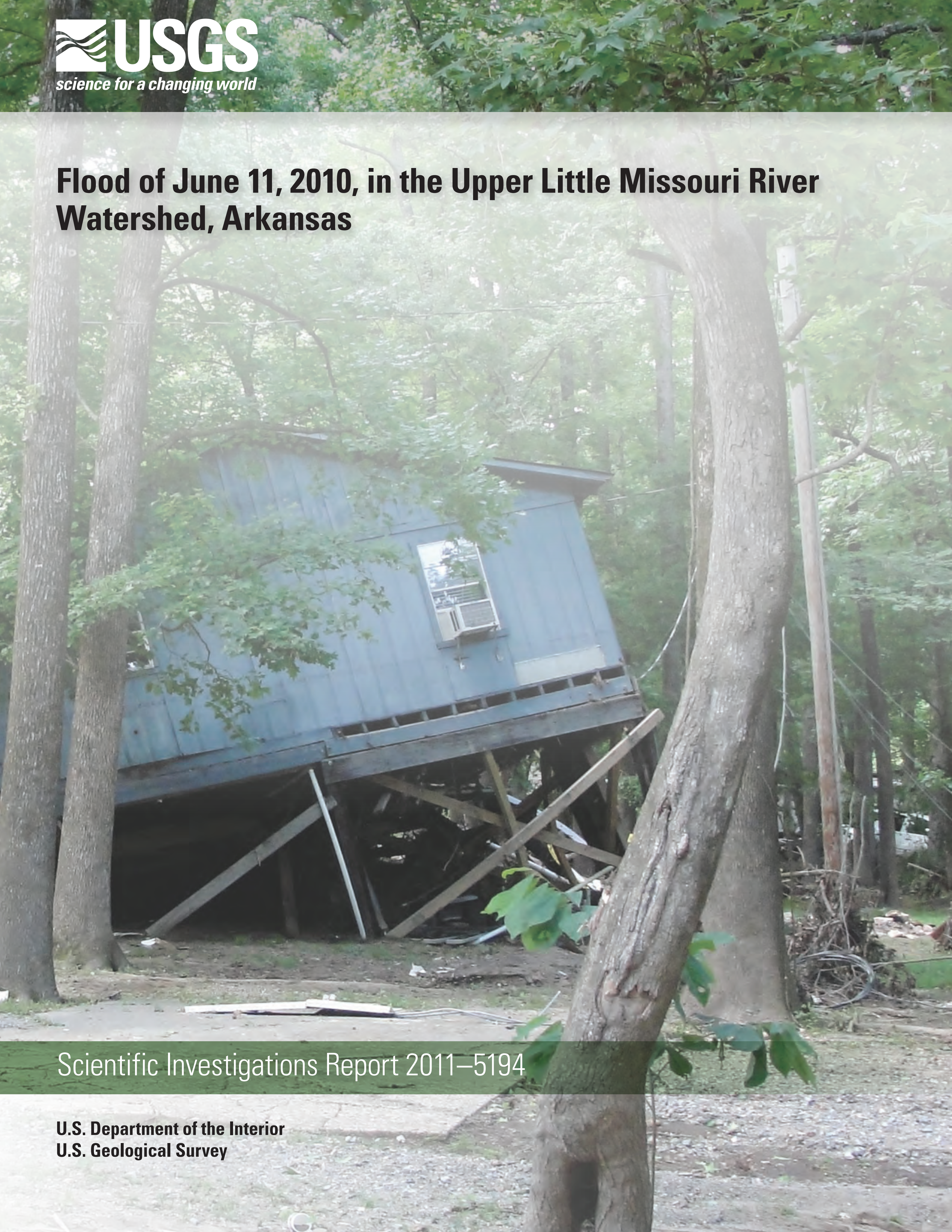

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Flood of June 11, 2010, in the Upper Little Missouri River Watershed, Arkansas

Scientific Investigations Report 2011–5194

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

Cover. Aftermath of the flood of June 11, 2010, in the Albert Pike Recreation Area, Arkansas. Photographs by Robert Holmes, U.S. Geological Survey.

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By Robert R. Holmes, Jr. and Daniel M. Wagner

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2011

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	kilometer (km)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
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]
mile per hour (mi/h)	1.609	kilometer per hour (km/h)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

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).

Flood of June 11, 2010, in the Upper Little Missouri River Watershed, Arkansas

By Robert R. Holmes, Jr. and Daniel M. Wagner

Abstract

Catastrophic flash flooding occurred in the early morning hours of June 11, 2010, in the upper Little Missouri River and tributary streams in southwest Arkansas. The flooding, which resulted in 20 fatalities and substantial property damage, was caused by as much as 4.7 inches of rain falling in the upper Little Missouri River watershed in 3 hours. The 4.7 inches of rain in 3 hours corresponds to estimated annual exceedance probability of approximately 2 percent for a 3-hour duration storm. The maximum total estimated rainfall in the upper Missouri River watershed was 5.3 inches in 6 hours. Peak streamflows and other hydraulic properties were determined at five ungaged locations and one gaged location in the upper Little Missouri River watershed.The peak streamflow for the Little Missouri River at Albert Pike, Arkansas was 40,100 cubic feet per second, estimated to have occurred between 4:00 AM and 4:30 AM the morning of June 11, 2010. The peak streamflow resulted in average water depths in the nearby floodplain (Area C of the Albert Pike Campground) of 7 feet flowing at velocities potentially as great as 11 feet per second. Peak streamflow 9.1 miles downstream on the Little Missouri at the U.S. Geological Survey streamgage near Langley, Arkansas was 70,800 cubic feet per second, which corresponds to an estimated annual exceedance probability of less than 1 percent.

Introduction

The Little Missouri River (fig. 1) and tributaries are located in the southern Ouachita Mountain region of southwest Arkansas, which is a part of the southern Midwestern United States and has been recognized as an area of “relatively large flows” (O’Connor and Costa, 2003). Watersheds in the Ouachita Mountain region are characterized by steep forested hillslopes, narrow valleys, and channels composed of rock, gravel, and boulders. The stream slopes in the upper Little Missouri River watershed were greater than 48 feet per mile (ft/mi) (0.009 foot per foot [ft/ft]). The steep hill and channel slopes combined with the proximity to abundant moisture from the Gulf of Mexico can result in flash flooding for rivers in this area.

The Little Missouri River watershed is a beautiful and picturesque location with clear streams and numerous recreational opportunities, including the U.S. Forest Service Albert Pike Recreation Area (Albert Pike) and surrounding Ouachita National Forest lands. The onset of flooding in the early morning hours of June 11, 2010 caught numerous people asleep and unaware at campsites and in cabins along the rivers and streams in the Little Missouri River watershed. Twenty fatalities occurred with many more people barely escaping the rampaging waters. Numerous automobiles, cabins, and recreational vehicles were destroyed, and additionally parts of the physical facilities of the Albert Pike campground sustained substantial damage. Most of the cabins were located in the privately owned Camp Albert Pike (fig. 2).

Purpose and Scope

Flooding is a leading cause of death from natural hazards, killing about 140 people each year and causing $6 billion in property damage (U.S. Geological Survey, 2006). Preventing the devastating effects from floods is a major societal challenge, requiring good scientific understanding of the flood processes, as well as education of the general public and policy makers. Properly documenting catastrophic floods is an important part of the scientific study of floods, a service that the U. S. Geological Survey (USGS) has provided throughout its history (for example, Murphy, 1904; Follansbee and Jones, 1922; Grover, 1938; Wells, 1955; McCain and others, 1979; Parrett and others, 1993; Holmes and others, 2010). The National Research Council Committee on U.S. Geological Survey Water Resources Research (Committee) (1999) reports that:

> “The USGS is well known as the nation’s primary supplier of reliable streamflow and water-level data and this role is essential. But the USGS should also expand its efforts to document and analyze extreme hydrologic events, both during and after their occurrence. The agency is ideally positioned to collect and archive the critical hydrologic information necessary to improve our understanding of how and why such extreme events happen and to improve our ability to predict them.”

This report and the field and interpretive work preceding it are part of the ongoing USGS effort toward documenting and analyzing extreme hydrologic events, the importance of which has been reinforced by the Committee. Additionally, documentation reports, such as this report, enable a ready supply of flood case histories, which can be used for educational purposes. This report documents the occurrence, magnitude, and probability of occurrence of the flood of June 11, 2010, in the upper Little Missouri River watershed.

Methods of Flood-Data Collection

The USGS operates as many as 7,500 streamgages in the United States, providing the data at most of these streamgages in near real-time to a variety of users, including the general public (*http://waterdata.usgs.gov/nwis/*). The presence of a USGS streamgage usually means that time series data (frequently collected at 15-minute intervals) of stage and streamflow are available. How these data are collected warrants explanation.

USGS streamgages operate autonomously (24 hours a day), with the stage data collected by direct measurement and the streamflow data typically computed by applying a stage-streamflow rating curve (rating) (fig. 3) to the collected stage data. Construction of the rating requires on-site measurements of streamflow by USGS hydrographers at various stages. The shape and position of the rating is controlled by the geometry and hydraulics of the stream channel. Once an initial rating is determined, because natural streams change through time, streamflow measurements continue to be needed for re-calibration of the rating, particularly during flood conditions.

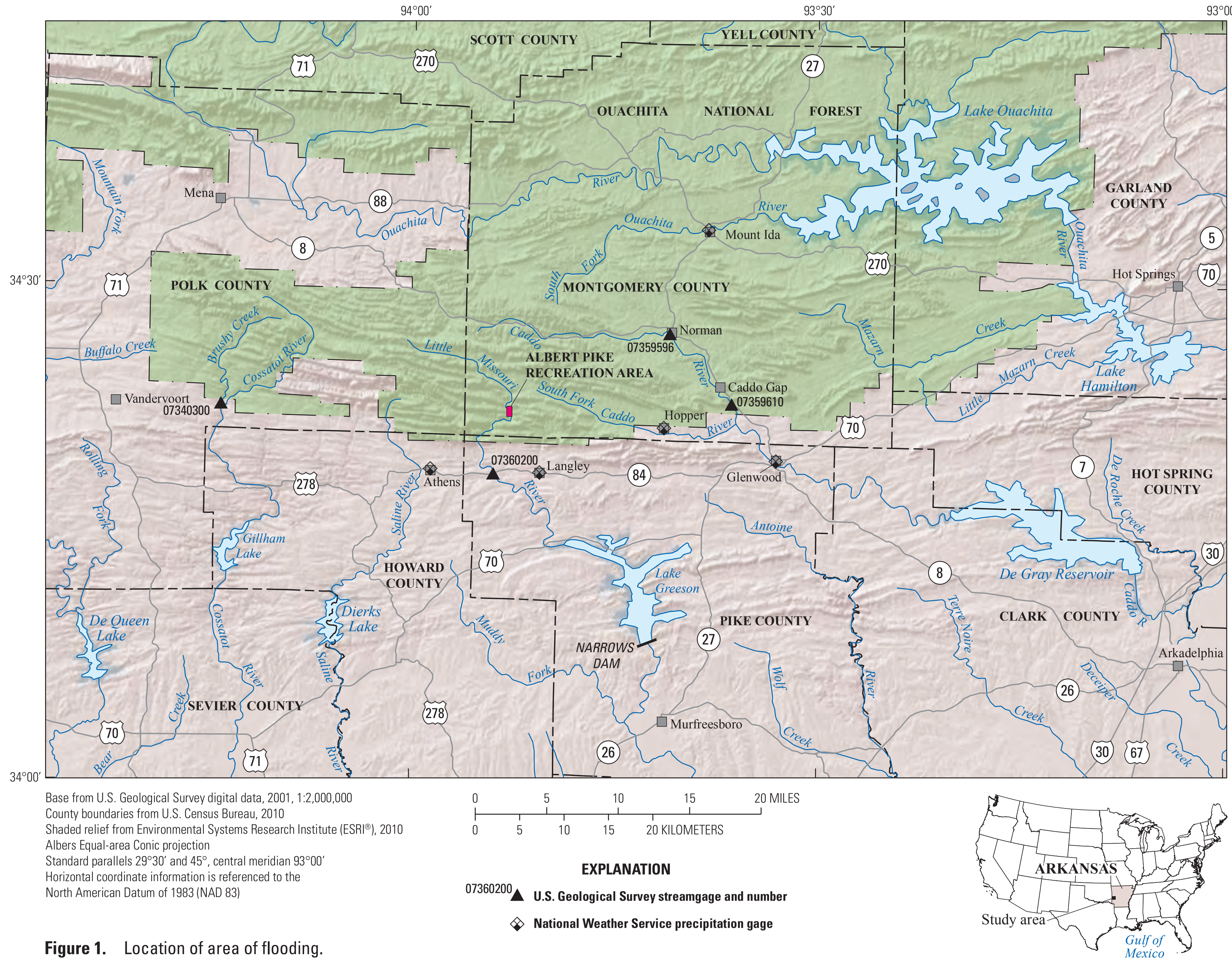
On-site measurements of streamflow can be collected by direct or indirect methods. Direct methods use instruments to “directly” measure the stream velocity and depth at various locations across the stream cross section during the flow event, and then the streamflow is computed using the measurements (Sauer and Turnipseed, 2010). Indirect methods (Benson and Dalrymple, 1967) are required when the streamflow cannot be measured with instruments directly, but rather the on-site measurement of streamflow has to be measured “indirectly” using methodology based on conservation of energy principles with input parameters of water-surface slope (from high water marks), stream channel cross-sectional geometry, and channel boundary roughness.

For USGS streamgages, indirect methods usually are used only if USGS personnel are unable to reach the streamgage location before the river stage of interest recedes or stream conditions are such that direct measurement is impossible or unsafe. Indirect methods also are often used at ungaged locations to determine the peak streamflow. For this study, indirect measurements of peak streamflow were made using the slope-area technique (Dalrymple and Benson, 1967) using the USGS computer model SAC version 97-01 (Fulford, 1994).

Accuracy of the slope-area indirect measurement depends on selection of the river reach for the indirect measurement. Ideally, the reach selected should be as uniform and straight as possible, where the energy losses of the flowing water are attributable to boundary friction. Diverging channel geometry (expanding in width and cross-sectional area) should be avoided, if at all possible, as energy loss attributable to flow separation and eddies is poorly accounted for in the slope-area indirect method. A minimum of three cross sections are typically surveyed in the reach, with cross sections located at any apparent discontinuities in the water surface. The length of the reach is optimized between maximizing the fall in water surface, staying in the near-optimal uniform reach between cross sections, and the economics of conducting the field work.

High-water marks (HWMs) are the “evidence of the highest stage reached by the flood” (Benson and Dalrymple, 1967) and are used to determine the water-surface elevation for use in the indirect measurement computation procedure. HWMs are of various forms, such as, wash lines on stream banks, drift (fine organic debris, leaves, and needles) deposited on the banks, mud lines on walls of structures and trees, and material deposited on the trunks of medium to large diameter trees. During the peak flow of the floods, seeds and decomposed organic material often are deposited on the trunks of trees in slackwater areas at the edge of floodplains where velocities are minimized. These seed and organic matter lines on the trunks of trees are often the most reliable indicators of the true high water from a flood. In all indirect measurements, it is desirable to collect as many HWMs as possible.

HWMs were flagged immediately after the June 11, 2010 flood at locations in the Little Missouri River watershed where knowledge of the peak streamflow was desirable (fig. 2, noted as indirect measurement locations). In addition, HWMs were flagged at an existing streamgage, Little Missouri River near Langley, Arkansas (USGS streamgage 07360200, fig. 1), where a direct peak streamflow measurement was not made during the flood. The HWMs (allowing for determination of water-surface slope) and channel cross-sectional geometry were surveyed in the days immediately following the flood using a total station surveying instrument. Channel roughness was determined by field observations, utilizing comparative photos from known channel roughness measurements (Barnes, 1967), various theoretical equations for channel roughness, and engineering judgment. The water-surface slope, channel geometry, and channel roughness are used in computation of the peak streamflow by the slope-area indirect measurement technique (Dalrymple and Benson, 1967).



Base from U.S. Geological Survey digital data, 2001, 1:2,000,000
County boundaries from U.S. Census Bureau, 2010
Shaded relief from Environmental Systems Research Institute (ESRI®), 2010
Albers Equal-area Conic projection
Standard parallels 29°30′ and 45°, central meridian 93°00′
Horizontal coordinate information is referenced to the
North American Datum of 1983 (NAD 83)

Figure 1. Location of area of flooding.

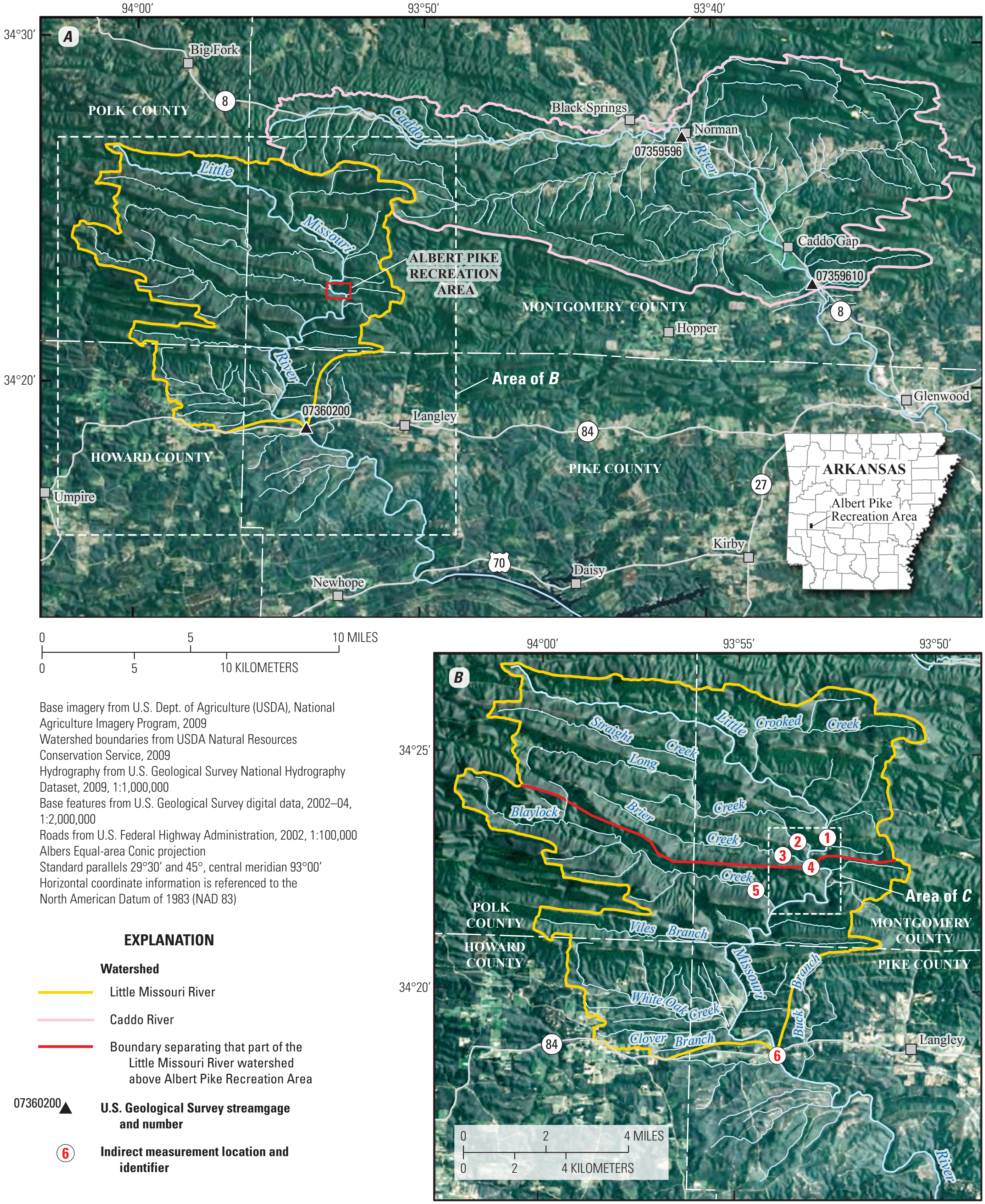
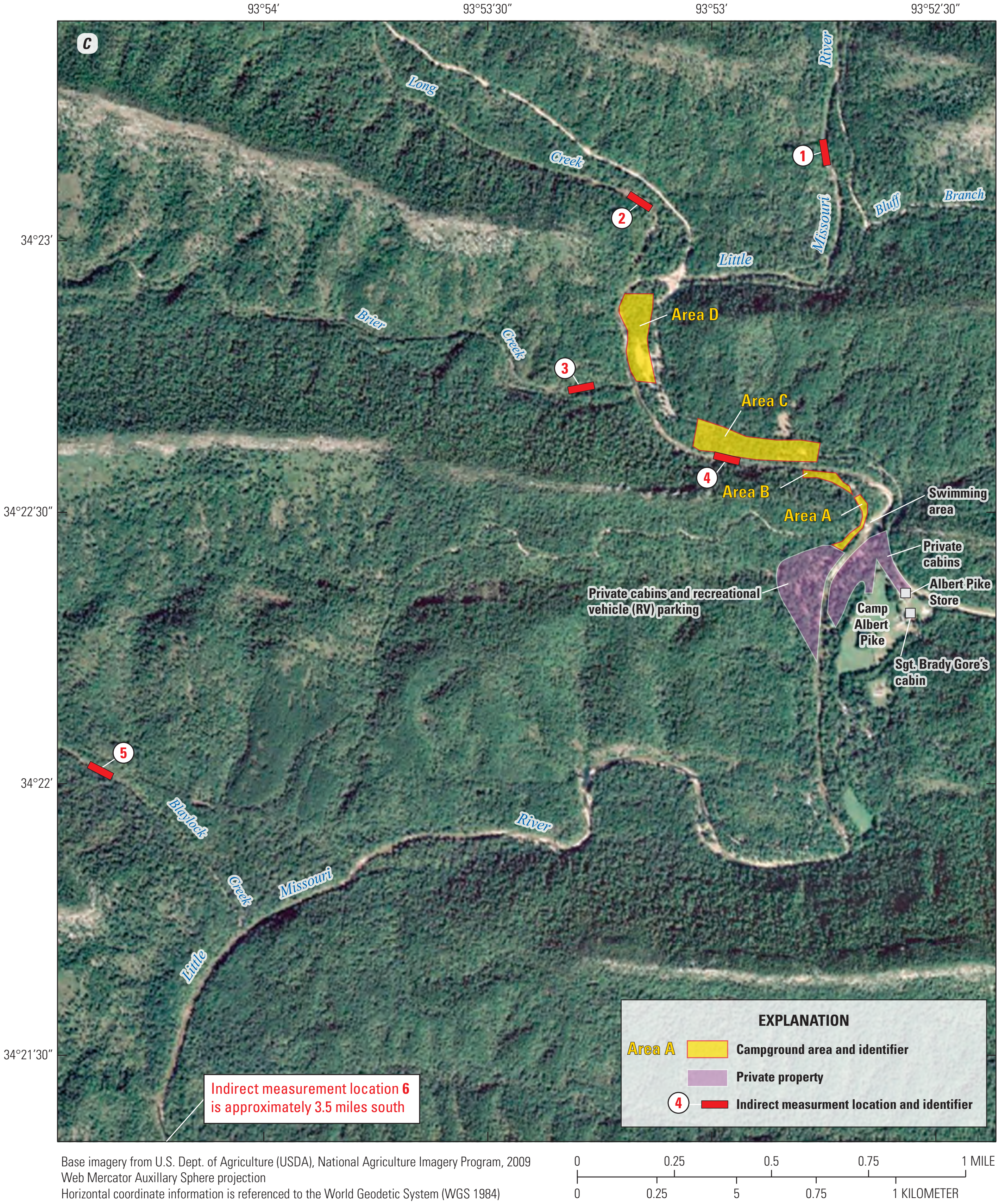


Figure 2. *A*, Little Missouri River and Caddo River watersheds and streamgages; *B*, Little Missouri River and tributaries and indirect measurement locations in the immediate vicinity of the Albert Pike Recreation Area; and *C*, Albert Pike Recreation Area campgrounds, Camp Albert Pike, and indirect measurement locations.



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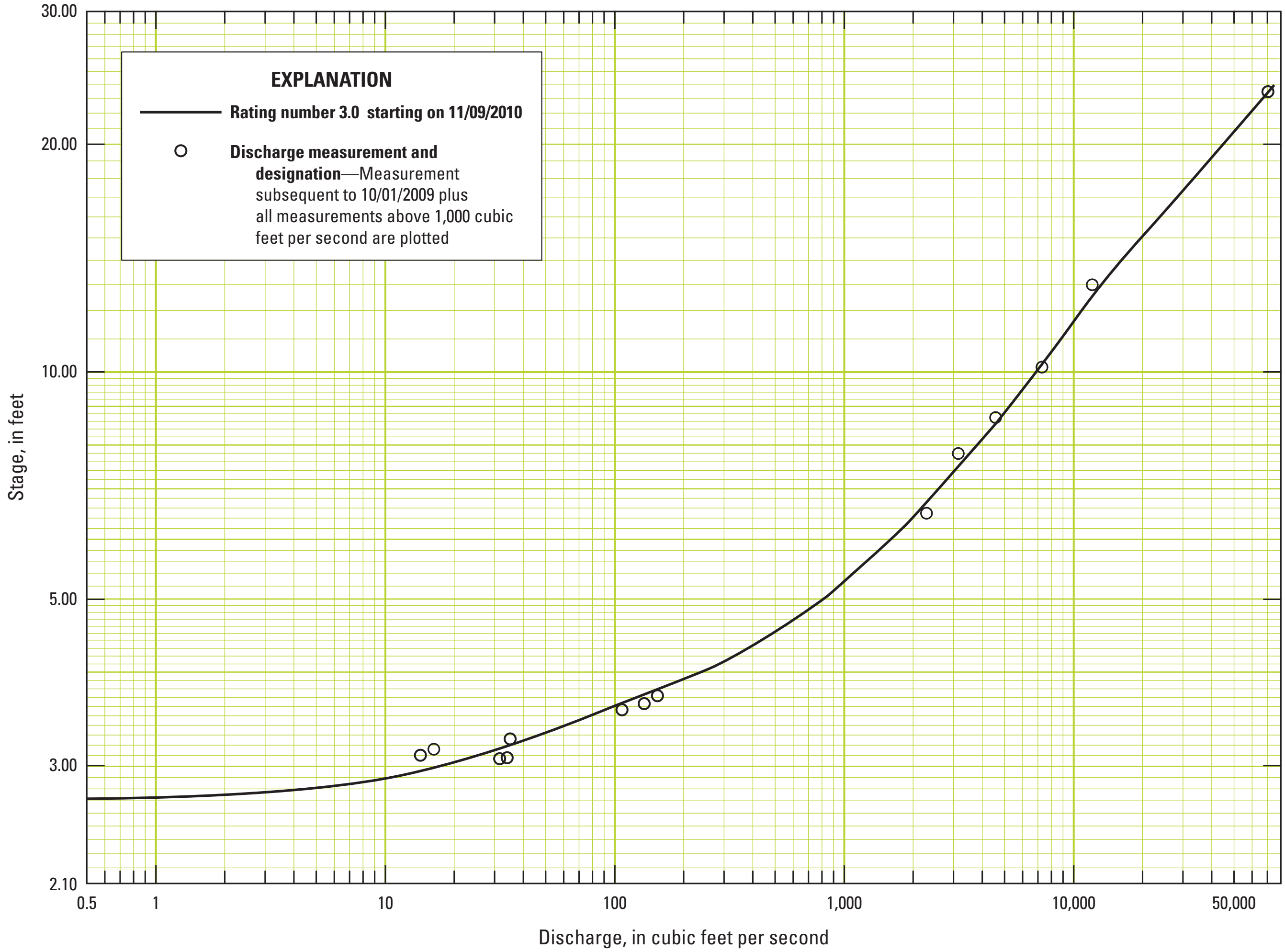


Figure 3. Stage-streamflow rating curve for the Little Missouri River near Langley, Arkansas (fig. 1) (U.S. Geological Survey streamgage 07360200).

The Setting

The Little Missouri River watershed is located in the rugged southern part of the Ouachita Mountains physiographic region (Fenneman, 1938) in Montgomery and Polk Counties in southwestern Arkansas (figs. 1 and 4). A 15.7-mile section of the Little Missouri River was designated a National Wild and Scenic River by the U.S. Congress as part of the Wild and Scenic Rivers Act created in 1968 (Public Law 90-542; 16 U.S.C. 1271). Albert Pike Recreation Area (fig. 1) (Albert Pike) is located in the Ouachita National Forest on the banks of the Little Missouri River within the National Wild and Scenic River section and is a popular public access point for camping, fishing, hiking, and whitewater kayaking.

Geology and Soils

The Ouachita Mountains were formed from Paleozoic strata that were deposited in deep water settings and subsequently deformed (folded and faulted) into long, east-west trending ridges by compressional events associated with the Ouachita orogeny (mountain-building event) that occurred during the late Paleozoic era (Manger, 1983). The ridgelines in the immediate vicinity of Albert Pike, known as the "Cossatot Mountains," are composed of resistant sandstone or novaculite bedrock, whereas the valleys between are underlain by less-resistant shale or impure sandstone (fig. 5). Soils in the Ouachita Mountains of Montgomery County are well-drained, cobbly/gravelly sandy loams or silt loams with low available water capacity and typically high saturated hydraulic conductivity values. Depth to bedrock is on average less than 40 in. (Olson, 2007), but in many locations the soils are much thinner.

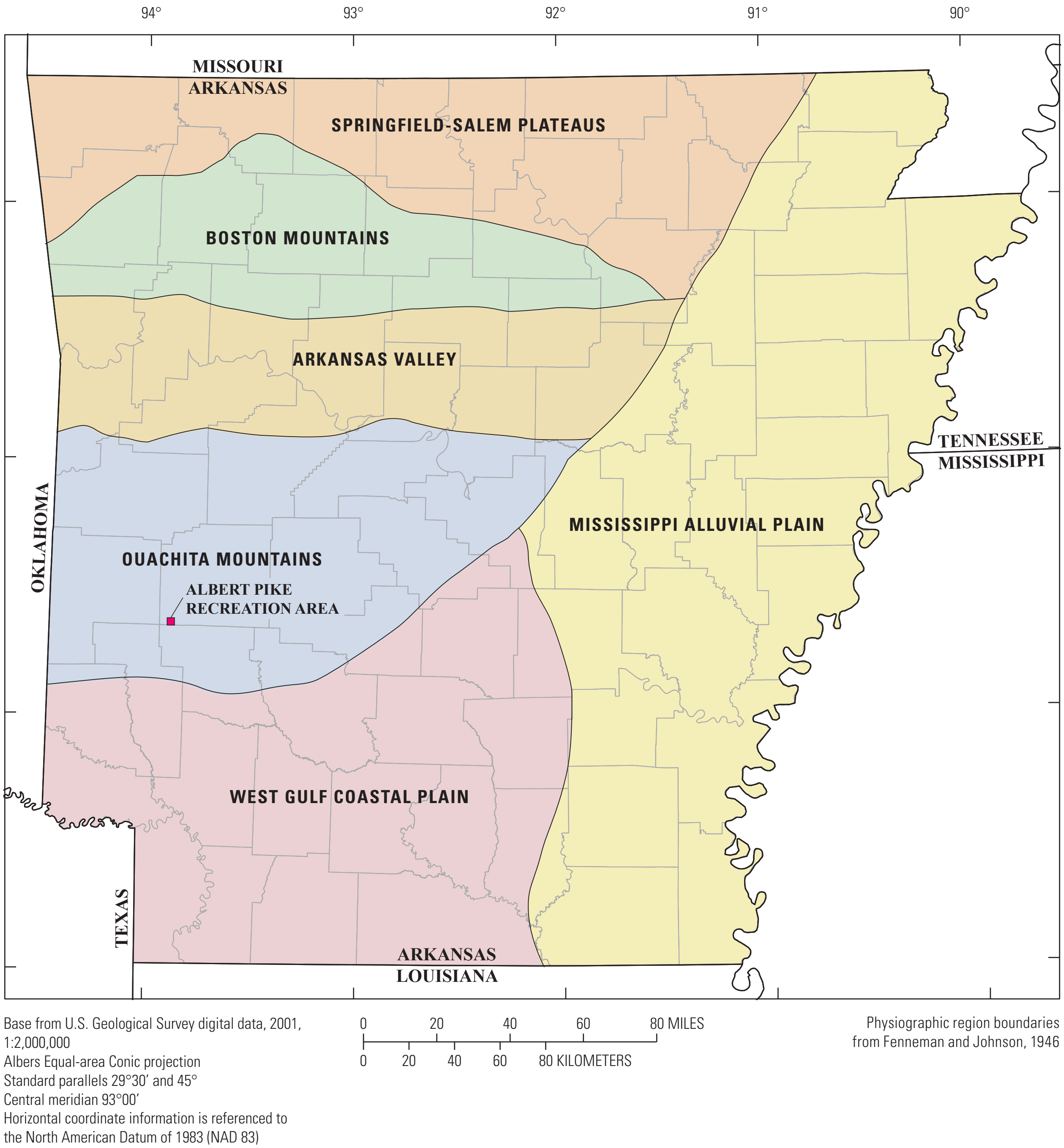


Figure 4. Physiographic regions of Arkansas.

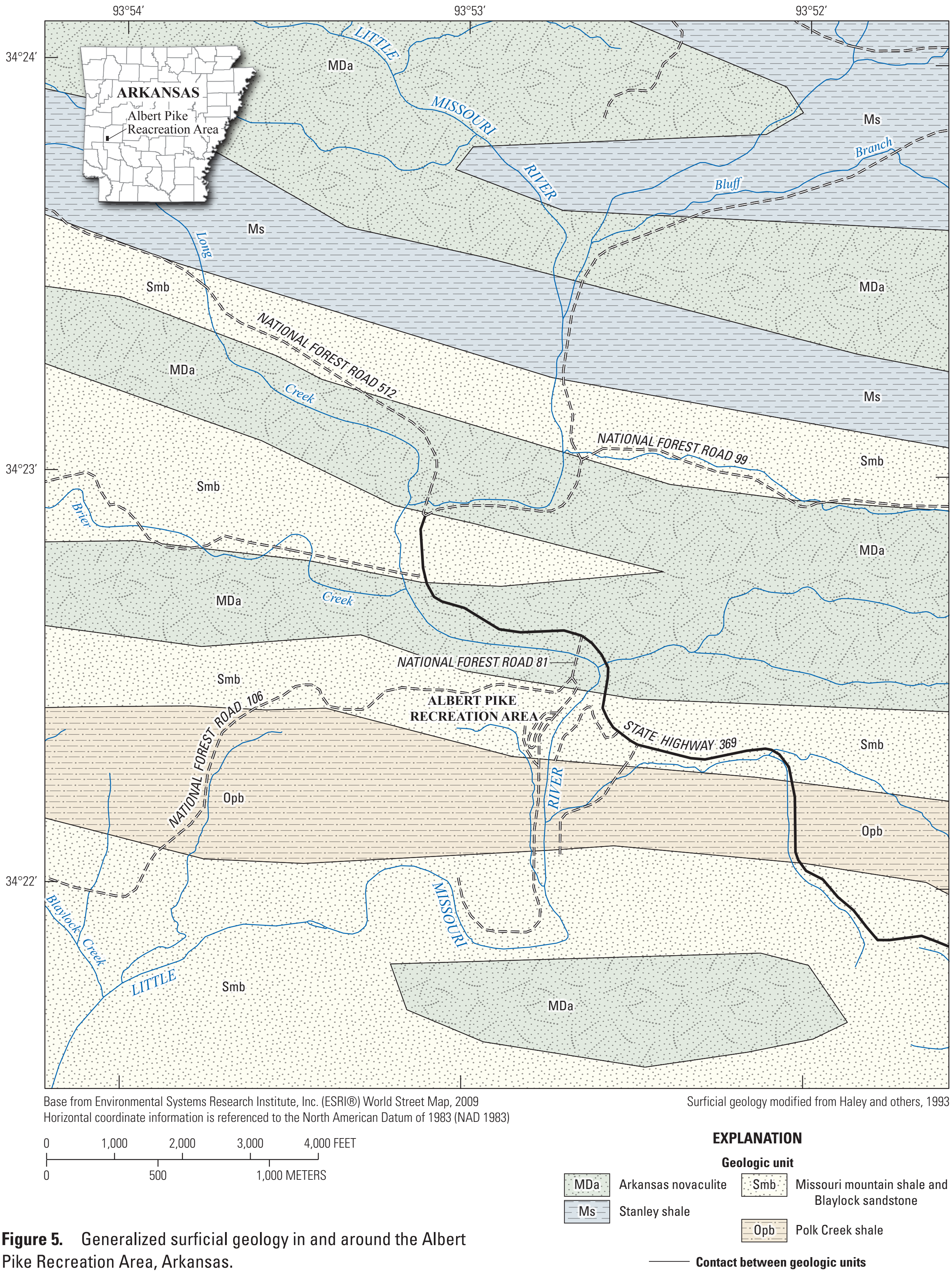


Figure 5. Generalized surficial geology in and around the Albert Pike Recreation Area, Arkansas.

Terrain

Albert Pike is located on the Little Missouri River at elevation 900 ft North American Vertical Datum of 1988 (NAVD 88). Albert Pike is surrounded by steep, rugged mountain topography of the Cossatot Range, the peaks of which rise as high as 2,000 ft NAVD 88 resulting in local relief ranging from 800 to 1,000 ft (fig. 6). Stark sandstone and novaculite rock outcroppings are abundant.

The topography of the area is controlled by the geology, with streams in the watershed upstream from Albert Pike exhibiting a trellis drainage pattern, common to mountain ranges where the bedrock is folded and faulted, in which the locations of river channels are controlled by the orientation and resistance of the rock layers. The trellis drainage pattern can cause high synchronicity of tributary flow delivery to the downstream locations. The main stream channels occupy long valleys between the resistant rocks of the east-west trending ridges, with tributary streams joining the main stream at near right angles as they run down the sides of the ridges. Streams occasionally cut through the ridges, creating narrow, steep-sided gaps as they flow north or south to the next east-west trending valley (figs. 6 and 7).

Watershed Description

The Little Missouri River's watershed upstream from Albert Pike covers 35 mi^2 and by the time the river reaches Highway 84, the watershed nearly doubles in size to 68 mi^2 (fig. 6). The red line on figure 6 separates the aforementioned parts of the Little Missouri watershed above Highway 84. The channel and floodplain corridor upstream and through Albert Pike is narrow. The narrow corridor results in rapid rises in water levels during times of heavy rainfall and rapid runoff. The steep stream gradients also contribute to swift water velocities in the Little Missouri and tributaries. From the river's headwaters to the Arkansas State Highway 84 bridge at Langley, a distance of 21.5 river miles, the average channel slope is 48 ft/mi (0.009 ft/ft); upstream from Albert Pike Recreation Area, the average channel slope is 65 ft/mi (0.012 ft/ft). Average channel slopes of the major tributary streams to the upper Little Missouri River in the vicinity of Albert Pike also are large with Long Creek at 58 ft/mi (0.011 ft/ft), Blaylock Creek at 77 ft/mi (0.014 ft/ft), and Brier Creek at 110 ft/mi (0.021 ft/ft).

Climate

The southern Ouachita Mountains exhibit a humid subtropical climate type characterized by hot, humid summers and cool winters. The NWS has maintained a climate station at nearby Mt. Ida, Arkansas (Mt. Ida, fig. 1) since 1971 (National Weather Service, 2010A). Based on data from 1971 to 2000, the average annual precipitation is approximately 58 in., with 48 percent of this precipitation (28 in.) falling during the months of April–September, demonstrating that the rainfall in this area typically is evenly distributed throughout the year. The heaviest recorded 24-hour rainfall for Mt. Ida was 9.95 in. on December 3, 1982. Thunderstorms, which generally are the producers of the largest floods on small watersheds, occur on approximately 57 days per year, with the greatest number occurring during the month of July. Average relative humidity at dawn is 84 percent, whereas average relative humidity in mid-afternoon is 57 percent (National Weather Service, 2010A).

The Ouachita Mountains near Albert Pike exhibit the greatest average annual precipitation (58 in.) and runoff (24 to 32 in.) in the State of Arkansas (Friewald, 1984). The moisture source for precipitation in the Ouachita Mountains is the Gulf of Mexico. Often, particularly in summer months, warm, moist air over the Gulf surges northward across the West Gulf Coastal Plain on southern or southwesterly winds, and can be affected by movement of low-pressure systems. Just north of Arkansas Highway 84, the first high ridges of the Ouachita Mountains appear, reaching 1,000 ft above the West Gulf Coastal Plain. These ridges, which are the headwaters of the Little Missouri, Caddo, and Cossatot Rivers, can, at times, produce orographic lifting of the warm, moist air mass, which then cools and condenses, ultimately forming precipitation, and depending on the abundance of moisture from the Gulf, the precipitation can be of high quantity and intensity. Abundant intense precipitation, narrow channel corridors, and steep hillslopes and stream gradients in the southern Ouachita Mountains create conditions highly conducive to flash flooding, such as the flooding that occurred on June 11, 2010.

The Storm

The movement of water through the landscape (the rainfall-runoff response) is governed by the watershed characteristics that are dependent upon geography, geology, meteorology, land use, and topography of the watershed. The intensity and severity of a meteorological flood (a flood caused by rainfall) for a given location is governed by the aforementioned watershed characteristics coupled with the antecedent hydrologic conditions and storm characteristics (precipitation magnitude and intensity). The predominant moisture source for the Ouachita region is the Gulf of Mexico, intensified by orographic lifting over the Ouachita Mountains. When it occurs, the orographic effect serves to intensify the rainfall associated with the convective thunderstorms that are typical in Midwestern summers. The antecedent conditions and storm characteristics resulting in the June 11, 2010 flood in the upper Little Missouri River watershed are discussed in the following two sections of this report.

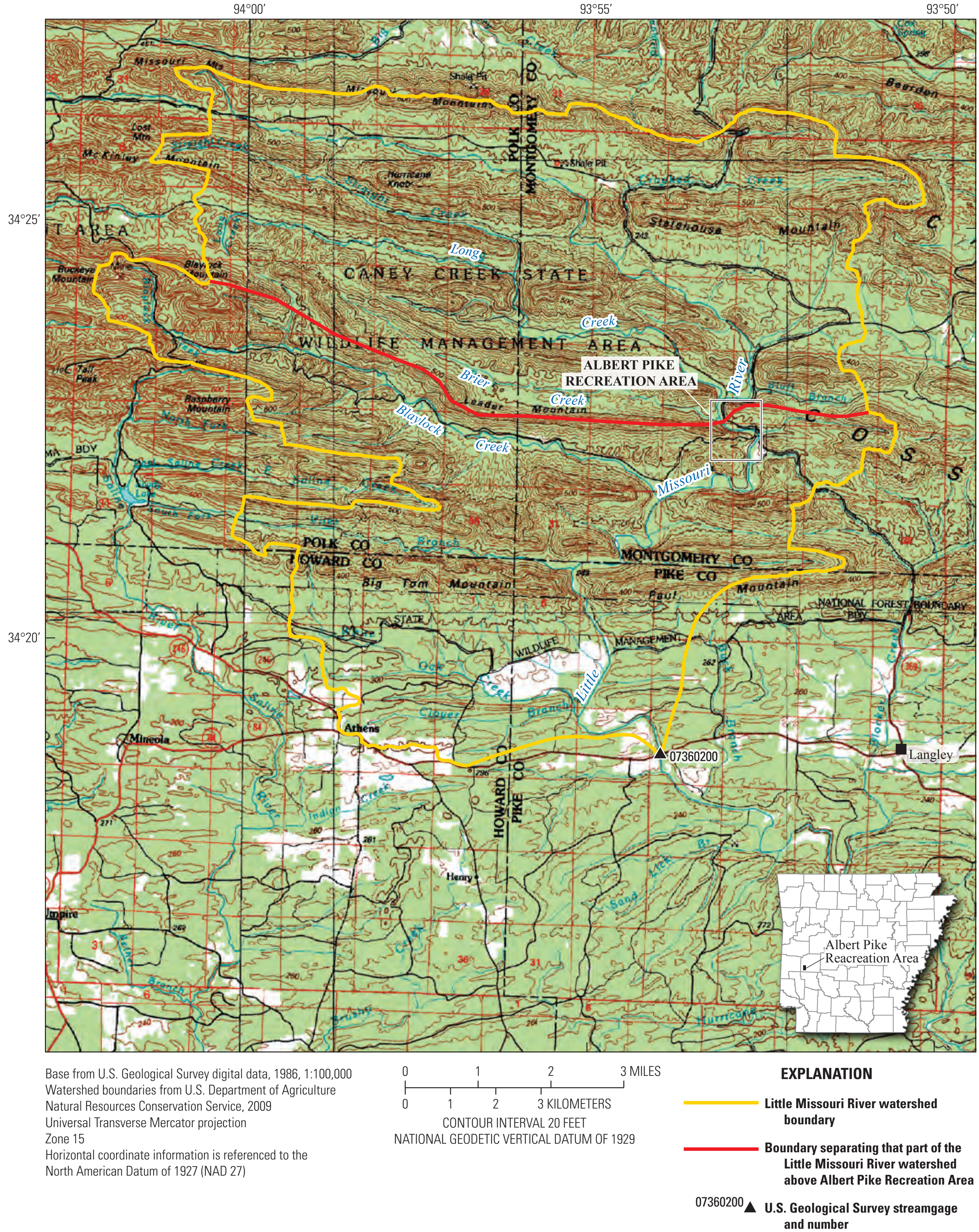
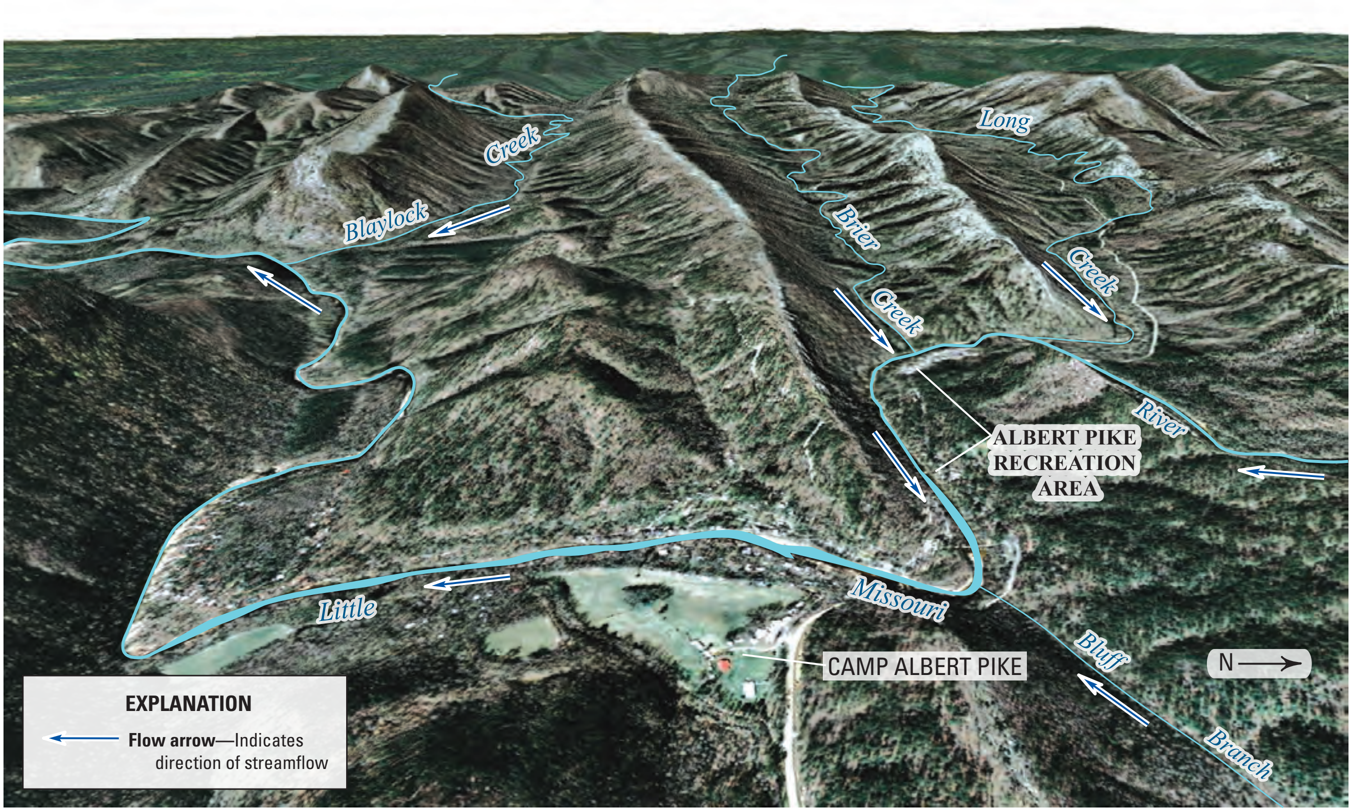


Figure 6. Topography in the Upper Little Missouri River watershed upstream from the Little Missouri River near Langley, Arkansas streamgage (U.S. Geological Survey streamgage 07360200).



Base from Environmental Systems Research Institute (ESRI®) Arc Globe Service, 2011

Figure 7. Oblique three-dimensional view of the Little Missouri River watershed in the vicinity of the Albert Pike Recreation Area. Vertical height of terrain has been exaggerated in this view.

Antecedent Hydrologic Conditions

The winter and early spring of 2010 were average to below average in terms of the precipitation in the southern Ouachita Mountains. At Glenwood, Arkansas (fig. 1), the monthly precipitation totals for January-May 2010 were generally below average (National Weather Service, 2010B; table 1).

The week before June 11, 2010 was relatively dry in regards to precipitation in the southern Ouachita Mountain region. From June 1–9, 0.23 inches of total rainfall was recorded at Mt. Ida and 0.18 inches of total rainfall at Mena, Arkansas and only a trace of precipitation was recorded at Hot Springs, Arkansas (National Weather Service, 2010B). Streams in the region were at normal levels on June 10 (fig. 8).

Table 1. Monthly precipitation for Jan–May 2010 at Glenwood, Arkansas (National Weather Service, 2010B).

Month	Montly average precipitation, in inches, 1971–2000	2010 precipitation
January	3.78	3.52
February	4.18	5.54
March	5.54	2.83
April	5.28	2.02
May	6.06	5.90

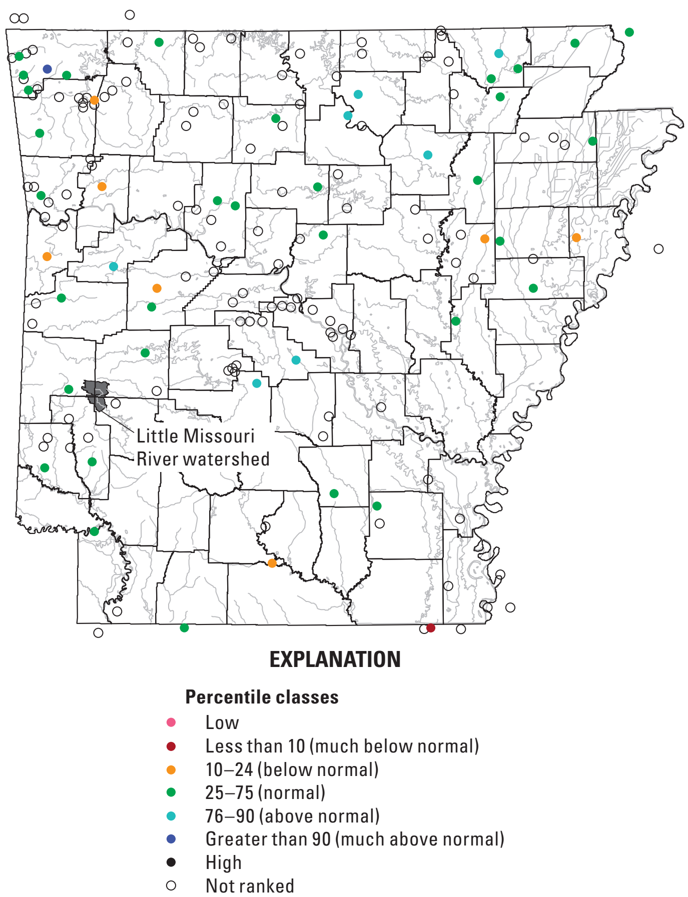


Figure 8. Streamflow conditions on June 10, 2010, prior to the Little Missouri River watershed, Arkansas flood of June 11, 2010 (U.S. Geological Survey, 2010).

Storm Characteristics and Precipitation

On June 10, 2011, high pressure was building over the southeastern United States while a low pressure center and associated storm system aloft slowly moved around the high pressure center from south central to northeastern Texas (fig. 9). The storm system produced over 6.5 inches of rain in parts of southeast Texas , which caused flooding that resulted in at least one fatality and necessitated rooftop rescues and evacuations (National Oceanic and Atmospheric Administration, 2010). A day later, on June 10, similar precipitation amounts (8.14 inches) closed roads in northeastern Texas, again necessitating rescues from flooded homes (National Oceanic Atmospheric Administration, 2010).

At around 5:00 PM on June 10, mesoscale thunderstorms began to move from northeastern Texas into southwestern Arkansas. Interpretation of NEXRAD estimated rainfall amounts (fig. 10) indicates that occasional showers and thunderstorms occurred in southwestern Arkansas between 11:00 PM on Thursday, June 10 and 1:00 AM on Friday, June 11, 2010, with heavier rain that moved into the upper Little Missouri River watershed area after 1:00 AM. Between 1:00 AM and 3:00 AM, torrential downpours ensued, with NEXRAD estimating a maximum estimate of 4.73 inches of rain near Albert Pike in the upper Little Missouri River watershed. By 5:15 AM on June 11, the rain had ended in the upper Little Missouri River watershed, dumping more than 5 inches of rain in less than 6 hours in certain locations in the watershed. Using the hourly NEXRAD rainfall estimates, the maximum values of the 1-hour, 2-hour, 3-hour, and 6-hour cumulative precipitation values were estimated at 1.88 inches, 3.46 inches, 4.73 inches, and 5.3 inches of rain. Use of the Department of Commerce rainfall probability estimates for various durations (Department of Commerce Weather Bureau, 1961) estimated the annual exceedance probabilities (AEP) for these rainfall values at 40-percent, 8-percent, 2-percent, and less than 4-percent respectively (fig. 11). Precipitation totals for the 2-day period of June 10–11 were 9.12 inches at Athens, Arkansas; 7.74 inches at Langley, Arkansas; 7.55 inches at Glenwood, Arkansas; 7.48 inches at Hopper, Arkansas; and 6.83 inches at Mt. Ida (National Oceanic Atmospheric Administration, 2010). NWS radar estimates indicate that similar amounts of rain fell at Albert Pike in this same 24-hour period (fig. 12). To emphasize the localized nature of the intense rainfall, the National Weather Service reported only 3.06 inches of rain at Mena, Arkansas for the 2-day period of June 10–11, and only 1.95 inches at Hot Springs, Arkansas (National Weather Service, 2010C).

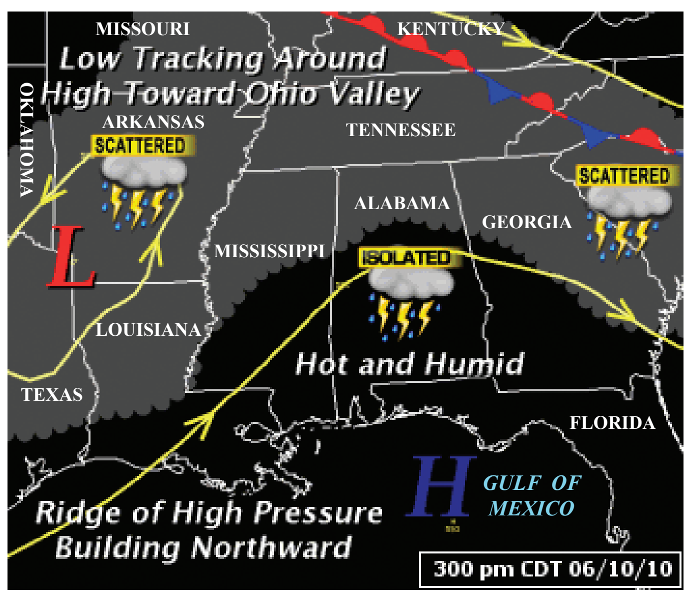


Figure 9. Track of warm, moist air from Gulf of Mexico to Arkansas for June 10, 2010 (from Tabitha Clarke, National Weather Service, written commun., July 2010).

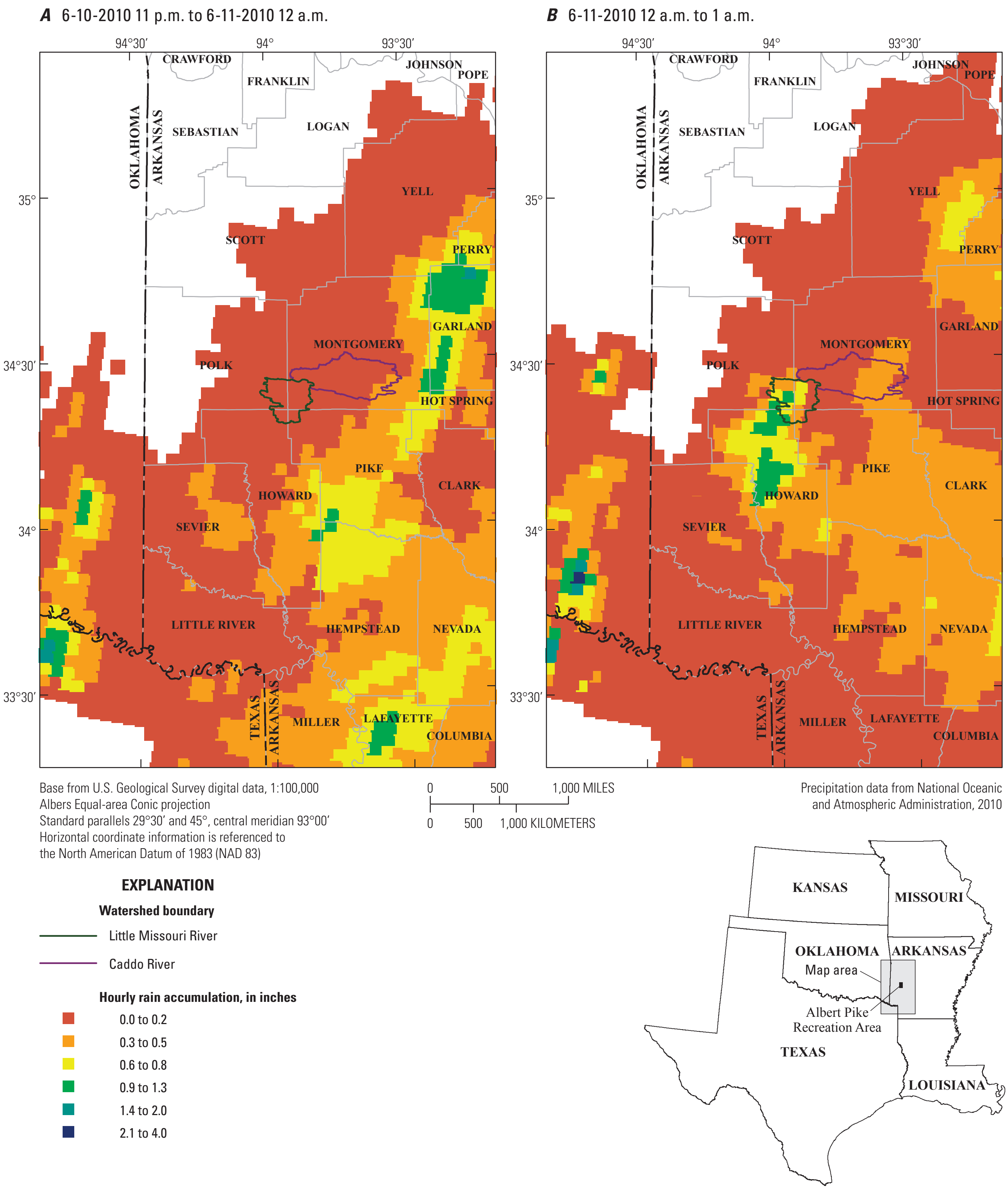
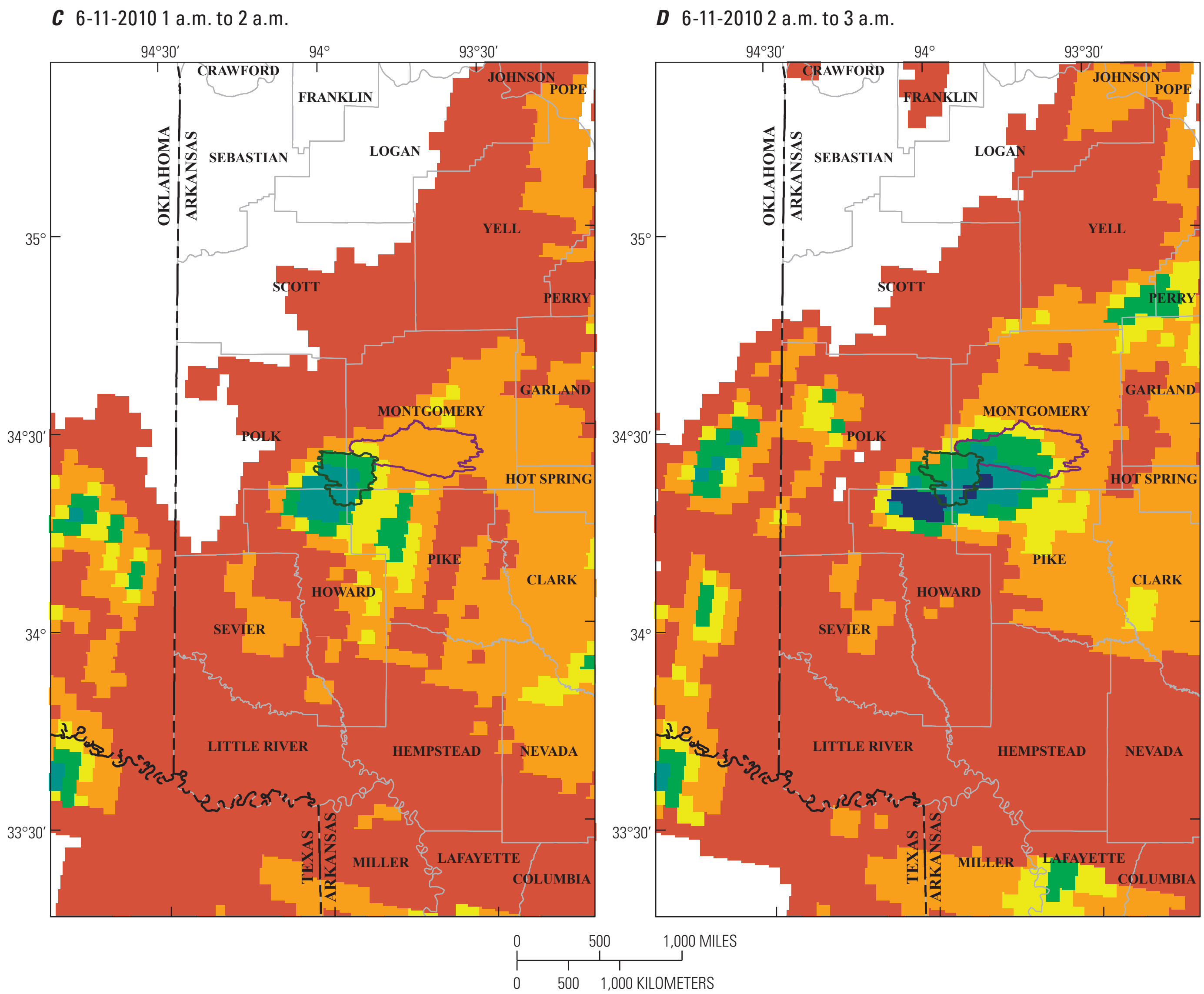


Figure 10. Hourly precipitation totals estimated from NEXRAD (NEXt-generation RADar) for four time periods from 11 p.m. Central Daylight Savings Time June 10, 2010, to 3 a.m. Central Daylight Savings Time June 11, 2010 (National Oceanic Atmospheric Administration, 2010).



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The Flood: Hydrologic Analysis

During the June 11, 2010, flood, only one USGS streamgage existed in the Little Missouri River watershed upstream from Lake Greeson (in the area of catastrophic flooding), Little Missouri River near Langley, Arkansas (Langley) (USGS streamgage 07360200, fig 1). Besides the Langley streamgage, peak streamflow was determined at two ungaged locations along the Little Missouri River in and near Albert Pike, as well as three ungaged tributaries flowing into the Little Missouri River near Albert Pike (fig. 2 and table 2).

Flood Chronology, Hydrographs, and Timing

At 5:00 PM on June 10, 2010, the Langley streamgage had a stage of 3.27 ft, which corresponded to a streamflow of 55.1 ft^3/s (fig. 13). For a stage of 3.27 ft, the mean stream depth at this location is approximately 1.0 ft. Although there were showers and thunderstorms throughout the afternoon and evening of June 10, 2010, in southwest Arkansas, the Langley streamgage only rose 0.13 ft from 5:00 PM to midnight throughout the evening of June 10, 2010, where a recorded stage of 3.40 ft occurred at midnight (fig. 13). The occurrence of intense torrential rainfall in the Little Missouri River watershed after 1:00 AM on June 11, 2010 resulted in the start

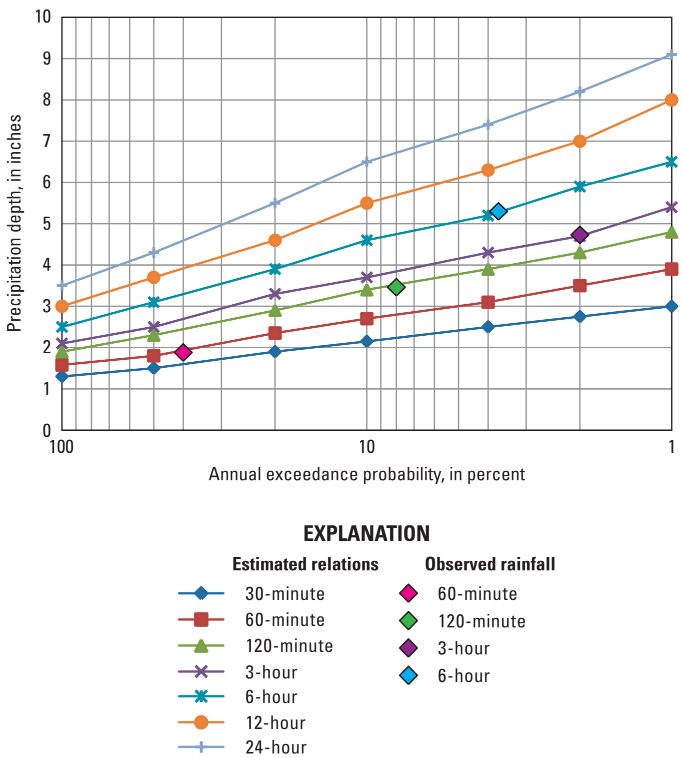


Figure 11. Rainfall-probability-duration relations for the upper Little Missouri River watershed from relations presented by Department of Commerce Weather Bureau (1961).

of the rapid rise in stage at the Langley streamgage between 1:15 AM and 1:30 AM. The maximum rate of rise recorded at the Langley streamgage was 2.76 ft in 15 minutes between 3:00 AM and 3:15 AM, with the peak stage of 23.46 ft and streamflow of 70,800 ft^3/s, as determined by indirect measurement of streamflow, occurring at 5:30 AM on June 11, 2010 (fig. 13).

The timing of the flood peak and rate of streamflow rise at Albert Pike and other locations was estimated using anecdotal evidence in combination with the streamflow data at Langley (fig. 13). Compared with the Langley streamgage, the onset of flooding and peak stage and streamflow of the Little Missouri River would have occurred earlier in the Albert Pike campground, which is approximately 9.1 miles upstream. The initial calls to Montgomery County, Arkansas 911 Central Dispatch from Albert Pike occurred around 2:38 AM from the campground host (U.S. Department of Agriculture, 2010). At 3:04 AM, a caller advised the Montgomery County, Arkansas Sheriff's Department that " the bridge near the cabins at Albert Pike area is under water and it is still rising" (U.S. Department of Agriculture, 2010). A 3:30 AM NWS broadcast indicated that

> "law enforcement was trying to move campers to safer locations around the Albert Pike Recreation Area….with high water rescues expected." (National Weather Service, 2010A).

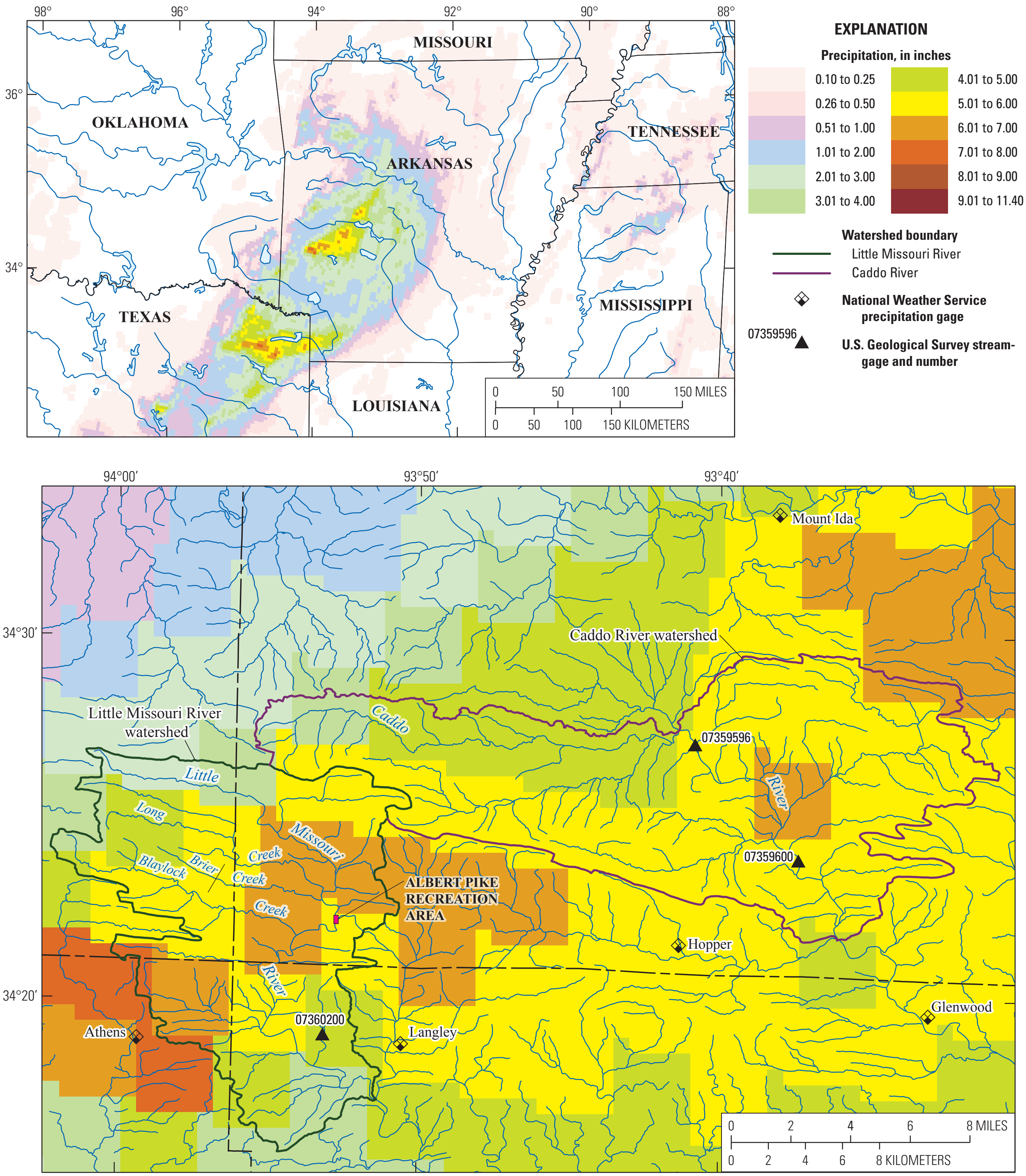
Sergeant Brady Gore, an off-duty Arkansas State Policeman, was staying at a family member's cabin at Camp Albert Pike (fig. 2*C*), when he was awakened at approximately 3:30 AM on June 11, 2010, by neighbors beating on his cabin door. According to Sergeant Gore,

> "…upon waking up and looking out the back door, I saw that the water level from the Little Missouri was just below our back deck, by the time I made two quick phone calls including one to my father at 3:38 AM….he owns the cabin….the water had risen another several feet and was now over the deck. This could not have been more than 5 minutes or so. I have been coming to Albert Pike since I was a kid and have never seen anything like it. The speed of rise was unbelievable going up 5 to 6 feet in about 5 minutes. Around when I got off the phone with my father, I went outside and this seemed to be about the peak of the flood as it did not seem to rise much more…… it seemed like the water stayed up at this level for about an hour before it quickly started to fall out as fast as it rose. I was amazed at how quickly it fell and I distinctly recall the rate of fall because I was working with some others who were trying to rescue a lady who was clinging to a light pole. She had been washed down from D Loop (Area D of the Albert Pike Recreational Area campground, fig. 2*C*) and I kept noticing how we kept being able to walk out farther and farther to her. You could actually see the river fall….it was that fast. It was around 5:00 AM before the river really began the rapid fallout."

At 5:34 AM, a U.S. Forest Service patrol captain arrived on scene in Area D of the Albert Pike campground and reported seeing a pickup truck, with survivors inside, in place horizontally across the road. The captain also noted other survivors hanging high in trees (U.S. Department of Agriculture, 2010), further corroborating the timing of the crest and rapid decrease of the water levels at Albert Pike.

Based on the eyewitness accounts and time-stamped logs from U.S. Forest Service radio transmissions, a reasonable estimate of the timing of the peak for the Little Missouri at Albert Pike is between 4:00 AM and 4:30 AM. The approximate travel time of the crest from Albert Pike down to the streamgage at Langley is approximately 1 to 1.5 hours, with the flood wave speed of approximately 13.3 ft/s (9.1 mi/hr). The flood wave speed is the speed of the peak of the flood as it moves down the channel, which is not the same as the water velocity at any particular location during the flood.

The localized nature of this flood is demonstrated by comparing the June 11, 2010, streamflow hydrograph for the Little Missouri River at the Langley streamgage with the streamflow hydrograph for the Cossatot River near Vandervoort, Arkansas (Vandervoort, USGS streamgage 07340300) whose watershed is located 20 miles to the west. The June 11, 2010, streamflow hydrograph for Vandervoort (drainage



Base maps from U.S. Geological Survey digital data, 2001, 1:2,000,000; watershed boundaries from U.S. Deptartment of Agriculture Natural Resources Conservation Service, 2009; hydrography from U.S. Geological Survey National Hydrography Dataset, 2009, 1:1,000,000
Albers Equal-area Conic projection, standard parallels 29°30′ and 45°, central meridian 93°00′
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83)

Figure 12. Cumulative 24-hour precipitation totals from National Oceanic and Atmospheric Administration NEXRAD (NEXt-generation RADar) ending 7:00 a.m. June 11, 2010, National Weather Service precipation gages, and U.S. Geological Survey streamgages in the vicinity of the Albert Pike Recreation Area, Arkansas.

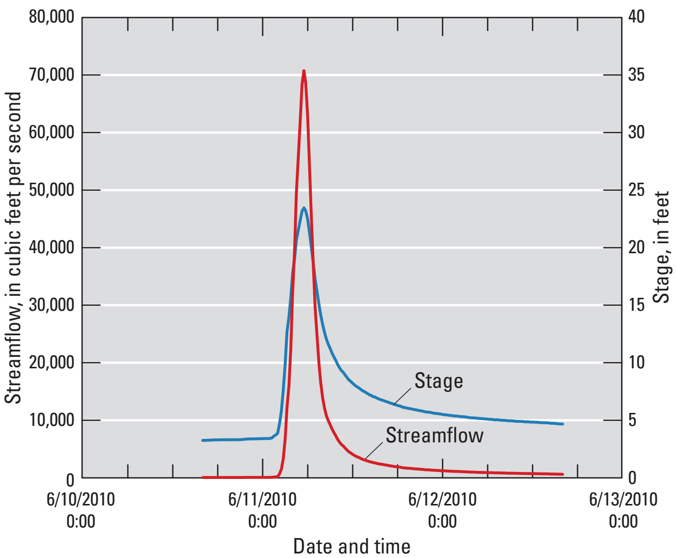


Figure 13. Stage and streamflow hydrograph for the Little Missouri River near Langley, Arkansas (U.S. Geological Survey streamgage 07360200).

area 89.5 mi^2) had only a 1,200 ft^3/s increase in streamflow (approximately 3-ft increase in stage) resulting from the storm precipitation, whereas Langley, with a smaller drainage area (68.4 mi^2), had an increase of more than 70,000 ft^3/s (greater than a 20-ft increase in stage).

Peak Streamflows and Hydraulic Properties

Of the 20 fatalities from the June 11, 2010, flood, 17 came from the Area D campground of Albert Pike and 3 came from an unofficial camp site along Long Creek. Given that the death toll in the area of Albert Pike and the nearest USGS streamgage was approximately 9.1 miles downstream, it was deemed desirable to determine and document the peak streamflow at five ungaged locations (fig. 2*C*) in or near Albert Pike. These locations included two sites on the Little Missouri River (upstream from Albert Pike and in Albert Pike) and three additional sites, one each in the following major tributaries to the Little Missouri River near Albert Pike: Long Creek, Brier Creek, and Blaylock Creek.

Long Creek flows into the right descending bank of the Little Missouri River just upstream from Albert Pike. Brier Creek flows into the right descending bank of the Little Missouri River at Area D of Albert Pike. Blaylock Creek flows into the right descending bank approximately 3 river miles downstream from Area D of Albert Pike (fig. 2*C*). The peak streamflow for the major tributaries was determined as close to the mouth as possible, limited by the need to stay away from backwater effects from the Little Missouri River. Each of the five ungaged locations were assigned USGS station numbers (table 2).

From the surveys of the high water marks and channel geometry, the hydraulic properties of area, mean depth, maximum depth, and water slope were determined. Using these hydraulic properties along with estimates of the observed channel roughness, the peak streamflow and associated velocities were estimated by use of the hydraulic computation program SAC (Version 97-01, Fulford, 1994) (table 2). The details and computation from these measurements can be reviewed at *http://water.usgs.gov/osw/floods/reports/LittleMOJune2010/Indirects*.

The peak streamflow for the Little Missouri at Albert Pike (site 4, fig. 2*C*), occurring sometime between 4:00 AM and 4:30 AM, was estimated to be 40,100 ft^3/s . Upstream (site 1, fig. 2*C*) above the inflow of Long and Brier Creeks, the peak streamflow was 28,200 ft^3/s. Long Creek (site 2, fig. 2*C*) had a peak streamflow of 13,000 ft^3/s and Brier Creek (site 3, fig. 2*C*) had a peak streamflow of 6,530 ft^3/s. Although summation of the Little Missouri River above Long Creek peak streamflow and peak streamflow for Long and Brier Creeks can be done to give a rough comparison with the measured value for the Little Missouri River at Albert Pike, there is a great deal of uncertainty because of the unknown timing of peak streamflows of Long and Brier Creeks along with the Little Missouri River above Long Creek.

The timing of the peak streamflow for Blaylock Creek (site 5, fig. 2*C*) is estimated to be before the crest of the Little Missouri River at the mouth of Blaylock Creek. This finding results from the severe bending (greater than 30 degrees from vertical) in the downstream direction of the small diameter (less than 2 inches) trees adjacent to the banks at the mouth of Blaylock Creek coupled with the nearly flat water surface-profile of the high water marks of Blaylock Creek at this same location. The flat water-surface profile indicates that Blaylock Creek at this location was in backwater from the Little Missouri, with insufficient velocity to cause the amount of downstream bending of the trees that was observed. The crest of Blaylock Creek is not likely to have occurred after that of the Little Missouri River at this location as at least one of the fatalities from Albert Pike was found at the mouth of Blaylock Creek. This final location of the body would not likely have been at this location if the peak of Blaylock Creek, with the velocities great enough to bend trees, had occurred after the Little Missouri River crest.

The peak streamflow for the Little Missouri at Langley (site 6, fig. 2) was 70,800 ft^3/s. The crest occurred at 5:30 AM as determined by the recording streamgage.

The main channel at Albert Pike (located adjacent to Area C of the Albert Pike campground) had an average depth of 17.3 ft with an average main channel velocity of approximately 11.7 ft/s (8 mi/hr) as computed by the SAC model (Fulford, 1994). The floodplain (Area C of the Albert Pike campground) had an average velocity of approximately 9.0 ft/s (6 mi/hr) as estimated from the SAC model and average depth of 7 ft. The SAC model estimate of 9.0 ft/s was affected by field measurements of the “run-up” water surface on the front of the bathhouse in the floodplain at Area C. Run-up occurs in flowing water where an obstruction causes the velocity to go to zero on the upstream side of the obstruction. The run-up is the conversion of kinetic energy to potential energy and corresponds to the square of the velocity divided by twice the acceleration of gravity (Julien, 1995). The difference in HWM elevations between the upstream facing wall of the Area C bathhouse (where run-up occurred) and inside the electrical room (5 ft downstream from the upstream face of the bathhouse along the wall parallel to the flow) was 1.25 ft. Given the run-up value is approximately equal to the velocity head of the stream, the computed velocity from this value of run-up is 9.0 ft/s.

Maximum velocities near the water surface away from the edge of the floodplain would be greater than the cross-sectionally averaged velocities. Assuming a logarithmic velocity profile (Julien, 1995), the maximum floodplain velocity was estimated to be potentially as large as 11 ft/s (7.5 mi/hr) and the main channel maximum velocity estimated to be potentially as great as 15.6 ft/s (11 mi/hr).

Estimates of the mean main channel and mean overbank velocities also were calculated for the other 5 locations using the SAC model (Fulford, 1994). These estimated values are contained in table 2.

Fluvial Processes and Flow Competence

Fluvial processes involve, among other things, the flow-induced movement of sediment through erosion and deposition in a river system. These erosional and depositional processes are the primary controls on the morphology (shape and form) of the river. Periods of flooding play an important role in the pace and effect of the fluvial processes on river morphology. Extreme floods generate forces capable of moving bed material that are orders of magnitude larger than can be moved, either in routine streamflows or annual floods.

Although flows were quite destructive to various roads and structures in the floodplain (fig. 14), the Little Missouri River and its major tributary streams in and near Albert Pike showed only minor bank instability from the June 11, 2010, flood. However, postflood field work revealed evidence of movement of large bed sediments, including boulder-size material (greater than 0.84 ft in diameter), at various locations in the main channel and on floodplains. Among the most dramatic evidence of erosion and deposition occurred just below the constricted reach of the Little Missouri River at the swimming hole in the main channel adjacent to Area A of Albert Pike campground (fig. 2*C*). According to local residents, the swimming hole was longitudinally scoured out during the June 11, 2010, flood by several tens of feet, uncovering a large rock outcrop/boulder, and creating a large gravel and boulder bar on the downstream left bank (fig. 15 and 16). The relative stability of the spatial extent of the swimming hole through the last several decades (per anecdotal evidence) lends further evidence to the 2010 flood being the largest flood to occur, as a minimum, in the last few decades.

Measurement and documentation of the size of material moved by a flood can serve as an indicator of flow competence and velocities. As originally defined by Gilbert (1914), flow competence is an amalgam of the “controlling factors” that enable a stream to move a certain size of sediment. Many investigators (for example, Baker and Ritter, 1975; Costa, 1983; Carling and others, 2002) have utilized either physically or empirically derived relations to form a relation between the geometry of fluvial deposits moved by a flood and the flow velocity. The use of such relations to relate postflood sediment deposits to flood streamflow velocities often is referred to as flow-competence methods. Substantial complexities exist in the entrainment and movement of sediment particles from the channel bed (Garcia, 2008) involving among other things randomness of particle placement on the channel bed, availability of a large range of sediment sizes, and the interplay and variability of the hydraulic, gravitational, and lifting forces. This complexity prevents precision and accuracy in the estimates of velocity given by flow-competence methods. Because of the uncertainty of such methods, no estimates of flow velocities derived by flow-competence methods will be given in this report.

Upstream from Area D of the Albert Pike campground, two large boulders used as traffic barriers were moved more than a 100 feet from their original location as verified by U.S. Forest Service Law Enforcement (fig. 17). The intermediate axis for the larger of the two boulders was 3 ft. The hydraulics at this location would have been fairly complicated with large amounts of turbulence as the original boulder location was on the downstream left bank of the low-water bridge upstream from Area D of the Albert Pike campground. The final location of the boulder was near the roadway leading down to Area D of Albert Pike campground. Along the reach where the indirect discharge measurement was collected on Brier Creek (fig. 2*C*), field reconnaissance revealed the flood moved a large boulder with an intermediate axis of 3.8 ft (fig. 18).

Flood Annual Exceedance Probability

Humans live in a world with inherent hazards as they conduct daily activities. The simple acts of walking down the street or driving a car can result in injury or loss of life. To mitigate these inherent dangers, one assesses the risk of undertaking the activity and takes action to mitigate (or diminish) the risk. Risk is the combination of the likelihood (or probability) of an occurrence of a hazardous event and the severity of damage or injury that can be caused by that event. As such, understanding the risk requires an understanding of the probability of occurrence. For flooding, the relation between annual exceedance probability (AEP) and flood peak streamflow magnitude is estimated for use in assessing risk. The AEP is the probability, or chance, of a flood of a given streamflow magnitude being equaled or exceeded in any given year.

Flood probability can be discussed in terms of flood frequency (peak-streamflow frequency) by listing the T-year

Table 2. Summary of peak streamflow, watershed, and hydraulic properties for selected locations in the Little Missouri River watershed, Arkansas.

[USGS, U.S. Geological Survey; mi², square miles; ft, feet; ft³/s, cubic feet per second; ft², square feet; ft/mile, feet per mile; ft/s feet per second; --, no value]

Site number (fig. 2)	Site name	USGS station number	Latitude	Longitude	Contributing drainage area (mi²)	Peak stage (ft)	Peak streamflow (ft³/s)	Unit peak streamflow (ft³/s/mi²)	Cross-sectional area (ft²)	Average channel slope[1] (ft/mi)	Water-surface slope (ft/mi)	Estimated mean main channel velocity[2] (ft/s)	Estimated mean left overbank velocity[3] (ft/s)	Estimated mean right overbank velocity[4] (ft/s)
1	Little Missouri River above Long Creek near Albert Pike, Ark.	[5]07360176	N 34°23′21″	W 93°52′43″	18.2	[6]--	28,200	1,550	3,360	65	32.0	10.8	8.7	4.6
2	Long Creek near Langley, Ark.	[5]07360178	N 34°23′15″	W 93°53′40″	10.7	[6]--	13,000	1,210	1,450	58	39.9	10.1	2.6	--
3	Brier Creek near Langley, Ark.	[5]07360183	N 34°22′51″	W 93°53′51″	3.32	[6]--	6,530	1,970	726	110	60.7	9.6	6.3	--
4	Little Missouri River at Albert Pike, Ark.	[5]07360187	N 34°22′35″	W 93°52′50″	34.1	[6]--	40,100	1,180	3,650	65	29.6	11.7	9.0	--
5	Blaylock Creek near Langley, Ark.	[5]07360195	N 34°22′02″	W 93°54′21″	10.7	[6]--	14,200	1,330	1,580	77	55.6	11.4	5.4	--
6	Little Missouri River near Langley, Ark.	07360200	N 34°18′42″	W 93°53′59″	68.4	23.46	70,800	1,120	5,750	48	31.7	14.0	--	8.3

[1]Slope was computed by the authors as the elevation difference between the most upstream discernible channel thalweg and the channel thalweg at the site location divided by the distance along the channel between these points. Elevations were estimated from the digital elevation model.

[2]Average of the main channel velocites for each of the individual cross sections in the indirect discharge measurement reach.

[3]Average of the left descending overbank (floodplain) velocities for each of the individual cross sections in the indirect discharge measurement reach. No value (--) indicates a left floodplain area does not exist in this reach.

[4]Average of the right descending overbank (floodplain) velocities for each of the individual cross sections in the indirect discharge measurement reach. No value (--) indicates a right floodplain area does not exist in this reach.

[5]Ungaged location with no continuous streamgage. Site assigned a U.S. Geological Survey station identification number.

[6]No streamgage datum was established, thus, no stage is reported.

Figure 14. Remnants of the asphalt pavement in Area D of the Albert Pike campground.

recurrence interval for a particular flood quantile (for example, the “100-year flood”). Use of the T-year recurrence interval to describe flood probability is discouraged by the USGS, Federal Emergency Management Agency (FEMA), and NWS because it can serve as a source of confusion to the general public. A T-year recurrence interval sometimes is interpreted to imply that there is a definitive and exact set time interval between floods of a specific magnitude when, in fact, floods are random processes that are best understood using probabilistic terms. The use of an AEP to describe a flood is preferred because of clear communication, by the terminology, that the peak streamflow is being characterized by its probability or chance of occurrence in any given year. The reader can easily convert from the AEP to the T-year recurrence interval by simply taking the reciprocal of the AEP. For example, a 1-percent AEP flood corresponds to the streamflow magnitude that is equaled or exceed by a probability (expressed as a decimal) of 0.01 in any given year. The reciprocal of 0.01 is 100, thus the T-year recurrence interval for the 1-percent AEP flood is the 100-year flood. Equivalence of selected AEP and recurrence intervals are as follows:

AEP (percent)	Recurrence interval (years)
50	2
20	5
10	10
4	25
2	50
1	100
0.2	500

In locations where long-term streamflow data is available, AEP is determined by flood probability analysis, which involves determining the parameters needed to estimate a probability distribution from a set of observed peak streamflow data. The probability distribution relates probability to the magnitude of a certain sized flood being equaled or exceeded. For consistency, Federal agencies that estimate flood frequencies follow standard guidelines, known as Bulletin 17B (Interagency Advisory Committee on Water Data,

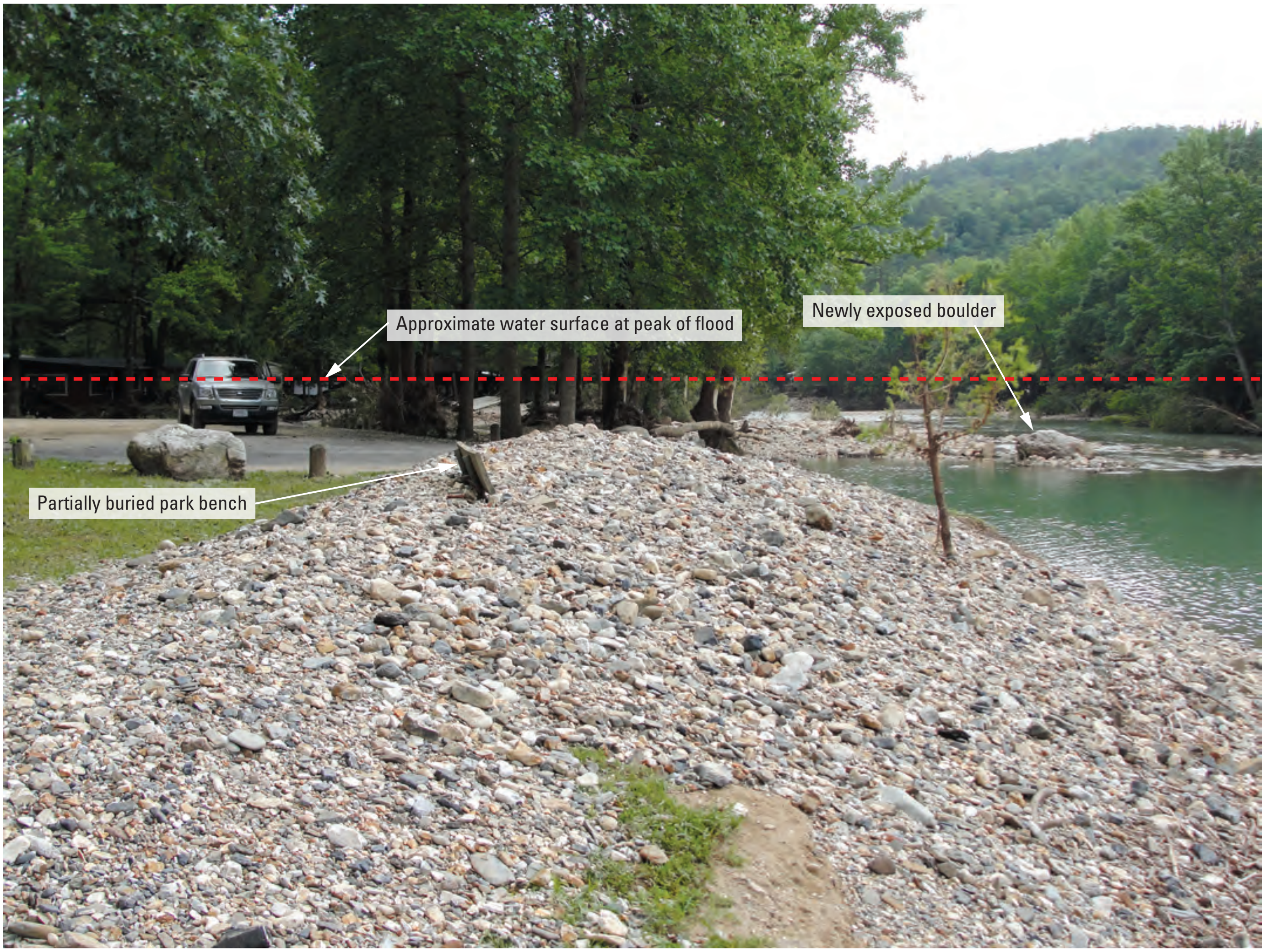


Figure 15. Downstream view of the left descending bank of the Little Missouri River along the swimming hole.

Figure 16. Panoramic view of the swimming hole on the Little Missouri River adjacent to Area A of the Albert Pike campground. Photograph taken from downstream looking upstream.

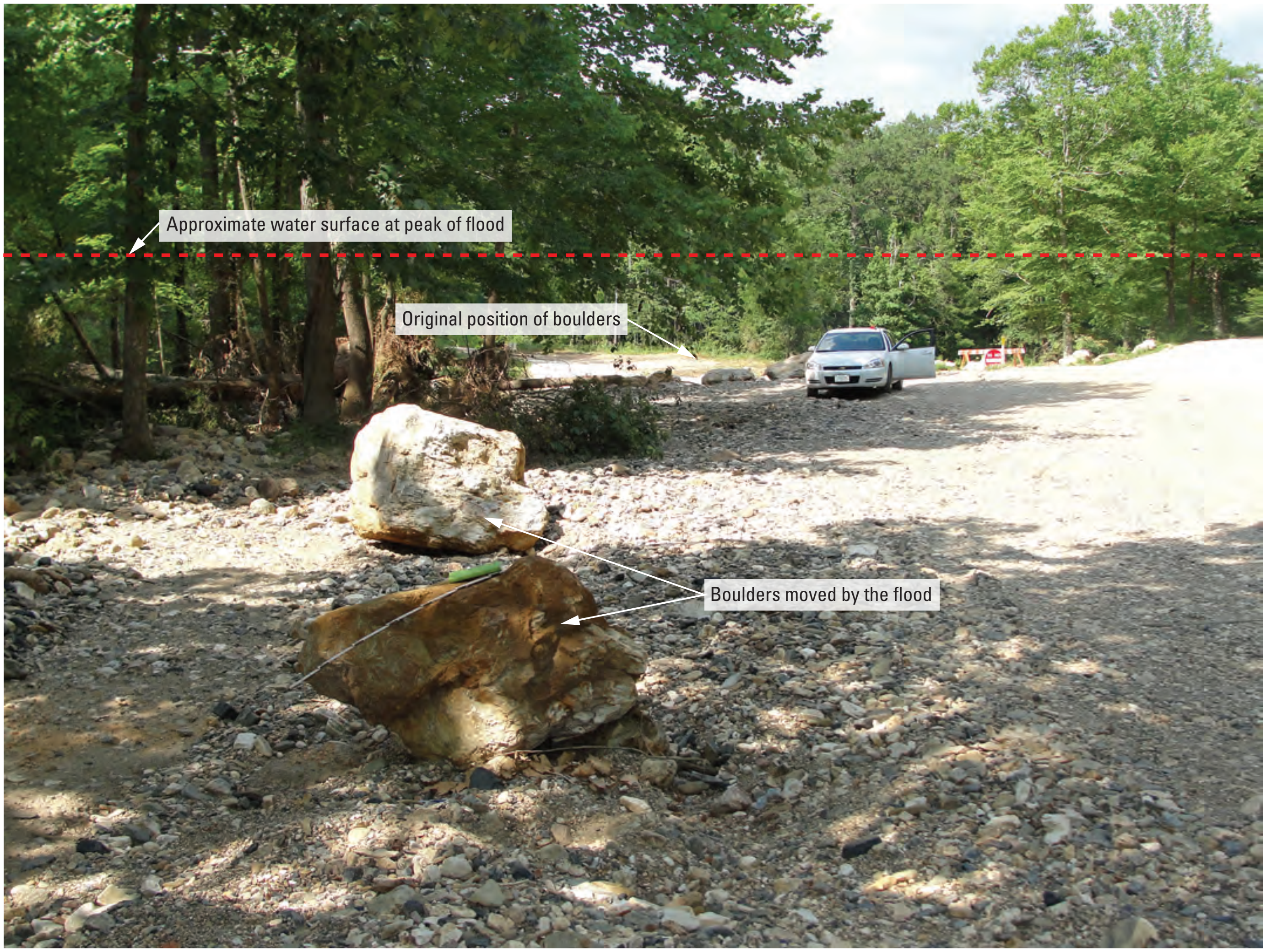


Figure 17. Boulders moved by the Little Missouri River during the June 11, 2010 flood. Photograph taken on left floodplain looking upstream along the Little Missouri River approximately 900 feet upstream from Area D of the Albert Pike Campground and immediately downstream from a low-water bridge over the Little Missouri River.

Figure 18. Boulder moved by Brier Creek during the June 11, 2010, flood. Photograph taken in the middle of the channel.

1982), which recommend the use of the log-Pearson type III (LPIII) distribution and the "method of moments" for estimating the distribution parameters (mean, standard deviation, and skewness of the data). The analysis is based on annual peak streamflow data.

Besides estimating AEP flood quantiles by Bulletin 17B methods, another way to obtain an AEP flood quantile estimate is by using regional regression equations (RRE). RRE are developed by using regression techniques that relate the flood-probability data at many streamgages in a particular region to the watershed characteristics of the streams being monitored by the streamgages (Jennings and others, 1994). For any location along a stream (gaged or ungaged), a user can enter the watershed characteristics (drainage area, watershed slope, and so on) as independent variables into the equations and compute various streamflow characteristics, such as the 1-percent AEP flood quantile.

For this report, the RRE were not used because the mean basin elevations, one of the watershed characteristics used in the RRE for this region of Arkansas (Hodge and Tasker, 1995), of the Langley streamgage and five ungaged sites of interest were all greater than the mean basin elevations used to develop the RRE by Hodge and Tasker. For the upper Little Missouri River watershed, only the Langley streamgage had long-term peak streamflow data available to estimate the AEP flood quantiles by Bulletin 17B methods, with no AEP flood quantiles being estimated for the five ungaged locations in the Little Missouri.

The Bulletin 17B analysis for the Langley streamgage utilized the weighted skew method, with a generalized skew of -0.3 used to weight the station skew (from the systematic record) of 1.46. The historic adjustment option was used as the 2010 flood peak at Langley was determined to be the largest peak streamflow since 1968. The Bulletin 17B fit of the data to the log-Pearson type III probability distribution shows the poor fit of the highest peak, which corresponds to the June 11, 2010 flood (fig. 19) . The June 11, 2010, peak streamflow at Langley is estimated to have an AEP of less than 1 percent. Given the uncertainty in the Bulletin 17B analysis, no specific value for the peak streamflow is given, simply a range, which in this case is stated as less than 1-percent AEP. Table 3 shows the 95-percent confidence limits for the 2-percent, 1-percent, and 0.2-percent flood quantile.

The Aftermath

The flood on the Little Missouri River and tributaries lasted less than 7 hours, but the impact to life and property during those hours was tremendous. The June 11, 2010 flood killed twenty people and caused substantial property damage.

Rescue efforts by local residents and campers began during the actual flood and continued for several hours involving law enforcement and other emergency services personnel. Some people survived by clinging to trees or scrambling up

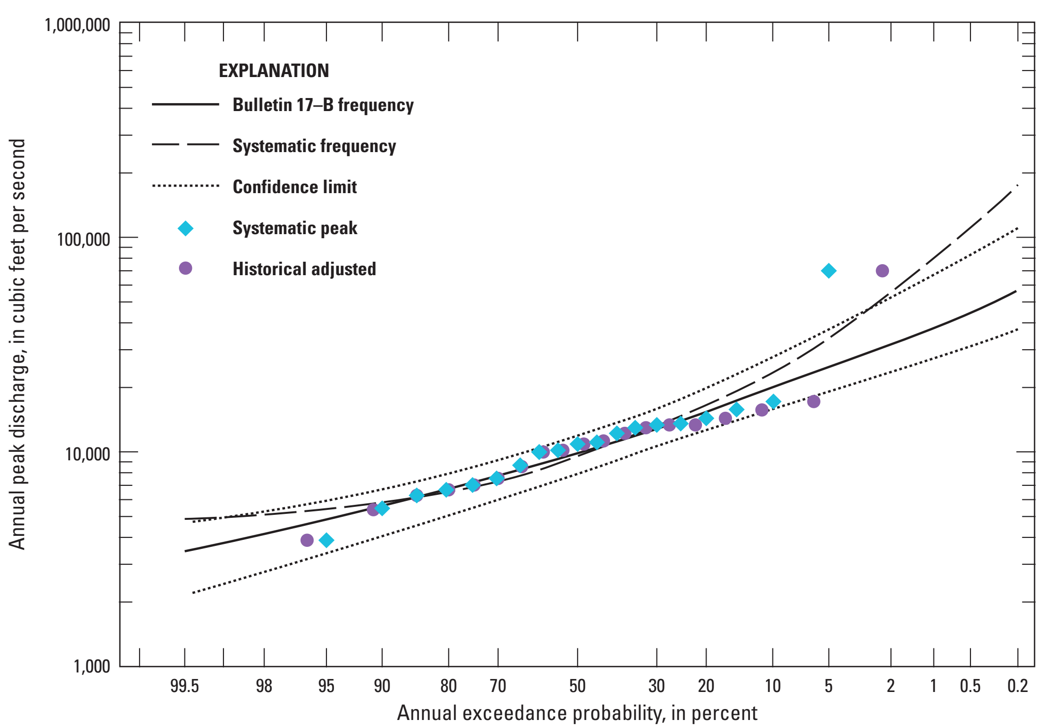


Figure 19. Little Missouri River near Langley, Arkansas (U.S. Geological Survey streamgage 07360200) data fit to the log-Pearson type III probability distribution for flood probability.

Table 3. Flood probability estimates for the Little Missouri River near Langley, Arkansas (U.S. Geological Survey streamgage 07360200).

[mi^2, square miles; ft, feet; ft^3/s, cubic feet per second; AEP, annual exceedance probability; <, less than]

Site number (fig. 2)	Contributing drainage area (mi^2)	Peak stage (ft)	Peak streamflow (ft^3/s)	Estimated AEP for observed peak streamflow (percent)	Expected peak streamflows for selected AEP with 95-percent confidence limits								
					2-percent AEP (50-year recurrence)	Confidence limit		1-percent AEP (100-year recurrence)	Confidence limit		0.2-percent AEP (500-year recurrence)	Confidence limits	
						Low	High		Low	High		Low	High
6	68.4	23.46	70,800	<1.0	31,700	23,500	51,500	38,100	27,300	65,700	56,000	37,400	111,000

Figure 20. Views of destroyed automobiles, recreational vehicles, and structures.

the steep hillsides bounding the floodplains until the water receded. A massive search after the flood, involving search and rescue teams from multiple states, recovered the bodies of those missing, with the last body found on Monday, June 14, 2010, three days after the flood. All the flood fatalities were campers, with most of the flood fatalities being people who were camped in recreational vehicles parked in Area D of the Albert Pike campground.

The Albert Pike campground experienced substantial damage with roads and campsites destroyed and buildings damaged. The lead author observed at least 25 destroyed or damaged cars and trucks and at least 20 recreational vehicles (fig. 20) destroyed or damaged along the reach of the Little Missouri River stretching from above the inflow to Long Creek to below Camp Albert Pike (fig. 2). Along both sides of the Little Missouri River, the lead author observed at least 20 privately owned cabins downstream from Albert Pike campground were destroyed or severely damaged (fig. 21). Although no total damage estimate is available, from the number of observed vehicles, recreational vehicles, recreation area damage, and cabins destroyed, property damage was susbstantial.

Figure 21. Views of damaged or destroyed cabins. Hydrologist pointing to high-water mark left from the June 11, 2011 flood.

Comparison with Other Floods

Placing a flood in context with other floods, in the same watershed and in similarly sized watersheds is important. The June 11, 2010, flood is placed in context first with past floods in the upper Little Missouri River, next with floods in other watersheds—starting with the Caddo River, which is close to the Little Missouri River watershed in Arkansas—and finally with floods nationally.

Floods in the Upper Little Missouri River

Collection of continuous streamflow data at the Langley streamgage (fig. 1) began in October 1997. Before that date, peak streamflow data were collected at the site since 1988. The ten highest peak stages and their associated streamflows and maximum rates of rise for the Langley streamgage since streamflow data collection began in 1988 are shown in table 4. The maximum rate of rise reported in table 4 is the greatest 15-minute change of stage and is reported in feet per 15 minutes (ft/15). The June 11, 2010, rate of rise, 2.76 ft in 15 minutes, is the greatest rate of rise measured since October 1997, when the continuous monitoring began at the streamgage, which is nearly twice the next highest maximum rate of rise measured. During each of the nine 15-minute intervals between 2:15 AM and 4:30 AM on June 11, 2010, the stage at the gage rose 1.18 ft or more, and rose more than 2.00 ft during three of the nine 15-minute intervals (fig. 13).

Major floods in the upper Little Missouri River watershed for which some data are available to enable comparison with the 2010 flood are the March 30, 1945, and the May 13, 1968,

Table 4. Ten highest peak stages, streamflow, and associated maximum rates of rise at the Little Missouri River near Langley, Arkansas (U.S. Geological Survey streamgage 07360200), 1988 to 2010 (Note: Continuous streamflow record is only available from 1998 to 2010).

[ft, feet; ft^3/s, cubic feet per second; ft/15 minutes, 15-minute change of stage, in feet; --, no value]

Date	Peak stage, ft gage datum	Peak streamflow, ft^3/s	Maximum rate of rise, ft/15 minutes
6/11/2010	23.46	70,800	2.76
5/6/2009	15.49	17,400	1.29
8/11/2008	14.66	15,600	1.33
3/8/1990	14.00	14,200	[1]--
9/14/2008	13.93	14,000	1.02
9/17/2009	13.23	12,600	.58
11/18/2003	13.21	13,400	1.38
12/3/1993	13.21	13,400	[1]--
2/16/2001	13.05	13,000	[2]--
5/28/2001	12.92	12,800	1.45

[1]Station operated as peak-only streamgage during this period.

[2]Float hung up in stilling well before peak stage, rate unknown.

flood events. The March 30, 1945, flood occurred before construction of Narrows Dam in 1950 and the subsequent impoundment of Lake Greeson (fig. 1). Approximately 11 mi downstream from the Narrows Dam, streamflow data has been collected for the Little Missouri River near Murfreesboro, Arkansas (USGS streamgage 07361000) from 1928 to present (2011). The USGS operated the streamgage from 1928 to 1949 and the U.S. Army Corps of Engineers has been operating the streamgage from 1949 to 2011. The peak streamflow for March 30, 1945, was 120,000 ft^3/s. The corresponding peak stage of 19.84 ft was 1.16 ft less than the peak stage that occurred on April 15, 1927, which was determined from high-water marks surveyed to the same gage datum as the current (2011) streamgage. No peak streamflow value for the April 27, 1927, flood is available as that was before the commencement of the operation of the streamgage at that location (Hodge and Tasker, 1995).

The completion of the Narrows Dam in 1950 complicates the hydrology of the Little Missouri River watershed, preventing use of post-1950 peak streamflows at the Little Missouri River near Murfreesboro, Arkansas for inferences of the upstream watershed flood hydrology because of Lake Greeson storage effects. As such, the combination of Lake Greeson storage rates and outflow at the Narrows Dam are combined to estimate the total inflow into Lake Greeson. During the May 1968 flood, water flowed over the spillway at Narrows Dam for the first time since its completion in 1950. The peak stage of Lake Greeson at Narrows Dam during the flood was 564.6 ft. The computed maximum hourly inflow to Lake Greeson on May 13, 1968, was 97,000 ft^3/s. Although no lives were reported lost during the flood, property damage in the region was estimated at $18 million (Gilstrap, 1970). Janice McRae, a longtime resident of the area near Albert Pike, recalled that in May 1968, the rain began early in the month and continued daily until the flood on May 13, a day in which she recalls the rain was particularly intense. Official rainfall totals for the 1968 rainstorm ranged from 3.4 to 7.9 inches for the period of May 7–12, with an additional 8 to 10 inches reported on May 13 (Gilstrap, 1970).

For the June 11, 2010, flood, an average 1-hour maximum inflow rate estimated at 64,000 ft^3/s into Lake Greeson was computed using hourly lake stage reports, a stage-storage relation for Lake Greeson, and the outflow through Narrows Dam (U.S. Army Corps of Engineers, Vicksburg District, written commun., October 2010). The peak inflow rate of 64,000 ft^3/s for the June 11,2010 flood allows for comparison with the 1968 peak estimated 1-hour inflow into Lake Greeson of 97,000 ft^3/s, which the authors assume was computed similarly to how the June 11, 2010, peak 1-hour inflow was estimated.

Comparison of the May 13, 1968, and June 11, 2010, peak streamflow magnitudes in the vicinity of Albert Pike (approximately 24 mi. upstream from Lake Greeson) was made possible through discussions with Ms. Janice McRae. Ms. McRae noted that the Camp Albert Pike cabin she now owns was built by her father to a floor elevation that was 1 ft above the May 13, 1968, flood peak stage. A survey of the cross-section geometry and elevation of the cabin floor elevation was conducted. The June 11, 2010, flood left high water marks approximately 0.5 ft higher than the cabin floor elevation.

The Manning's uniform flow equation (Chow, 1959) is

$$Q = {}^{1.49}\!/_{n}\, AR^{2/3} S^{1/2} \qquad (1)$$

where

- n is Manning's roughness,
- A is the cross-section area,
- R is the hydraulic radius, which is the cross-sectional area (A) divided by the wetted perimeter (P), and
- S is the slope of the water surface.

Knowing the measured peak streamflow for the June 11, 2010, flood, a water slope for the June 11, 2010, flood in the Camp Albert Pike reach was back-computed using the computed cross-sectional area, channel roughness, and wetted perimeter. The wetted perimeter is the portion of the perimeter of a stream channel cross section which is in contact with the water. Assuming the channel on May 13, 1968, had approximately the same geometry and roughness as in 2010, using the estimated May 13, 1968, high-water mark, the channel cross-sectional area, wetted perimeter, and current channel roughness was used with the 2010 water slope to estimate

31,000 ft^3/s for the May 13, 1968, peak streamflow using Manning's uniform flow equation (eq. 1). The estimate of 31,000 ft^3/s could have significant error (greater than 25 percent) because of (1) uncertainty in the true elevation of the peak high water for the May 13, 1968 flood event, (2) an assumption that the cross-sectional geometry and boundary roughness in 2010 is representative of the cross section in 1968, and (3) the approximation that the water-surface slope in the May 13, 1968, flood was equal to the water-surface slope computed for the June 11, 2010, flood event.

Assuming the estimate of the May 13, 1968, peak streamflow at Albert Pike is reasonable, the June 11, 2010, peak streamflow at Albert Pike is 9,100 ft^3/s (29 percent) higher than the May 1968 peak streamflow. Contrasting that difference at Albert Pike with the estimated hourly peak streamflow of the Little Missouri flowing into Lake Greeson, where the June 11, 2010, estimated hourly peak streamflow was 33,000 ft^3/s (34 percent) less than the May 13, 1968, hourly peak streamflow. The opposite differences in peak streamflow magnitudes for the two events in the two locations indicates that the May 13, 1968, event had a wider distribution of rainfall over the upper Little Missouri River watershed compared to the June 11, 2010, flood event, further demonstrating the localized nature of the June 11, 2010, event.

Floods in Other Watersheds

2010 Flood on the Caddo River

The Caddo River watershed is located to the north and east of the Little Missouri River watershed (fig. 2). The river's headwaters, located adjacent to the headwaters of the Little Missouri River, also experienced intense thunderstorms and major flooding in the early hours of June 11, 2010. At Caddo River near Caddo Gap, Arkansas (USGS streamgage 07359610) (Caddo Gap), the watershed (132 mi^2), is much larger than the watershed of the Little Missouri River at the USGS streamgage at Langley (68 mi^2). At Caddo Gap, the Caddo River also has a lower average stream-channel gradient (30 ft/mi), than the upper Little Missouri River upstream from the Langley streamgage (48 ft/mi). On June 11, 2010, Caddo Gap reached a stage of 25.39 ft and peak streamflow of 59,000 ft^3/s (fig. 22), a stage that had not been experienced since December 1993. The peak streamflow of 59,000 ft^3/s corresponded with an AEP of between 4-percent and 2-percent as determined by flood probability analysis following Bulletin 17B guidelines.

Floods Nationally

For watersheds up to a certain size (certainly those less than 10,000 mi^2) in much of the United States , the magnitude of peak streamflow at a particular location is strongly correlated with the size of the watershed. As has been mentioned already, efforts to characterize and assess the potential for flooding often are done through flood probability analysis and estimation of the AEP. Another means to characterize the magnitude of flooding is to construct envelope curves or relations for hydrologically similar regions based on the maximum observed peak streamflows for various watershed drainage areas in that region. One such study is that of Crippen and Bue (1977), whereby a series of envelope curves were developed for various regions of the United States. The envelope curves shown in figure 23 are the Crippen and Bue (1977) envelope curve for the United States, and the envelope curve for the region of the United States (Crippen and Bue Region 8) that contains the Little Missouri River watershed. The points on figure 23 show the peak streamflow values for the six locations in the upper Little Missouri River watershed where peak streamflow was determined for this report (table 2 and fig 2). The peak streamflows for this flood are at or near the envelope curve for this region, indicating that the 2010 flood is large in magnitude compared with all the floods observed in this region of the United States.

For a nationwide perspective on the magnitude of the 2010 upper Little Missouri River watershed flood, the peak streamflows are plotted along with the Crippen and Bue (1977) envelope curve for the entire United States and the largest peak streamflow for each of 7,768 active (as of 2010) USGS streamgages in the United States (fig. 24). Although not the highest peak streamflows for their size of watershed, the June 11, 2010, peak streamflows on the upper Little Missouri River plot toward the extreme limit of the peak streamflows as compared with most of the peaks of the active USGS streamgages. To add additional perspective, the peak streamflows, which Costa and Jarrett (2008) identified as those large

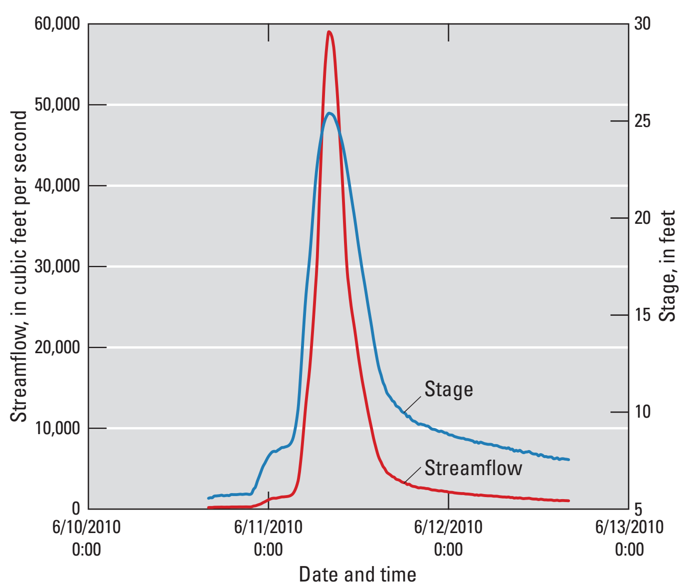


Figure 22. Stage and streamflow hydrograph for the Caddo River near Caddo Gap, Arkansas (U.S. Geological Survey streamgage 07359610) from 16:00 hours on June 10, 2010, to 16:00 hours on June 12, 2010.

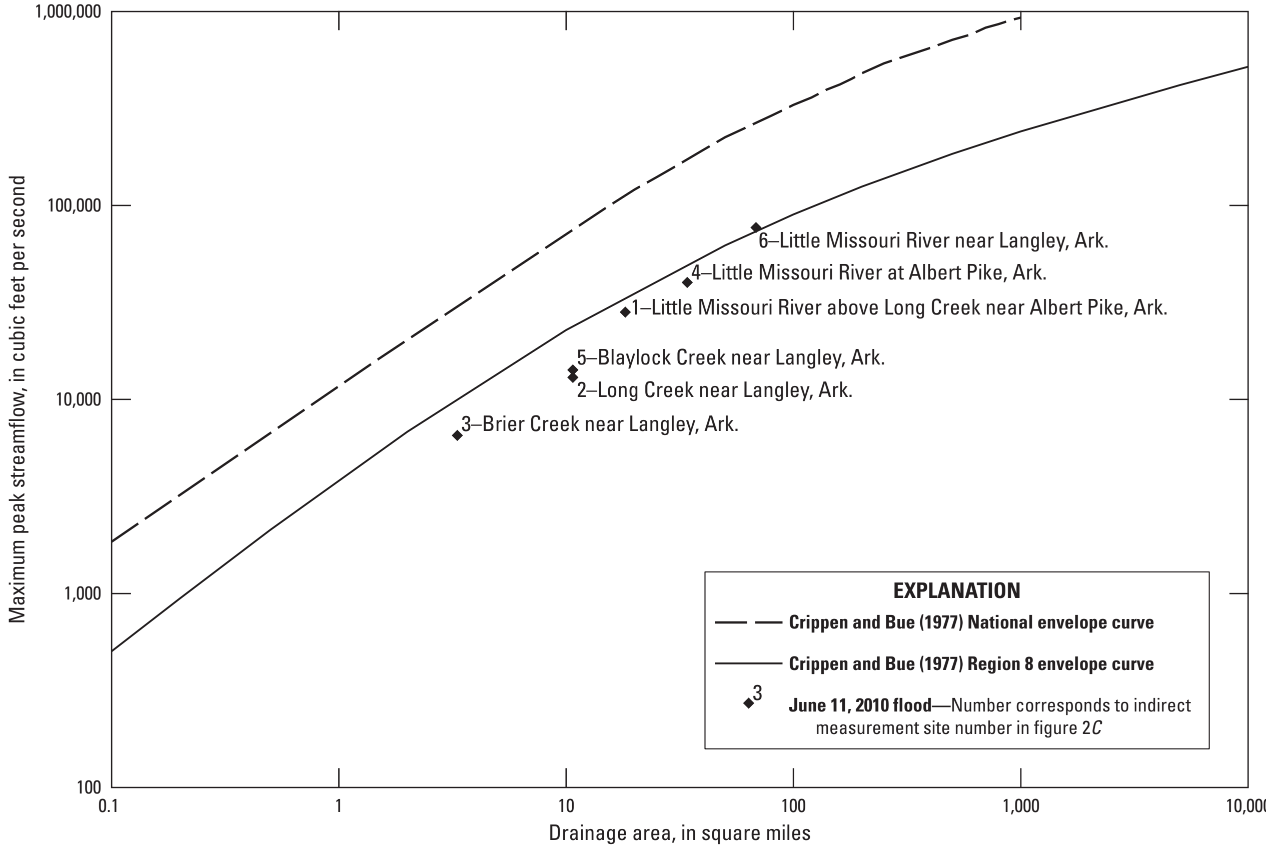


Figure 23. Peak streamflow versus drainage area for the six Little Missouri River watershed indirect measurement sites where peak streamflow was computed, and Crippen and Bue (1977) envelope curve for the United States and for Crippen and Bue Region 8 which encompasses the Little Missouri River watershed.

floods that define the envelope of rainfall-runoff flooding in the United States, also are plotted on figure 24, as are the peak streamflow for three tragic floods in the United States that saw a large number of fatalities. These floods include: the 1972 Black Hills-Rapid City, South Dakota flood (238 killed, Schwarz and others, 1975; Carter and others, 2002), the 1976 Big Thompson River, Colorado floods (144 killed, Jarrett and Costa, 2006; McCain and others, 1979), and the 1977 Kansas City, Missouri flood (25 killed, Hauth and Carswell, 1978).

Summary

The June 11, 2010, flood on the Little Missouri River, Arkansas was a localized extreme flash flood that took 20 lives and resulted in substantial property damage. The peak streamflow for the Little Missouri River near Langley, Arkansas had an annual exceedance probability of less than 1-percent. The Little Missouri River is located in the Ouachita Mountain Region of southwest Arkansas, an area long recognized for its extreme flood potential because of the great potential for large magnitude, intense rainstorms; thin soils with limited storage capacity; steep watershed gradients that promote rapid runoff; and a trellis drainage pattern, which can cause high synchronicity of tributary flow delivery to the downstream locations. Orographic effects from the Ouchita mountains also may play a role in the extreme rainfall of this region.

The catastrophic flooding was caused by more than 5 inches of rain falling in a little under 6 hours on the Little Missouri River watershed upstream from Langley, Arkansas. Peak streamflows and other hydraulic properties were determined at five ungaged locations and one gaged location in the upper Little Missouri River watershed. In the reach of the Little Missouri River at Albert Pike Recreation Area, the peak streamflow was 40,100 ft^3/s with average water depths through the floodplain of 7 feet flowing at velocities potentially as great as 11 ft/s. Peak streamflow 9.1 miles downstream on the Little Missouri at the U.S. Geological Survey streamgage near Langley, Arkansas was 70,800 ft^3/s, which corresponds to an estimated annual exceedance probability of less than 1 percent. For comparatively sized drainage areas, the June 11, 2010, flood on the upper Little Missouri River and its major tributaries experienced peak streamflows that are among the largest in their region of the country and across the United States.

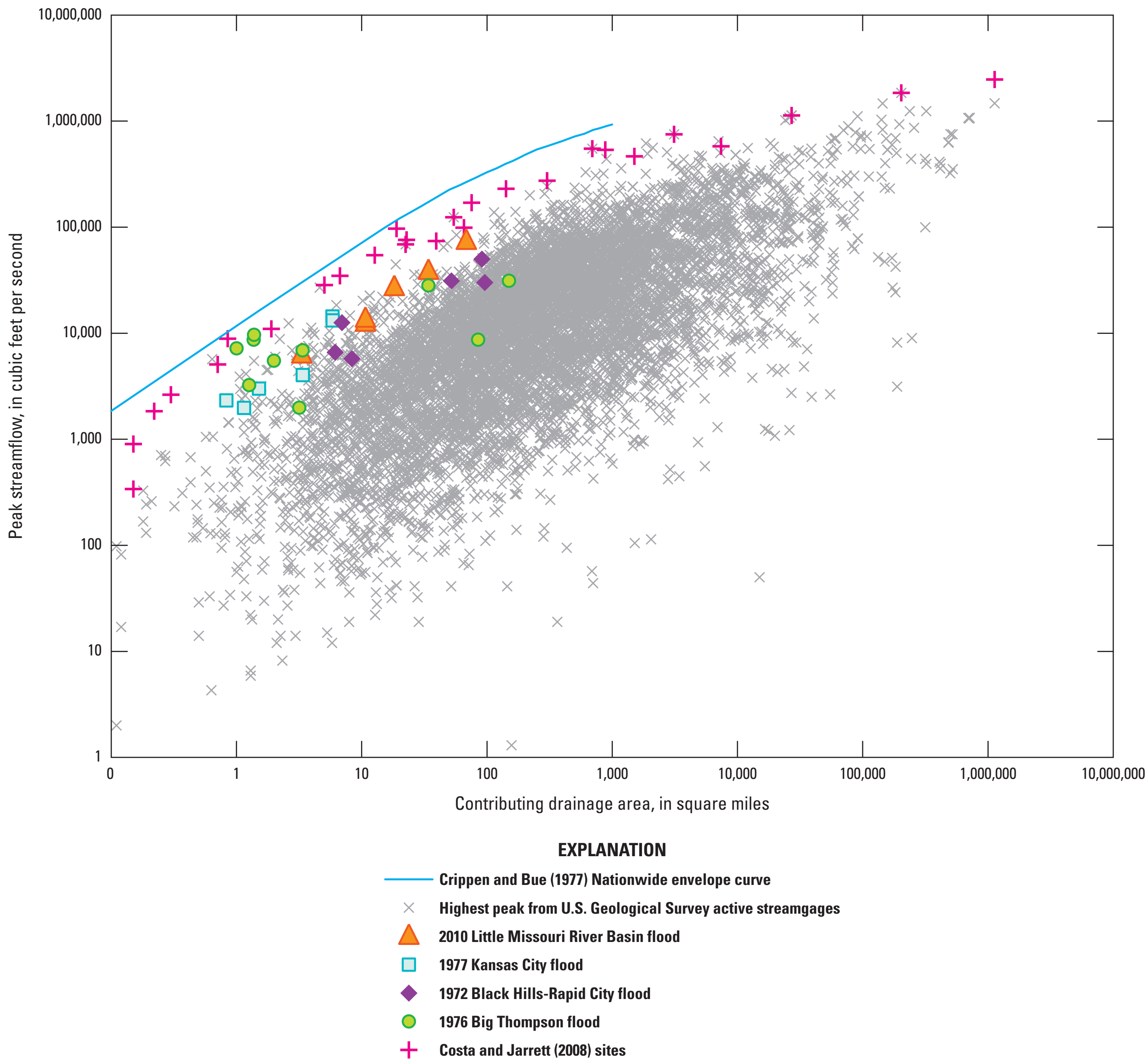


Figure 24. Peak streamflow versus contributing drainage area for the largest peak streamflow at all active U.S. Geological Survey streamgages, the peak streamflows measured in the Little Missouri River basin for the June 11, 2010, flood, and for selected flash floods in the United States.

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