Prepared in cooperation with the National Park Service

Alluvial Bars of the Obed Wild and Scenic River, Tennessee

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The river gorges of the Cumberland Plateau are notable for their biological diversity. The upland surface of the Plateau, sandstone cliffs, forested hillslopes, and whitewater river channels provide diverse habitats that support a wide variety of plants and animals, including many listed as rare, threatened, or endangered (RTE) by State or Federal government agencies (Schmalzer and others, 1985; Rouse, 1986; Schmalzer, 1989; Bailey and Coe, 2001). Protecting these diverse habitats is an important justification for the establishment of the Obed Wild and Scenic River (Obed WSR; fig. 1) and other National and State parks in Tennessee and nearby States. Seasonally flooded alluvial bars—discrete deposits of river sediment—are among the richest habitats for RTE plants in the Obed River and other Plateau gorges.

The Obed Wild and Scenic River offers visitors a variety of outdoor recreational activities.

It is hereby declared to be the policy of the United States that certain selected rivers of the Nation which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values, shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations. The Congress declares that the established national policy of dams and other construction at appropriate sections of the rivers of the United States needs to be complemented by a policy that would preserve other selected rivers or sections thereof in their free-flowing condition to protect the water quality of such rivers and to fulfill other vital national conservation purposes.

—Wild & Scenic Rivers Act, October 2, 1968

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Alluvial bars make up only a small part of the land surface in the Plateau gorges, but they support a disproportionately large number of RTE plants. For example, Schmalzer and others (1985) reported 9 of 16 (56 percent) RTE plant species growing in the Obed WSR on alluvial bars. Bailey and Coe (2001) reported that six of eight RTE plant species (75 percent) found along the Clear Fork and New River branches of the Big South Fork of the Cumberland River in Tennessee grow exclusively on alluvial bars. Despite the importance of alluvial bars as plant habitat, few scientific studies have focused on their geographic and physical characteristics or the role of hydrology in forming and maintaining these features in the Obed WSR and other Cumberland Plateau gorges.

Introduction

In 2004, the U.S. Geological Survey (USGS) and the National Park Service (NPS) initiated a reconnaissance study of alluvial bars along the Obed WSR, in Cumberland and Morgan Counties, Tennessee (fig. 1). The study was partly driven by concern that trapping of sand by upstream impoundments might threaten RTE plant habitat by reducing the supply of sediment to the alluvial bars. The objectives of the study were to: (1) develop a preliminary understanding of the distribution, morphology, composition, stability, and vegetation structure of alluvial bars along the Obed WSR, and (2) determine whether evidence of human alteration of sediment dynamics in the Obed WSR warrants further, more detailed examination.

This report presents the results of the reconnaissance study of alluvial bars along the Obed River, Clear Creek, and Daddys Creek in the Obed WSR (fig. 1). The report is based on: (1) field-reconnaissance visits by boat to 56 alluvial bars along selected reaches of the Obed River and Clear Creek; (2) analysis of aerial photographs, topographic and geologic maps, and other geographic data to assess the distribution of alluvial bars in the Obed WSR; (3) surveys of topography, surface particle size, vegetation structure, and ground cover on three selected alluvial bars; and (4) analysis of hydrologic records.

Aerial view of Clear Creek. (Photograph courtesy of the National Park Service.)

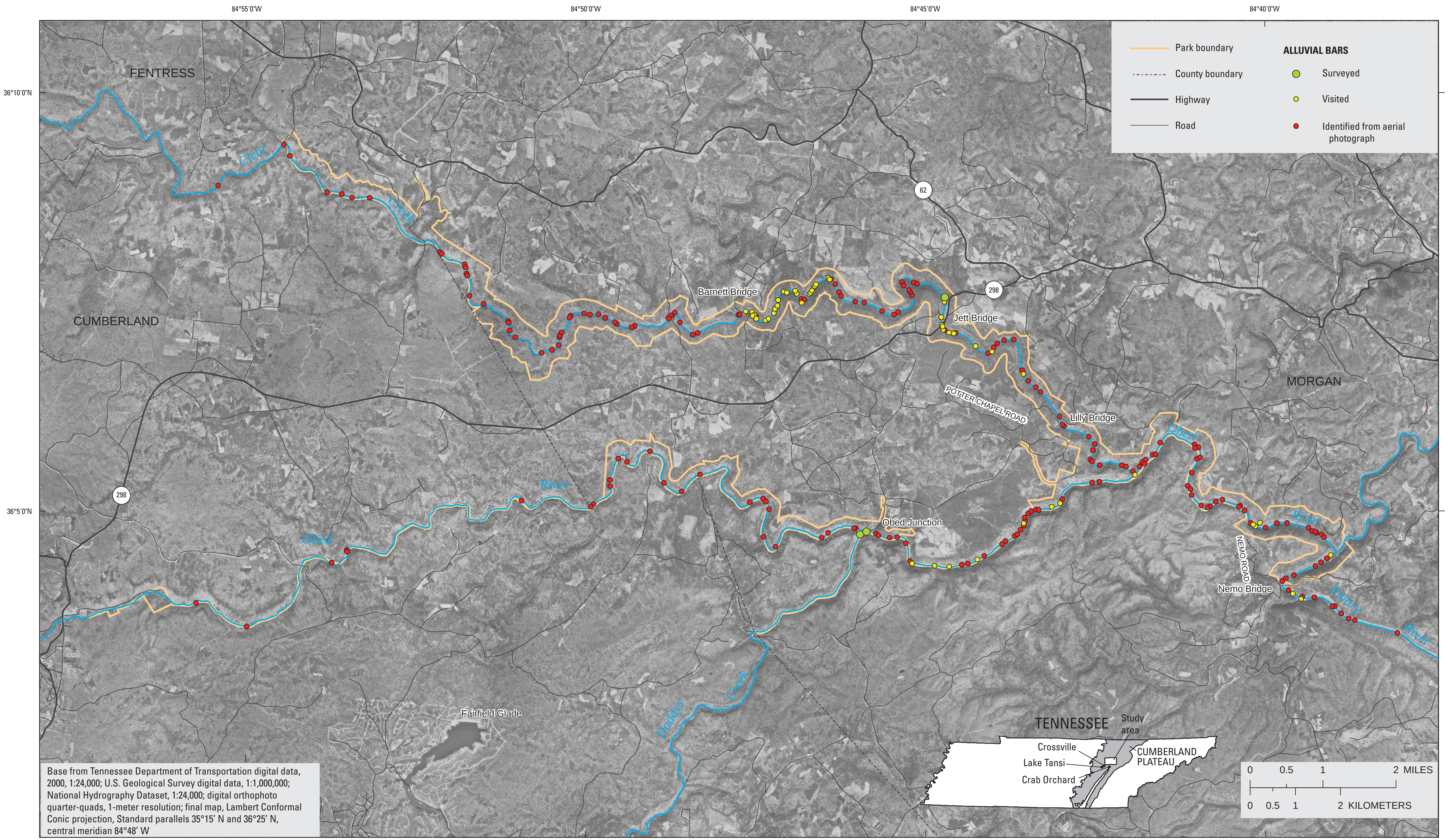

Figure 1. The Obed Wild and Scenic River and locations of alluvial bars along the Obed River and Clear Creek that were identified from aerial photographs or visited by boat. [Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).]

What is an alluvial bar?

Alluvial bars are discrete (not continuous along the length of the channel) deposits of stream sediment (alluvium). Alluvial bars are commonly classified by composition, which can vary from clay to large boulders. Some alluvial bars appear, disappear, or shift position with every flood. Others were formed during extreme floods thousands of years ago and have changed little since. Alluvial bars can be rarely or frequently inundated or permanently underwater. They can be devoid of vegetation or heavily vegetated.

The alluvial bars described in this report are seasonally flooded, vegetated *boulder bars*—composed largely of rock particles at least 10.08 inches, or 256 millimeters, in diameter (boulders). Boulders make up the structural framework of these alluvial bars and cover much of their surface area (fig. 2). Smaller cobbles (2.52–10.08 inches or 64–256 millimeters in diameter) are common on most of these bars. Typically, the spaces between the boulders and cobbles are filled with sandy alluvium. Surface deposits of sand and silt are common.

Information on the geometry of alluvial bars in the Obed WSR is limited. The three alluvial bars that were surveyed during this study ranged from 190 to 330 feet (58 to 100 meters) in length and from 105 to 150 feet (32 to 46 meters) in maximum width. The tops of the surveyed alluvial bars were 3 to 5 feet higher than the summer base-flow water surface.

How do alluvial bars form?

The boulders that dominate the composition of alluvial bars in the Obed WSR originate in the sandstone cliffs of the gorge walls. Sandstone blocks, periodically dislodged from the cliffs, may fall or roll to the bottom of the gorge (mass movement) (Remo, 1999), or they may be transported by debris flows down steep tributaries to the main channel (Moore, 1999). These processes supply enough boulders to the Obed River and other streams within the Obed WSR to provide the dominant bed material (fig. 3).

Boulder bars indicate hydraulic forces in the Obed River and its major tributaries sufficient to transport and deposit boulders. Determining what hydrologic conditions produce such forces and how frequently these conditions occur is problematic. The shapes and arrangement of boulders and other particles in the channel complicate the movement of coarse sediment. Rounded boulders need less energy to move than flat ones; isolated boulders are easier to move than those wedged together; boulders resting on a smooth channel bed move more readily than those on a rough bed. The relation between streamflow and boulder movement is further complicated by local variations in channel slope, water velocity, bed roughness, and similar factors.

In general, these complicating factors raise the water depth and velocity needed to move a given particle above theoretical or empirical thresholds based on simplifying assumptions about channel geometry, interactions between boulders, energy gradients, and turbulence (Williams, 1983; Komar and Li, 1986; Wohl, 1992). Despite their limitations, such thresholds provide a useful starting point for considering the hydrologic conditions that produced the alluvial bars of the Obed WSR. Williams (1983) derived a set of empirical thresholds of water velocity, channel-bed shear stress, and stream power needed to initiate movement of boulders and cobbles, based on a review of published studies. Williams' lower thresholds are not explicitly linked to boulder shape, orientation, or bed characteristics, but probably apply to the most easily moved boulders.

Applying Williams' (1983) lower boulder-movement thresholds to streamflow records suggests that minimum conditions to move 3-foot boulders along the channel beds are common in the Obed WSR. For the Obed River near Lancing, discharge was related to channel-bed shear stress using two assumed channel slopes: 0.0045, based on the Lancing topographic quadrangle (U.S. Geological Survey, 1967), and 0.003, based on an indirect measurement of the

Figure 2. Photograph of the interior of a typical alluvial bar in the Obed Wild and Scenic River showing the central clearing, imbricated (leaning against each other with diagonal surfaces upstream) boulders, and forest vegetation near the boundary between the bar and the non-alluvial streambank.

Figure 3. Boulders are the dominant bed material of streams in the Obed Wild and Scenic River.

May 27, 1973, flood (Charles Gamble, retired, U.S. Geological Survey, written commun., 1973). Depending on which assumed slope is used, the estimated minimum flow needed to move a 3-foot boulder at the bottom of the channel is between 14,000 and 32,000 cubic feet per second (ft^3/s), with a recurrence interval of 1 or 2 years near Lancing (fig. 5).

Given frequent transport of large boulders in the channel, the most plausible mechanism for the formation of boulder bars is through the accretion of boulders in relatively stable locations. Alluvial bars form in places where sediment-laden flow loses power. In boulder-bed rivers, such locations commonly include major confluences, eddies or deflections of flow caused by large non-alluvial boulders (fig. 4) or other obstructions, and bends in the channel. Alluvial bars form as boulders accumulate in these low-energy locations. Each new depositional event raises the surface of the bar, increasing the energy needed to bring subsequent boulders onto the new higher bar surface or to transport those already in place. Because the bars are located in relatively low-energy locations within powerful, boulder-rich channels, flows capable of transporting boulders across bar surfaces are likely to deposit more material than they remove.

Boulders transported by high-energy flow to locations of lower energy arrive as individual particles, but they form an ordered structure as they settle. Boulders at the surface of alluvial bars in the Obed WSR typically are imbricated—lain slantwise on each other, like shingles, with the downstream end higher than the upstream end (fig. 2). The imbricated arrangement of boulders on the alluvial bars is field evidence for deposition by flowing water and contributes to the stability of the bar surfaces through the mutual armoring and slanted upstream surfaces of the imbricated boulders.

Figure 4. Non-alluvial boulders are too large to be moved by observed river flows. These large boulders strongly influence river morphology, including the location of the alluvial bars, rapids, and pools.

How stable are the alluvial bars in the Obed WSR?

Evidence from published topographic maps and aerial photographs suggests that the locations and footprints of seasonally flooded alluvial bars in the Obed WSR are stable under current climatic conditions. The flood of May 27, 1973, with a peak flow for the Obed River near Lancing of about 105,000 ft^3/s (fig. 5) and a recurrence interval of about 500 years, provides an opportunity to examine the effects of severe flooding on alluvial bars and channel geometry in general. Comparison of a pre-flood topographic map (U.S. Geological Survey, 1967) of the river channel near Nemo Bridge with a 1985 aerial photograph provided from the Tennessee Valley Authority (TVA) (fig. 6) shows little apparent change in the location and shape of major channel features, including numerous alluvial bars. Bars near the mouths of Clear Creek and Daddys Creek show similar stability.

Stable locations and footprints do not necessarily mean that the bar surfaces are stable. On the contrary, the alluvial bars of the Obed WSR are "low energy" relative only to large rapids, cascades, hydraulic holes, and other sites of violently powerful flood flow. The surfaces of alluvial bars are high-energy settings when compared to most permanently vegetated habitats. Based on the deformation of a living maple tree on one alluvial bar, at least one large (greater than 3 feet) boulder was observed that had shifted position. Movement of smaller boulders across the surface of many bars may be relatively commonplace. Several of the visited bars had accumulations of large woody debris, including tree trunks with diameters of 2 feet or greater, that had been swept across the bar surface before coming to rest.

Field observations and stream-gage records suggest that alluvial bars in the Obed WSR are flooded at intervals of years rather than decades. Flood debris, in the form of dead plant material, was observed in trees and shrubs several feet above the surface of several bars visited in spring and summer of 2004 (fig. 7). The largest floods that could have deposited the debris occurred in February and March 2004. The flood of February 6, 2004, had peak discharges of 41,700 and 16,900 ft^3/s for the Obed River near Lancing and for Clear Creek at Lilly Bridge, respectively. Both discharges are near the 5-year flood for their respective stations. The March 6, 2004, flood approached the 10-year flood at Daddys Creek near Hebbertsburg, with a peak flow of 11,000 ft^3/s.

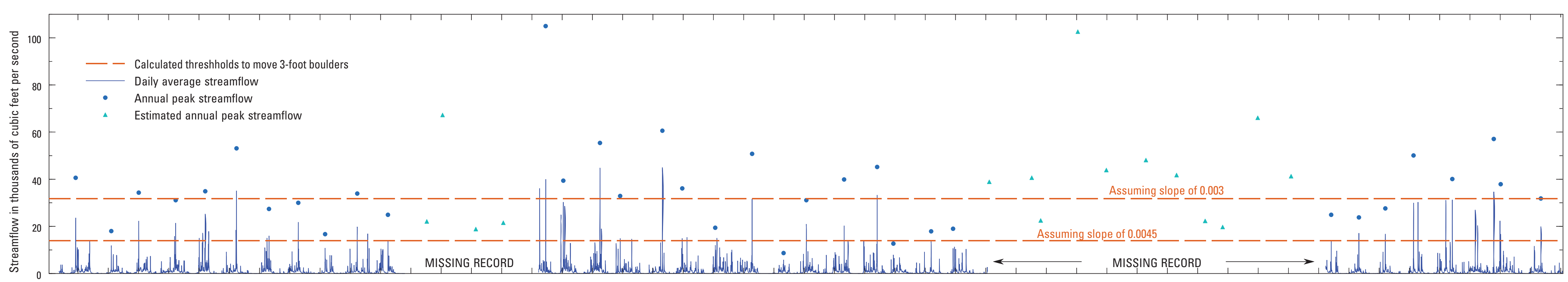

Figure 5. Streamflow record of the Obed River near Lancing from May 1, 1957, through December 31, 2006. [Annual peaks for periods with missing record estimated by simple linear regression from streamflow records of the Emory River at Oakdale. Assumed slope of 0.0045 based on the Lancing topographic quadrangle, scale 1:24,000 (U.S. Geological Survey, 1967). Assumed slope of 0.003 based on high-water marks used for indirect streamflow measurement following the May 27, 1973, flood.]

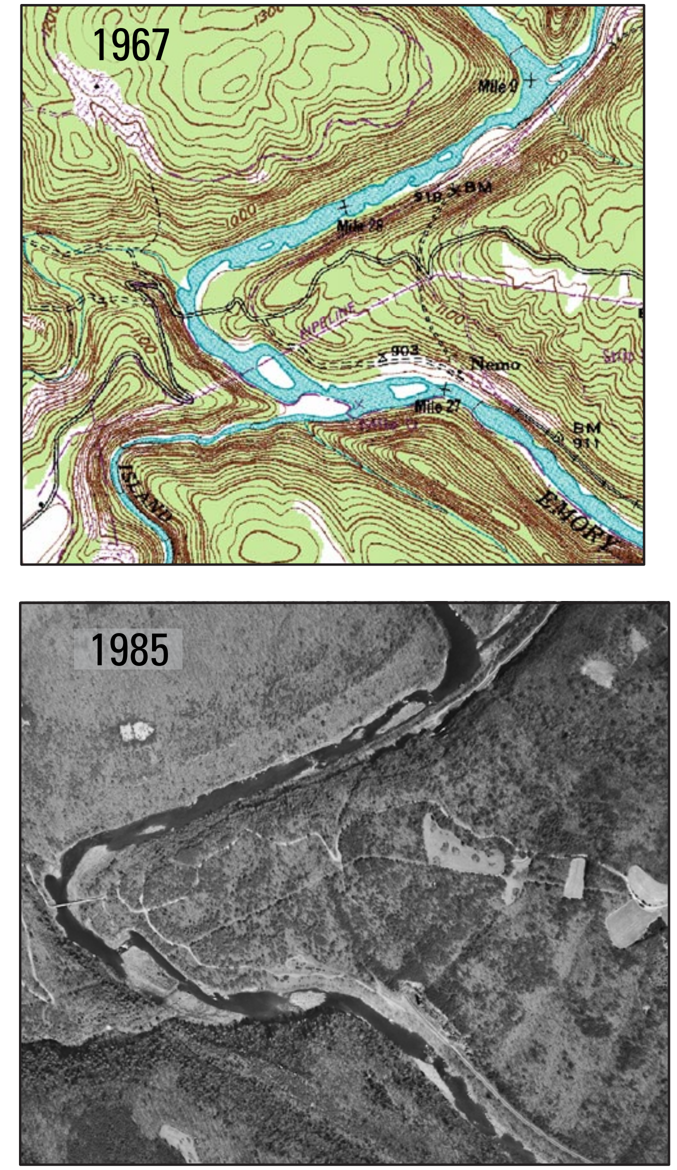

Figure 6. Before and after the 500-year flood. Footprints of alluvial bars along the Emory River near Nemo Bridge show little apparent change following the 105,000 cubic-feet-per-second flood of May 27, 1973. The USGS Lancing topographic quadrangle (top) was revised and published in 1967 and based on 1952 aerial photographs. The aerial photograph on the bottom was taken by the Tennessee Valley Authority in March 1985.

Spatial distribution of alluvial bars

Two sets of aerial photographs were used to examine the frequency and distribution of alluvial bars along the Obed River and Clear Creek. The primary set, covering the entire Obed WSR, was provided by the NPS Appalachian Highlands Inventory and Monitoring Network, Asheville, North Carolina. These photos are color-infrared (IR), taken in August 2001 with a nominal scale of 1:12,000, scanned at 600 dots per inch (DPI), and geo-rectified. For Clear Creek downstream from Barnett Bridge and the Obed River downstream from Obed Junction (fig. 1), these color-IR photos were supplemented by aerial photographs on loan from TVA, taken in March 1985 at a nominal scale of 1:12,000 and scanned at 600 DPI. The third set of photos used in this analysis is the USGS orthophotographic quadrangle coverage, based on photos taken in 1997 at a nominal scale of 1:12,000.

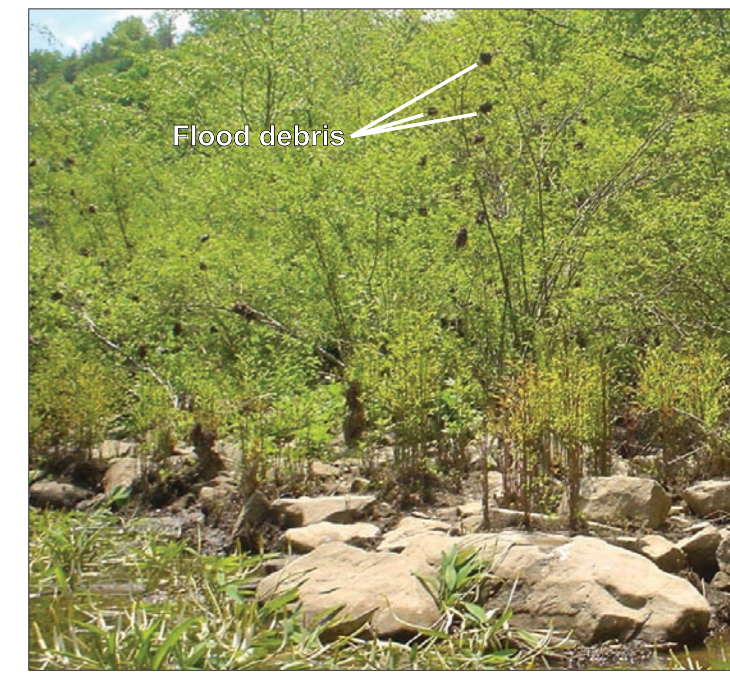

Figure 7. Flood debris, in the form of plant material hanging in the branches of trees and shrubs, 3 to 8 feet above the surface of an alluvial bar along Clear Creek, downstream from Jett Bridge.

The color-IR photos and orthophotographic quadrangles were imported into a geographic information system (GIS) and examined using the GIS mapping program. The approximate center of each alluvial bar that could be identified was marked and saved as a point feature. Many of the bars could be distinguished from the valley side slopes by their shape, location, color, and texture. In some locations, shadows or photographic distortions made interpretation more difficult. Where available, the supplementary photos from TVA were used to resolve ambiguities in the interpretation.

This analysis includes only alluvial bars that are clearly identifiable in at least one aerial photograph. Nearly half (26 of 56) of the alluvial bars visited during field reconnaissance were too small, too heavily vegetated, or too obscured by shadow or distortion to be included. The three surveyed bars, with approximate areas of 15,000 to 30,000 square feet (ft^2), were all clearly discernible on the photos. The analysis thus understates the number of alluvial bars in the Obed WSR and mainly reflects large (greater than 10,000 ft^2 in area) bars with clearings.

Aerial photographic analysis identified 201 alluvial bars along the 43 miles of Clear Creek and Obed River channel within the Obed WSR. The overall average density of the photo-mapped bars is 5 bars per mile of channel. Along the Obed River and the Emory River downstream from its confluence with the Obed, bar density appears to increase downstream (fig. 1). The average density of photo-mapped bars is 2 bars per channel mile from the upstream park boundary to Obed Junction and 7 bars per channel mile between Obed Junction and the downstream park boundary.

What is the ecological significance of alluvial bars in the Obed WSR?

Narrowly confined valleys and high energy regimes limit floodplain development in the Obed WSR. In the absence of floodplains, alluvial bars provide much of the available seasonally-flooded habitat. The distinctive geomorphic and hydrologic conditions of these bars have produced and maintained characteristic patterns of vegetation structure and composition.

Sunny, glade-like clearings form the most striking feature of vegetation structure on the seasonally-flooded alluvial bars. The clearings dominate the highest, driest areas of the bar tops and commonly include exposures of imbricated boulders (fig. 2). Sandy or silty alluvium deposited on the surface or filling spaces between boulders provides the rooting medium for plants. Ample sunlight, permeable substrate, elevations 3 to 5 feet above summer base flow, and the absence of surface runoff other than floods give the bar-top clearings a distinctly xeric character, reflected in a characteristic flora of drought-resistant grasses, herbs, and low shrubs. Most of the RTE plants noted by Schmalzer and others (1985) on alluvial bars in the Obed WSR were found in the bar-top clearings.

Plant assemblages of the bar-top clearings include several RTE species not normally found together (Schmalzer and others, 1985). Cumberland sandreed (*Calamovilfa arcuata*) grows in widely scattered locations from Tennessee to Oklahoma. Shortleaf sneezeweed (*Helenium brevifolium*) and pineywoods dropseed (*Sporobolus junceus*) are Coastal Plain natives. Cumberland rosemary (*Conradina verticillata*) (fig. 8) is endemic to the Obed gorge system and a few similar settings.

Background photograph: Clear Creek from the Lilly Bluff Overlook.
Courtesy of the National Park Service.

Thickets of flood-resistant shrubs typically dominate areas of the alluvial bars along the edge of water. These thickets typically include smooth alder (*Alnus serrulata*), common ninebark (*Physocarpus opulifolius*), Arrowwood species (*Viburnum dentatum* and *V. nudum* var. *cassinoides*), and rhododendrons (*Rhododendron spp*.). One bar visited during this study had a large stand of Virginia spiraea (*Spiraea virginiana*), a federally listed RTE plant (fig. 8). The shrub thickets typically are rooted in alluvial silt deposits. Bars in contact with the valley wall typically have forest vegetation along their landward edge.

Figure 8. Two federally listed plants found on alluvial bars in the Obed Wild and Scenic River: Virginia spiraea (*Spiraea virginiana*) (left) and Cumberland rosemary (*Conradina verticillata*) (right, photo by Tara Littlefield, Kentucky State Nature Preserves Commission, used with permission).

What factors threaten plant communities on the alluvial bars?

Field observations do not indicate that trapping of sand by upstream impoundments is a major threat to plant habitats on alluvial bars in the Obed WSR. Surface deposits of sand and silt were found at most sites visited during this study. Because streamflow in the Obed WSR is frequently competent to transport sand and silt, the surface deposits indicate continuing supply of these materials to the channel. At sites where boulders dominated the surface, plants were observed rooted in sand or silt deposited in cracks between the boulders. The boulders at the surface act as an armor layer, protecting the interstitial sand and silt from erosive flows.

The distinctive plant communities of the bar-top clearings depend on seasonal patterns of flood and drought to resist competitive pressure from the surrounding trees and shrubs. Seasonal flooding suppresses upland forest vegetation on the bar tops through inundation and mechanical scouring. The shrub thickets at water's edge are adapted to flooding but not to the drought conditions of the bar tops.

A major shift in the balance between flood and drought could leave the bar-top clearings vulnerable to shading by encroaching trees or shrubs. Significant reduction of the frequency or severity of flooding would remove or reduce the periodic inundation and flood scouring that make the bar tops inhospitable to upland forest vegetation. Analysis of streamflow records indicates that no such reduction is presently occurring in the Obed WSR. Conversely, increased summer base flow may have potential to reduce drought stress for flood-tolerant shrubs on the bar tops. Steamflow records for the Emory River at Oakdale show the running average of the 5th percentile flow (exceeded 95 percent of the time) doubled from 11.29 ft^3/s in 1949 to 22.58 ft^3/s in 2005 in response to wastewater releases from Crossville and nearby communities and increased regional precipitation (George S. Law, U.S. Geological Survey, written commun., 2007). It is unclear how much of an increase would be needed to affect vegetation structure on the bars or how sewage releases affect nutrient dynamics on the alluvial bars and other riverine habitats.

Urban development has the potential to adversely affect water quality in the Obed WSR. The watershed of the Obed WSR includes the rapidly growing communities of Crossville, Fairfield Glade, Crab Orchard, and Lake Tansi. As these communities continue to grow, urban runoff will make up an increased proportion of streamflow in the Obed River and its tributaries. Urban runoff contains elevated levels of nutrients, pesticides, herbicides, metals, and organic solvents (Hampson and others, 2000). Any of these contaminants is a potential threat to the biota of the Obed WSR, including plants on the alluvial bars. The seriousness of this threat remains largely unexamined.

A more immediate threat to bar-top vegetation is the presence of non-native invasive plants (IPPs). IPPs were noted on at least 8 of 56 alluvial bars visited in 2004. Five IPP species were identified: Sericea lespedeza (*Lespedeza cuneata*), autumn olive (*Elaeagnus umbellate*), silktree mimosa (*Albizia julibrissin*), crown vetch (*Coronilla varia*), and multiflora rose (*Rosa multiflora*). Multiflora rose was common on at least one of the bars and represents a serious threat to shade-intolerant native plants.

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Conversion factors

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
	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)

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