pool elevations ranged from -0.01 percent (site 60) to 0.03 percent (sites 67 and 69).

Of 16 reservoirs analyzed, 11 had upward trends in their annual maximum daily pool elevations and 5 had downward trends (fig. 12B, table 9). Eight sites had statistically significant trends that were upward at six (sites 58 and 65–69) and downward at two (sites 43 and 61). Of the six sites that had statistically significant upward trends, five were reservoirs in HUC 1101 (sites 65–69), while the remaining one was Lake Ouachita (site 58) in HUC 0804. Two sites had statistically significant downward trends, Lake Chicot in HUC 0805 (site 43) and Millwood Lake in HUC 1114 (site 61). Sen slopes corresponding to statistically significant trends in annual maximum daily pool elevations ranged from -0.14 ft/yr (site 43) to 0.37 ft/yr (site 69). Expected annual rates of change corresponding to statistically significant trends in annual maximum daily pool elevations ranged from -0.12 percent (site 43) to 0.06 percent (site 67).

Figure 11. Results of Mann-Kendall test for monotonic trends in seasonal mean daily streamflows of unregulated continuous-record U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma during *A*, autumn, *B*, winter; *C*, spring; and *D*, summer, 1951–2011.

Figure 12. Results of Mann-Kendall test for monotonic trends in *A*, annual mean daily pool elevations; *B*, annual maximum daily pool elevations; and *C*, annual minimum daily pool elevations of selected U.S. Army Corps of Engineers reservoirs in Arkansas and Missouri, 1951–2011.

Figure 12. Results of Mann-Kendall test for monotonic trends in A, annual mean daily pool elevations; B, annual maximum daily pool elevations; and C, annual minimum daily pool elevations of selected U.S. Army Corps of Engineers reservoirs in Arkansas and Missouri, 1951–2011.—Continued

Figure 12. Results of Mann-Kendall test for monotonic trends in *A*, annual mean daily pool elevations; *B*, annual maximum daily pool elevations; and *C*, annual minimum daily pool elevations of selected U.S. Army Corps of Engineers reservoirs in Arkansas and Missouri, 1951–2011.—Continued

Of 16 reservoirs analyzed, 13 had upward trends in their annual minimum daily pool elevations, while only 3 (sites 60, 62, and 63) had downward trends (fig. 12C, table 10). Thirteen sites had statistically significant trends that were upward at 12 and downward at 1 (site 60). Sites that had statistically significant upward trends included all reservoirs in HUC 1101 (sites 44 and 65–69), two in HUC 1111 (sites 56 and 57), and two in HUC 0804 (sites 58 and 59). The one site that had a statistically significant downward trend (site 60) was DeGray Lake, located in HUC 0804. Sen slopes corresponding to statistically significant trends in annual minimum daily pool elevations ranged from -0.05 ft/yr (site 60) to 0.30 ft/yr (site 65); expected annual rates of change corresponding to statistically significant trends in annual minimum daily pool elevations ranged from -0.01 percent (site 60) to 0.04 percent (sites 43 and 69).

Trends in Annual Releases from U.S. Army Corps of Engineers Reservoirs and Dams on the Arkansas River

Of the 15 reservoirs for which releases were analyzed (releases from site 43, Lake Chicot, were not analyzed), 10 had upward trends in annual mean daily releases and 5 had downward trends (fig. 13A, table 11). Four sites had statistically significant trends that were upward at three (sites 44, 65, and 67) and downward at one (site 62). Of the sites that had statistically significant upward trends, all were reservoirs in HUC 1101 (sites 44, 65, and 67). The one site that had a statistically significant downward trend was DeQueen Lake (site 62) in HUC 1114. All 11 dams on the Arkansas River had upward trends in their annual mean daily releases; however, none of the trends was statistically significant. Sen slopes corresponding to statistically significant trends in annual mean daily releases ranged from -4.65 (ft³/s)/yr (site 62) to 39.29 (ft³/s)/yr (site 67); expected annual rates of change corresponding to statistically significant trends in annual mean daily releases ranged from -0.25 percent (site 62) to 0.84 percent (site 65).

Of 15 reservoirs analyzed, 9 had upward trends in their annual maximum daily releases and 6 had downward trends (fig. 13B, table 12). Nine sites had statistically significant trends that were upward at six (sites 44, 56, 65–67, and 69) and downward at three (sites 60, 62–63). Of the six sites that had statistically significant upward trends, five were reservoirs in HUC 1101 (sites 44, 65–67, and 69), and the other was Blue Mountain Lake in HUC 1111 (site 56). Of the three sites that had statistically significant downward trends, two were reservoirs in HUC 1114 (sites 62 and 63), and the other was DeGray Lake in HUC 0804 (site 60). All 11 Arkansas River

dams analyzed had upward trends in their annual maximum daily releases; however, none of the trends was significant. Sen slopes corresponding to statistically significant trends in annual maximum daily releases ranged from -8.14 (ft³/s)/yr (site 60) to 137.62 (ft³/s)/yr (site 67). Expected annual rates of change corresponding to statistically significant trends in annual maximum daily releases ranged from -0.32 percent (site 63) to 1.26 percent (site 65).

Twelve of 15 reservoirs analyzed had upward trends in the annual number of low-flow days, while 3 had downward trends (fig. 14, table 13). Eight sites had statistically significant trends that were upward at seven (sites 44, 58–60, 62, 63, and 67) and downward at one (site 57). The seven sites that had statistically significant upward trends were two reservoirs in HUC 1101 (sites 44 and 67), three in HUC 0804 (sites 58–60), and two in HUC 1114 (sites 62 and 63). Of 11 dams on the Arkansas River, 9 had upward trends and 2 had downward trends (sites 54 and 55); 8 of the upward trends were statistically significant and occurred at all dams from Wilbur D. Mills Dam (Dam 2) upstream to Arthur V. Ormond Lock and Dam (Lock and Dam 9) (sites 45–52).

Discussion of Spatial Patterns of Trends

Trends in Annual Precipitation

Sen slopes and expected annual rates of change corresponding to trends in mean annual precipitation were greater for HUC regions and physiographic sections in northern and western Arkansas than for those in southern and eastern Arkansas with the exception of the Ouachita Mountains. The Ouachita Mountains and physiographic sections and HUC regions in northern and western Arkansas (the Springfield-Salem plateaus and HUCs 1101, 1107, and 1111) all had Sen slopes of approximately 0.11 to 0.12 in/yr and expected annual rates of change of 0.19 percent or greater; trends in annual mean precipitation were statistically significant ($p \leq 0.10$) in these regions (fig. 8; table 3). Regions in southern and eastern Arkansas (the West Gulf Coastal Plain, the Mississippi Alluvial Plain, and HUCs 0802, 0804, 0805, and 1114) all had Sen slopes of 0.10 in/yr or less and expected annual rates of change of 0.21 percent or less; trends in annual mean precipitation were not statistically significant in these regions. The Boston Mountains and the Mississippi Alluvial Plain had the lowest Sen slopes (less than 0.03 in/yr) and expected annual rates of change (less than 0.06 percent) in mean annual precipitation.

Figure 13. Results of Mann-Kendall test for monotonic trends in **A**, annual mean daily releases and **B**, annual maximum daily releases from selected U.S. Army Corps of Engineers reservoirs in Arkansas and Missouri and from U.S. Army Corps of Engineers dams on the Arkansas River in Arkansas, 1951–2011.

Figure 13. Results of Mann-Kendall test for monotonic trends in *A*, annual mean daily releases and *B*, annual maximum daily releases from selected U.S. Army Corps of Engineers reservoirs in Arkansas and Missouri and from U.S. Army Corps of Engineers dams on the Arkansas River in Arkansas, 1951–2011.—Continued

Figure 14. Results of Mann-Kendall test for monotonic trends in annual number of days below 10th percentile daily release from selected U.S. Army Corps of Engineers (USACE) reservoirs in Arkansas and Missouri and annual number of days below 1,000 cubic feet per second daily release from USACE dams on the Arkansas River in Arkansas, 1951–2011.

Statewide droughts coincided with large negative departures from the long-term median precipitation and to downward cycles in the 5-year weighted average of departures from the long-term median precipitation (fig. 6). Two long-term periods of drought were experienced from 1952 to 1956 and 1962 to 1967. Although not as severe, the early 1980s (1980 to 1983) have been referenced as a major period of drought in Arkansas (Mahon and Poynter, 1993) that instigated changes in water-use policy and reporting (Baker, 1990); 1980 was the fifth driest year during the analysis period and the ninth overall since the late 19th century according to records from the National Oceanic and Atmospheric Administration (2013). A more recent period of drought occurred from 2003 to 2007; in fact, the second largest negative departure from the long-term median precipitation during the period from 1951 to 2011 occurred in 2005.

Years having large positive departures from the long-term median annual precipitation did not necessarily indicate years during which extreme flooding occurred, as flooding is often localized and factors such as preexisting hydrologic conditions, duration of precipitation, and timing of precipitation determine whether or not precipitation results in flooding. For example, although 1957 and 2009 were the two wettest years during the analysis period, widespread flooding was not reported during those years, and despite record flooding that occurred in southern and central Arkansas in 1968 (Gilstrap, 1972) and in northern and eastern Arkansas in 2011 (Westerman and others, 2013), 1968 and 2011 had only moderate positive departures of approximately 10 and 6 in/yr, respectively, from the long-term median annual precipitation (fig. 6).

Trends in Seasonal Precipitation

The Ouachita Mountains received more precipitation than the other physiographic sections in Arkansas during all seasons except summer and winter, and the Springfield-Salem plateaus received less precipitation than other regions during all seasons except summer (fig. 7A, table 3). Physiographic sections in southern and eastern Arkansas (the Ouachita Mountains, West Gulf Coastal Plain, and Mississippi Alluvial Plain) received more precipitation during autumn and winter than those in northern and western Arkansas (the Springfield-Salem plateaus, Boston Mountains, and Arkansas Valley). All physiographic sections in Arkansas received more precipitation during spring than any other season, with a long-term mean of more than 13 inches observed in all regions (table 3). Most physiographic sections in Arkansas received less precipitation during summer than any other season, with the exception of the two northern-most sections, the Springfield-Salem plateaus and the Boston Mountains, which received the least amount of precipitation during winter. The Ouachita Mountains received slightly more precipitation during summer than the Boston Mountains.

In similar fashion, HUC regions in southern and eastern Arkansas (0802, 0804, 0805, and 1114) received more precipitation during autumn and winter than those in northern and western Arkansas (1101, 1107, and 1111), which received the least amount of precipitation during winter (fig. 7B, table 3). All HUC regions in Arkansas except 0805 received more precipitation during spring than any other season, with a long-term mean of more than 13 inches observed in all regions (table 3). HUC regions in northern and western Arkansas (1101, 1107, and 1111) received more precipitation during summer than those in southern and eastern Arkansas (0802, 0805, and 1114), which received the least amount of precipitation during summer.

Autumn and winter were the only two seasons that had statistically significant trends in precipitation. Five of six physiographic sections and six of seven HUC regions in Arkansas had statistically significant upward trends in precipitation during autumn, with Sen slopes of approximately 0.06 to 0.10 in/yr (fig. 9A, E, table 3). The observed trends are consistent with increases in autumn precipitation observed nationwide during the period from 1940 to 1999 (Lins and Slack, 1999). Trends in winter precipitation were not as widespread as those in autumn precipitation; statistically significant downward trends in winter precipitation were observed for only one of six physiographic sections and one of seven HUC regions, both located in eastern Arkansas.

Trends in the autumn precipitation had greater significance (lower p-values), greater Sen slopes, and higher expected annual rates of change in the Ouachita Mountains and in HUC 0802 in eastern Arkansas than in other physiographic sections or HUC regions (fig. 9A, E, table 3). Sen slopes were 0.06 to 0.08 in/yr in all regions with statistically significant trends except the Ouachita Mountains, which had a Sen slope of approximately 0.10 in/yr. Expected annual rates of change were approximately 0.60 percent for most regions but were higher in the Ouachita Mountains (0.70 percent) and HUC 0802 in eastern Arkansas (0.73 percent). The Boston Mountains in northern Arkansas and HUC 1107 in far northwestern Arkansas were the only two regions analyzed that did not have statistically significant upward trends in the autumn precipitation.

Statistically significant downward trends in winter precipitation occurred in the Mississippi Alluvial Plain and HUC 0802 in eastern Arkansas (fig. 9B, F, table 3). The trends in winter precipitation were associated with less significance (higher p-values), lesser Sen slopes (approximately -0.04 in/yr), and lower expected annual rates of change (approximately -0.30 percent) than the trends in the autumn precipitation (table 3).

Trends in Annual Streamflows

Sixteen sites had statistically significant upward trends in the annual mean daily streamflow and were located on streams that drained physiographic sections or HUC regions with

statistically significant upward trends in annual precipitation (the Springfield-Salem plateaus or Ouachita Mountains, and HUCs 1101, 1107, and 1111) (figs. 8, 10A). Ten of these 16 sites were located on the upper St. Francis River (sites 1 and 2) or the Black River and its tributaries (sites 9–16) in southeastern Missouri or northeastern Arkansas. Trends in the annual mean daily streamflows of sites on regulated streams were generally consistent with trends in the annual mean daily releases from upstream reservoirs (fig. 13A). Expected annual rates of change corresponding to statistically significant trends in annual mean daily streamflows, which ranged from 0.32 to 0.88 percent, were greater than those corresponding to regions with statistically significant upward trends in annual precipitation, which ranged from 0.19 to 0.28 percent, suggesting that the observed trends in regional annual precipitation do not fully account for the observed trends in annual mean daily streamflows (tables 3–4). Other factors, including (but not limited to) watershed-scale variability in precipitation, evapotranspiration, wastewater-treatment plant discharges, withdrawals for water supply, and stream losses to or gains from groundwater, may account for the difference between the expected annual rates of change observed in annual mean daily streamflows and regional annual precipitation.

Trends in annual maximum daily streamflows were similar to trends in the annual mean daily streamflows—only seven of 42 sites analyzed (sites 2, 31–34, 38, and 39) had differences in the directions of the trends in the two metrics—but were only statistically significant at seven sites (figs. 10A, B; tables 4–5). Only two of the seven statistically significant trends were downward, and both occurred at sites on regulated streams (sites 2 and 33). Trends at these and other sites on regulated streams were generally consistent with the trends in the annual maximum daily releases from the upstream reservoirs (figs. 10B, 13B, tables 5, 12). Expected annual rates of change corresponding to the statistically significant trends in the annual maximums were generally greater than those corresponding to the statistically significant trends in the annual means (tables 4–5). An area of interest with respect to annual maximum daily streamflows is the Boston Mountains; streams that drain the southern part of the region (sites 24–26) had statistically significant upward trends, while streams that drain the northern part of the region (sites 6 and 21) had upward trends that were not statistically significant. The greater significance of trends at sites in the southern part of the region (table 5) is attributed to orographic effects of the Boston Mountains. Storm systems typically approach the Boston Mountains from the southwest and experience orographic lifting as they move north toward the high ridges that form the divide between the watersheds of the White River (HUC 1101) and the Arkansas River (HUC 1111), resulting in more rain falling in watersheds on the southern side of the Boston Mountains than in those on the northern side. Areas of relatively higher precipitation in the Boston Mountains can be seen in the contour map of mean annual

precipitation for Arkansas, 1951–2011 (Pugh and Westerman, in press).

There were more statistically significant trends (28 of 42 sites) and greater expected annual rates of change in the annual minimum daily streamflows than in the annual means or maximums (fig. 10; tables 4–6). Sites located in regions in northern and western Arkansas and southeastern Missouri generally had upward trends in their annual minimum daily streamflows, while sites in eastern and southern Arkansas generally had downward trends. Trends in the annual minimum daily streamflows at sites on regulated streams were not necessarily consistent with trends in the annual number of low-flow days at upstream reservoirs (figs. 10C, 14).

Fifteen of the 28 sites that had statistically significant trends in the annual minimum daily streamflow had expected annual rates of change that exceeded ± 1 percent (table 6). Trends at these sites were likely influenced by factors other than precipitation, such as diversions for irrigation or water supply, losses to groundwater, evapotranspiration, wastewater-treatment plant discharges, or reservoir regulation. Seven sites in eastern and southern Arkansas and northern Louisiana (sites 4, 18, 31, 34, 40, 41, and 42) had statistically significant ($p \leq 0.10$) downward trends in annual minimum daily streamflows that were among the most statistically significant trends in the metric (all but sites 4 and 34 had p -values less than 0.01). Expected annual rates of change associated with these sites ranged from -1.67 percent (site 34) to -4.92 percent (site 31). Parts of the watersheds of the seven sites are within or near to one of three critical groundwater areas (Arkansas Natural Resources Commission, 2006) (fig. 10C). The trends at these sites are attributed, at least in part, to stream losses to groundwater owing to declining groundwater levels in those areas. Two sites in southwestern Missouri (sites 5 and 19) and three sites in northern and western Arkansas (sites 20, 22, and 23) had statistically significant upward trends in the annual minimum daily streamflows and expected annual rates of change that were greater than those associated with sites on other streams (for example, see sites 7, 24, and 26) and ranged from 0.74 percent (site 5) to 4.91 percent (site 22) (table 6). The trends at these sites are attributed, at least in part, to increases in discharge from wastewater-treatment plants into the watersheds of these streams during the analysis period. Perhaps the best example is the Illinois River in northwestern Arkansas. Three of the largest municipalities in northwestern Arkansas, Fayetteville, Springdale, and Rogers, discharge treated wastewater into tributaries of the Illinois River upstream from the USGS streamflow-gaging station at Watts, Okla. (site 20). The populations of the three cities and discharges from their wastewater-treatment plants have increased substantially during the period of 1951–2011. Fayetteville's population increased from approximately 17,000 in 1950 to approximately 73,000 in 2010 (U.S. Census Bureau, 2013); annual mean daily discharge from the wastewater-treatment plant increased from approximately 4.1 million gallons per day (Mgal/d) in 1989 to approximately

6.3 Mgal/d in 2011, a 54-percent increase (Duyen Tran, CH2M Hill, written commun., 2013). Springdale's population increased from approximately 6,000 in 1950 to slightly less than 70,000 in 2010 (U.S. Census Bureau, 2013); annual mean daily discharge from the wastewater-treatment plant increased from approximately 2.6 Mgal/d in 1989 to approximately 4.3 Mgal/d in 2011, a 65-percent increase (Jennifer Enos, Springdale Water Utilities, written commun., 2013). Rogers' population increased from approximately 5,000 in 1950 to slightly less than 56,000 in 2010 (U.S. Census Bureau, 2013); annual mean daily discharge from the wastewater-treatment plant increased from approximately 3.6 Mgal/d in 1989 to approximately 7.7 Mgal/d in 2011, a 114-percent increase (Patrick Pruitt, Rogers Water Utilities, written commun., 2013).

Trends in Seasonal Streamflows

Trends in seasonal mean streamflows were analyzed for 30 USGS streamflow-gaging stations on unregulated streams. Trends were generally upward in autumn and winter (fig. 11A, B), but during spring and summer, sites in northern and western Arkansas, southern Missouri, and eastern Oklahoma had upward trends, while sites in southern and eastern Arkansas and northern Louisiana tended to have downward trends (fig. 11C, D). Despite autumn being the only season that had statistically significant upward trends in precipitation (fig. 9), statistically significant upward trends were observed in streamflows during all seasons except spring.

Of 30 sites analyzed, 10 had statistically significant upward trends in the autumn mean daily streamflow (fig. 11A). Expected annual rates of change corresponding to these trends ranged from 0.43 to 1.61 percent (table 7), but most sites were similar to those corresponding to statistically significant trends in regional autumn precipitation, which ranged from 0.53 to 0.73 percent (table 3). Sites that had statistically significant upward trends in the autumn mean daily streamflow were located on the upper St. Francis River in southeastern Missouri (site 1), the Black River and its tributaries in southeastern Missouri and northeastern Arkansas (sites 11–16), or streams that drain the northeastern part of the Ouachita Mountains (sites 30, 31, and 39). Upward trends observed in autumn streamflows are consistent with increases in low- to moderate-percentile streamflows, which typically occur during late summer and autumn, observed nationwide during the period from 1940 to 1999 (Lins and Slack, 1999).

Similar to autumn, most sites analyzed had upward trends in the winter mean daily streamflow; however, there were only six statistically significant trends, one of which was downward (fig. 11B) (table 7). The Cache River (site 18) in eastern Arkansas had a statistically significant downward trend that was consistent with statistically significant downward trends observed in the winter mean precipitation in the Mississippi Alluvial Plain and HUC 0802 (fig. 9B, F). The five remaining

sites that had statistically significant trends (sites 5, 13, 14, 19, and 20) were located in southern Missouri or northern Arkansas in the Springfield-Salem plateaus or HUCs 1101, 1107, or 1111.

Spring mean daily streamflows generally trended upward for sites in northern and western Arkansas, eastern Oklahoma, and southern Missouri, and downward for sites in southern and eastern Arkansas and northern Louisiana (fig. 11C). None of the 30 sites analyzed had statistically significant trends in the spring mean daily streamflows (table 7).

Summer mean daily streamflows generally trended upward in northern and western Arkansas, eastern Oklahoma, and southern Missouri, and downward in southern and eastern Arkansas and northern Louisiana (fig. 11D). Nine of 30 sites analyzed had statistically significant trends, eight of which were upward (table 7). Similar to trends in the annual mean and minimum and autumn mean daily streamflows, sites on the Black River and its tributaries in southeastern Missouri and northeastern Arkansas (sites 9 and 11–16) had statistically significant upward trends. Despite having parts of their watersheds located within critical groundwater areas, the Cache River (site 18) and Bayou Bartholomew (site 40) had statistically significant upward trends. These anomalously upward trends may be the result of increases in irrigation return flows during the analysis period, as statistically significant trends were not observed in summer precipitation in eastern Arkansas (fig. 9D, H) and other sites in the region had downward trends. A statistically significant downward trend was observed in the summer mean daily streamflow of Cadron Creek (site 29), which also had nonsignificant downward trends in all annual streamflow metrics (fig. 10A, table 7) and in all seasonal streamflows except autumn (fig. 11, table 7). The downward trends are attributed in part to reported diversions from Cadron Creek upstream from the site, which have increased from approximately 5,000 gallons per day (gal/d) (0.01 ft³/s, 0.05 percent of the median summer streamflow) in 2007 to 1.61 Mgal/d (2.49 ft³/s, 13 percent of the median summer streamflow) in 2011 (Terrance W. Holland, U.S. Geological Survey, written commun., 2013), and to the rain shadow effect of the Ouachita Mountains on the Arkansas Valley, which is evident on the contour map of mean annual precipitation for Arkansas for the period from 1951 to 2011 (Pugh and Westerman, in press).

Trends in Annual Pool Elevations of U.S. Army Corps of Engineers Reservoirs

Trends in the annual mean, maximum, and minimum daily pool elevations of USACE reservoirs were consistent between metrics for reservoirs in the White River watershed (HUC 1101, sites 44 and 65–69), the Arkansas River watershed (HUC 1111, sites 56 and 57), and the Ouachita River watershed (HUC 0804, sites 58–60) (fig. 12A–C), while trends varied between metrics at DeQueen Lake (HUC 1114,

site 62), Millwood Lake (HUC 1114, site 61), and Lake Chicot (HUC 0805, site 43). Most of the statistically significant trends in pool elevation metrics were upward and gradual—Sen slopes were less than 0.37 ft/yr (tables 8, 9, 10)—and were likely the result of changes in reservoir regulation plans. The White River system, for example, has experienced several changes in regulation procedures since the reservoirs were completed. A flood regulation plan was first developed in 1952 for Bull Shoals and Norfork Dams. Following the completion of Beaver Dam in 1963, a new regulation plan was implemented for the Beaver, Table Rock, Bull Shoals, and Norfork reservoir system; this plan was revised in 1966, 1993, and, finally, in 1998 (U.S. Army Corps of Engineers, 2013). The changes to the regulation plan have resulted in many benefits that include, but are not limited to, increased storage for water supply and the prevention of losses to agricultural resources downstream. The increased retention has resulted in statistically significant upward trends in pool elevation metrics for lakes in the White River watershed. Similar revisions have been made to regulation plans for the other USACE reservoirs in the study area, and trends in pool elevation metrics for those reservoirs can likely be attributed to changes in operational procedures.

Trends in Annual Releases from U.S. Army Corps of Engineers Reservoirs

Trends in the annual mean and maximum daily releases from USACE reservoirs were generally upward in all HUC regions except 1114 (fig. 13A, B, tables 11, 12). Statistically significant upward trends occurred in one or both metrics at Blue Mountain Lake (site 56) and all reservoirs in the White River watershed (HUC 1101) except Norfork Lake (site 68), while statistically significant downward trends in one or both metrics occurred at three reservoirs (sites 60, 62, 63) in the southern part of the Ouachita Mountains (HUCs 0804 and 1114). There were few statistically significant trends (only 4 of 26 sites) in the annual mean daily releases because the reservoirs are operated to maintain a regulation stage at a downstream site according to guidelines set forth in the regulation plans of the reservoirs. Statistically significant upward trends in the annual maximum daily releases from reservoirs on the main stem of the White River (Beaver, Table Rock, and Bull Shoals Lakes) result, at least in part, from record releases late in the analysis period during the spring floods of 2008 and 2011.

The annual number of low-flow days was both increasing and decreasing for reservoirs in northern Arkansas and southern Missouri and generally increasing for reservoirs in southern Arkansas (fig. 14, table 13). In northern Arkansas, statistically significant ($p \leq 0.10$) upward trends were observed in the annual number of low-flow days at two reservoirs, Clearwater and Bull Shoals Lakes (sites 44 and 67, respectively). In southern Arkansas, statistically significant upward trends were observed in the annual number of

low-flow days at reservoirs in the Ouachita and Little River watersheds (HUC 0804, sites 58–60 and HUC 1114, sites 62 and 63) and at all dams on the Arkansas River downstream from and including Arthur V. Ormond Lock and Dam (HUC 1111, sites 45–52). The upward trends in the number of low-flow days in the lower reaches of the Arkansas River may result from public and private withdrawals from surface water and groundwater for water supply and irrigation. Previous studies have shown that the Arkansas River recharges the Arkansas River alluvial aquifer (Kilpatrick and Ludwig, 1990), and that intensive pumping of groundwater can induce flow from the Arkansas River to the alluvial aquifer (Mahon and Poynter, 1993; Bedinger and others, 1963; Bedinger and Jeffery, 1964).

Summary

Water managers at the Arkansas Natural Resources Commission needed to understand trends in the occurrence and availability of surface water to facilitate proper water resources management in the future. The U.S. Geological Survey (USGS) and the U.S. Army Corps of Engineers (USACE), in cooperation with the Arkansas Natural Resources Commission, conducted a statistical analysis of trends in precipitation, streamflow, reservoir pool elevations, and reservoir releases in Arkansas and parts of Louisiana, Missouri, and Oklahoma for the period from 1951 to 2011.

Annual and seasonal mean precipitation were computed from Parameter-elevation Regressions on Independent Slopes Model (PRISM) data for the entire State of Arkansas, six physiographic sections within the State, and seven regional four-digit hydrologic unit code regions (HUC). Annual mean, maximum, and minimum daily streamflows were computed from daily mean streamflow records of 42 continuous-record USGS streamflow-gaging stations. Seasonal mean daily streamflows were computed for 30 of the 42 streamflow-gaging stations that were located on unregulated streams. Annual mean, maximum, and minimum daily reservoir pool elevations and releases and the annual number of days below the 10th percentile daily release were computed from daily time-series data for 16 USACE reservoirs in Arkansas and Missouri. The annual mean and maximum release and the annual number of days below a 1,000 cubic feet per second (ft³/s) release were computed from daily time-series data for 11 USACE dams on the Arkansas River in Arkansas.

The Mann-Kendall test for Kendall's tau was used to test for monotonic trends in the daily time-series data of the various precipitation, streamflow, reservoir pool elevation, and reservoir release metrics. Results having a 10-percent level of significance ($p \leq 0.10$) were considered statistically significant. The USGS graphical user interface for R was used to compute summary statistics of the daily time-series data and execute the Mann-Kendall test. Kendall's tau (τ), the p-value, the Sen slope, the median of the input dataset, and the expected annual rate of change (computed as the ratio of the Sen slope to the

median, expressed as a percentage) corresponding to the trend in each metric were reported.

The mean annual precipitation for Arkansas for the period from 1951 to 2011 was 49.79 inches. Statewide droughts coincided with large negative departures from the long-term median annual precipitation and to downward cycles in the 5-year weighted average of departures from the long-term median annual precipitation. Years having large positive departures from the long-term median annual precipitation, such as 1957 and 2009, did not necessarily indicate years during which extreme flooding occurred, and widespread flooding in southern and central Arkansas in 1968 and in northern and eastern Arkansas in 2011 resulted in only moderate positive departures from the long-term median annual precipitation. A statistically significant upward trend in annual precipitation was observed for the State, with a Sen slope of approximately 0.10 inch per year. HUC regions in northern and western Arkansas, eastern Oklahoma, and southern Missouri, the Springfield-Salem Plateaus, and the Ouachita Mountains all had statistically significant upward trends in annual precipitation, with Sen slopes of approximately 0.10 to 0.12 inch per year.

Autumn and winter were the only two seasons that had statistically significant trends in precipitation. Five of six physiographic sections and six of seven HUC regions in Arkansas had statistically significant upward trends in autumn precipitation, with Sen slopes of approximately 0.06 to 0.10 in/yr. The observed trends are consistent with increases in autumn precipitation observed nationwide during the period from 1940 to 1999. Trends in winter precipitation were not as widespread as those in autumn precipitation; statistically significant downward trends in winter precipitation were observed for only one of six physiographic sections and one of seven HUC regions, both located in eastern Arkansas.

Of 42 streamflow-gaging stations analyzed, 39 had upward trends in the annual mean daily streamflow, while only three had downward trends. Sixteen sites had statistically significant upward trends in the annual mean daily streamflow and were located on streams that drained regions with statistically significant upward trends in annual precipitation (the Springfield-Salem plateaus or Ouachita Mountains, and HUCs 1101, 1107, and 1111). Ten of these 16 sites were located on the upper St. Francis River (sites 1 and 2) or the Black River and its tributaries (sites 9-16) in southeastern Missouri or northeastern Arkansas. Trends in the annual mean daily streamflows of sites on regulated streams were generally consistent with trends in the annual mean daily releases from upstream reservoirs. Expected annual rates of change corresponding to statistically significant trends, which ranged from 0.32 percent (site 11) to 0.88 percent (site 21), were greater than those corresponding to regions with statistically significant upward trends in annual precipitation, which ranged from 0.19 to 0.28 percent, suggesting that the observed trends in regional annual precipitation do not fully account for the observed trends in annual mean daily streamflows. Factors

including (but not limited to) watershed-scale variability in precipitation, evapotranspiration, wastewater-treatment plant discharges, withdrawals for water supply, and stream losses to or gains from groundwater may account for the difference between the expected annual rates of change observed in annual mean daily streamflows and regional annual precipitation.

Trends in annual maximum daily streamflows were similar to trends in the annual mean daily streamflows—only seven of 42 streamflow-gaging stations analyzed had differences in the directions of the trends in the two metrics—but were only statistically significant at seven sites. Trends at sites on regulated streams were generally consistent with the trends in the annual maximum daily releases from the upstream reservoirs. Expected annual rates of change corresponding to statistically significant trends in the annual maximum daily streamflows were greater than those corresponding to trends in the annual means and ranged from -1.13 to 1.41 percent.

There were more statistically significant trends (28 of 42 sites) and greater expected annual rates of change in the annual minimum daily streamflows than in the annual means or maximums. Sites located in regions in northern and western Arkansas and southeastern Missouri generally had upward trends in their annual minimum daily streamflows, while sites in eastern and southern Arkansas generally had downward trends. Statistically significant trends were upward at 18 sites and downward at 10. Sites that had statistically significant upward trends were located in all HUC regions except 0805, while sites that had statistically significant downward trends were located in all HUC regions except 0805 and 1107. Trends in the annual minimum daily streamflows at sites on regulated streams were not necessarily consistent with trends in the annual number of low-flow days at upstream reservoirs.

Fifteen of the 28 sites that had statistically significant trends in the annual minimum daily streamflow had expected annual rates of change that exceeded ± 1 percent. Trends at these sites were likely influenced by factors other than precipitation, such as diversions for irrigation or water supply, losses to groundwater, evapotranspiration, wastewater-treatment plant discharges, or reservoir regulation.

Trends in seasonal mean streamflows were analyzed for 30 USGS streamflow-gaging stations on unregulated streams. Trends were generally upward in autumn and winter, but in the spring and summer, sites in northern and western Arkansas, southern Missouri, and eastern Oklahoma had upward trends, while sites in southern and eastern Arkansas and northern Louisiana tended to have downward trends. Despite autumn being the only season that had statistically significant upward trends in seasonal precipitation, statistically significant upward trends in streamflows occurred in all seasons except spring. Trends in seasonal mean daily streamflows were statistically significant at 10 sites during autumn, 6 sites during winter, and 9 sites during summer. Expected annual rates of change

corresponding to statistically significant trends in seasonal mean daily streamflows ranged from 0.43 to 1.61 percent in autumn, -0.71 to 0.99 percent in winter, and -2.99 to 1.30 percent in summer.

Trends in the annual mean, maximum, and minimum daily pool elevations of USACE reservoirs were consistent between metrics for reservoirs in the White, Arkansas, and Ouachita River watersheds, while trends varied between metrics at DeQueen Lake, Millwood Lake, and Lake Chicot. Most of the statistically significant trends in pool elevation metrics were upward and gradual—Sen slopes were less than 0.37 foot per year—and were likely the result of changes in reservoir regulation plans.

Trends in the annual mean and maximum daily releases from USACE reservoirs were generally upward in all HUC regions. There were few statistically significant trends in the annual mean daily releases because the reservoirs are operated to maintain a regulation stage at a downstream site according to guidelines set forth in the regulation plans of the reservoirs. Statistically significant ($p \leq 0.10$) upward trends occurred in one or both metrics at Blue Mountain Lake and all reservoirs in the White River watershed except Norfork Lake, while statistically significant downward trends occurred in one or both metrics at three reservoirs in the southern Ouachita Mountains. Statistically significant upward trends in the annual maximum daily releases from reservoirs on the White River (Beaver, Table Rock, and Bull Shoals Lakes) may result, in part, from record releases late in the analysis period during the spring floods of 2008 and 2011.

The annual number of low-flow days was both increasing and decreasing for reservoirs in northern Arkansas and southern Missouri and generally increasing for reservoirs in southern Arkansas. Statistically significant upward trends in the number of days below a 1,000 ft³/s release from dams on the Arkansas River downstream from and including Arthur V. Ormond Lock and Dam (Lock and Dam 9) may result from public and private withdrawals from surface water and groundwater for water supply and irrigation. Previous studies have shown that the Arkansas River recharges the Arkansas River alluvial aquifer and that intensive pumping of groundwater can induce flow from the Arkansas River to the alluvial aquifer.

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Table 1. Station information for selected continuous-record U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma.[HUC, four-digit hydrologic unit code region; mi, mile; mi², square miles; NA, not applicable]

Site identification number (fig. 1)	HUC	Station number	Station name	Contributing drainage area (mi ²)	Period of record	Regulated period	Period(s) used
Unregulated stations							
1	0802	07037500	St. Francis River at Patterson, Mo.	956	June 1921–December 2011	NA	January 1951–December 2011
5	1101	07052500	James River at Galena, Mo.	987	October 1921–December 2011	NA	January 1951–December 2011
6	1101	07056000	Buffalo River at St. Joe, Ark.	829	October 1939–December 2011	NA	January 1951–December 2011
7	1101	07057500	North Fork of White River near Tecumseh, Mo.	561	October 1944–December 2011	NA	January 1951–December 2011
9	1101	07061500	Black River near Annapolis, Mo.	484	April 1939–December 2011	NA	January 1951–December 2011
11	1101	07067500	Big Spring near Van Buren, Mo.	Unknown	October 1921–December 2011	NA	January 1951–December 2011
12	1101	07068000	Current River near Doniphan, Mo.	2,038	June 1921–December 2011	NA	January 1951–December 2011
13	1101	07069500	Spring River near Imboden, Ark.	1,180	April 1936–December 2011	NA	January 1951–December 2011
14	1101	07071000	Greer Spring near Greer, Mo.	Unknown	October 1921–December 2011	NA	January 1951–December 2011
15	1101	07072000	Eleven Point River near Ravenden Springs, Ark.	1,130	October 1929–December 2011	NA	January 1951–December 2011
16	1101	07072500	Black River at Black Rock, Ark.	7,370	October 1929–December 2011	NA	January 1951–December 2011
18	0802	07077500	Cache River at Patterson, Ark.	1,040	October 1927–November 2010	NA	January 1951–November 2010
19	1107	07189000	Elk River near Tiff City, Mo.	851	October 1939–December 2011	NA	January 1951–December 2011
20	1111	07195500	Illinois River near Watts, Okla.	630	October 1955–December 2011	NA	January 1956–December 2011
21	1111	07196900	Baron Fork at Dutch Mills, Ark.	40.6	April 1958–December 2011	NA	January 1959–December 2011
23	1111	07249400	James Fork near Hackett, Ark.	147	April 1958–December 2011	NA	January 1959–December 2011
24	1111	¹ 07249985	Lee Creek near Short, Okla. ¹	420	October 1930–December 2011	NA	January 1951–December 2011
25	1111	07252000	Mulberry River near Mulberry, Ark.	373	June 1938–December 2011	NA	January 1951–December 2011
26	1111	² 07257006	Big Piney Creek at Hwy 164 near Dover, Ark. ²	306	October 1950–December 2011	NA	January 1951–December 2011
27	1111	07258500	Petit Jean River near Booneville, Ark.	241	November 1938–December 2011	NA	January 1951–December 2011
29	1111	07261000	Cadron Creek near Guy, Ark.	169	October 1954–December 2011	NA	January 1955–December 2011
30	1111	07261500	Fourche LaFave River near Grav-elly, Ark.	410	March 1938–December 2011	NA	January 1951–December 2011
31	0802	07264000	Bayou Meto near Lonoke, Ark.	207	October 1954–December 2011	NA	January 1955–December 2011
34	0804	07348700	Bayou Dorcheat near Springhill, La.	605	October 1957–December 2011	NA	January 1958–December 2011
35	0804	07356000	Ouachita River near Mt. Ida, Ark.	414	October 1941–December 2011	NA	January 1951–December 2011
37	0804	07361500	Antoine River at Antoine, Ark.	178	October 1954–December 2011	NA	January 1955–December 2011
39	0804	07363500	Saline River near Rye, Ark.	2,100	October 1937–December 2011	NA	January 1951–December 2011
40	0804	07364150	Bayou Bartholomew near McGehee, Ark.	576	October 1938–December 2011	NA	January 1951–December 2011
41	0804	07364200	Bayou Bartholomew near Jones, La.	1,187	October 1957–December 2011	NA	January 1958–December 2011
42	0804	07366200	Little Corney Bayou near Lillie, La.	208	October 1955–December 2011	NA	January 1956–December 2011

Table 1. Station information for selected continuous-record U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma.—Continued[HUC, four-digit hydrologic unit code region; mi, mile; mi², square miles; NA, not applicable]

Site identification number (fig. 1)	HUC	Station number	Station name	Contributing drainage area (mi ²)	Period of record	Regulated period	Period(s) used
Regulated stations							
2	0802	07039500	St. Francis River at Wappapello, Mo.	1,311	October 1940–December 2011	August 1941–December 2011	January 1951–December 2011
3	0802	07040450	St. Francis River at Lake City, Ark.	2,370	January 1931–November 2010	August 1941–December 2011	January 1951–November 2010
4	0802	07047800	St. Francis River at Parkin, Ark.	³ 6,475	January 1935–April 2011	August 1941–December 2011	January 1951–December 2010
8	1101	07060500	White River at Calico Rock, Ark.	9,980	October 1939–December 2011	January 1945–December 2011	January 1951–December 2011
10	1101	07064000	Black River near Corning, Ark.	1,750	October 1938–December 2011	May 1948–December 2011	January 1951–December 2011
17	1101	07074500	White River at Newport, Ark.	19,900	October 1927–December 2011	May 1948–December 2011	January 1951–December 2011
22	1111	07247000	Poteau River at Cauthron, Ark.	203	March 1939–December 2011	September 1974–December 2011	January 1951–December 2011 January 1951–December 1974 (preregulation) January 1975–December 2011 (postregulation)
28	1111	07260500	Petit Jean River near Danville, Ark.	764	June 1916–December 2011	September 1947–December 2011	January 1951–December 2011
32	1114	07337000	Red River near Index, Ark.	48,000	October 1936–December 2011	October 1943–December 2011	January 1951–December 2011
33	1114	07340000	Little River near Horatio, Ark.	2,660	April 1931–December 2011	October 1968–December 2011	January 1951–December 2011 January 1951–December 1968 (preregulation) January 1969–December 2011 (postregulation)
36	0804	07359002	Ouachita River at Rammel Dam above Jones Mill, Ark.	1,550	October 1928–December 2011	October 1928–December 2011	January 1951–December 2011
38	0804	07362000	Ouachita River at Camden, Ark.	5,360	October 1928–December 2011	October 1928–December 2011	January 1951–December 2011

¹Prior to Oct. 1, 1992, station was located 3.8 mi downstream from current location and published as 07250000 Lee Creek near Van Buren, Ark. Drainage area at former location was 426 mi².²Prior to Oct. 1, 1992, station was located 4.7 mi upstream from current location and published as 07257000 Big Piney Creek near Dover, Ark.; prior to Oct. 1967, published as 07257000 Piney Creek near Dover, Ark. Drainage area at former location was 274 mi².³Combined drainage areas of stations 07047800 St. Francis River at Parkin, Ark. and 07047900 St. Francis Bay at Riverfront, Ark.

Table 2. Station information for selected U.S. Army Corps of Engineers reservoirs in Arkansas and Missouri and selected U.S. Army Corps of Engineers dams on the Arkansas River in Arkansas.

[HUC, four-digit hydrologic unit code region; mi², square miles]

Site identification number (fig. 1)	HUC	Reservoir or dam	Contributing drainage area (mi ²)	Period of record	Period used
Reservoirs					
43	0805	Lake Chicot	Unknown	January 1938–December 2011	January 1951–December 2011
44	1101	Clearwater Lake	898	April 1948–December 2011	January 1951–December 2011
56	1111	Blue Mountain Lake	488	March 1947–December 2011	January 1951–December 2011
57	1111	Nimrod Lake	680	January 1944–December 2011	January 1951–December 2011
58	0804	Lake Ouachita (Blakely Mountain Dam)	1,105	January 1961–December 2011	January 1961–December 2011
59	0804	Lake Greeson (Narrows Dam)	237	January 1962–December 2011	January 1951–2011 (releases); January 1962–December 2011 (pool elevation)
60	0804	DeGray Lake	435	January 1972–December 2011	January 1972–December 2011
61	1114	Millwood Lake	4,144	August 1966–December 2011	January 1967–December 2011
62	1114	DeQueen Lake	169	August 1973–December 2011	January 1974–December 2011
63	1114	Dierks Lake	114	December 1972–December 2011	January 1973–December 2011
64	1114	Gillham Lake	271	July 1973–December 2011	January 1974–December 2011
65	1101	Beaver Lake	1,186	February 1963–December 2011	January 1964–December 2011
66	1101	Table Rock Lake	4,020	September 1956–December 2011	January 1957–December 2011
			¹ 2,834		
67	1101	Bull Shoals Lake	6,036	January 1951–December 2011	January 1951–December 2011
			¹ 2,016		
68	1101	Norfork Lake	1,806	January 1945–December 2011	January 1951–December 2011
69	1101	Greers Ferry Lake	1,146	January 1962–December 2011	January 1962–December 2011
Arkansas River Dams					
45	0802	Wilbur D. Mills Dam (Dam 2)	160,475	July 1969–December 2011	January 1971–December 2011
			¹ 1,457		
46	0802	Joe Hardin Lock and Dam (Lock and Dam 3)	159,018	December 1968–December 2011	January 1971–December 2011
			¹ 241		
47	1111	Emmet Sanders Lock and Dam (Lock and Dam 4)	158,777	December 1968–December 2011	January 1971–December 2011
			¹ 99		
48	1111	Colonel Charles D. Maynard Lock and Dam (Lock and Dam 5)	158,678	December 1968–December 2011	January 1971–December 2011
			¹ 249		
49	1111	David D. Terry Lock and Dam (Lock and Dam 6)	158,429	September 1968–December 2011	January 1971–December 2011
			¹ 399		

Table 2. Station information for selected U.S. Army Corps of Engineers reservoirs in Arkansas and Missouri and selected U.S. Army Corps of Engineers dams on the Arkansas River in Arkansas.—Continued

[HUC, four-digit hydrologic unit code region; mi², square miles]

Site identification number (fig. 1)	HUC	Reservoir or dam	Contributing drainage area (mi ²)	Period of record	Period used
Arkansas River Dams—Continued					
50	1111	Murray Lock and Dam (Lock and Dam 7)	158,030 ¹ 1,627	October 1969-December 2011	January 1971–December 2011
51	1111	Toad Suck Ferry Lock and Dam (Lock and Dam 8)	156,403 ¹ 1,454	November 1969-December 2011	January 1971–December 2011
52	1111	Arthur V. Ormond Lock and Dam (Lock and Dam 9)	154,949 ¹ 1,283	November 1969-December 2011	January 1971–December 2011
53	1111	Dardanelle Lock and Dam (Lock and Dam 10)	153,666 ¹ 1,865	October 1964-December 2011	January 1971–December 2011
54	1111	Ozark Lock and Dam (Lock and Dam 12)	151,801 ¹ 1,254	December 1969-December 2011	January 1971–December 2011
55	1111	James W. Trimble Lock and Dam (Lock and Dam 13)	150,547 ¹ 2,463	December 1969-December 2011	January 1971–December 2011

¹Drainage area for areas between the upstream dam and selected dam.

Table 3. Precipitation metrics and results of Mann-Kendall test for monotonic trends in mean annual and seasonal precipitation in Arkansas, 1951–2011.

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). Expected annual rate of change is the ratio of the Sen slope to the median precipitation, expressed as a percentage. in., inches; in/yr, inches per year; HUC, four-digit hydrologic unit code region]

Region	Metric	Mean (in.)	Kendall's tau (τ)	p -value	Sen slope (in/yr)	Median (in.)	Expected annual rate of change (percent)	Minimum (in.)	Year minimum occurred	Maximum (in.)	Year maximum occurred
Statewide	Annual precipitation	49.79	0.15	0.08	0.0996	48.29	0.21	32.59	1963	71.40	1957
	Autumn precipitation	13.02	0.20	0.02	0.0770	12.69	0.61	4.13	2000	23.68	1984
	Winter precipitation	12.09	-0.05	0.55	-0.0136	11.45	-0.12	6.23	1967	21.94	1987
	Spring precipitation	14.16	0.04	0.66	0.0137	13.57	0.10	6.77	1988	25.73	1957
	Summer precipitation	10.52	-0.10	0.27	-0.0276	10.33	-0.27	4.84	1967	19.14	2011
Physiographic sections											
Springfield-Salem Plateaus	Annual precipitation	45.51	0.16	0.07	0.1190	44.80	0.27	28.08	1963	65.72	1973
	Autumn precipitation	11.43	0.18	0.04	0.0695	11.27	0.62	2.45	1972	24.67	1984
	Winter precipitation	10.02	0.03	0.77	0.0062	10.16	0.06	4.21	1965	18.99	1958
	Spring precipitation	13.47	0.05	0.56	0.0101	13.22	0.08	7.22	2005	25.66	1984
	Summer precipitation	10.59	0.04	0.62	0.0119	10.21	0.12	4.83	1954	17.00	1957
Mississippi Alluvial Plain	Annual precipitation	49.89	0.04	0.62	0.0308	48.08	0.06	33.48	1963	72.81	1957
	Autumn precipitation	13.13	0.21	0.02	0.0802	12.00	0.67	4.14	2005	24.59	2001
	Winter precipitation	13.13	-0.15	0.08	-0.0376	12.76	-0.29	6.42	1983	22.64	1990
	Spring precipitation	13.70	0.01	0.92	0.0027	13.04	0.02	5.73	1988	23.63	1991
	Summer precipitation	9.92	-0.12	0.19	-0.0267	9.81	-0.27	3.89	2000	17.88	2009
Boston Mountains	Annual precipitation	49.07	0.14	0.12	0.0308	48.08	0.06	27.20	1963	74.13	1973
	Autumn precipitation	12.43	0.14	0.11	0.0604	12.35	0.49	2.19	1989	26.17	1984
	Winter precipitation	10.66	-0.01	0.93	-0.0021	10.48	-0.02	4.12	1972	20.40	1990
	Spring precipitation	14.74	0.05	0.61	0.0159	14.44	0.11	7.79	1981	30.90	1957
	Summer precipitation	11.23	-0.06	0.51	-0.0193	10.93	-0.18	5.45	1962	19.61	2008
Arkansas Valley	Annual precipitation	48.31	0.14	0.11	0.0891	46.15	0.19	30.06	1963	72.31	1957
	Autumn precipitation	12.65	0.20	0.02	0.0838	12.95	0.65	3.18	1989	27.22	1984
	Winter precipitation	11.05	-0.05	0.54	-0.0139	10.54	-0.13	4.68	1972	21.20	1990
	Spring precipitation	14.04	0.05	0.54	0.0180	13.49	0.13	7.52	1988	27.87	1957
	Summer precipitation	10.56	-0.07	0.40	-0.0194	10.82	-0.18	4.76	2000	19.01	2009
Ouachita Mountains	Annual precipitation	52.84	0.15	0.09	0.0974	51.49	0.19	33.94	1963	77.20	1973
	Autumn precipitation	13.98	0.22	0.01	0.0969	13.76	0.70	4.02	1965	27.22	1984
	Winter precipitation	12.20	-0.01	0.90	-0.0038	11.86	-0.03	5.73	1972	21.20	1957
	Spring precipitation	15.38	0.08	0.39	0.0276	14.33	0.19	7.74	1988	27.87	1957
	Summer precipitation	11.27	-0.11	0.20	-0.0315	11.41	-0.28	4.79	2000	19.01	2009

Table 3. Precipitation metrics and results of Mann-Kendall test for monotonic trends in mean annual and seasonal precipitation in Arkansas, 1951–2011.—Continued

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). Expected annual rate of change is the ratio of the Sen slope to the median precipitation, expressed as a percentage. in., inches; in/yr, inches per year; HUC, four-digit hydrologic unit code region]

Region	Metric	Mean (in.)	Kendall's tau (τ)	p -value	Sen slope (in/yr)	Median (in.)	Expected annual rate of change (percent)	Minimum (in.)	Year minimum occurred	Maximum (in.)	Year maximum occurred
Physiographic sections—Continued											
West Gulf Coastal Plain	Annual precipitation	51.42	0.13	0.15	0.1028	49.91	0.21	33.30	2005	80.86	2009
	Autumn precipitation	13.69	0.15	0.09	0.0791	12.67	0.62	3.82	2005	28.95	2009
	Winter precipitation	12.98	0.03	0.75	0.0076	13.22	0.06	6.51	1964	24.23	1990
	Spring precipitation	14.24	0.02	0.78	0.0106	13.55	0.08	6.15	1988	25.79	1957
	Summer precipitation	10.51	-0.07	0.40	-0.0261	10.22	-0.26	4.37	1999	21.25	2009
HUCs											
Lower Mississippi-St. Francis (0802)	Annual precipitation	49.04	0.08	0.39	0.0563	48.35	0.12	32.12	1963	73.95	1957
	Autumn precipitation	12.82	0.21	0.02	0.0838	11.50	0.73	4.34	1965	23.03	1999
	Winter precipitation	12.59	-0.17	0.06	-0.0389	12.03	-0.32	6.59	1986	21.02	1987
	Spring precipitation	13.72	0.0268	0.77	0.0109	13.49	0.08	5.68	1988	24.47	1955
	Summer precipitation	9.96	-0.0842	0.34	-0.0174	9.98	-0.17	3.84	1999	16.10	2007
Lower Red-Ouachita (0804)	Annual precipitation	53.01	0.13	0.14	0.0960	51.36	0.19	35.76	2005	78.90	2009
	Autumn precipitation	13.94	0.18	0.04	0.0793	12.70	0.62	4.57	2005	28.10	2009
	Winter precipitation	13.66	-0.01	0.95	-0.0031	13.81	-0.02	7.03	1986	25.09	1990
	Spring precipitation	14.52	0.04	0.65	0.0143	13.74	0.10	6.60	1986	26.31	1958
	Summer precipitation	10.89	-0.09	0.33	-0.0269	10.65	-0.25	4.72	2000	20.77	2008
Boeuf-Tensas (0805)	Annual precipitation	52.80	0.10	0.28	0.0927	50.08	0.19	33.13	2010	74.99	1991
	Autumn precipitation	13.79	0.18	0.04	0.0816	12.86	0.63	4.99	2005	31.72	1982
	Winter precipitation	15.03	-0.04	0.63	-0.0190	15.69	-0.12	5.36	1986	26.78	1990
	Spring precipitation	13.80	-0.02	0.82	-0.0076	13.28	-0.06	4.98	1988	30.55	1991
	Summer precipitation	10.18	0.00	1.00	0.0000	10.40	0.00	4.13	2000	22.76	2008
Upper White (1101)	Annual precipitation	45.72	0.17	0.06	0.1113	44.68	0.25	30.21	1953	65.59	1973
	Autumn precipitation	11.55	0.17	0.05	0.0633	11.20	0.57	2.76	1989	23.87	1982
	Winter precipitation	10.05	0.01	0.96	0.0005	9.96	0.01	4.70	1972	18.80	2006
	Spring precipitation	13.47	0.07	0.45	0.0169	13.36	0.13	6.99	2005	27.19	1955
	Summer precipitation	10.74	0.04	0.68	0.0100	10.64	0.09	4.05	1953	17.06	1975
Neosho-Vergidris (1107)	Annual precipitation	42.77	0.16	0.07	0.1151	41.69	0.28	21.40	1963	65.62	1973
	Autumn precipitation	9.74	0.10	0.26	0.0317	9.24	0.34	2.56	1989	18.92	1984
	Winter precipitation	7.49	0.11	0.20	0.0238	6.75	0.35	2.45	1972	17.06	1991
	Spring precipitation	14.42	0.10	0.27	0.0349	14.11	0.25	6.75	1983	31.58	1957
	Summer precipitation	11.13	0.08	0.39	0.0285	10.99	0.26	4.83	1954	19.96	1961

Table 3. Precipitation metrics and results of Mann-Kendall test for monotonic trends in mean annual and seasonal precipitation in Arkansas, 1951–2011.—Continued

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). Expected annual rate of change is the ratio of the Sen slope to the median precipitation, expressed as a percentage. in., inches; in/yr, inches per year; HUC, four-digit hydrologic unit code region]

Region	Metric	Mean (in.)	Kendall's tau (τ)	p -value	Sen slope (in/yr)	Median (in.)	Expected annual rate of change (percent)	Minimum (in.)	Year minimum occurred	Maximum (in.)	Year maximum occurred
HUCs—Continued											
Lower Arkansas (1111)	Annual precipitation	48.17	0.17	0.06	0.1079	48.16	0.22	27.29	1973	70.64	1963
	Autumn precipitation	12.28	0.20	0.03	0.0790	12.21	0.65	2.90	1989	26.70	1984
	Winter precipitation	10.44	-0.03	0.75	-0.0057	9.98	-0.06	4.10	1972	20.91	1991
	Spring precipitation	14.61	0.09	0.28	0.0276	13.96	0.20	7.50	1983	29.15	1957
	Summer precipitation	10.82	-0.09	0.33	-0.0290	10.81	-0.27	5.18	1954	18.49	1961
Red-Sulphur (1114)	Annual precipitation	49.95	0.07	0.41	0.0723	48.66	0.15	29.64	2005	70.35	1957
	Autumn precipitation	13.13	0.18	0.05	0.0729	13.79	0.53	3.12	2005	23.18	2009
	Winter precipitation	11.62	0.08	0.35	0.0258	11.51	0.22	5.21	2011	22.11	2009
	Spring precipitation	14.56	0.00	0.99	0.0019	14.12	0.01	5.65	1965	27.25	1957
	Summer precipitation	10.63	-0.14	0.12	-0.0439	10.61	-0.41	4.10	1963	20.59	1974

Table 4. Results of Mann-Kendall test for monotonic trends in annual mean daily streamflows at selected continuous-record U.S. Geological Survey streamflow gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma, 1951–2011.

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median annual mean daily streamflow, expressed as a percentage. HUC, four-digit hydrologic unit code region; (ft³/s)/yr, cubic feet per second per year; ft³/s, cubic feet per second; mi, mile]

Site identification number (fig. 10A)	HUC	Station number	Station name	Metric	Kendall's tau (τ)	p -value	Sen slope [(ft ³ /s)/yr]	Median annual mean daily streamflow (ft ³ /s)	Expected annual rate of change (percent)
Unregulated stations									
1	0802	07037500	St. Francis River near Patterson, Mo.	Annual mean daily streamflow	0.18	0.04	6.82	1,060	0.64
5	1101	07052500	James River at Galena, Mo.	Annual mean daily streamflow	0.18	0.04	6.70	971	0.69
6	1101	07056000	Buffalo River near St. Joe, Ark.	Annual mean daily streamflow	0.08	0.35	3.48	958	0.36
7	1101	07057500	North Fork of White River near Tecumseh, Mo.	Annual mean daily streamflow	0.14	0.12	2.90	713	0.41
9	1101	07061500	Black River near Annapolis, Mo.	Annual mean daily streamflow	0.16	0.07	3.40	531	0.64
11	1101	07067500	Big Spring near Van Buren, Mo.	Annual mean daily streamflow	0.19	0.04	1.41	446	0.32
12	1101	07068000	Current River near Doniphan, Mo.	Annual mean daily streamflow	0.17	0.05	13.81	2,670	0.52
13	1101	07069500	Spring River at Imboden, Ark.	Annual mean daily streamflow	0.25	0.01	10.77	1,380	0.78
14	1101	07071000	Greer Spring at Greer, Mo.	Annual mean daily streamflow	0.20	0.02	1.47	347	0.42
15	1101	07072000	Eleven Point River near Ravenden Springs, Ark.	Annual mean daily streamflow	0.20	0.03	7.30	1,160	0.63
16	1101	07072500	Black River at Black Rock, Ark.	Annual mean daily streamflow	0.15	0.09	39.79	8,240	0.48
18	0802	07077500	Cache River at Patterson, Ark.	Annual mean daily streamflow	-0.06	0.50	-2.43	1,180	-0.21
19	1107	07189000	Elk River near Tiff City, Mo.	Annual mean daily streamflow	0.16	0.06	4.34	692	0.63
20	1111	07195500	Illinois River near Watts, Okla.	Annual mean daily streamflow	0.14	0.13	4.23	628	0.67
21	1111	07196900	Baron Fork at Dutch Mills, Ark.	Annual mean daily streamflow	0.19	0.04	0.39	44	0.88
23	1111	07249400	James Fork of Poteau River near Hackett, Ark.	Annual mean daily streamflow	0.13	0.18	0.92	130	0.71
24	1111	07249985	Lee Creek near Short, Okla.	Annual mean daily streamflow	0.19	0.03	3.36	541	0.62
25	1111	07252000	Mulberry River near Mulberry, Ark.	Annual mean daily streamflow	0.14	0.12	2.14	500	0.43
26	1111	07257006	Big Piney Creek at Hwy 164 near Dover, Ark.	Annual mean daily streamflow	0.13	0.15	1.61	385	0.42
27	1111	07258500	Petit Jean River near Booneville, Ark.	Annual mean daily streamflow	0.03	0.75	0.39	207	0.19
29	1111	07261000	Cadron Creek near Guy, Ark.	Annual mean daily streamflow	-0.09	0.32	-0.81	253	-0.32
30	1111	07261500	Fourche LaFave River near Gravelly, Ark.	Annual mean daily streamflow	0.13	0.16	2.82	502	0.56
31	0802	07264000	Bayou Meto near Lonoke, Ark.	Annual mean daily streamflow	0.05	0.59	0.42	275	0.15
34	1114	07348700	Bayou Dorcheat near Springhill, La.	Annual mean daily streamflow	-0.01	0.90	-0.17	495	-0.03
35	0804	07356000	Ouachita River near Mt. Ida, Ark.	Annual mean daily streamflow	0.09	0.32	1.45	695	0.21
37	0804	07361500	Antoine River at Antoine, Ark.	Annual mean daily streamflow	0.08	0.40	0.66	253	0.26
39	0804	07363500	Saline River near Rye, Ark.	Annual mean daily streamflow	0.07	0.44	6.58	2,310	0.28
40	0804	07364150	Bayou Bartholomew near McGehee, Ark.	Annual mean daily streamflow	0.04	0.65	0.85	585	0.15
41	0804	07364200	Bayou Bartholomew near Jones, La.	Annual mean daily streamflow	0.01	0.89	0.83	1,140	0.07
42	0804	07366200	Little Corney Bayou near Lillie, La.	Annual mean daily streamflow	0.05	0.57	0.49	184	0.27

Table 4. Results of Mann-Kendall test for monotonic trends in annual mean daily streamflows at selected continuous-record U.S. Geological Survey streamflow gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma, 1951–2011.—Continued

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median annual mean daily streamflow, expressed as a percentage. HUC, four-digit hydrologic unit code region; (ft³/s)/yr, cubic feet per second per year; ft³/s, cubic feet per second; mi, mile]

Site identification number (fig. 10A)	HUC	Station number	Station name	Metric	Kendall's tau (τ)	p -value	Sen slope [(ft ³ /s)/yr]	Median annual mean daily streamflow (ft ³ /s)	Expected annual rate of change (percent)
Regulated stations									
2	0802	07039500	St. Francis River at Wappapello, Mo.	Annual mean daily streamflow	0.15	0.04	6.82	1,370	0.50
3	0802	07040450	St. Francis River at Lake City, Ark.	Annual mean daily streamflow	0.08	0.41	7.66	2,870	0.27
4	0802	³ 07047800	St. Francis River at Parkin, Ark.	Annual mean daily streamflow	0.04	0.65	10.92	7,430	0.15
8	1101	07060500	White River at Calico Rock, Ark.	Annual mean daily streamflow	0.14	0.11	53.50	9,600	0.56
10	1101	07064000	Black River near Corning, Ark.	Annual mean daily streamflow	0.19	0.04	12.19	1,810	0.67
17	1101	07074500	White River at Newport, Ark.	Annual mean daily streamflow	0.14	0.11	100.45	21,700	0.46
22	1111	07247000	Poteau River at Cauthron, Ark. (preregulation)	Annual mean daily streamflow	0.13	0.39	1.82	247	0.74
22	1111	07247000	Poteau River at Cauthron, Ark. (postregulation)	Annual mean daily streamflow	0.09	0.46	1.55	192	0.81
22	1111	07247000	Poteau River at Cauthron, Ark. (entire analysis period)	Annual mean daily streamflow	0.16	0.07	1.47	212	0.69
28	1111	07260500	Petit Jean River at Danville, Ark.	Annual mean daily streamflow	0.11	0.22	3.59	794	0.45
32	1114	07337000	Red River at Index, Ark.	Annual mean daily streamflow	0.14	0.11	74.51	10,400	0.72
33	1114	07340000	Little River near Horatio, Ark. (preregulation)	Annual mean daily streamflow	-0.19	0.29	-66.96	3,120	-2.15
33	1114	07340000	Little River near Horatio, Ark. (postregulation)	Annual mean daily streamflow	0.02	0.85	1.89	3,660	0.05
33	1114	07340000	Little River near Horatio, Ark. (entire analysis period)	Annual mean daily streamflow	0.11	0.23	12.00	3,650	0.33
36	0804	07359002	Ouachita River at Rammel Dam above Jones Mill, Ark.	Annual mean daily streamflow	0.12	0.17	9.45	2,310	0.41
38	0804	07362000	Ouachita River at Camden, Ark.	Annual mean daily streamflow	0.15	0.09	33.11	7,260	0.46

¹Prior to Oct. 1, 1992, gaging station was located 3.8 mi downstream from current location and published as 07250000 Lee Creek near Van Buren, Ark.

²Prior to Oct. 1, 1992, gaging station was located 4.7 mi upstream from current location and published as 07257000 Big Piney Creek near Dover, Ark; prior to Oct. 1967, published as 07257000 Piney Creek near Dover, Ark.

³Represents combined streamflows of gaging stations 07047800 St. Francis River at Parkin, Ark., and 07047900 St. Francis Bay at Riverfront, Ark.

Table 5. Results of Mann-Kendall test for monotonic trends in annual maximum daily streamflows at selected continuous-record U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma, 1951–2011.

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median annual maximum daily streamflow, expressed as a percentage. HUC, four-digit hydrologic unit code region; (ft³/s)/yr, cubic feet per second per year; ft³/s, cubic feet per second; mi, mile]

Site identification number (fig. 10B)	HUC	Station number	Station name	Metric	Kendall's tau (τ)	Sen slope [(ft ³ /s)/yr]	p-value	Median annual maximum daily streamflow (ft ³ /s)	Expected annual rate of change (percent)
Unregulated stations									
1	0802	07037500	St. Francis River near Patterson, Mo.	Annual maximum daily streamflow	0.12	128.30	0.17	24,500	0.52
5	1101	07052500	James River at Galena, Mo.	Annual maximum daily streamflow	0.14	115.12	0.11	16,700	0.69
6	1101	07056000	Buffalo River near St. Joe, Ark.	Annual maximum daily streamflow	0.13	160.00	0.14	23,600	0.68
7	1101	07057500	North Fork of White River near Tecumseh, Mo.	Annual maximum daily streamflow	0.07	32.38	0.42	7,980	0.41
9	1101	07061500	Black River near Annapolis, Mo.	Annual maximum daily streamflow	0.13	86.39	0.16	11,200	0.77
11	1101	07067500	Big Spring near Van Buren, Mo.	Annual maximum daily streamflow	0.11	1.23	0.24	950	0.13
12	1101	07068000	Current River near Doniphan, Mo.	Annual maximum daily streamflow	0.12	148.71	0.17	24,000	0.62
13	1101	07069500	Spring River at Imboden, Ark.	Annual maximum daily streamflow	0.12	166.67	0.20	22,050	0.76
14	1101	07071000	Greer Spring at Greer, Mo.	Annual maximum daily streamflow	0.22	2.07	0.01	657	0.32
15	1101	07072000	Eleven Point River near Ravenden Springs, Ark.	Annual maximum daily streamflow	0.14	82.50	0.13	9,600	0.86
16	1101	07072500	Black River at Black Rock, Ark.	Annual maximum daily streamflow	0.11	152.86	0.22	34,700	0.44
18	0802	07077500	Cache River at Patterson, Ark.	Annual maximum daily streamflow	-0.13	-20.20	0.16	5,660	-0.36
19	1107	07189000	Elk River near Tiff City, Mo.	Annual maximum daily streamflow	0.13	102.65	0.14	16,300	0.63
20	1111	07195500	Illinois River near Watts, Okla.	Annual maximum daily streamflow	0.08	69.06	0.41	12,650	0.55
21	1111	07196900	Baron Fork at Dutch Mills, Ark.	Annual maximum daily streamflow	0.11	11.07	0.27	1,530	0.72
23	1111	07249400	James Fork of Poteau River near Hackett, Ark.	Annual maximum daily streamflow	0.11	32.97	0.26	4,870	0.68
24	1111	07249985	Lee Creek near Short, Okla.	Annual maximum daily streamflow	0.27	177.66	<0.01	12,600	1.41
25	1111	07252000	Mulberry River near Mulberry, Ark.	Annual maximum daily streamflow	0.18	101.17	0.05	11,100	0.91
26	1111	07257006	Big Piney Creek at Hwy 164 near Dover, Ark.	Annual maximum daily streamflow	0.15	66.67	0.10	9,970	0.67
27	1111	07258500	Petit Jean River near Booneville, Ark.	Annual maximum daily streamflow	0.08	34.66	0.46	8,020	0.43
28	1111	07260500	Petit Jean River at Danville, Ark.	Annual maximum daily streamflow	0.13	43.49	0.14	9,380	0.46
29	1111	07261000	Cadron Creek near Guy, Ark.	Annual maximum daily streamflow	-0.07	-24.95	0.45	6,490	-0.38
30	1111	07261500	Fourche LaFave River near Gravelly, Ark.	Annual maximum daily streamflow	0.15	137.12	0.10	17,000	0.81
31	0802	07264000	Bayou Meto near Lonoke, Ark.	Annual maximum daily streamflow	-0.04	-4.87	0.65	2,020	-0.24
34	1114	07348700	Bayou Dorcheat near Springhill, La.	Annual maximum daily streamflow	0.04	21.25	0.66	7,400	0.29
35	0804	07356000	Ouachita River near Mt. Ida, Ark.	Annual maximum daily streamflow	0.06	46.83	0.47	16,000	0.29
37	0804	07361500	Antoine River at Antoine, Ark.	Annual maximum daily streamflow	0.00	0.24	1.00	7,300	0.00
39	0804	07363500	Saline River near Rye, Ark.	Annual maximum daily streamflow	-0.03	-28.04	0.74	21,800	-0.13
40	0804	07364150	Bayou Bartholomew near McGehee, Ark.	Annual maximum daily streamflow	0.13	12.65	0.14	3,530	0.36
41	0804	07364200	Bayou Bartholomew near Jones, La.	Annual maximum daily streamflow	0.10	13.50	0.31	4,910	0.27
42	0804	07366200	Little Corney Bayou near Lillie, La.	Annual maximum daily streamflow	0.12	23.95	0.22	3,300	0.73

Table 5. Results of Mann-Kendall test for monotonic trends in annual maximum daily streamflows at selected continuous-record U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma, 1951–2011.—Continued

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median annual maximum daily streamflow, expressed as a percentage. HUC, four-digit hydrologic unit code region; (ft³/s)/yr, cubic feet per second per year; ft³/s, cubic feet per second; mi, mile]

Site identification number (fig. 10B)	HUC	Station number	Station name	Metric	Kendall's tau (τ)	Sen slope [(ft ³ /s)/yr]	p-value	Median annual maximum daily streamflow (ft ³ /s)	Expected annual rate of change (percent)
Regulated stations									
2	0802	07039500	St. Francis River at Wappapello, Mo.	Annual maximum daily streamflow	-0.15	-23.75	0.10	7,190	-0.33
3	0802	07040450	St. Francis River at Lake City, Ark.	Annual maximum daily streamflow	0.09	51.32	0.30	14,900	0.34
4	0802	³ 07047800	St. Francis River at Parkin, Ark.	Annual maximum daily streamflow	0.14	115.71	0.16	30,500	0.38
8	1101	07060500	White River at Calico Rock, Ark.	Annual maximum daily streamflow	0.06	129.70	0.51	44,600	0.29
10	1101	07064000	Black River near Corning, Ark.	Annual maximum daily streamflow	0.07	35.56	0.42	11,650	0.31
17	1101	07074500	White River at Newport, Ark.	Annual maximum daily streamflow	0.05	122.02	0.57	68,900	0.18
22	1111	07247000	Poteau River at Cauthron, Ark. (preregulation)	Annual maximum daily streamflow	0.10	94.61	0.51	7,160	1.32
22	1111	07247000	Poteau River at Cauthron, Ark. (postregulation)	Annual maximum daily streamflow	0.14	72.04	0.23	7,000	1.03
22	1111	07247000	Poteau River at Cauthron, Ark. (entire analysis period)	Annual maximum daily streamflow	0.06	14.47	0.50	7,090	0.20
32	1114	07337000	Red River at Index, Ark.	Annual maximum daily streamflow	-0.07	-185.75	0.42	68,000	-0.27
33	1114	07340000	Little River near Horatio, Ark. (preregulation)	Annual maximum daily streamflow	-0.23	-1,181.25	0.20	38,900	-3.04
33	1114	07340000	Little River near Horatio, Ark. (postregulation)	Annual maximum daily streamflow	-0.14	-125.00	0.21	26,200	-0.48
33	1114	07340000	Little River near Horatio, Ark. (entire analysis period)	Annual maximum daily streamflow	-0.35	-314.26	<0.01	27,900	-1.13
36	0804	07359002	Ouachita River at Remmel Dam above Jones Mill, Ark.	Annual maximum daily streamflow	0.02	19.44	0.82	21,200	0.09
38	0804	07362000	Ouachita River at Camden, Ark.	Annual maximum daily streamflow	-0.02	-34.21	0.85	57,300	-0.06

¹Prior to Oct. 1, 1992, gaging station was located 3.8 mi downstream from current location and published as 07250000 Lee Creek near Van Buren, Ark.

²Prior to Oct. 1, 1992, gaging station was located 4.7 mi upstream from current location and published as 07257000 Big Piney Creek near Dover, Ark; prior to Oct. 1967, published as 07257000 Piney Creek near Dover, Ark.

³Represents combined streamflows of gaging stations 07047800 St. Francis River at Parkin, Ark., and 07047900 St. Francis Bay at Riverfront, Ark.

Table 6. Results of Mann-Kendall test for monotonic trends in annual minimum daily streamflows at selected continuous-record U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma, 1951–2011.

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median annual minimum daily streamflow, expressed as a percentage. HUC, four-digit hydrologic unit code region; (ft³/s)/yr, cubic feet per second per year; ft³/s, cubic feet per second; mi, mile]

Site identification number (fig. 10C)	HUC	Station number	Station name	Metric	Kendall's tau (τ)	Sen slope [(ft ³ /s)/yr]	p-value	Median annual minimum daily streamflow (ft ³ /s)	Expected annual rate of change (percent)
Unregulated stations									
1	0802	07037500	St. Francis River near Patterson, Mo.	Annual minimum daily streamflow	0.21	0.28	0.02	35.0	0.80
5	1101	07052500	James River at Galena, Mo.	Annual minimum daily streamflow	0.20	0.78	0.02	105	0.74
6	1101	07056000	Buffalo River near St. Joe, Ark.	Annual minimum daily streamflow	-0.13	-0.19	0.16	29.0	-0.66
7	1101	07057500	North Fork of White River near Tecumseh, Mo.	Annual minimum daily streamflow	0.08	0.37	0.38	280	0.13
9	1101	07061500	Black River near Annapolis, Mo.	Annual minimum daily streamflow	0.35	0.83	<0.01	105	0.79
11	1101	07067500	Big Spring near Van Buren, Mo.	Annual minimum daily streamflow	0.21	0.61	0.02	298	0.20
12	1101	07068000	Current River near Doniphan, Mo.	Annual minimum daily streamflow	0.18	3.00	0.05	1,200	0.25
13	1101	07069500	Spring River at Imboden, Ark.	Annual minimum daily streamflow	0.15	1.07	0.10	375	0.29
14	1101	07071000	Greer Spring at Greer, Mo.	Annual minimum daily streamflow	0.19	1.01	0.03	205	0.49
15	1101	07072000	Eleven Point River near Ravenden Springs, Ark.	Annual minimum daily streamflow	0.14	1.38	0.13	420	0.33
16	1101	07072500	Black River at Black Rock, Ark.	Annual minimum daily streamflow	0.17	7.28	0.05	2,650	0.27
18	0802	07077500	Cache River at Patterson, Ark.	Annual minimum daily streamflow	-0.29	-0.69	<0.01	24.0	-2.88
19	1107	07189000	Elk River near Tiff City, Mo.	Annual minimum daily streamflow	0.19	0.58	0.03	71.0	0.82
20	1111	07195500	Illinois River near Watts, Okla.	Annual minimum daily streamflow	0.41	1.63	<0.01	88.5	1.84
21	1111	07196900	Baron Fork at Dutch Mills, Ark.	Annual minimum daily streamflow	0.06	0.00	0.53	0.30	0.00
23	1111	07249400	James Fork of Poteau River near Hackett, Ark.	Annual minimum daily streamflow	0.16	0.01	0.09	0.42	2.38
24	1111	07249985	Lee Creek near Short, Okla.	Annual minimum daily streamflow	-0.06	0.00	0.49	0.65	0.00
25	1111	07252000	Mulberry River near Mulberry, Ark.	Annual minimum daily streamflow	0.16	0.02	0.08	1.38	1.45
26	1111	07257006	Big Piney Creek at Hwy 164 near Dover, Ark.	Annual minimum daily streamflow	0.01	0.00	0.96	0.65	0.00
27	1111	07258500	Petit Jean River near Booneville, Ark.	Annual minimum daily streamflow	-0.01	0.00	0.91	0.00	0.00
29	1111	07261000	Cadron Creek near Guy, Ark.	Annual minimum daily streamflow	-0.03	0.00	0.74	0.00	0.00
30	1111	07261500	Fourche LaFave River near Gravelly, Ark.	Annual minimum daily streamflow	-0.19	-0.01	0.04	0.34	-2.94
31	0802	07264000	Bayou Meto near Lonoke, Ark.	Annual minimum daily streamflow	-0.33	-0.03	<0.01	0.61	-4.92
34	1114	07348700	Bayou Dorcheat near Springhill, La.	Annual minimum daily streamflow	-0.23	-0.02	0.02	1.20	-1.67
35	0804	07356000	Ouachita River near Mt. Ida, Ark.	Annual minimum daily streamflow	0.15	0.14	0.10	19.0	0.74
37	0804	07361500	Antoine River at Antoine, Ark.	Annual minimum daily streamflow	-0.01	0.00	0.95	0.30	0.00
39	0804	07363500	Saline River near Rye, Ark.	Annual minimum daily streamflow	-0.06	-0.12	0.52	37.0	-0.32
40	0804	07364150	Bayou Bartholomew near McGehee, Ark.	Annual minimum daily streamflow	-0.29	-0.31	<0.01	17.0	-1.82
41	0804	07364200	Bayou Bartholomew near Jones, La.	Annual minimum daily streamflow	-0.51	-2.00	<0.01	51.0	-3.92
42	0804	07366200	Little Corney Bayou near Lillie, La.	Annual minimum daily streamflow	-0.29	-0.03	<0.01	1.07	-2.80

Table 6. Results of Mann-Kendall test for monotonic trends in annual minimum daily streamflows at selected continuous-record U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma, 1951–2011.—Continued

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median annual minimum daily streamflow, expressed as a percentage. HUC, four-digit hydrologic unit code region; (ft³/s)/yr, cubic feet per second per year; ft³/s, cubic feet per second; mi, mile]

Site identification number (fig. 10C)	HUC	Station number	Station name	Metric	Kendall's tau (τ)	Sen slope [(ft ³ /s)/yr]	p-value	Median annual minimum daily streamflow (ft ³ /s)	Expected annual rate of change (percent)
Regulated stations									
2	0802	07039500	St. Francis River at Wappapello, Mo.	Annual minimum daily streamflow	0.40	0.21	<0.01	40.0	0.53
3	0802	07040450	St. Francis River at Lake City, Ark.	Annual minimum daily streamflow	-0.08	-1.03	0.38	243	-0.42
4	0802	³ 07047800	St. Francis River at Parkin, Ark.	Annual minimum daily streamflow	-0.22	-8.89	0.03	880	-1.01
8	1101	07060500	White River at Calico Rock, Ark.	Annual minimum daily streamflow	-0.21	-7.51	0.02	920	-0.82
10	1101	07064000	Black River near Corning, Ark.	Annual minimum daily streamflow	0.06	0.43	0.52	354	0.12
17	1101	07074500	White River at Newport, Ark.	Annual minimum daily streamflow	-0.01	-0.55	0.93	5,350	-0.01
22	1111	07247000	Poteau River at Cauthron, Ark. (postregulation)	Annual minimum daily streamflow	0.33	0.04	<0.01	0.64	6.65
22	1111	07247000	Poteau River at Cauthron, Ark. (preregulation)	Annual minimum daily streamflow	0.29	0.01	0.07	0.10	10.56
22	1111	07247000	Poteau River at Cauthron, Ark. (entire analysis period)	Annual minimum daily streamflow	0.39	0.02	<0.01	0.39	4.91
28	1111	07260500	Petit Jean River at Danville, Ark.	Annual minimum daily streamflow	-0.21	-0.06	0.01	2.80	-2.14
32	1114	07337000	Red River at Index, Ark.	Annual minimum daily streamflow	-0.05	-2.86	0.56	1,460	-0.20
33	1114	07340000	Little River near Horatio, Ark. (preregulation)	Annual minimum daily streamflow	0.14	1.55	0.43	40.0	3.88
33	1114	07340000	Little River near Horatio, Ark. (postregulation)	Annual minimum daily streamflow	0.13	1.21	0.21	227	0.53
33	1114	07340000	Little River near Horatio, Ark. (entire analysis period)	Annual minimum daily streamflow	0.48	4.50	<0.01	194	2.32
36	0804	07359002	Ouachita River at Rammel Dam above Jones Mill, Ark.	Annual minimum daily streamflow	0.30	2.75	<0.01	256	1.07
38	0804	07362000	Ouachita River at Camden, Ark.	Annual minimum daily streamflow	0.19	4.50	0.04	750	0.60

¹Prior to Oct. 1, 1992, gaging station was located 3.8 mi downstream from current location and published as 07250000 Lee Creek near Van Buren, Ark.

²Prior to Oct. 1, 1992, gaging station was located 4.7 mi upstream from current location and published as 07257000 Big Piney Creek near Dover, Ark; prior to Oct. 1967, published as 07257000 Piney Creek near Dover, Ark.

³Represents combined streamflows of gaging stations 07047800 St. Francis River at Parkin, Ark., and 07047900 St. Francis Bay at Riverfront, Ark.

Table 7. Results of Mann-Kendall test for monotonic trends in seasonal mean daily streamflows at selected continuous-record, unregulated U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma, 1951–2011.

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median seasonal mean daily streamflow, expressed as a percentage. HUC, four-digit hydrologic unit code region; (ft³/s)/yr, cubic feet per second per year; ft³/s, cubic feet per second]

Site identification number (fig. 11)	HUC	Station number	Station name	Metric	Kendall's tau (τ)	p -value	Sen slope [(ft ³ /s)/yr]	Median seasonal mean daily streamflow (ft ³ /s)	Expected annual rate of change (percent)
1	0802	07037500	St. Francis River at Patterson, Mo.	Autumn mean daily streamflow	0.18	0.05	6.69	719	0.93
				Winter mean daily streamflow	0.03	0.71	1.72	1,620	0.11
				Spring mean daily streamflow	0.13	0.14	11.16	1,390	0.80
				Summer mean daily streamflow	0.10	0.26	0.85	152	0.56
5	1101	07052500	James River at Galena, Mo.	Autumn mean daily streamflow	0.10	0.26	2.88	518	0.56
				Winter mean daily streamflow	0.17	0.05	10.17	1,310	0.78
				Spring mean daily streamflow	0.09	0.29	6.04	1,100	0.55
				Summer mean daily streamflow	0.11	0.20	1.79	314	0.57
6	1101	07056000	Buffalo River at St. Joe, Ark.	Autumn mean daily streamflow	0.07	0.45	2.91	557	0.52
				Winter mean daily streamflow	0.08	0.37	6.51	1,490	0.44
				Spring mean daily streamflow	-0.04	0.67	-2.81	1,380	-0.20
				Summer mean daily streamflow	0.01	0.94	0.08	136	0.06
7	1101	07057500	North Fork of White River near Tecumseh, Mo.	Autumn mean daily streamflow	0.11	0.21	1.94	475	0.41
				Winter mean daily streamflow	0.14	0.12	3.83	772	0.50
				Spring mean daily streamflow	0.08	0.34	2.70	925	0.29
				Summer mean daily streamflow	0.08	0.38	0.79	408	0.19
9	1101	07061500	Black River near Annapolis, Mo.	Autumn mean daily streamflow	0.12	0.16	2.66	424	0.63
				Winter mean daily streamflow	0.07	0.44	1.69	717	0.24
				Spring mean daily streamflow	0.11	0.21	3.34	679	0.49
				Summer mean daily streamflow	0.15	0.08	1.03	196	0.53
11	1101	07067500	Big Spring near Van Buren, Mo.	Autumn mean daily streamflow	0.16	0.02	1.56	368	0.43
				Winter mean daily streamflow	0.14	0.12	1.41	473	0.30
				Spring mean daily streamflow	0.12	0.17	1.25	526	0.24
				Summer mean daily streamflow	0.25	0.01	1.53	371	0.41
12	1101	07068000	Current River near Doniphan, Mo.	Autumn mean daily streamflow	0.08	0.07	10.44	2,040	0.51
				Winter mean daily streamflow	0.14	0.12	14.15	3,050	0.46
				Spring mean daily streamflow	0.10	0.23	13.83	3,490	0.40
				Summer mean daily streamflow	0.17	0.06	5.45	1,580	0.35
13	1101	07069500	Spring River near Imboden, Ark.	Autumn mean daily streamflow	0.20	0.03	10.66	1,100	0.97
				Winter mean daily streamflow	0.16	0.09	10.48	1,750	0.60
				Spring mean daily streamflow	0.08	0.38	5.80	1,720	0.34

Table 7. Results of Mann-Kendall test for monotonic trends in seasonal mean daily streamflows at selected continuous-record, unregulated U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma, 1951–2011.—Continued

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median seasonal mean daily streamflow, expressed as a percentage. HUC, four-digit hydrologic unit code region; (ft³/s)/yr, cubic feet per second per year; ft³/s, cubic feet per second]

Site identification number (fig. 11)	HUC	Station number	Station name	Metric	Kendall's tau (τ)	p -value	Sen slope [(ft ³ /s)/yr]	Median seasonal mean daily streamflow (ft ³ /s)	Expected annual rate of change (percent)
14	1101	07071000	Greer Spring near Greer, Mo.	Summer mean daily streamflow	0.19	0.04	2.68	607	0.44
				Autumn mean daily streamflow	0.20	0.02	1.66	276	0.60
				Winter mean daily streamflow	0.20	0.02	1.77	372	0.48
				Spring mean daily streamflow	0.11	0.21	1.11	429	0.26
15	1101	07072000	Eleven Point River near Ravenden Springs, Ark.	Summer mean daily streamflow	0.17	0.06	1.34	285	0.47
				Autumn mean daily streamflow	0.18	0.05	5.12	767	0.67
				Winter mean daily streamflow	0.10	0.28	5.95	1,230	0.48
				Spring mean daily streamflow	0.07	0.42	4.47	1,450	0.31
16	1101	07072500	Black River at Black Rock, Ark.	Summer mean daily streamflow	0.18	0.06	3.19	670	0.48
				Autumn mean daily streamflow	0.16	0.07	34.96	5,380	0.65
				Winter mean daily streamflow	0.10	0.25	37.77	10,700	0.35
				Spring mean daily streamflow	0.05	0.60	19.58	11,000	0.18
18	0802	07077500	Cache River at Patterson, Ark.	Summer mean daily streamflow	0.14	0.11	14.71	3,948	0.37
				Autumn mean daily streamflow	0.12	0.18	8.46	753	1.12
				Winter mean daily streamflow	-0.15	0.10	-12.56	1,770	-0.71
				Spring mean daily streamflow	-0.12	0.18	-6.84	1,100	-0.62
19	1107	07189000	Elk River near Tiff City, Mo.	Summer mean daily streamflow	0.26	0.00	7.18	552	1.30
				Autumn mean daily streamflow	0.14	0.12	2.86	410	0.70
				Winter mean daily streamflow	0.15	0.08	8.19	828	0.99
				Spring mean daily streamflow	0.08	0.36	5.22	932	0.56
20	1111	07195500	Illinois River near Watts, Okla.	Summer mean daily streamflow	0.08	0.39	1.02	252	0.40
				Autumn mean daily streamflow	0.13	0.17	3.37	447	0.75
				Winter mean daily streamflow	0.17	0.07	6.85	715	0.96
				Spring mean daily streamflow	0.02	0.83	0.61	734	0.08
21	1111	07196900	Baron Fork at Dutch Mills, Ark.	Summer mean daily streamflow	0.13	0.15	2.13	268	0.79
				Autumn mean daily streamflow	0.08	0.39	0.17	29.0	0.57
				Winter mean daily streamflow	0.15	0.13	0.59	50.3	1.17
				Spring mean daily streamflow	0.02	0.84	0.08	50.8	0.16
23	1111	07249400	James Fork near Hackett, Ark.	Summer mean daily streamflow	0.11	0.24	0.06	6.03	1.06
				Autumn mean daily streamflow	0.00	0.98	0.02	125	0.02
				Winter mean daily streamflow	0.12	0.22	1.73	208	0.83

Table 7. Results of Mann-Kendall test for monotonic trends in seasonal mean daily streamflows at selected continuous-record, unregulated U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma, 1951–2011.—Continued

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median seasonal mean daily streamflow, expressed as a percentage. HUC, four-digit hydrologic unit code region; (ft³/s)/yr, cubic feet per second per year; ft³/s, cubic feet per second]

Site identification number (fig. 11)	HUC	Station number	Station name	Metric	Kendall's tau (τ)	p -value	Sen slope [(ft ³ /s)/yr]	Median seasonal mean daily streamflow (ft ³ /s)	Expected annual rate of change (percent)
24	1111	07249985	Lee Creek near Short, Okla. ¹	Spring mean daily streamflow	-0.03	0.75	-0.34	163	-0.21
				Summer mean daily streamflow	-0.03	0.75	-0.03	10.7	-0.26
				Autumn mean daily streamflow	0.06	0.52	1.52	311	0.49
				Winter mean daily streamflow	0.11	0.22	3.79	838	0.45
25	1111	07252000	Mulberry River near Mulberry, Ark.	Spring mean daily streamflow	0.00	0.98	0.18	692	0.03
				Summer mean daily streamflow	0.12	0.17	0.53	51.0	1.03
				Autumn mean daily streamflow	0.11	0.22	2.46	318	0.77
				Winter mean daily streamflow	0.08	0.38	3.14	798	0.39
26	1111	07257006	Big Piney Creek at Hwy 164 near Dover, Ark. ²	Spring mean daily streamflow	0.01	0.88	0.48	699	0.07
				Summer mean daily streamflow	0.11	0.21	0.35	49.0	0.71
				Autumn mean daily streamflow	0.06	0.51	1.67	251	0.66
				Winter mean daily streamflow	0.07	0.46	1.52	664	0.23
27	1111	07258500	Petit Jean River near Booneville, Ark.	Spring mean daily streamflow	0.05	0.58	1.20	514	0.23
				Summer mean daily streamflow	0.08	0.38	0.20	27.1	0.74
				Autumn mean daily streamflow	0.14	0.18	1.45	101	1.43
				Winter mean daily streamflow	-0.02	0.85	-0.42	328	-0.13
29	1111	07261000	Cadron Creek near Guy, Ark.	Spring mean daily streamflow	-0.07	0.51	-0.87	219	-0.40
				Summer mean daily streamflow	-0.01	0.91	-0.01	16.2	-0.04
				Autumn mean daily streamflow	0.07	0.47	0.87	213	0.41
				Winter mean daily streamflow	-0.07	0.47	-1.16	464	-0.25
30	1111	07261500	Fourche LaFave River near Gravelly, Ark.	Spring mean daily streamflow	-0.09	0.35	-1.24	247	-0.50
				Summer mean daily streamflow	-0.26	0.00	-0.57	19.1	-2.99
				Autumn mean daily streamflow	0.16	0.07	5.35	343	1.56
				Winter mean daily streamflow	0.03	0.73	1.29	791	0.16
31	0802	07264000	Bayou Meto near Lonoke, Ark.	Spring mean daily streamflow	-0.02	0.85	-0.49	685	-0.07
				Summer mean daily streamflow	0.05	0.62	0.14	27	0.52
				Autumn mean daily streamflow	0.16	0.08	2.62	220	1.19
				Winter mean daily streamflow	0.01	0.95	0.06	480	0.01
34	0804	07348700	Bayou Dorcheat near Springhill, La.	Spring mean daily streamflow	-0.12	0.19	-2.38	310	-0.77
				Summer mean daily streamflow	-0.10	0.26	-0.34	44.2	-0.77
				Autumn mean daily streamflow	-0.04	0.64	-0.49	202	-0.25
				Winter mean daily streamflow	0.03	0.74	1.40	1,000	0.14

Table 7. Results of Mann-Kendall test for monotonic trends in seasonal mean daily streamflows at selected continuous-record, unregulated U.S. Geological Survey streamflow-gaging stations in Arkansas, Louisiana, Missouri, and Oklahoma, 1951–2011.—Continued

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median seasonal mean daily streamflow, expressed as a percentage. HUC, four-digit hydrologic unit code region; (ft³/s)/yr, cubic feet per second per year; ft³/s, cubic feet per second]

Site identification number (fig. 11)	HUC	Station number	Station name	Metric	Kendall's tau (τ)	p -value	Sen slope [(ft ³ /s)/yr]	Median seasonal mean daily streamflow (ft ³ /s)	Expected annual rate of change (percent)
35	0804	07356000	Ouachita River near Mt. Ida, Ark.	Spring mean daily streamflow	-0.07	0.48	-2.73	490	-0.56
				Summer mean daily streamflow	-0.14	0.14	-0.55	45.8	-1.20
				Autumn mean daily streamflow	0.14	0.12	6.40	633	1.01
				Winter mean daily streamflow	-0.01	0.95	-0.18	985	-0.02
37	0804	07361500	Antoine River at Antoine, Ark.	Spring mean daily streamflow	-0.04	0.68	-1.62	730	-0.22
				Summer mean daily streamflow	0.03	0.73	0.18	95.1	0.19
				Autumn mean daily streamflow	0.11	0.23	1.66	203	0.82
				Winter mean daily streamflow	0.08	0.40	1.38	412	0.34
39	0804	07363500	Saline River near Rye, Ark.	Spring mean daily streamflow	-0.08	0.35	-1.51	289	-0.52
				Summer mean daily streamflow	-0.00	0.99	-0.00	19.9	-0.00
				Autumn mean daily streamflow	0.17	0.05	18.87	1,170	1.61
				Winter mean daily streamflow	0.04	0.61	7.47	4,640	0.16
40	0804	07364150	Bayou Bartholomew near McGehee, Ark.	Spring mean daily streamflow	-0.10	0.24	-13.70	2,870	-0.48
				Summer mean daily streamflow	-0.02	0.85	-0.34	213	-0.16
				Autumn mean daily streamflow	0.10	0.24	1.79	266	0.67
				Winter mean daily streamflow	0.03	0.75	2.15	1,250	0.17
41	0804	07364200	Bayou Bartholomew near Jones, La.	Spring mean daily streamflow	-0.09	0.29	-3.23	629	-0.51
				Summer mean daily streamflow	0.16	0.07	0.99	104	0.95
				Autumn mean daily streamflow	-0.06	0.51	-1.85	464	-0.40
				Winter mean daily streamflow	0.05	0.59	6.26	2,360	0.27
42	0804	07366200	Little Corney Bayou near Lillie, La.	Spring mean daily streamflow	-0.08	0.38	-5.97	1,230	-0.49
				Summer mean daily streamflow	-0.02	0.83	-0.29	201	-0.15
				Autumn mean daily streamflow	0.13	0.17	0.78	88.5	0.88
				Winter mean daily streamflow	0.11	0.23	1.70	357	0.48
				Spring mean daily streamflow	-0.12	0.20	-1.19	185	-0.64
				Summer mean daily streamflow	-0.05	0.57	-0.08	15.9	-0.53

¹Prior to Oct. 1, 1992, gaging station was located 3.8 mi downstream from current location and published as 07250000 Lee Creek near Van Buren, Ark.

²Prior to Oct. 1, 1992, gaging station was located 4.7 mi upstream from current location and published as 07257000 Big Piney Creek near Dover, Ark; prior to Oct. 1967, published as 07257000 Piney Creek near Dover, Ark.

Table 8. Results of Mann-Kendall test for monotonic trends in annual mean daily pool elevations of selected U.S. Army Corps of Engineers reservoirs in Arkansas and Missouri, 1951–2011.

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median annual mean daily pool elevation, expressed as a percentage. HUC, four-digit hydrologic unit code region; ft/yr, feet per year; ft, feet]

Site number (fig. 12A)	HUC	Reservoir	Metric	Kendall's tau (τ)	Sen slope (ft/yr)	<i>p</i> -value	Median annual mean daily pool elevation (ft)	Expected annual rate of change (percent)
43	0805	Lake Chicot	Annual mean daily pool elevation	0.12	0.01	0.19	104.82	0.01
44	1101	Clearwater Lake	Annual mean daily pool elevation	0.22	0.06	0.01	497.92	0.01
56	1111	Blue Mountain Lake	Annual mean daily pool elevation	0.23	0.05	<0.01	386.70	0.01
57	1111	Nimrod Lake	Annual mean daily pool elevation	0.20	0.04	0.02	344.75	0.01
58	0804	Lake Ouachita (Blakely Mountain Dam)	Annual mean daily pool elevation	0.25	0.06	<0.01	574.84	0.01
59	0804	Lake Greeson (Narrows Dam)	Annual mean daily pool elevation	0.41	0.11	<0.01	542.73	0.02
60	0804	DeGray Lake	Annual mean daily pool elevation	-0.27	-0.06	0.01	404.56	-0.01
61	1114	Millwood Lake	Annual mean daily pool elevation	0.09	0.0067	0.41	259.49	0.00
62	1114	DeQueen Lake	Annual mean daily pool elevation	0.03	0.03	0.84	454.81	0.01
63	1114	Dierks Lake	Annual mean daily pool elevation	-0.15	-1.33	0.20	526.34	-0.25
64	1114	Gillham Lake	Annual mean daily pool elevation	0.03	0.0089	0.81	503.59	0.00
65	1101	Beaver Lake	Annual mean daily pool elevation	0.38	0.25	<0.01	1,118.30	0.02
66	1101	Table Rock Lake	Annual mean daily pool elevation	0.29	0.13	<0.01	912.14	0.01
67	1101	Bull Shoals Lake	Annual mean daily pool elevation	0.34	0.23	<0.01	663.44	0.03
68	1101	Norfork Lake	Annual mean daily pool elevation	0.33	0.13	<0.01	549.93	0.02
69	1101	Greers Ferry Lake	Annual mean daily pool elevation	0.41	0.15	<0.01	458.75	0.03

Table 9. Results of Mann-Kendall test for monotonic trends in annual maximum daily pool elevations of selected U.S. Army Corps of Engineers reservoirs in Arkansas and Missouri, 1951–2011.

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median annual maximum daily pool elevation, expressed as a percentage. HUC, four-digit hydrologic unit code region; ft/yr, feet per year; ft, feet]

Site identification number (fig. 12B)	HUC	Reservoir	Metric	Kendall's tau (τ)	Sen slope (ft/yr)	p -value	Median annual maximum daily pool elevation (ft)	Expected annual rate of change (percent)
43	0805	Lake Chicot	Annual mean daily pool elevation	-0.51	-0.14	<0.01	109.52	-0.12
44	1101	Clearwater Lake	Annual mean daily pool elevation	0.07	0.11	0.40	521.15	0.02
56	1111	Blue Mountain Lake	Annual mean daily pool elevation	0.06	0.05	0.49	403.10	0.01
57	1111	Nimrod Lake	Annual mean daily pool elevation	0.06	0.04	0.50	362.00	0.01
58	0804	Lake Ouachita (Blakely Mountain Dam)	Annual mean daily pool elevation	0.29	0.09	<0.01	580.80	0.02
59	0804	Lake Greeson (Narrows Dam)	Annual mean daily pool elevation	0.12	0.07	0.21	550.60	0.01
60	0804	DeGray Lake	Annual mean daily pool elevation	-0.05	-0.02	0.63	410.50	0.00
61	1114	Millwood Lake	Annual mean daily pool elevation	-0.21	-0.0661	0.04	264.50	-0.03
62	1114	DeQueen Lake	Annual mean daily pool elevation	-0.0053	-0.0029	0.98	453.99	0.00
63	1114	Dierks Lake	Annual mean daily pool elevation	-0.02	-0.02	0.86	539.35	0.00
64	1114	Gillham Lake	Annual mean daily pool elevation	0.15	0.28	0.21	529.10	0.05
65	1101	Beaver Lake	Annual mean daily pool elevation	0.39	0.24	<0.01	1,125.30	0.02
66	1101	Table Rock Lake	Annual mean daily pool elevation	0.19	0.10	0.04	919.40	0.01
67	1101	Bull Shoals Lake	Annual mean daily pool elevation	0.30	0.37	<0.01	663.40	0.06
68	1101	Norfork Lake	Annual mean daily pool elevation	0.26	0.17	<0.01	558.40	0.03
69	1101	Greers Ferry Lake	Annual mean daily pool elevation	0.28	0.22	<0.01	467.85	0.05

Table 10. Results of Mann-Kendall test for monotonic trends in annual minimum daily pool elevations of selected U.S. Army Corps of Engineers reservoirs in Arkansas and Missouri, 1951–2011.

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median annual minimum daily pool elevation, expressed as a percentage. HUC, four-digit hydrologic unit code region; ft/yr, feet per year; ft, feet]

Site identification number (fig. 12C)	HUC	Reservoir	Metric	Kendall's tau (τ)	Sen slope (ft/yr)	p -value	Median annual minimum daily pool elevation (ft)	Expected annual rate of change (percent)
43	0805	Lake Chicot	Annual mean daily pool elevation	0.25	0.04	<0.01	102.42	0.04
44	1101	Clearwater Lake	Annual mean daily pool elevation	0.46	0.01	<0.01	493.80	0.00
56	1111	Blue Mountain Lake	Annual mean daily pool elevation	0.49	0.03	<0.01	383.72	0.01
57	1111	Nimrod Lake	Annual mean daily pool elevation	0.24	0.02	<0.01	341.37	0.01
58	0804	Lake Ouachita (Blakely Mountain Dam)	Annual mean daily pool elevation	0.20	0.06	0.04	569.40	0.01
59	0804	Lake Greeson (Narrows Dam)	Annual mean daily pool elevation	0.48	0.18	<0.01	534.99	0.03
60	0804	DeGray Lake	Annual mean daily pool elevation	-0.17	-0.05	0.10	399.54	-0.01
61	1114	Millwood Lake	Annual mean daily pool elevation	0.22	0.02	0.04	256.76	0.01
62	1114	DeQueen Lake	Annual mean daily pool elevation	-0.07	-0.03	0.60	434.58	-0.01
63	1114	Dierks Lake	Annual mean daily pool elevation	-0.16	-0.07	0.17	521.73	-0.01
64	1114	Gillham Lake	Annual mean daily pool elevation	0.0015	0.00056	1.00	497.96	0.00
65	1101	Beaver Lake	Annual mean daily pool elevation	0.37	0.30	<0.01	1,110.50	0.03
66	1101	Table Rock Lake	Annual mean daily pool elevation	0.40	0.28	<0.01	904.22	0.03
67	1101	Bull Shoals Lake	Annual mean daily pool elevation	0.43	0.20	<0.01	644.88	0.03
68	1101	Norfork Lake	Annual mean daily pool elevation	0.34	0.17	<0.01	542.35	0.03
69	1101	Greers Ferry Lake	Annual mean daily pool elevation	0.44	0.17	<0.01	452.09	0.04

Table 11. Results of Mann-Kendall test for monotonic trends in annual mean daily releases from selected U.S. Army Corps of Engineers reservoirs in Arkansas and Missouri and annual mean daily releases from U.S. Army Corps of Engineers dams on Arkansas River in Arkansas, 1951–2011.

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median annual mean daily release, expressed as a percentage. HUC, four-digit hydrologic unit code region; (ft³/s)/yr, cubic feet per second per year; ft³/s, cubic feet per second]

Site identification number (fig. 13A)	HUC	Reservoir or dam	Metric	Kendall's tau (τ)	Sen slope [(ft ³ /s)/yr]	<i>p</i> -value	Median annual mean daily release (ft ³ /s)	Expected annual rate of change (percent)
Reservoirs								
44	1101	Clearwater Lake	Annual mean daily release	0.22	6.39	0.01	791	0.81
56	1111	Blue Mountain Lake	Annual mean daily release	0.08	1.89	0.37	491	0.38
57	1111	Nimrod Lake	Annual mean daily release	0.00090	0.07	1.00	867	0.01
58	0804	Lake Ouachita (Blakely Mountain Dam)	Annual mean daily release	0.08	5.77	0.40	1,610	0.36
59	0804	Lake Greeson (Narrows Dam)	Annual mean daily release	0.04	0.46	0.67	401	0.11
60	0804	DeGray Lake	Annual mean daily release	-0.10	-3.29	0.37	770	-0.43
61	1114	Millwood Lake	Annual mean daily release	-0.05	-10.94	0.63	5,240	-0.21
62	1114	DeQueen Lake	Annual mean daily release	-0.32	-4.65	<0.01	1,860	-0.25
63	1114	Dierks Lake	Annual mean daily release	-0.15	-1.33	0.20	156	-0.85
64	1114	Gillham Lake	Annual mean daily release	-0.07	-1.42	0.56	471	-0.30
65	1101	Beaver Lake	Annual mean daily release	0.17	10.80	0.09	1,280	0.84
66	1101	Table Rock Lake	Annual mean daily release	0.14	21.83	0.16	3,960	0.55
67	1101	Bull Shoals Lake	Annual mean daily release	0.16	39.29	0.07	5,480	0.72
68	1101	Norfork Lake	Annual mean daily release	0.0045	0.24	0.96	1,620	0.01
69	1101	Greers Ferry Lake	Annual mean daily release	0.10	9.27	0.30	1,470	0.63
Arkansas River dams								
45	0802	Wilbur D. Mills Dam (Dam 2)	Annual mean daily release	0.04	211.04	0.71	46,200	0.46
46	0802	Joe Hardin Lock and Dam (Lock and Dam 3)	Annual mean daily release	0.04	170.07	0.71	46,100	0.37
47	1111	Emmet Sanders Lock and Dam (Lock and Dam 4)	Annual mean daily release	0.03	175.89	0.76	44,900	0.39
48	1111	Colonel Charles D. Maynard Lock and Dam (Lock and Dam 5)	Annual mean daily release	0.04	167.80	0.71	43,900	0.38
49	1111	David D. Terry Lock and Dam (Lock and Dam 6)	Annual mean daily release	0.05	161.41	0.63	44,000	0.37
50	1111	Murray Lock and Dam (Lock and Dam 7)	Annual mean daily release	0.04	166.53	0.71	44,300	0.38
51	1111	Toad Suck Ferry Lock and Dam (Lock and Dam 8)	Annual mean daily release	0.05	168.00	0.63	41,400	0.41
52	1111	Arthur V. Ormond Lock and Dam (Lock and Dam 9)	Annual mean daily release	0.06	209.85	0.62	39,800	0.53
53	1111	Dardanelle Lock and Dam (Lock and Dam 10)	Annual mean daily release	0.05	137.52	0.69	38,600	0.36
54	1111	Ozark Lock and Dam (Lock and Dam 12)	Annual mean daily release	0.07	196.50	0.52	37,500	0.52
55	1111	James W. Trimble Lock and Dam (Lock and Dam 13)	Annual mean daily release	0.08	170.38	0.50	36,000	0.47

Table 12. Results of Mann-Kendall test for monotonic trends in annual maximum daily releases from selected U.S. Army Corps of Engineers reservoirs in Arkansas and Missouri and in annual maximum daily releases from U.S. Army Corps of Engineers dams on Arkansas River in Arkansas, 1951–2011.

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median annual maximum daily release, expressed as a percentage; HUC, four-digit hydrologic unit code region. (ft³/s)/yr, cubic feet per second per year; ft³/s, cubic feet per second]

Site identifica- tion number (fig. 13B)	HUC	Reservoir or dam	Metric	Kendall's tau (τ)	Sen slope [(ft ³ /s)/yr]	p-value	Median annual maxi- mum daily release (ft ³ /s)	Expected annual rate of change (percent)
Reservoirs								
44	1101	Clearwater Lake	Annual mean daily release	0.31	1.00	<0.01	3,740	0.03
56	1111	Blue Mountain Lake	Annual mean daily release	0.22	9.48	0.01	2,800	0.34
57	1111	Nimrod Lake	Annual mean daily release	-0.05	-3.18	0.53	5,520	-0.06
58	0804	Lake Ouachita (Blakely Mountain Dam)	Annual mean daily release	0.09	17.86	0.38	6,370	0.28
59	0804	Lake Greeson (Narrows Dam)	Annual mean daily release	0.05	5.05	0.58	2,470	0.20
60	0804	DeGray Lake	Annual mean daily release	-0.23	-8.14	0.04	5,490	-0.15
61	1114	Millwood Lake	Annual mean daily release	-0.05	-49.32	0.63	29,200	-0.17
62	1114	DeQueen Lake	Annual mean daily release	-0.27	-3.86	0.02	1,860	-0.21
63	1114	Dierks Lake	Annual mean daily release	-0.29	-2.84	0.01	896	-0.32
64	1114	Gillham Lake	Annual mean daily release	-0.13	-3.20	0.28	2,830	-0.11
65	1101	Beaver Lake	Annual mean daily release	0.38	104.36	<0.01	8,300	1.26
66	1101	Table Rock Lake	Annual mean daily release	0.22	121.23	0.02	15,000	0.81
67	1101	Bull Shoals Lake	Annual mean daily release	0.20	137.62	0.02	21,800	0.63
68	1101	Norfork Lake	Annual mean daily release	0.10	19.09	0.23	6,240	0.31
69	1101	Greers Ferry Lake	Annual mean daily release	0.18	17.74	0.07	7,130	0.25
Arkansas River dams								
45	0802	Wilbur D. Mills Dam (Dam 2)	Annual mean daily release	0.07	652.30	0.56	210,000	0.31
46	0802	Joe Hardin Lock and Dam (Lock and Dam 3)	Annual mean daily release	0.06	615.17	0.62	211,000	0.29
47	1111	Emmet Sanders Lock and Dam (Lock and Dam 4)	Annual mean daily release	0.14	1,309.67	0.20	210,000	0.62
48	1111	Colonel Charles D. Maynard Lock and Dam (Lock and Dam 5)	Annual mean daily release	0.07	620.37	0.52	215,000	0.29
49	1111	David D. Terry Lock and Dam (Lock and Dam 6)	Annual mean daily release	0.16	1,066.83	0.14	222,000	0.48
50	1111	Murray Lock and Dam (Lock and Dam 7)	Annual mean daily release	0.14	1,117.43	0.21	209,000	0.53
51	1111	Toad Suck Ferry Lock and Dam (Lock and Dam 8)	Annual mean daily release	0.13	913.52	0.23	215,000	0.42
52	1111	Arthur V. Ormond Lock and Dam (Lock and Dam 9)	Annual mean daily release	0.11	835.34	0.32	206,000	0.41
53	1111	Dardanelle Lock and Dam (Lock and Dam 10)	Annual mean daily release	0.06	652.30	0.58	213,000	0.31
54	1111	Ozark Lock and Dam (Lock and Dam 12)	Annual mean daily release	0.10	778.87	0.36	180,000	0.43
55	1111	James W. Trimble Lock and Dam (Lock and Dam 13)	Annual mean daily release	0.09	771.73	0.40	157,000	0.49

Table 13. Results of Mann-Kendall test for monotonic trends in the annual number of low-flow days at selected U.S. Army Corps of Engineers reservoirs in Arkansas and Missouri and selected U.S. Army Corps of Engineers dams on the Arkansas River in Arkansas, 1951–2011.

[Shaded rows indicate statistically significant trends ($p \leq 0.10$). The expected annual rate of change is the ratio of the Sen slope to the median annual number of low-flow days, expressed as a percentage. HUC, four-digit hydrologic unit code region; days/yr, days per year; ft³/s, cubic feet per second]

Site identification number (fig. 14)	HUC	Reservoir or dam	Metric	Kendall's tau (τ)	Sen slope (days/yr)	p -value	Median annual number of low-flow days (ft)	Expected annual rate of change (percent)
Reservoirs								
44	1101	Clearwater Lake	Annual number of days below the 10th percentile release	0.31	1.00	<0.01	54	1.85
56	1111	Blue Mountain Lake	Annual number of days below the 10th percentile release	0.01	0.00	0.88	25	0.00
57	1111	Nimrod Lake	Annual number of days below the 10th percentile release	-0.30	-0.68	<0.01	31	-2.21
58	0804	Lake Ouachita (Blakely Mountain Dam)	Annual number of days below the 10th percentile release	0.22	0.72	0.02	34	2.12
59	0804	Lake Greeson (Narrows Dam)	Annual number of days below the 10th percentile release	0.20	0.00	0.05	0	0.00
60	0804	DeGray Lake	Annual number of days below the 10th percentile release	0.19	0.85	0.07	112	0.76
61	1114	Millwood Lake	Annual number of days below the 10th percentile release	0.02	0.00	0.88	22	0.00
62	1114	DeQueen Lake	Annual number of days below the 10th percentile release	0.22	1.33	0.07	44	3.03
63	1114	Dierks Lake	Annual number of days below the 10th percentile release	0.30	1.63	0.01	53	3.08
64	1114	Gillham Lake	Annual number of days below the 10th percentile release	0.15	0.67	0.21	34	1.96
65	1101	Beaver Lake	Annual number of days below the 10th percentile release	0.01	0.00	0.90	76	0.00
66	1101	Table Rock Lake	Annual number of days below the 10th percentile release	-0.06	-0.15	0.54	34	-0.45
67	1101	Bull Shoals Lake	Annual number of days below the 10th percentile release	0.21	0.42	0.02	30	1.39
68	1101	Norfork Lake	Annual number of days below the 10th percentile release	-0.11	-0.22	0.21	32	-0.69
69	1101	Greers Ferry Lake	Annual number of days below the 10th percentile release	0.02	0.07	0.82	59	0.12
Arkansas River dams								
45	0802	Wilbur D. Mills Dam (Dam 2)	Annual number of days below a 1,000 ft ³ /s release	0.21	0.23	0.06	9	2.58
46	0802	Joe Hardin Lock and Dam (Lock and Dam 3)	Annual number of days below a 1,000 ft ³ /s release	0.21	0.20	0.06	8	2.50
47	1111	Emmet Sanders Lock and Dam (Lock and Dam 4)	Annual number of days below a 1,000 ft ³ /s release	0.29	0.22	0.01	7	3.12
48	1111	Colonel Charles D. Maynard Lock and Dam (Lock and Dam 5)	Annual number of days below a 1,000 ft ³ /s release	0.29	0.21	<0.01	7	3.06
49	1111	David D. Terry Lock and Dam (Lock and Dam 6)	Annual number of days below a 1,000 ft ³ /s release	0.25	0.19	0.02	8	2.34
50	1111	Murray Lock and Dam (Lock and Dam 7)	Annual number of days below a 1,000 ft ³ /s release	0.27	0.24	0.02	8	2.97
51	1111	Toad Suck Ferry Lock and Dam (Lock and Dam 8)	Annual number of days below a 1,000 ft ³ /s release	0.40	0.22	<0.01	3	7.19
52	1111	Arthur V. Ormond Lock and Dam (Lock and Dam 9)	Annual number of days below a 1,000 ft ³ /s release	0.23	0.08	0.04	4	2.08
53	1111	Dardanelle Lock and Dam (Lock and Dam 10)	Annual number of days below a 1,000 ft ³ /s release	0.00	0.00	0.99	13	0.00
54	1111	Ozark Lock and Dam (Lock and Dam 12)	Annual number of days below a 1,000 ft ³ /s release	-0.05	-0.07	0.69	10	-0.69
55	1111	James W. Trimble Lock and Dam (Lock and Dam 13)	Annual number of days below a 1,000 ft ³ /s release	-0.12	-0.17	0.28	9	-1.85

Arkansas: 6/11/2010 1-Day Observed Precipitation
Valid at 6/11/2010 1200 UTC- Created 6/13/10 23:30 UTC