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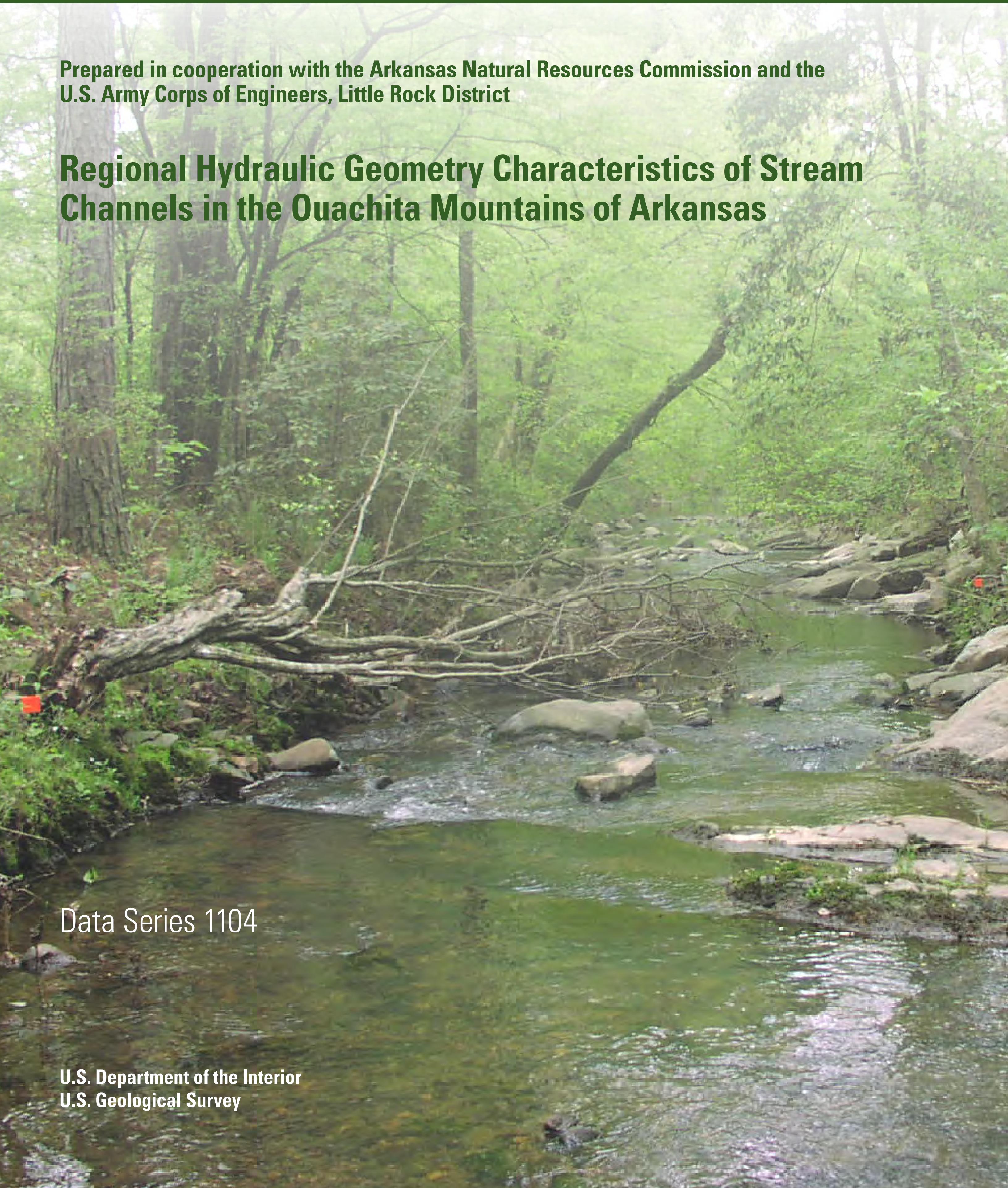
Regional Hydraulic Geometry Characteristics of Stream Channels in the Ouachita Mountains of Arkansas



Data Series 1104

U.S. Department of the Interior
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Cover. Little Sugarloaf Creek near Bonnerdale, Arkansas (photograph by Aaron Pugh, U.S. Geological Survey, April 16, 2002).

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Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Pressure	
pound per square foot (lb/ft^2)	0.04788	kilopascal (kPa)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as
°C = (°F – 32) / 1.8.

Datum

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

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

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

Abbreviations

ANRC	Arkansas Natural Resources Commission
EPA	U.S. Environmental Protection Agency
NRCS	Natural Resources Conservation Service
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

Regional Hydraulic Geometry Characteristics of Stream Channels in the Ouachita Mountains of Arkansas

By Aaron L. Pugh[1] and Ronald K. Redman[2]

Abstract

Many stream channel infrastructure, habitat, and restoration projects are being undertaken on small streams throughout Arkansas by various Federal, State, and local agencies and by private organizations and businesses with limited data on local geomorphology and streamflow relations. Equations are needed that relate drainage area above stable stream reaches and the associated basin characteristics to bankfull streamflow and the associated channel dimensions. These equations, along with streambed material particle information, provide information that can improve stream channel projects. The U.S. Geological Survey and the Arkansas Natural Resources Commission in cooperation with the U.S. Army Corps of Engineers, Little Rock District, undertook a study to develop these equations for streams in the Ouachita Mountains of Arkansas.

Seventeen streamgages operated by the U.S. Geological Survey, located on streams in the Ouachita Mountains, were selected for analysis. Regional hydraulic geometry curves that express the mathematical relation between the bankfull channel dimensions (cross-sectional area, top width, mean depth, and streamflow) and the contributing drainage areas were developed. Streambed material measurements were collected to develop descriptive statistics of the streambed particle-size distributions and percentages of substrate type at each study site. Stream reaches at each study site were classified to the Rosgen level II stream type based on the average of stream channel metrics collected from site cross sections and profiles. Of the 17 selected Ouachita Mountain stream reaches, 6 were classified as B stream types, and 11 were classified as C stream types. The B stream types have infrequently spaced pools; very stable plan forms, profiles, and banks; and narrow, gently sloping valleys, where bank vegetation is a moderate component of stability. The C stream types are meandering, point bar, riffle-pool channels associated with broad valleys having well-defined flood plains and terraces composed of alluvial soils, where bank vegetation is typically a high component of stability.

[1]U.S. Geological Survey.

[2]Arkansas Natural Resources Commission.

Introduction

Natural stream channels continually adjust their form, dimension, and slope through natural fluvial processes to establish and maintain equilibrium between streamflow and the erosion, transport, and deposition of sediment (Rosgen, 1996). When a stable natural stream channel exhibits long-term stability, it may laterally reposition itself in its valley and (or) undergo minor aggradation or deposition of the streambed over time without excessive changes in the top width and mean depth. Conversely, when a natural stream channel is unstable, there is an imbalance between the erosive and depositional forces. This imbalance may cause extreme lateral movement and streambed aggradation and (or) deposition resulting in large changes in the top width and mean depth and excessive streambank erosion. The overall stability of a stream channel and the rate of associated stream channel adjustments are the direct result of natural and (or) anthropogenic changes imposed on the watershed and (or) channel.

Bedload is the part of the total sediment load that is transported by intermittent contact with the streambed by rolling, sliding, or bouncing. The bedload transport process is controlled by the interaction between the stream channel hydraulics and bed material conditions that govern the stream channel morphology. Knowledge of bedload transport is necessary to understand the causes and consequences of changes in fluvial form and to make informed management decisions that affect stream channel morphology and function.

Scientists and engineers have long resorted to classification schemes as a means of describing the variability of the physical nature of rivers. Recent stream classification systems are process based and incorporate cross section, longitudinal profile, and channel material characteristics (Schumm and others, 1984; Simon, 1989; Montgomery and Buffington, 1993; Whiting and Bradley, 1993; Rosgen, 1994, 1996). Rosgen (1996) developed a stream classification system to address specific, applied objectives related to conditions and processes, to predict behavior from appearance, to develop specific hydraulic and sediment relations for given stream types, to provide a mechanism for extrapolation of site-specific data to streams of similar types, and to provide a consistent frame of reference to aid communication about river morphology and condition among various disciplines.

In addition to stream classification systems, regional hydraulic geometry curves are a useful planning tool for stream assessments, natural stream design, stream restoration, and habitat enhancement (Rosgen, 1994; U.S. Army Corps of Engineers, 1994; Brookes and Shields, 1996; Thorne and others, 1997). Regional hydraulic geometry curves are empirical relations constructed from observations of bankfull dimensions and other measurements made at stable stream reaches on gaged streams within a relatively homogeneous region. Bankfull geometry dimensions are developed from topographic surveys at stable stream reaches and include point locations defining the channel thalweg and bankfull profiles and riffle and pool cross sections. Bankfull geometry dimensions (cross-sectional area, top width, and mean depth) from stable riffle sections and the associated bankfull streamflow are plotted against the contributing drainage area. Regression equations derived from hydraulic geometry curves express the mathematical relation (power functions, $Y=aX^b$) between the bankfull channel dimensions (Y) and the contributing drainage areas (X) for stable stream reaches within the same physiographic area. The curves and equations created for gaged streams can be used to provide estimates of bankfull channel dimensions and bankfull streamflow and to allow for comparisons to be made between riffle dimensions with stable, ungaged streams within the same physiographic region.

The U.S. Geological Survey (USGS) and the Arkansas Natural Resources Commission (ANRC) in cooperation with the U.S. Army Corps of Engineers (USACE), Little Rock District, conducted this study, in part, to provide the USACE Regulatory (Permits) program with fluvial geomorphic information to better fulfill the mission of protecting the aquatic resources of the Nation while allowing reasonable development through fair, flexible, and balanced permit decisions. The USACE evaluates permit applications for essentially all construction activities that occur in waterways in the United States.

A large part of the fieldwork conducted for this study was done by personnel from the ANRC, the U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS), and the USGS from July 2001 through June 2006. This earlier work was not published, but a preliminary set of regional curves for the Ouachita Mountains developed from this work was used in a report summarizing the channel geomorphic characteristics of the Middle Fork Saline River (Pugh and others, 2008).

Many stream channel infrastructure, habitat, and restoration projects are being undertaken on small streams throughout Arkansas by various Federal, State, and local agencies and by private organizations and businesses with limited data on local geomorphology and streamflow relations. Stream channel projects using natural channel design are often based on bankfull streamflow and basin characteristics to ensure that the channel accommodates the streamflow and sediment transport without excessive erosion or deposition. This report presents the methodology used (1) to conduct longitudinal profile and cross-section surveys, (2) to collect and analyze bar material and streambed material samples, (3) to classify stream reaches, and (4) to create regional hydraulic geometry curves for 17 selected streamflow-gaging stations and their associated stream reaches located in the Ouachita Mountains region of Arkansas.

All data are available in Pugh and Redman (2019) and include (1) the bankfull channel-morphology characteristics, (2) the bankfull streamflow and associated recurrence interval, (3) the distribution of streambed material particle sizes, (4) the stream reach classification, (5) basin characteristics, and (6) an analysis of the regional relations among bankfull channel width, bankfull mean depth, bankfull cross-sectional area, and bankfull streamflow to drainage areas for the Ouachita Mountains region of Arkansas. The scope of this investigation was confined to streams in the Ouachita Mountains physiographic section (fig. 1) (Fenneman, 1938) that have streamflow measurement data collected by the USGS.

Data Release

Many of the larger datasets or tables assembled for this study are not presented in this report but are publicly available in Pugh and Redman (2019). The datasets or comma-separated value (CSV) files to support this study include the following:

- Geographic information system (GIS) shape files of the study site locations (point file) and the associated contributing watersheds (polygon file).
- CSV files of the streambed and point bar particle measurements made at stream reaches and the associated graphs of particle-size distributions and particle-shape analysis.
- A CSV file containing the USGS streamflow gage location, basin characteristics, bankfull channel characteristics, and stream classification for each site.
- A CSV file that contains descriptions of the selected study sites including the reach beginning and ending locations; the geology and soils at the reach; the land cover within the watershed; the streambed substrate type within the reach; the entrenchment ratio, width-to-depth ratio, and sinuosity for the reach; the observed reach morphology; and the stream type classification for the reach.
- Photographs documenting the selected stream reaches.

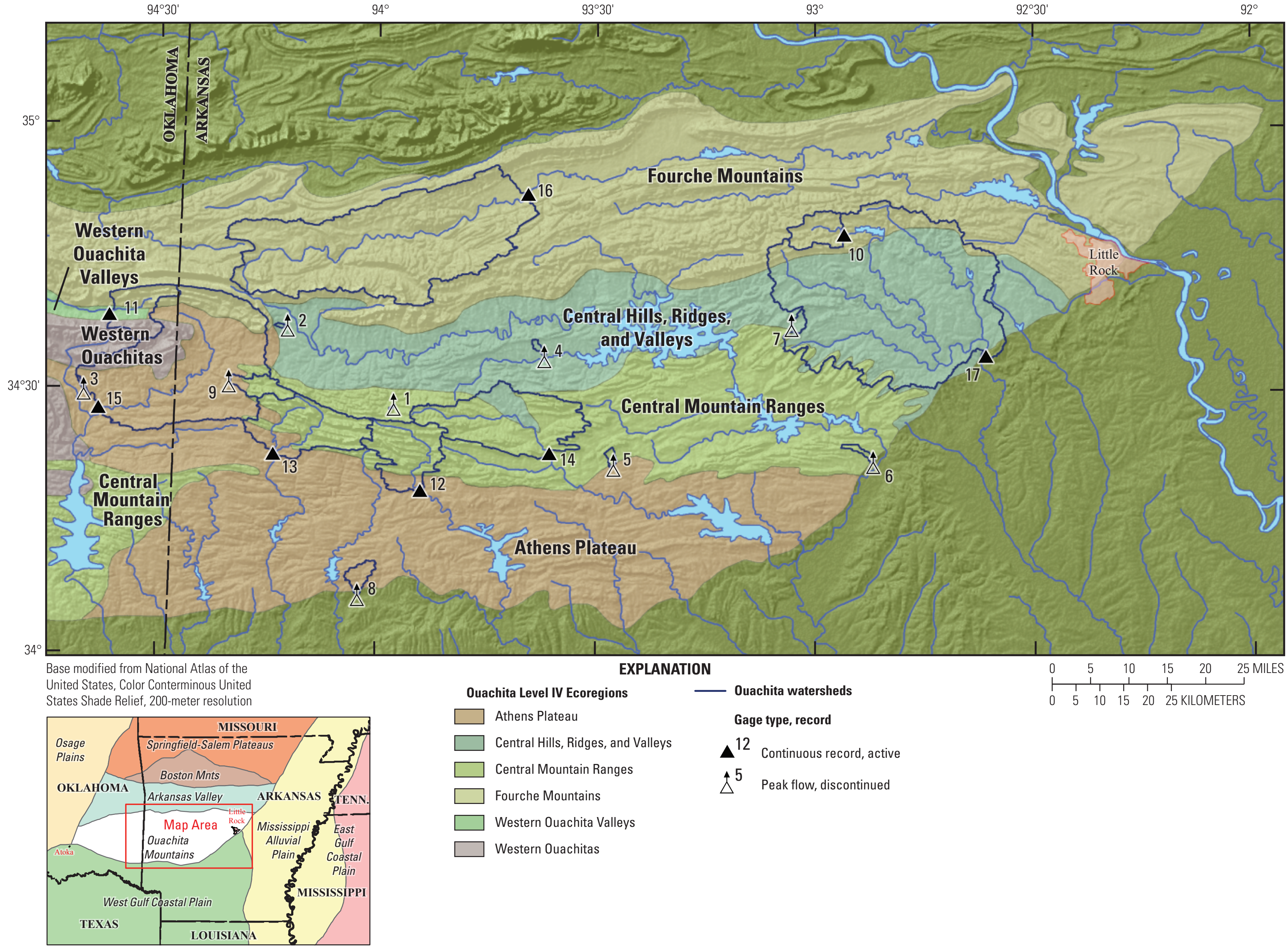


Figure 1. Study sites and the Ouachita Mountains physiographic section and ecoregions.

Description of the Ouachita Mountains

The current conditions of streams and their watersheds are the result of the interactions between the local geology, land cover, and climate. To help characterize the watersheds of the Ouachita Mountains (hereafter referred to as “the Ouachitas”), it is essential to understand how the landscape has evolved over time—on both a human and geological time scale. This section contains descriptions of the location, topography, geology, soils, land cover and population, and climate of the Ouachitas.

Location

The Ouachitas are located in west-central and central Arkansas and southeastern Oklahoma, extending approximately 225 miles from east of Little Rock, Ark., westward to Atoka, Okla., and approximately 50–60 miles from the Arkansas Valley southward to the northern margin of the West Gulf Coastal Plain (fig. 1). Physiographically, the Ouachitas are located within the Ouachita Mountains physiographic section (fig. 1) (Fenneman, 1938). The Ouachita Mountains physiographic section generally aligns with the U.S. Environmental Protection Agency (EPA) Level III Ecoregion (Omernik, 1987). The EPA has further subdivided the Ouachitas into six Level IV Ecoregions (fig. 1) (Omernik and Griffith, 2014).

Hydrologically, the Ouachitas in Arkansas contain all or parts of 14 cataloging hydrologic (8-digit code) units that are parts of two different regional (2-digit code) hydrologic units (table 1, fig. 2). The Ouachitas are about evenly divided between two regional hydrologic units—the Lower Mississippi and the Arkansas-White-Red. The majority of the Ouachitas are within two of the four subregional hydrologic units—the Lower Red-Ouachita and the Lower Arkansas. The Ouachita Headwaters cataloging unit comprises 24.5 percent of the study area and is entirely contained within the Arkansas Ouachitas. Similarly, the Fourche LaFave cataloging unit is almost entirely contained within the Ouachitas, comprising 17 percent. The Lower White-Bayou Des Arc and Kiamichi cataloging units have a minimal presence in the Ouachitas of Arkansas. The percentages of the Ouachitas in Arkansas within specific hydrologic units (table 1) were determined by using a GIS to divide the areas of specific hydrologic units, as defined by the national Watershed Boundary Dataset layer (U.S. Geological Survey, 2016), by the total area of the Ouachitas in Arkansas, as defined by the ecoregions dataset layer (U.S. Environmental Protection Agency, 2016) (fig. 2).

Table 1. Hydrologic units within the Ouachita Mountains of Arkansas.

[Horizontal length of the blue bars represents the percentage of the cataloging hydrologic unit within the Ouachita Mountains of Arkansas; HUC, Hydrologic Unit Code; <, less than. Ouachita boundary from Fenneman, 1938; watershed boundaries from U.S. Geological Survey, 2016]

Hydrologic unit number–Basin name				Percentage of Arkansas Ouachitas in HUC
Regional (2-digit)	**Subregional (4-digit)**	**Accounting (6-digit)**	**Cataloging (8-digit)**	
08 Lower Mississippi	0802 Lower Mississippi - St. Francis	080203 Lower White	08020301–Lower White - Bayou Des Arc	0.5
		080204 Lower Arkansas	08020402–Bayou Meto	2.3
	0804 Lower Red - Ouachita	080401 Upper Ouachita	08040101–Ouachita Headwaters	24.5
			08040102–Upper Ouachita	9.9
			08040103–Little Missouri	9.3
		080402 Lower Ouachita	08040203–Upper Saline	9.5
11 Arkansas - White - Red	1111 Lower Arkansas	111101 Robert S. Kerr Reservoir	11110105–Poteau	2.9
		111102 Lower Arkansas - Fourche LaFave	11110203–Lake Conway-Point Remove	2.1
			11110204–Petit Jean	1.7
			11110206–Fourche LaFave	17.0
			11110207–Red-Sulphur	6.0
	1114 Red - Little	111401 Bois d’ Arc - Island	11140105–Kiamichi	< 0.01
			11140108–Mountain Fork	3.8
			11140109–Lower Little	10.5

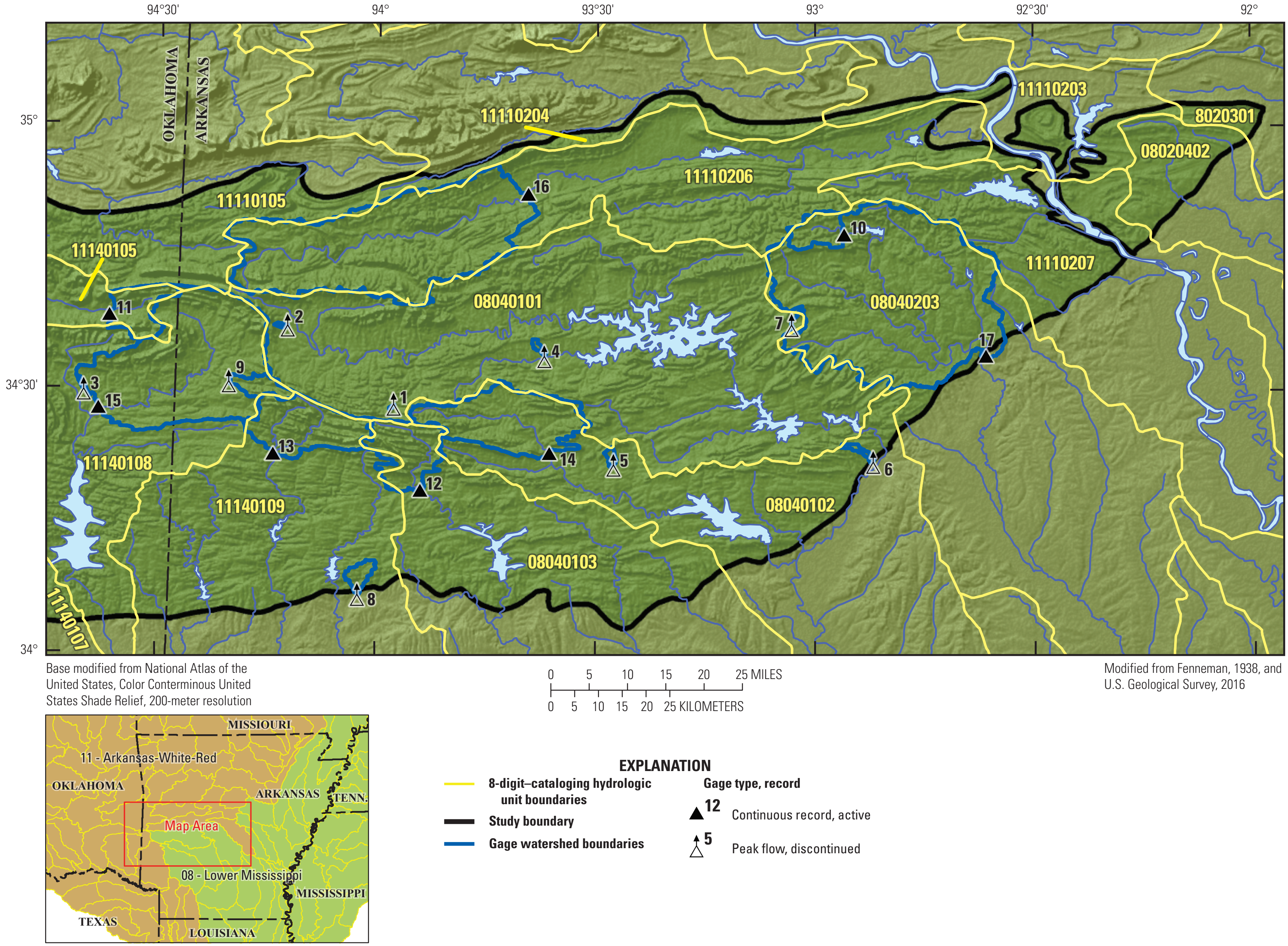


Figure 2. Hydrologic units within the Ouachita Mountains of Arkansas.

Topography

The Ouachitas in Arkansas consist of generally east-west trending valley and ridge topography. The topography is directly related to the regional geology. The relief or differences in elevation from the ridge tops to the valley floors generally range from 500 to 800 feet (ft), but can range from 1,000 to 2,000 ft, and are the result of the compression and uplift of Paleozoic rocks and the subsequent erosion and entrenchment of drainage channels into the land surface. The ridges form straight to zigzag patterns characterized by long, hogback ridges. Ridge top elevations generally increase in a westerly direction with elevations ranging between 600 and 2,950 ft above sea level with the highest elevation on Rich Mountain in Le Flore County, Okla., near the Arkansas-Oklahoma border. Ridges generally have long north and south facing slopes. The north facing slopes tend to be steeper than the south facing slopes because of the way the rock strata have fractured (Croneis, 1930).

Geology

Aber (2014) described the geology of the Ouachitas in detail:

> "During the Late Proterozoic eon and Paleozoic era, the southern margin of North America underwent a complete geophysical cycle of continental rifting, ocean opening and closing, and collision that in part created the Ouachita Mountains, the Appalachian Mountains, and the Central Plateau of Texas. To the east of the Ouachitas, the structural and stratigraphic features are buried by Cretaceous and Tertiary systems sediments and alluvial deposits of the Mississippi Embayment; to the west, the structural trend curves south and is buried by Cretaceous System strata of the Central Plains.
>
> In the Late Proterozoic eon, along the southern margin of North America, rifting occurred along a network of transforms and spreading zones. Structurally, rift valleys are block-fault graben bordered by horst with normal faults between them. Initially, the axial valley floor was subaerial, but as the graben continued to subside, the sea inundated the area creating a marine basin.
>
> From the Late Cambrian through the Devonian systems, the continental margin was a passive region of subsidence, where shelf sediments accumulated near land and a deep ocean basin developed farther offshore. The Ouachita system display a phase of development from Late Ordovician through Devonian systems referred to as the "starved basin" phase. Chert and shale formations were deposited slowly as nearly flat layers of mud and oceanic ooze in the deep water of the subsiding ocean basin, and occasional sand formations were deposited by ocean currents and as fans at the heads of submarine canyons.
>
> By the Early Mississippian period and through the Pennsylvanian period, the Ouachita Basin had become a narrow trough into which large volumes of sand and mud entered the ocean from rivers with deltas near present day Poteau, Okla. These deposits accumulated to reach thicknesses of 45,000 ft. Ultimately, the region was uplifted as the South American Plate drifted northward, riding up over the denser North American continental crust in a mountain building process known as the Ouachita orogeny. The Ouachita orogeny intensely deformed and metamorphosed parts of the oceanic oolitic and deltaic deposits with compressive forces directed north toward the stable interior of the American continent producing prominent east-west folds and large thrust faults. The Ouachita orogeny culminated by the end of Pennsylvanian period and the shallow sea was drained by the end of the Permian system. The Ouachita orogeny is distinctive in that volcanism, metamorphism, and intrusion are notably absent throughout most of the system."

The region was again subjected to continental rifting during the Jurassic and Cretaceous systems, as evidenced by the Gulf Coastal Plain sedimentary sequence. During the Cretaceous system, veins of igneous rock intruded into the deformed rocks of the Paleozoic era (Croneis, 1930; Arkansas Geological Survey, 2015a).

Following the Ouachita orogeny, the region was eroded and dissected with minor arching and extensional faulting. During the Pleistocene epoch and Quaternary system, shale was eroded to form valleys, and sandstone, chert, and novaculite resisted erosion to form the dominant east-west ridges. Terrace, alluvial, and colluvial deposits represent some of the most recent products of these climatically related cycles of erosion and deposition (Croneis, 1930; Arkansas Geological Survey, 2015a, b) (fig. 3).

Soils

Over time, soils develop horizons that form because of physical and chemical weathering processes acting on the parent material. Soils that form in similar parent material, age, topography, and climate have soil horizons that are similar in texture, structure, colors, and thickness.

Examining the broadest level of soil classification used by the National Cooperative Soil Survey (U.S. Department of Agriculture, 1975), most soils of the Ouachitas are assigned to the ultisols order. Ultisols are intensively weathered and characterized by low fertility. Soils in this order are acidic because of long periods of weathering during the Pleistocene and Holocene epochs. These soils form in humid climates under pine-hardwood forests and are generally moist throughout the year. The soils are strongly leached, generally of medium texture, and moderate permeable (Steila and Pond, 1989).

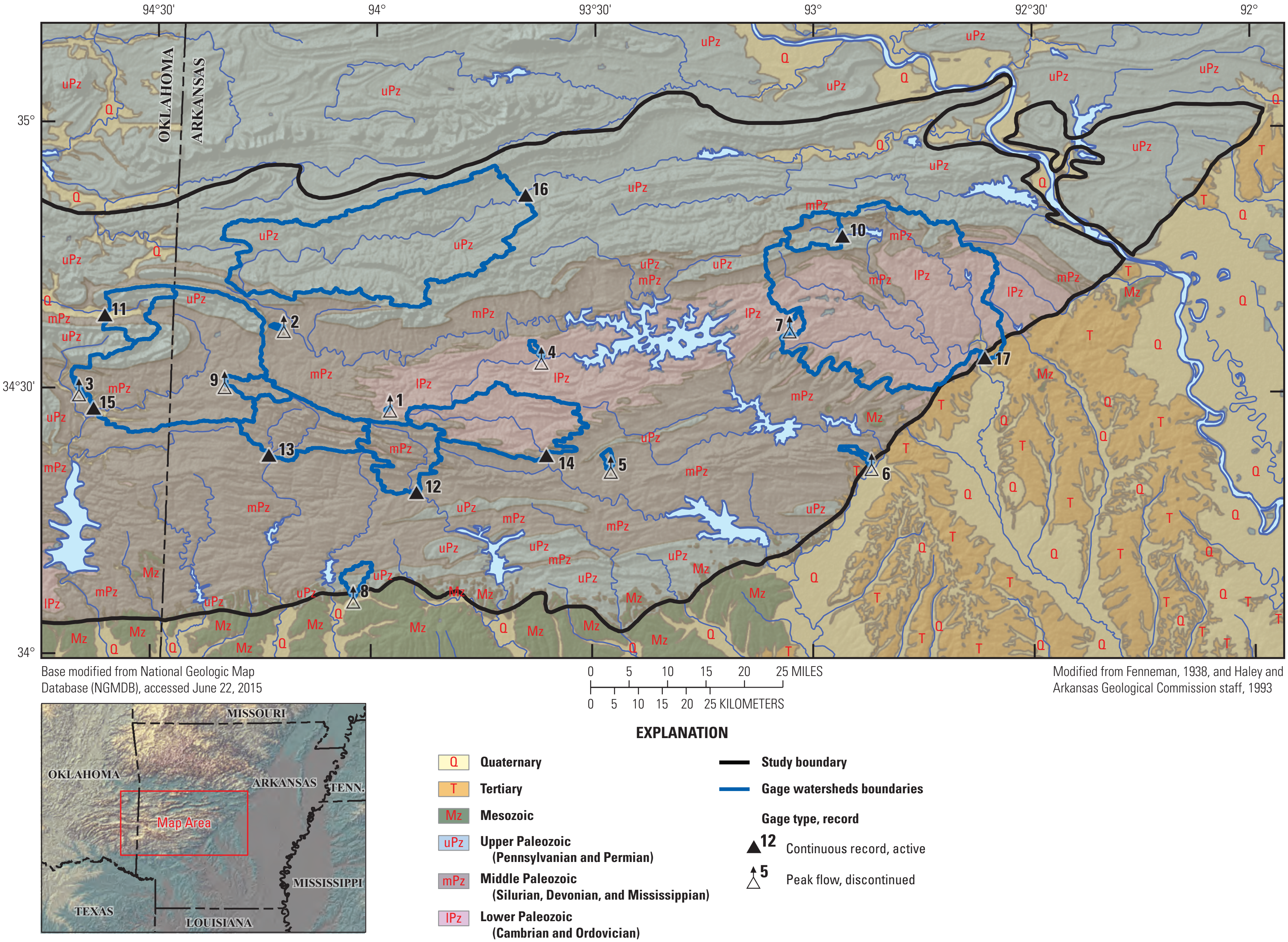


Figure 3. Generalized geology of the Ouachita Mountains.

Land Cover and Population

Pine plantations are the major land cover along with pasturelands and haylands within the broader valleys of the Ouachitas. The area supports oak-hickory-pine forests. The primary overstory species are southern red oak, black oak, white oak, and hickory. Pine constitutes as much as 40 percent of the cover (shortleaf pine in the uplands and loblolly pine on lower lying alluvial soils). The dry sandstone ridges of the Ouachitas are covered by a mixture of shortleaf pine, oak, and hickory on their southern slopes and by hardwood forests made up mainly of oak and hickory on their northern slopes. Hardwoods populate the rich bottom lands of the valleys, and pines predominate on the less fertile lands. Natural vegetation has been cleared for agriculture on about 25 percent of the Ouachitas. The major agricultural farming activities are pastureland and hayland with cattle and broiler chickens being the major farm products (U.S. Department of Agriculture, Forest Service, 1999).

The western part of the Little Rock metropolitan area (Pulaski County) and Hot Springs (Garland County) are the largest population centers in the Ouachitas. Little Rock is located on the eastern edge of the Ouachitas and accounts for approximately 56 percent of the population. Hot Springs and the surrounding retirement communities account for approximately 19 percent of the population. The rural and small-town populations of the Ouachitas in Arkansas account for approximately 25 percent of the population and have decreased in every census since the 1920s. Most of these small towns are located on the periphery of the Ouachitas where the mountains meet the West Gulf Coastal Plain (The Nature Conservancy, 2003).

Climate

Monthly mean temperatures are around 80 degrees Fahrenheit (°F) in summer, and winter monthly mean temperatures range from around 35 °F in the north to around 45 °F in the south. Maximum temperatures exceed 100 °F at times during July and August. Winters are short, with brief periods of below freezing temperatures. The growing season ranges from 180 days in the northwest to more than 230 days in the southeast. Late spring freezes are sometimes damaging to agriculture, but typically, crops mature before fall freezes occur. Extended warm and humid periods are common in summer (Office of the Arkansas State Climatologist, 2017).

Annual precipitation totals range roughly from 45 to 55 inches (in.). Precipitation results from middle latitude cyclones (lows), with warm, cold, and other frontal situations; tropical lows from the Gulf of Mexico; and thunderstorms, or orographic uplift, caused by hills and mountains. Rainfall is generally abundant throughout the year. December and January tend to be the wettest months in the southern counties. The driest month tends to be August, although the average precipitation for the month is about 3 in. The number of days with measurable precipitation averages about 100 per year. Most of the precipitation falls as rain; heavy local storms that result in precipitation totals from 5 to 10 in. over extensive areas are common. During fall, winter, and early spring, precipitation events are usually less intense and of longer duration. Annual snowfall totals range from 1 to 2 in., mainly in the northwestern parts of the Ouachitas. Snowfall is generally light and remains on the ground only briefly, but rare winter storms do occur with accumulations of as much as 10 in. in a 24-hour period. Ice storms are also infrequent but can be severe. Tornadoes are most frequent from March through May, with about 15–20 reported each year. About 60 thunderstorms are reported each year, most frequently in June and July (Office of the Arkansas State Climatologist, 2017).

Methods

The following discussions describe the selection of study sites and the sampling methods used at each location. Sampling methods included stream geometry surveys, streambed material particle sampling, and digital photography documentation.

Site Selection

At various times over the past 80 years, the USGS has maintained and operated approximately 50 streamflow-gaging stations throughout the Ouachitas. On the basis of the criteria listed below, 17 of these streamflow-gaging stations were selected for analysis (table 2, fig. 2). The most common reasons for stations not being selected were short flow records (less than 15 years), large percentage of controlled drainage (large dam/reservoirs above the site), and numerous stations with drainage areas similar to those selected.

- Approximately 20 years or more of flow record.
- A minimal amount of urbanization (developed land cover) in the watershed above the gaging station.
- A minimal amount of controlled drainage in the drainage basin above the gaging station.
- Upon inspection, the stream must be stable above and below the gaging station without excessive streambank failure and without excessive aggradation or degradation of the streambed.
- An even distribution of drainage basin sizes and geographic distribution across the Ouachitas to facilitate development of representative regional curves.

Table 2. Selected U.S. Geological Survey streamflow-gaging stations in the Ouachita Mountains of Arkansas.

[USGS, U.S. Geological Survey; mi^2, square mile; DMS, degrees, minutes, seconds; NAD 83, North American Vertical Datum of 1983; HUC-8, 8-digit Hydrologic Unit Code (from U.S. Geological Survey, 2016); Ark., Arkansas; Okla., Oklahoma]

Map number (fig. 2)	USGS station number	USGS station name	Drainage area (mi^2)	Number of years of gage record	Latitude (DMS) NAD 83	Longitude (DMS) NAD 83	HUC-8
1	07355900	Big Fork Tributary at Big Fork, Ark.	0.19	19	34°28’23”	93°57’38”	08040101
2	07355800	Lewis Creek Tributary near Mena, Ark.	0.65	44	34°37’15”	94°12’15”	08040101
3	07338780	Mountain Fork Tributary near Smithville, Okla.	0.68	20	34°29’48”	94°40’06”	11140108
4	07356700	Barnes Branch near Mount Ida, Ark.	1.85	21	34°33’57”	93°37’03”	08040101
5	07359750	Little Sugarloaf Creek near Bonnerdale, Ark.	2.32	21	34°21’40”	93°27’30”	08040102
6	07359520	Jackson Creek near Malvern, Ark.	2.95	20	34°22’01”	92°52’01”	08040102
7	07357700	Glazypeau Creek at Mountain Valley, Ark.	3.84	27	34°37’33.8”	93°03’09.6”	08040101
8	07341100	Rock Creek near Dierks, Ark.	9.46	23	34°36’46”	94°02’25”	11140109
9	07338700	Twomile Creek near Hatfield, Ark.	15.9	21	34°30’52”	94°20’14”	11140108
10	07362587	Alum Fork Saline River near Reform, Ark.	27.0	15	34°47’51”	92°56’02”	08040203
11	07335700	Kiamichi River near Big Cedar, Okla.	39.6	48	34°38’18”	94°36’45”	11140105
12	07360200	Little Missouri River near Langley, Ark.	68.4	27	34°18’42”	93°53’59”	08040103
13	07340300	Cossatot River near Vandervoort, Ark.	89.6	34	34°22’48”	94°14’11”	11140109
14	07359610	Caddo River near Caddo Gap, Ark.	136	18	34°22’58”	93°36’22”	08040102
15	07338750	Mountain Fork at Smithville, Okla.	322	25	34°27’44”	94°38’06”	11140108
16	07261500	Fourche LaFave River near Gravelly, Ark.	410	73	34°52’21”	93°39’26”	11110206
17	07363000	Saline River at Benton, Ark.	550	55	34°34’04”	92°36’37”	08040203

Longitudinal Profile and Cross-Section Surveys

Topographic surveys of stream longitudinal profiles and cross sections were conducted at each study site to obtain information on the thalweg and bankfull slopes and cross-sectional hydraulic geometry. Each topographic survey measured the location and elevation of points along the thalweg and bankfull profiles and along selected riffle and pool cross sections. Longitudinal profiles were acquired above and (or) below the gage location for approximately 10 times the bankfull width or for a total distance of approximately 20 times the bankfull stream channel width. All bankfull indicators that could be located and surveyed were measured and included points on both the left and right banks. Stage elevations associated with streamflows at the 1.5-year recurrence interval were used to aid in the identification of bankfull indicators during stream surveys. Cross-sectional surveys were acquired to an elevation high enough to include the flood prone elevation (twice the maximum bankfull depth).

Streambed Material Particle Sampling

Streambed material sampling was conducted to develop particle-size distribution plots from which particle-size quantile values, descriptive statistics of particle-size distributions, and particle-size distribution percentages of substrate type were calculated and to determine the shapes of the individual particles composing the streambeds for each study site. Grain-size ranges given for streambed material particle-size ranges and percentages of substrate type were based on the modified Wentworth scale (American Geological Institute, 1982). Information on streambed material particle-size distribution is a parameter used in the Rosgen stream reach classification system (Rosgen, 1994). Streambed material particle sizes were measured by using two methods: (1) a modified Wolman pebble count and (2) a sieve analysis of bar samples.

The modified Wolman pebble counts were conducted across the riffles and pools within each study reach (Harrelson and others, 1994). An observer with a metric ruler waded the stream by using a step-toe procedure to collect and measure approximately 100 streambed material samples at each riffle and pool. Materials only from the active streambed, defined as the area between the toes of the left and right bankfull terraces, were measured. For each sample selected, the longest axis (length, denoted “a-axis”), intermediate axis (width, denoted “b-axis”), and shortest axis (thickness, denoted “c-axis”) were measured and recorded (fig. 4). From the pebble count data, the bedrock tallies were removed, and cumulative frequency curves were developed. (Bedrock is defined as any exposure of native solid rock in the streambed or along the streambanks.) The median (D50) and one standard deviation from the median (D16 and D84) particle sizes were determined. Particle counts, cumulative frequency curves, descriptive statistics, and percent by substrate type for each stream reach are available from Pugh and Redman (2019).

The second streambed material particle-size sampling procedure was a sieve analysis of bar samples. A 5-gallon pail (approximately 55 pounds or 25 kilograms) of bar gravel was collected from the downstream face of a point bar at an elevation approximately midway between the thalweg and bankfull elevations. The sample was collected by first removing the armored layer of gravel and then collecting all of the particles from an area approximately the same diameter as the 5-gallon pail to a depth approximately twice the diameter of the largest particle size observed on the gravel bar. The sample was dried and weighed to the nearest tenth of a gram to determine the total sample weight. The sample was then placed in a nest of sieves (see table 3 for listing of sieve sizes used), and a mechanical sieve shaker was used to separate the sample. The sample from each sieve was then removed and weighed. The final total weights retained on each sieve were summed and compared to the original total weight before sieving. From the weight retained on each sieve, cumulative frequency curves were developed, and the median (D50) and one standard deviation from the median (D16 and D84) particles sizes were determined.

Streambed material particle-shape analysis can provide information about the particle transport history and aid facies differentiation and characterization of depositional environments. Particles are classified into four basic shapes according to the ratios of the three particle axes: the a-, b-, and c-axes (fig. 4). Sneed and Folk (1958) classified particle shapes in terms of compactness, platyness, bladedness, and elongatedness (fig. 5). Triangular diagrams (fig. 5), employing ratios of the three-orthogonal particle axis, have been advocated as the most appropriate method for unbiased presentation of primary particle-shape data (Graham and Midgley, 2000). The Sneed and Folk (1958) descriptive particle-shape plots for the Wolman pebble count data are provided in Pugh and Redman (2019).

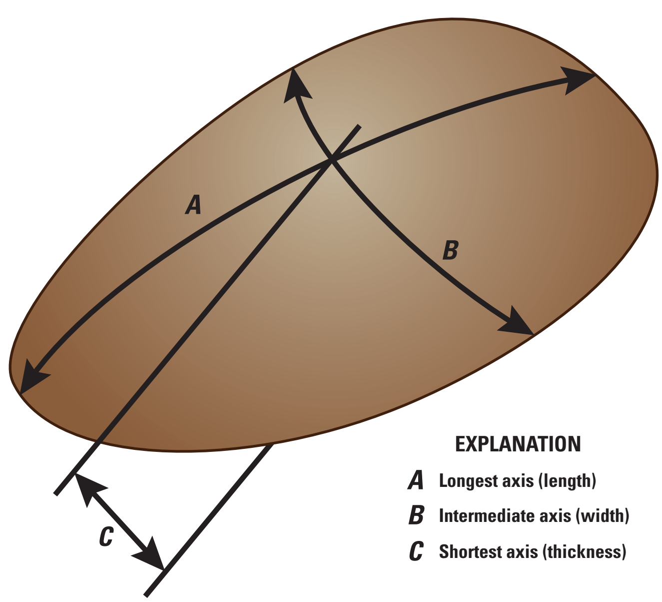


Figure 4. Particle axis measurement.

Table 3. Bar sediment sampling sieve sizes for streambed material particle-size sampling in selected stream reaches in the Ouachita Mountains of Arkansas.

Material	Sieve size	Opening (millimeter)
Medium sand	#60	0.25
Coarse sand	#35	0.50
Coarse sand	#30	0.59
Very fine gravel	#10	2.00
Very fine gravel	#6	3.35
Fine gravel	#4	4.75
Fine gravel	¼ inch	6.3
Medium gravel	½ inch	12.5
Coarse gravel	1 inch	25
Very coarse gravel	2 inch	50
Small cobble	3 inch	76
Medium cobble	4 inch	102

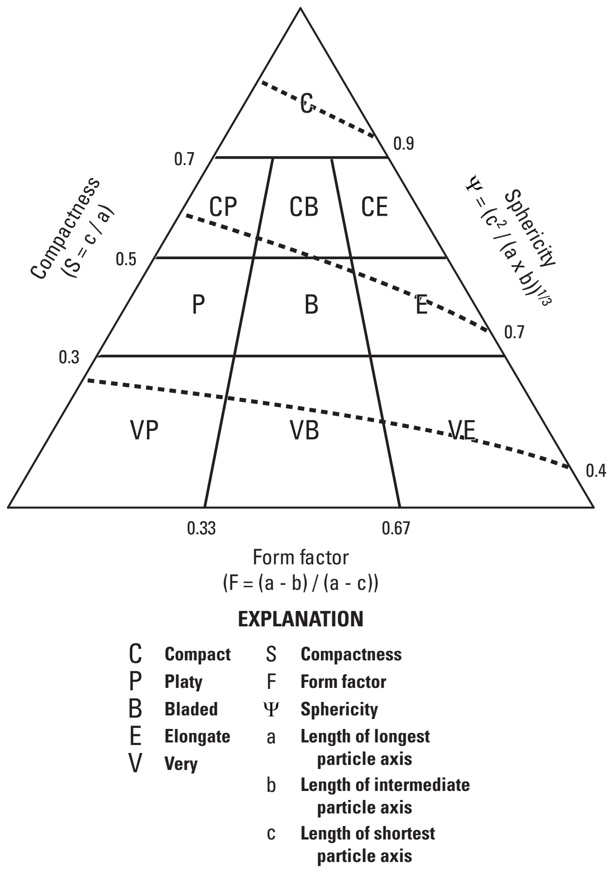


Figure 5. Descriptive particle-shape classes (modified from Sneed and Folk, 1958).

Streambed particle-shape analyses were not used in the regional analysis in this report. Particle shape affects the amount of area a particle has exposed to the forces of flow, drag, and lift acting on it. This difference in shape affects particle entrainment, transport, and deposition. Consequently, two particles having the same weight and b-axis lengths but with different a- and c-axis lengths (different shapes) will respond differently to streamflow. These data were collected, computed, and included in Pugh and Redman (2019) as a means of archiving the data until such time when, combined with other similar data, a sufficiently large dataset exists such that further analysis of streambed material particle shape can be made.

Classification of Natural River Reaches

Streams of similar drainage areas may differ in width, depth, and sinuosity because of climate, geology, valley type, slope, sediment load, and (or) streambed and bank materials, but because bankfull dimensions can characterize stream channels, it is possible to classify and make comparisons between streams with similar drainage areas. Rosgen (1994) developed a stream reach classification system dividing streams into seven major types and dozens of subtypes, each denoted by a letter and number based on stream form and pattern. Because streams may vary in character over relatively short distance, the Rosgen (1994) classification system describes individual reaches, not the entire stream system. Each study reach has been classified by using the Rosgen (1994) classification of natural rivers. The following channel metrics and measurements were used to classify stream reaches.

- Bankfull top width: the width of the stream channel, at bankfull stage elevation, in a riffle cross section.
- Bankfull mean depth: the mean depth of the stream channel, at bankfull stage elevation, in a riffle cross section, calculated by dividing the bankfull cross-sectional area by the bankfull width.
- Width-to-depth ratio: the bankfull width divided by the mean bankfull depth. A reach is considered to have a low width-to-depth ratio if the ratio is less than 12, moderate if the ratio is between 12 and 40, and very high if the ratio is greater than 40.
- Bankfull cross-sectional area: the area of the stream channel cross section, at bankfull stage, in a riffle section.
- Flood prone width: the channel width measured at the elevation of twice the maximum bankfull depth, in a riffle section.
- Entrenchment ratio: a field measurement of channel incision, defined as the flood prone width divided by the bankfull width. A reach is considered entrenched if the ratio is less than 1.4, moderately entrenched if the ratio is between 1.4 and 2.2, and slightly entrenched if the ratio is greater than 2.2.
- Median size (D50) of bed material: the median particle size, or the diameter that exceeds the diameter of 50 percent of all streambed material particles.
- Valley slope: the change in elevation divided by the length of valley. It is the slope of a valley for a given reach where the valley and reach intersect for some longer distance and includes several meanders or step pools.
- Water-surface slope: the difference between the water-surface elevation at the upstream end of a riffle to the upstream end of another riffle at least 20 bankfull widths downstream, divided by the distance between the riffles along the thalweg.
- Sinuosity: an index of channel pattern, determined from the ratio of the stream length divided by valley length or estimated from the ratio of the valley slope divided by the water-surface slope. A reach is considered to have a low sinuosity if the ratio is less than 1.2, moderate if the ratio is between 1.2 and 1.5, and high if the ratio is greater than 1.5.

Each reach was classified to the Rosgen level II stream type (Rosgen, 1994) based on the average of stream channel metrics collected at measured cross sections and profiles. Level I classification (types A through G) describes the geomorphic characteristics at a coarse scale and is based on the entrenchment ratio and width-to-depth ratio. Level II classification (subtypes A1 to A6, B1 to B6, and so forth) provides a more detailed morphological description of the stream through additional examination of the stream pattern, profile, and bed materials based on measured cross-section geometry, water-surface slope, and median size of the bed material (Rosgen, 1996). Rosgen (1996, 2006) provided a means for describing deviations of measured values from the average level II values by using the following suffixes. The suffix "a" designation indicates that streams classified as a B type have a slope that is between 4 percent and 9.9 percent. The suffix "c" designation indicates that streams classified as a B type have a slope that is less than 2 percent. The suffix "b" designation indicates that streams classified as a C type have a slope that is between 2 percent and 3.9 percent. The suffix "c-" designation indicates that streams classified as a C type have a slope that is less than 0.1 percent. The suffix "/1" designates the presence of bedrock within the study reach.

Photographs

Digital photographs were taken at all cross sections. The photographs include views looking along the centerline of the cross section at the left and right banks and looking upstream and downstream from the cross-section thalweg. These images are available in Pugh and Redman (2019).

Analysis of Regional Hydraulic Geometry Characteristics of Selected Ouachita Stream Channels

The following discussions analyze data collected from the 17 gaged reach locations within the Ouachita Mountains region of Arkansas. The analysis includes discussions of streambed materials, a general description of selected stream reaches, and regional hydraulic geometry relations.

Streambed Material Analysis

An example of the particle data analysis for Big Fork Tributary at Big Fork, Ark. (07355900; site no. 1 in fig. 2 and table 4), is shown in figure 6. The computed bed material particle-size quantiles (16, 50, and 84 percent) along with the percentage of bedrock for all cross sections were used for subsequent statistical and graphical analyses relating geomorphic characteristics to basin characteristics and in the determination of the stream reach classification. Bed material particle-size distributions for the 17 study sites are summarized in table 4. The same analysis was conducted by using the point bar material particle-size distribution data at sites 1 through 14, and data summaries are provided in table 4.

Point bar material particle-size distribution plots, particle-size quantile values of percent finer, descriptive statistics of particle-size distributions, and the particle-size distribution percentages of substrate type are available in Pugh and Redman (2019). These analyses were used to calculate percentages of point bar material particle-size ranges, percentages of substrate type, and point bar material particle-size quantiles (16, 50, and 84 percent) at selected sites and were used for subsequent statistical and graphical analyses relating geomorphic characteristics to basin characteristics.

General Description of Selected Stream Reaches

Geology is the primary framework upon which natural processes operate, largely governing the landforms observed today. Because of the differential erodability of the rock types underlying the Ouachitas, the ridges consist largely of sandstone and novaculite, while the valleys are largely underlain by shales. With the exception of four reaches, the study reaches are underlain by one of three shale formations, Polk Creek Shale, Stanley Shale, or Womble Shale. The Atoka Formation consisting of a sequence of marine silty sandstones and shales underlies the Fourche LaFave River near Gravelly, Ark. (site no. 16 in fig. 3 and table 6), reach (Arkansas Geological Survey, 2015a). Jackfork Sandstone with Stanley Shale upstream of the reach underlies the Alum Fork Saline River near Reform, Ark. (site no. 10 in fig. 3 and table 6), reach. The Midway Group that is associated with the Gulf Coastal Plain and composed of shale, limestone, sandstone, conglomerate, and clay shale underlies Jackson Creek near Malvern, Ark. (site no. 6 in fig. 3 and table 6), reach (Arkansas Geological Survey, 2015b). Lastly, the Rock Creek near Dierks, Ark. (site no. 8 in fig. 3 and table 6), reach is underlain by the Trinity Group that is associated with the Gulf Coastal Plain and is composed of sand, gravel, clay, limestone, and evaporite deposits (Arkansas Geological Survey, 2015b).

A listing of the geologic formations underlying each of the selected stream reaches is presented in table 5. The Arkansas Geological Survey 1:500,000-scale geologic map of Arkansas including a stratigraphic column of the geological formations underlying Arkansas, as well as the formation age, geologic history, distribution, and formation description, is provided in Haley and Arkansas Geological Commission staff (1993).

Table 4. Summary of streambed and point bar material analysis for selected stream reaches in the Ouachita Mountains of Arkansas.

[USGS, U.S. Geological Survey; mi^2, square mile; mm, millimeter; lbf/ft^2, foot pound per square foot; XS, riffle cross section, number in parentheses is number of cross sections included in analysis; Bar, point bar sample, number in parentheses is number of point bars included in analysis; Ark., Arkansas; Okla., Oklahoma; –, no data]

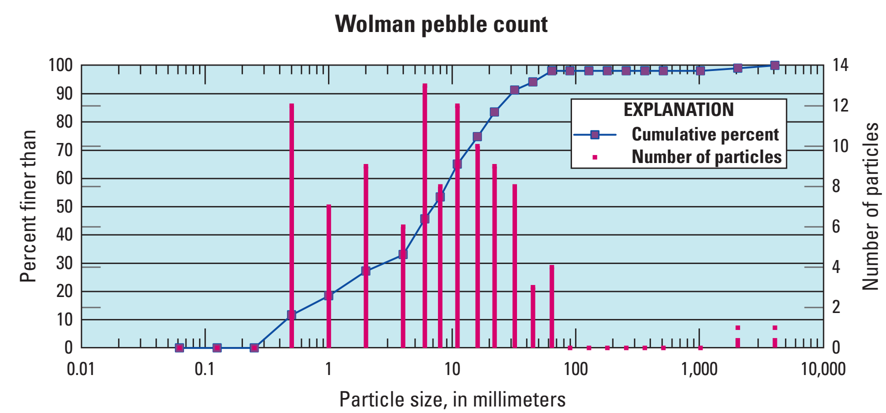
Map number (fig. 2)	USGS station number	USGS station name	Drainage area (mi^2)	Sample type	Percent less than - size (mm)			Bedrock (percent)	Bankfull shear stress[1] (lbf/ft^2)	Size of rock transported at bankfull (mm)
					D16	D50	D84			
1	07355900	Big Fork Tributary at Big Fork, Ark.	0.19	XS(6)	0.779	7.1	23	12	0.79	40
				Bar(1)	6.05	24.0	67	–		
2	07355800	Lewis Creek Tributary near Mena, Ark.	0.65	XS(6)	0.358	22.0	86	0	2.73	139
				Bar(1)	5.24	25.6	80	–		
3	07338780	Mountain Fork Tributary near Smithville, Okla.	0.68	XS(6)	0.346	25.5	88	3	0.64	33
				Bar(1)	4.89	15.4	64	–		
4	07356700	Barnes Branch near Mount Ida, Ark.	1.85	XS(1)	16.39	33.9	69	1	0.69	35
				Bar(1)	0.365	5.9	45	–		
5	07359750	Little Sugarloaf Creek near Bonnerdale, Ark.	2.32	XS(2)	2.03	3.8	8	40	1.00	51
				Bar(1)	0.791	5.6	13	–		
6	07359520	Jackson Creek near Malvern, Ark.	2.95	XS(2)	2.26	4.1	7	0	0.19	10
				Bar(1)	1.35	5.7	12	–		
7	07357700	Glazypeau Creek at Mountain Valley, Ark.	3.84	XS(3)	0.288	4.1	21	0	0.51	26
				Bar(1)	0.674	4.8	8	–		
8	07341100	Rock Creek near Dierks, Ark.	9.46	XS(2)	0.366	19.3	60	0	1.35	69
				Bar(1)	0.459	11.3	35	–		
9	07338700	Twomile Creek near Hatfield, Ark.	15.9	XS(1)	9.86	27.3	64	0	1.01	51
				Bar(1)	4.91	22.5	61	–		
10	07362587	Alum Fork Saline River near Reform, Ark.	27.0	XS(8)	0.321	20.5	60	11	1.52	77
				Bar(1)	5.67	17.5	52	–		
11	07335700	Kiamichi River near Big Cedar, Okla.	36.9	XS(2)	0.310	6.3	22	0	0.96	49
				Bar(1)	0.587	52.4	92	–		
12	07360200	Little Missouri River near Langley, Ark.	68.4	XS(4)	5.58	39.2	121	35	4.92	250
				Bar(1)	1.590	13.9	50	–		
13	07340300	Cossatot River near Vandervoort, Ark.	89.6	XS(7)	0.551	5.3	41	13	1.18	60
				Bar (1)	2.39	12.4	27	–		
14	07359610	Caddo River near Caddo Gap, Ark.	136	XS(3)	0.551	20.9	61	5	0.89	45
				Bar(1)	1.512	7.5	22	–		
15	07338750	Mountain Fork at Smithville, Okla.	322	XS (2)	28.727	89.3	194	22	0.76	123
				Bar (0)	–	–	–	–		
16	07261500	Fourche LaFave River near Gravelly, Ark.	410	XS(3)	0.37	46.6	100	3	0.67	113
				Bar(0)	–	–	–	–		
17	07363000	Saline River at Benton, Ark.	550	XS(1)	0.415	21.4	65	11	1.18	60
				Bar(0)	–	–	–	–		

[1]The bankfull shear stress column represents the average calculated bankfull shear stress along the bankfull wetted perimeter and the size of rock transported at bankfull column represents the median (D50) size of rock transported at bankfull flows based on shear stress calculations.

Intermediate axis pebble counts and percentages

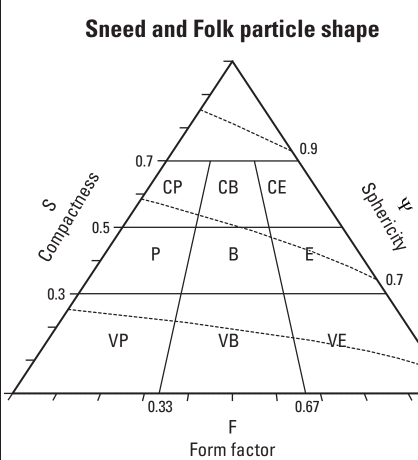
Material	Size Range (mm)		Count	Percent	Cumulative percent
Silt/clay	0	0.062	0	0	0
Very fine sand	0.062	0.13	0	0	0
Fine sand	0.13	0.25	0	0	0
Medium sand	0.25	0.5	12	12	12
Coarse sand	0.5	1	7	7	18
Very coarse sand	1	2	9	9	27
Very fine gravel	2	4	6	6	33
Fine gravel	4	6	13	13	46
Fine gravel	6	8	8	8	53
Medium gravel	8	11	12	12	65
Medium gravel	11	16	10	10	75
Coarse gravel	16	22	9	9	83
Coarse gravel	22	32	8	8	91
Very coarse gravel	32	45	3	3	94
Very coarse gravel	45	64	4	4	98
Small cobble	64	90	0	0	98
Medium cobble	90	128	0	0	98
Large cobble	128	180	0	0	98
Very large cobble	180	256	0	0	98
Small boulder	256	362	0	0	98
Small boulder	362	512	0	0	98
Medium boulder	512	1,024	0	0	98
Large boulder	1,024	2,048	1	1	99
Very large boulder	2,048	4,096	1	1	100
	Total particle count:		103	100	
Bedrock			14	12	
Hardpan			0	0	
Detritus/wood			0	0	
Artificial			0	0	
	Total substrate count: 117				

Date: October 24, 2002	**Big Fork Tributary at Big Fork, Arkansas**
Measurer: T. Garday	**Cross section 7, 6, 5, 4, 1.5, 2**
Recorder: A. Pugh	**Drainage area: 0.19 square mile**



Based on total particle count	Size percent less than millimeters					Particle size distribution			
	D16	D25	D50	D75	D84	Geo mean	Sorting	Skewness	Kurtosis
	0.779	1.68	7.1	16	23	4.2	5.4	1.4	0.1

Based on total substrate count	Percent by substrate type								
	Silt/clay	Sand	Gravel	Cobble	Boulder	Bedrock	Hardpan	Wood/det	Artificial
	0	24	62	0	2	12	0	0	0



EXPLANATION
Descriptive particle shape classes of Sneed and Folk (1958)

C Compact
P Platy
B Bladed
E Elongate
V Very

Big Fork Tributary at Big Fork, Arkansas
Cross section 7, 6, 5, 4, 1.5, 2
Drainage area: 0.19 square mile

Date: October 24, 2002
Measurer: T. Garday
Recorder: A. Pugh

Form factor
F = (a - b) / (a - c)
Compactness
S = c / a
Sphericity
Ψ = ((b * c) /a ^ 0.5) ^ 0.33

Note: Only particles with measured a, b, and c values plotted.

Number of particles plotted			
Sand	Gravel	Cobble	Boulder
16	73	0	0
Total number of particles plotted:			89

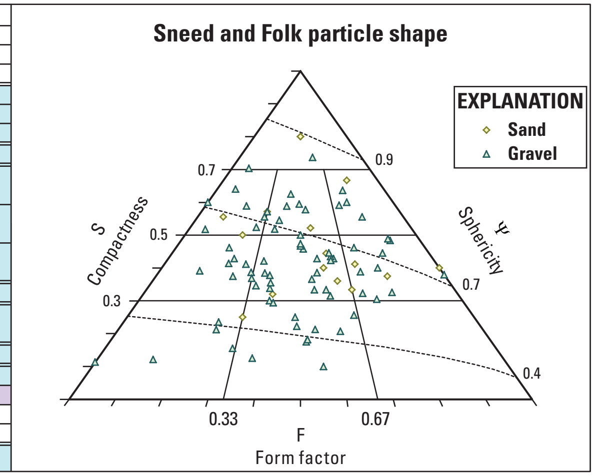


Figure 6. Bed material data for Big Fork Tributary at Big Fork, Arkansas (07355900).

Table 5. Geology and soil series at selected stream reaches in the Ouachita Mountains of Arkansas.

[USGS, U.S. Geological Survey; mi^2, square mile; Ark., Arkansas; Okla., Oklahoma; upstream, geologic unit is upstream of study reach]

Map number (fig. 2)	USGS station number	USGS station name	Drainage area (mi^2)	Geology[1]				Soil Parent Material[2]						
								Residuum			Colluvium			Alluvium
				Sandstone	Shale	Chert / novaculite	Alluvium	Sandstone	Shale	Chert / novaculite	Sandstone	Shale	Chert / novaculite	Flood-plain and terrace deposits
1	07355900	Big Fork Tributary at Big Fork, Ark.	0.19		Polk Creek Shale				Bismarck	Avant		Bengal	Yanush	Ceda
2	07355800	Lewis Creek Tributary near Mena, Ark.	0.65		Stanley Shale				Sherless Littlefir					Avilla Kenn
3	07338780	Mountain Fork Tributary near Smithville, Okla.	0.68		Stanley Shale			Clebit Sherwood	Carnasaw Stapp		Zafra			Ceda-Rubble
4	07356700	Barnes Branch near Mount Ida, Ark.	1.85	Blakely Sandstone upstream	Womble Shale				Littlefir Bismarck			Mazarn		Neff Mena
5	07359750	Little Sugarloaf Creek near Bonnerdale, Ark.	2.34		Stanley Shale	Arkansas Novaculite upstream		Pirum	Bonnerdale Sherless Littlefir					Woodall
6	07359520	Jackson Creek near Malvern, Ark.	3.00	Midway Group, Wilcox Group upstream		Arkansas Novaculite upstream		Pikeville Sacul Saffell Savannah	Carnasaw Bismarck					Ceda
7	07357700	Glazypeau Creek at Mountain Valley, Ark.	3.84		Womble Shale, Polk Creek Shale			Pirum Clebit	Leadvale Carnasaw	Avant		Mazarn	Yanush	Ceda
8	07341100	Rock Creek near Dierks, Ark.	9.46	Trinity Group, Jackfork Sandstone upstream			Alluvium and terrace deposits	Pirum Sacul Saffell	Pickens					Blevins Ozan
9	07338700	Twomile Creek near Hatfield, Ark.	15.9		Stanley Shale	Arkansas Novaculite upstream		Nashoba	Bismarck Sherless Littlefir			Mazarn		Kenn Ceda Speer
10	07362587	Alum Fork Saline River near Reform, Ark.	27.0	Jackfork Sandstone	Stanley Shale upstream			Pirum	Carnasaw Townley		Zafra	Leadvale		
11	07335700	Kiamichi River near Big Cedar, Okla.	40.1	Jackfork Sandstone	Stanley Shale		Alluvium and terrace deposits	Pirum Clebit	Tuskahoma Carnasaw		Octavia Caston	Bengal Panama		Ceda-Rubble Kenn Sallisaw Speer Neff Wetsaw

Table 5. Geology and soil series at selected stream reaches in the Ouachita Mountains of Arkansas.—Continued

[USGS, U.S. Geological Survey; mi², square mile; Ark., Arkansas; Okla., Oklahoma; upstream, geologic unit is upstream of study reach]

Map number (fig. 2)	USGS station number	USGS station name	Drainage area (mi²)	Geology[1]				Soil Parent Material[2]						
								Residuum			Colluvium			Alluvium
				Sandstone	Shale	Chert / novaculite	Alluvium	Sandstone	Shale	Chert / novaculite	Sandstone	Shale	Chert / novaculite	Flood-plain and terrace deposits
12	07360200	Little Missouri River near Langley, Ark.	68.4		Stanley Shale	Arkansas Novaculite upstream		Nashoba Pirum	Bismarck Littlefir Sherless Bonnerdale					Ceda Keen Speer Woodall
13	07340300	Cossatot River near Vandervoort, Ark.	89.6		Stanley Shale	Arkansas Novaculite upstream		Nashoba	Sherless Littlefir Bismarck	Bigfork			Yanush	Dela Kenn Ceda
14	07359610	Caddo River near Caddo Gap, Ark.	136		Stanley Shale	Arkansas Novaculite upstream		Naxhoba	Littlefir Bismarck Sherless	Avant Bigfork		Mazarn-Bengal	Yanush	Mena Neff Riverwash-Ceda Speer
15	07338750	Mountain Fork at Smithville, Okla.	322		Stanley Shale upstream		Alluvium and terrace deposits	Clebit Sherwood	Alikchi Carnasaw Stapp Pickens		Zafra			Ceda-Rubble Frizzel Rexor Sallisaw
16	07261500	Fouche LaFave River near Gravelly, Ark.	410	Atoka Formation	Atoka Formation			Clebit	Bismarck Carnasaw Sherless Littefir		Zafra	Guthrie Leadvale		Pickwick Spadra Avilla Kenn Ceda
17	07363000	Saline River at Benton, Ark.	550		Womble Shale		Alluvium and terrace deposits	Saffell Saffell-Urban Savanna Savanna-Urban Smithdale Smithdale-Urban	Carnasaw Townley			Leadvale		Avilla Ouachita

[1]Geology from Hayley and others (1993).

[2]Soil series from U.S. Department of Agriculture Natural Resources Conservation Service Web Soil Survey.

Soils provide insight into the evolution, age, and stability of the landform upon which they develop. The soil series mapped by the USDA NRCS at each of the selected stream reaches are arranged according to the soil parent material type and presented in table 5. Complete descriptions of the USDA soil series are available from the U.S. Department of Agriculture (1975), the U.S. Department of Agriculture, Natural Resources Conservation Service (2003, 2007b, 2010, 2015, 2017), and the U.S. Department of Agriculture Soil Conservation Service (1974, 1975, 1979, 1983, 1987, 1988, 1989), but a brief overview from those publications follows.

Alluvium or alluvial deposits represent the most recent deposition of sediment within a watershed and are present at each of the selected stream reaches in the channel and on the flood plains. Terraces are the oldest alluvial deposits, representing abandoned flood plains, and are present at a majority of the selected stream reaches. Ceda, Dela, Kenn, Neff, Ouachita, Ozan, Rexor, Speer, and Woodall soils are Quaternary alluvium on the flood plains. Avilla, Blevins, Frizzell, Mena, Pickwick, Sallisaw, Spadra, and Wetsaw soils are older Quaternary alluvium occupying terraces.

Residuum soils are residual soil material formed in place by weathering. Residuum soils are on the ridge tops and side slopes and constitute the upland valley floors in the larger valleys at an elevation above the flood plain or oldest alluvial terrace. Leadvale and Pickens soils are shale residuum on upland terraces. Alikchi, Bismarck, Bonnerdale, Carnasaw, and Stapp soils are shale residuum on upland valley floors. Pirum soils are sandstone residuum on valley uplands. Littlefir, Sherless, Townley, and Tuskahoma soils are shale residuum on ridge tops and side slopes. Clebit, Nashoba, and Sherwood soils are sandstone residuum on ridge tops and side slopes. Pikeville, Sacul, Saffell, and Savana soils are marine sediments on Coastal Plain uplands. Smithdale soils are marine sediment on Coastal Plain hilltops and side slopes. Avant and Bigfork soils are chert/novaculite residuum on ridge tops and side slopes.

Colluvial soils are unconsolidated sediments that have moved downslope because of gravitational forces. Leadvale and Mazarn soils are shale colluvium on upland drains (intermittent streams) and upland terraces along valley walls or on landslides. Bengal and Guthrie soils are shale colluvium on upland flats and depressions. Panama soils are shale colluvium, Caston and Octavial soils are sandstone colluvium, and Yanush soils are chert/novaculite colluvium, all found on upland terraces, ridge foot slopes, or coves. Zafra soils are sandstone soils on ridge side and foot slopes.

Land cover is the physical material covering the Earth's surface. Data from the National Land Cover Database 2011 (U.S. Geological Survey, 2011) were used to determine the land cover on each of the watersheds above the selected stream reaches. Forest (deciduous forest, evergreen forest, and mixed forest) is the dominant land cover in the selected watersheds. On average, the watersheds are 82.13 percent forest, ranging from 53.77 to 95.73 percent. The second largest land cover category on the selected watersheds is "natural" open land (shrub/scrub, grassland/herbaceous, or pasture/hay). On average, the selected watersheds are 12.71 percent "natural" open land, ranging from 2.16 to 39.24 percent. The third largest land cover category on the selected watersheds is developed (developed, open space; developed, low intensity; developed, medium intensity; or developed, high intensity). On average, the selected watersheds are 4.84 percent developed, ranging from 1.02 to 24.52 percent. These three land cover categories, forest, "natural" open land, and developed, account for greater than 98 percent of the land cover on all selected watersheds. A listing of the land cover in each of the watersheds above the selected stream reaches is presented in table 6.

The channel shape or morphology was measured at each of the selected stream reaches. Some of the morphological attributes measured or calculated at each of the selected stream reaches include the bankfull top width and mean depth, the flood prone width, and the water-surface and valley slopes. The ratios of the bankfull top width to mean depth (width-to-depth ratio), the flood prone width to bankfull top width (entrenchment ratio), and the water-surface slope to the valley slope (sinuosity) allow comparisons to be made between watersheds of different sizes. The width-to-depth ratio from the selected stream reaches ranged from 13.5 to 43.4, averaging 29.0. The entrenchment ratio ranged from 1.4 to 13.9, averaging 3.9. The sinuosity from the selected stream reaches ranged from 1.05 to 2.50, averaging 1.33. The stream reach width-to-depth ratio, entrenchment ratio, sinuosity, and level II classification (Rosgen, 1994) are presented in table 7.

Regional Hydraulic Geometry Relations

Regional hydraulic geometry curves were constructed by plotting measured bankfull geometry dimensions (cross-sectional area, top width, and mean depth) from stable riffle sections and the associated bankfull streamflow against the contributing drainage area (table 7, fig. 7). It should be noted that bankfull streamflow was not determined for three of the selected stream reaches because of funding constraints. Regression equations were derived from these hydraulic geometry curves and express the mathematical relation (power-functions, $Y=aX^b$) between the bankfull channel dimensions (Y) and the contributing drainage areas (X).

The regression equations and corresponding 95-percent confidence and prediction intervals are presented on the regional hydraulic geometry curves (fig. 7). The 95-percent confidence intervals define a range of values that have a 95-percent probability of encompassing the results for other B or C stream types within the Ouachitas region. The prediction intervals predict the 95-percent probability ranges for estimates of channel dimensions for a single stream of a given drainage area in the Ouachitas region.

Table 6. Land cover within watersheds above selected stream reaches in the Ouachita Mountains of Arkansas.

[USGS, U.S. Geological Survey; mi², square mile; Land cover from National Land Cover Database (2011); Ark., Arkansas; Okla., Oklahoma; horizontal length of the green bars represents the percentage of the land cover class within the watershed]

Map number (fig. 2)	USGS station number	USGS station name	Drainage area (mi²)	Land cover class within watershed (percent)														
				Open water	Developed, open space	Developed, low intensity	Developed, medium intensity	Developed high intensity	Barren land (rock/sand/clay)	Deciduous forest	Evergreen forest	Mixed forest	Shrub/scrub	Grassland/herbaceous	Pasture/hay	Cultivated crops	Woody wetlands	Emergent herbaceous wetlands
1	07355900	Big Fork Tributary at Big Fork, Ark.	0.19	0.00	1.02	0.00	0.00	0.00	0.00	55.69	16.87	23.17	0.00	3.25	0.00	0.00	0.00	0.00
2	07355800	Lewis Creek Tributary near Mena, Ark.	0.65	0.00	1.84	0.98	0.00	0.00	0.00	46.04	13.67	13.99	7.92	0.60	14.97	0.00	0.00	0.00
3	07338780	Mountain Fork Tributary near Smithville, Okla.	0.68	0.27	19.41	4.57	0.27	0.27	0.00	18.28	49.25	3.28	0.54	3.87	0.00	0.00	0.00	0.00
4	07356700	Barnes Branch near Mount Ida, Ark.	1.85	0.00	2.24	0.00	0.00	0.00	0.00	55.92	19.84	19.84	0.36	1.06	0.74	0.00	0.00	0.00
5	07359750	Little Sugarloaf Creek near Bonnerdale, Ark.	2.34	0.00	4.48	0.70	0.21	0.00	0.00	15.54	32.65	12.43	3.13	5.26	25.59	0.00	0.00	0.00
6	07359520	Jackson Creek near Malvern, Ark.	3.00	0.00	2.35	0.00	0.05	0.00	0.00	29.22	46.13	11.50	8.92	1.34	0.27	0.21	0.00	0.00
7	07357700	Glazypeau Creek at Mountain Valley, Ark.	3.84	0.00	5.46	1.37	0.15	0.05	1.31	44.60	15.88	15.86	4.55	9.89	0.88	0.00	0.00	0.00
8	07341100	Rock Creek near Dierks, Ark.	9.46	0.00	6.06	0.62	0.07	0.00	0.08	26.48	16.98	10.31	15.83	21.49	1.92	0.07	0.08	0.00
9	07338700	Twomile Creek near Hatfield, Ark.	15.9	0.00	2.85	0.17	0.03	0.00	0.02	54.69	23.58	11.64	2.98	2.77	1.22	<0.01	0.04	0.00
10	07362587	Alum Fork Saline River near Reform, Ark.	27.0	0.01	3.45	0.00	0.00	0.00	0.00	50.79	27.66	15.39	1.58	1.08	0.04	0.00	0.00	0.00
11	07335700	Kiamichi River near Big Cedar, Okla.	40.1	0.00	1.50	0.00	0.00	0.00	0.00	49.97	40.59	5.15	0.37	1.17	1.25	0.00	0.00	0.00
12	07360200	Little Missouri River near Langley, Ark.	68.4	<0.01	2.52	0.03	0.02	0.00	0.05	66.11	12.14	13.08	2.22	2.26	1.52	0.00	0.04	0.00
13	07340300	Cossatot River near Vandervoort, Ark.	89.6	<0.01	1.94	<0.01	0.00	0.00	0.00	58.83	20.96	14.26	1.76	1.66	0.58	0.00	<0.01	0.00
14	07359610	Caddo River near Caddo Gap, Ark.	136	0.02	2.61	0.41	0.09	0.01	0.11	53.59	12.92	16.13	1.47	1.69	10.75	0.02	0.14	0.04
15	07338750	Mountain Fork at Smithville, Okla.	322	0.21	3.37	0.51	0.10	0.02	0.09	37.76	27.64	7.04	4.29	7.94	10.82	0.03	0.15	0.02
16	07261500	Fouche LaFave River near Gravelly, Ark.	410	0.16	3.04	0.30	0.03	0.01	0.01	35.93	33.28	15.09	2.57	1.87	7.18	<0.01	0.47	0.06
17	07363000	Saline River at Benton, Ark.	550	1.09	5.81	0.98	0.19	0.06	0.08	39.22	26.14	13.22	4.58	3.97	4.15	0.05	0.44	0.01

Table 7. Summary of bankfull dimensions, stream morphological attributes, and reach classifications for selected stream reaches in the Ouachita Mountains of Arkansas.

[USGS, U.S. Geological Survey; mi^2, square mile; ft, foot; ft/ft; foot per foot; mm, millimeter; Ark., Arkansas; Okla., Oklahoma. Level II stream reach classifications from Rosgen, 1994]

Map number (fig. 2)	USGS station number	USGS station name	Drainage area (mi^2)	Bankfull top width (ft) / Bankfull mean depth (ft)	Width-to-depth ratio	Bankfull cross-sectional area (ft)	Flood prone width (ft) / Bankfull top width (ft)	Entrenchment ratio	D50 (mm)	Valley slope (ft/ft) / Water-surface slope (ft/ft)	Sinuosity	Level II stream reach classification
1	07355900	Big Fork Tributary at Big Fork, Ark.	0.19	10.3 / 0.66	15.6	6.82	18 / 10.3	1.7	7.1	0.019 / 0.019	1.05	B4
2	07355800	Lewis Creek Tributary near Mena, Ark.	0.65	31.7 / 0.98	32.3	31.2	124 / 31.7	3.9	22.0	0.035 / 0.033	1.05	$C4_{/1}$
3	07338780	Mountain Fork Tributary near Smithville, Okla.	0.68	22.9 / 0.97	23.6	22.2	82 / 22.9	3.6	25.5	0.013 / 0.011	1.18	$B4c_{/1}$
4	07356700	Barnes Branch near Mount Ida, Ark.	1.85	29.6 / 1.73	17.1	51.3	74 / 29.6	2.5	33.9	0.008 / 0.007	1.10	$C4_{/1}$
5	07359750	Little Sugarloaf Creek near Bonnerdale, Ark.	2.32	21.4 / 1.58	13.5	33.8	39 / 21.4	1.8	3.8	0.014 / 0.011	1.25	$B4c_{/1}$
6	07359520	Jackson Creek near Malvern, Ark.	2.95	37.5 / 1.68	22.3	50.4	87 / 37.5	2.3	4.1	0.002 / 0.002	1.14	C4
7	07357700	Glazypeau Creek at Mountain Valley, Ark.	3.84	37.3 / 1.86	20.1	69.6	287 / 37.3	7.7	4.1	0.006 / 0.005	1.38	C4
8	07341100	Rock Creek near Dierks, Ark.	9.46	70.8 / 2.67	26.5	188.9	510 / 70.8	7.2	20.5	0.012 / 0.008	1.49	C4
9	07338700	Twomile Creek near Hatfield, Ark.	15.9	112.6 / 2.95	38.2	331.9	373 / 112.6	3.3	27.3	0.007 / 0.006	1.20	$C4_{/1}$
10	07362587	Alum Fork Saline River near Reform, Ark.	27.0	123 / 3.68	33.5	436.9	321 / 123.4	2.6	20.5	0.007 / 0.007	1.07	$C4_{/1}$
11	07335700	Kiamichi River near Big Cedar, Okla.	36.9	138.5 / 4.04	34.3	559.5	542 / 189.5	2.9	6.3	0.005 / 0.004	1.22	C3
12	07360200	Little Missouri River near Langley, Ark.	68.4	161.1 / 4.67	34.5	752.3	303.04 / 161.1	1.9	39.2	0.003 / 0.002	1.26	$B4c_{/1}$
13	07340300	Cossatot River near Vandervoort, Ark.	89.6	270.9 / 6.24	43.4	1,691	377 / 270.9	1.4	5.3	0.004 / 0.003	1.48	$B4c_{/1}$
14	07359610	Caddo River near Caddo Gap, Ark.	136	219.1 / 5.89	37.2	1,290	385 / 219.1	1.8	20.9	0.004 / 0.002	1.48	$B4c_{/1}$
15	07338750	Mountain Fork at Smithville, Okla.	322	216.6 / 9.82	22.1	2,127	397 / 216.6	1.8	89.3	0.001 / 0.000	2.50	$B3c_{/1}$
16	07261500	Fourche LaFave River near Gravelly, Ark.	410	339.8 / 9.42	36.1	2,945	1,820 / 339.8	5.4	47.3	0.001 / 0.001	1.50	$C4c–_{/1}$
17	07363000	Saline River at Benton, Ark.	550	270.9 / 6.24	43.4	1,691	3,767 / 270.9	13.9	21.4	0.003 / 0.002	1.23	$C4_{/1}$

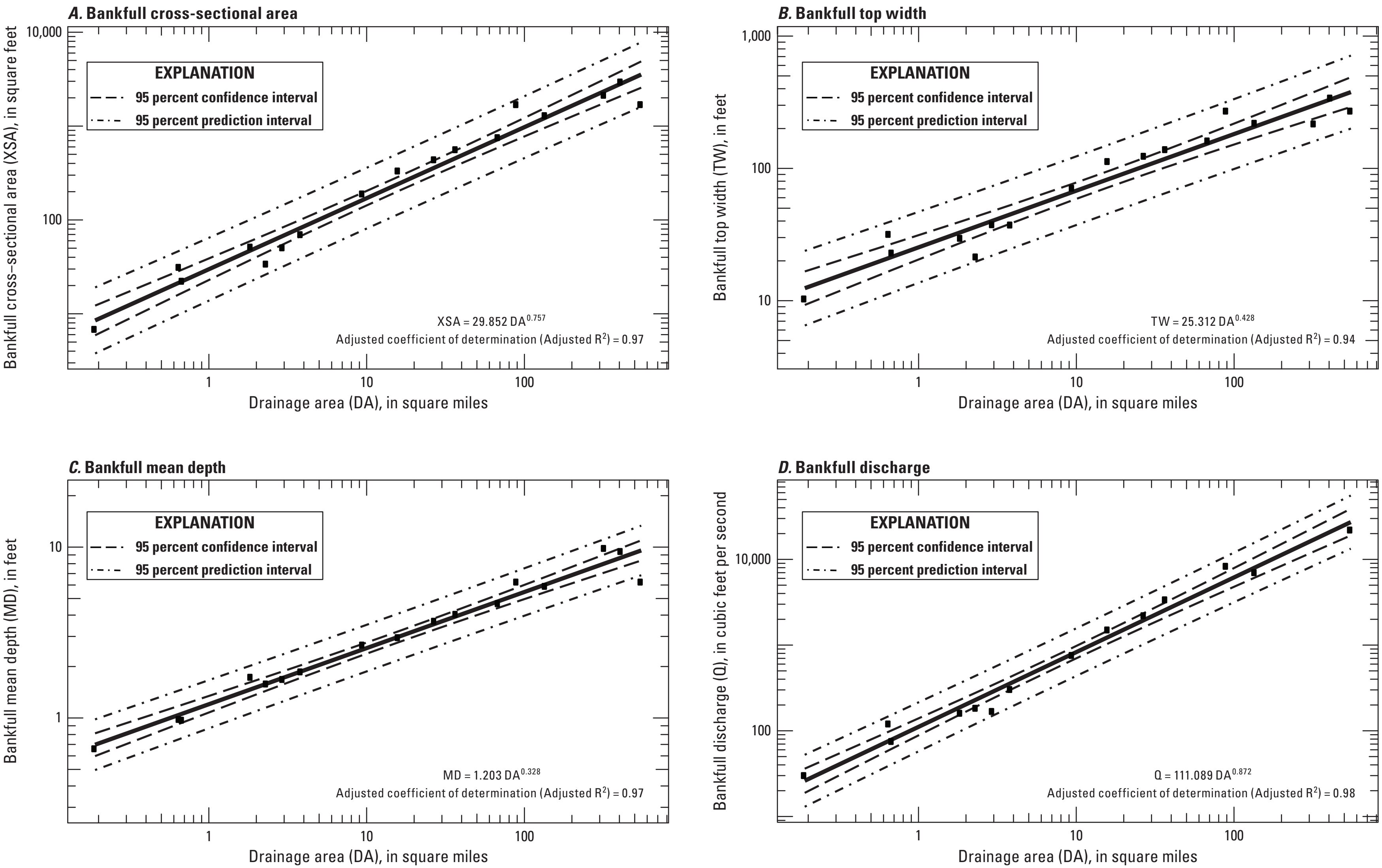


Figure 7. Regional hydraulic geometry curves of bankfull channel dimensions as a function of drainage area for selected streams in the Ouachita Mountains of Arkansas, with 95-percent confidence and prediction intervals.

The regression equations for bankfull channel cross-sectional area, top width, and mean depth and the associated bankfull streamflow as a function of the contributing drainage area for streams in Ouachita Mountains of Arkansas are

A. Bankfull cross-sectional area, in square feet: $XSA = 29.852 \times DA^{0.757}$, $R^2=0.97$
B. Bankfull top width, in feet: $TW = 25.312 \times DA^{0.428}$, $R^2=0.94$
C. Bankfull mean depth, in feet: $MD = 1.203 \times DA^{0.328}$, $R^2=0.97$
D. Bankfull streamflow (Q), in cubic feet per second: $Q = 111.089 \times DA^{0.872}$, $R^2=0.98$

where

DA is drainage area, in square miles; and
R^2 is the coefficient of determination in log space.

Limitations of This Study

For this study, the selection of bankfull stage was initially assumed to be associated with a streamflow that has a recurrence interval of approximately 1.5 years. This assumption may be an oversimplification (Thorne and others, 1997), even though other researchers have found bankfull stages associated with streamflows between 1- and 2-year recurrence intervals (Rosgen, 1994; Harman and Jennings, 1999). If the bankfull recurrence interval at a site is outside the assumed range of a 1- to 2-year recurrence interval, the bankfull channel may have been incorrectly identified (White, 2001). Additionally, B type stream channels do not have a true flood plain. Selection of bankfull indicators along B type steams is limited to discontinuous depositional surfaces along the channel banks.

The data and regional curves presented in this report are intended to serve as a reference document to provide users with stream hydraulic geometry information about the current conditions of stable stream types B and C in the Ouachita Mountains physiographic section of Arkansas. This study did not examine other stable stream types A, D, or E because no gaging stations were located on these stream types. The curves presented in this report should be applied to only B and C stream types.

Appropriate use of the data presented in this report is left to the user. These data are suitable for most assessment and planning activities including scaling natural stream restoration projects, habitat assessments of similar stream types, and prediction of natural stream channel geometry. These data should be used in conjunction with other data for design purposes including analysis of peak flows, watershed assessments, and stream stability assessments.

Summary

The locations of 17 streamgages, operated by the U.S. Geological Survey, distributed across the Ouachita Mountains of Arkansas were selected for analysis on the basis of the following criteria: the streamgage had approximately 20 years or more of streamflow record; the watershed above the streamgage had a minimal amount of urbanization and controlled drainage; the stream reaches above and below the streamgage were stable; and, as much as possible, the distribution of drainage basin sizes and geographic distribution across the Ouachita Mountains was sufficient to facilitate the development of representative regional hydraulic geometry curves.

The 17 selected streamgage locations have drainage basins ranging from 0.19 to 550 square miles and are distributed across 8 of the 14 8-digit hydrologic units that are partially or totally within the Ouachita Mountains of Arkansas. As a result of differential erosion of the rock types underlying the Ouachita Mountains, 13 of the 17 streamgage locations are underlain by shale formations. The land cover within the watersheds above the streamgage locations was on average 82.13 percent forest, 12.71 percent “natural” open land, and 4.84 percent developed.

Channel morphological metrics of stream cross sections and longitudinal profiles were measured at each of the 17 streamgage locations. Cross-section width-to-depth ratios ranged from 13.5 to 43.4, averaging 29.0; entrenchment ratios ranged from 1.4 to 13.9, averaging 3.9; sinuosity ranged from 1.05 to 2.50, averaging 1.33; and water-surface slopes ranged from 0.0004 to 0.0333. Gravel was the dominant particle size measured at 16 of the 17 streamgage locations with cobble being the dominant particle size at the remaining location. Bedrock outcrops were noted at 13 of the study sites. Based on these channel morphological metrics, 6 streamgage locations were classified as Rosgen level II B stream types, and 11 were classified as Rosgen level II C stream types.

Regional hydraulic geometry curves express the mathematical relation between the bankfull channel dimensions and the contributing drainage areas. Regional hydraulic curves for the Ouachita Mountains in Arkansas were constructed from the channel morphological metrics collected at the 17 streamgage locations by plotting measured bankfull geometry dimensions (cross-sectional area, top width, and mean depth) from stable riffle sections and the associated bankfull streamflow against the contributing drainage area. The resulting curves have adjusted coefficients of determination values ranging from 0.94 to 0.98.

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