Prepared in cooperation with the National Park Service

Hydrologic Data for the Obed River Watershed, Tennessee

Open-File Report 2014–1102

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

Cover photograph. Photo of large boulders in Clear Creek, a tributary to the Obed Wild and Scenic River. Photo taken by T. Wood and used with permission of the National Park Service.

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By Rodney R. Knight, William J. Wolfe, and George S. Law

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

Suggested citation:
Knight, R.R., Wolfe, W.J., and Law, G.S., 2014, Hydrologic data for the Obed River watershed, Tennessee: U.S. Geological Survey Open-File Report 2014–1102, 24 p., *http://dx.doi.org/10.3133/ofr20141102*.

ISBN 978-1-4113-3795-4

ISSN 0196-1497 (print)

ISSN 2331-1258 (online)

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

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

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Acronyms

NPS National Park Service

USGS U.S. Geological Survey

WSR Wild and Scenic River

WTTP wastewater treatment plant

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Abstract

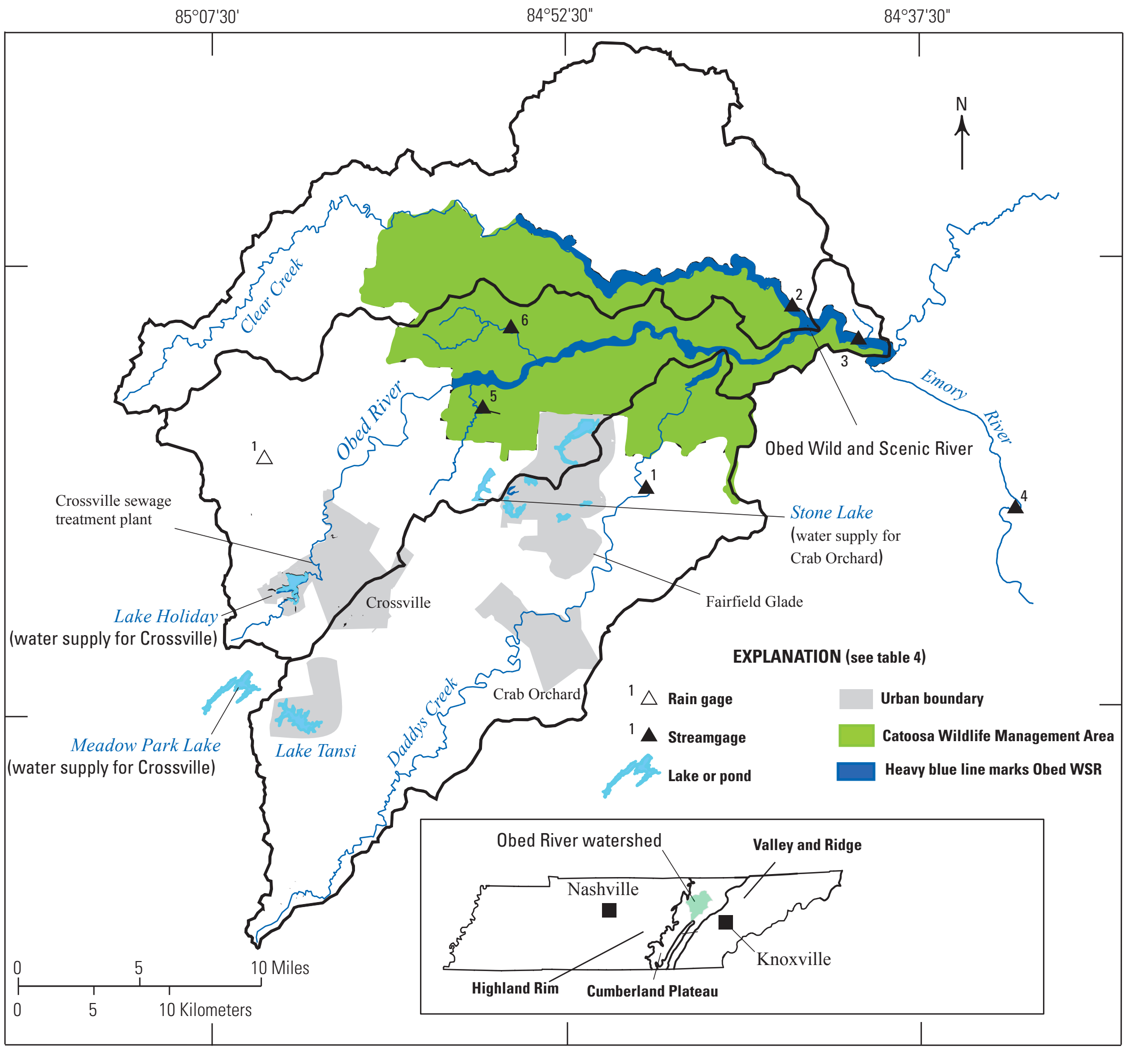
The Obed River watershed drains a 520-square-mile area of the Cumberland Plateau physiographic region in the Tennessee River basin. The watershed is underlain by conglomerate, sandstone, and shale of Pennsylvanian age, which overlie Mississippian-age limestone. The larger creeks and rivers of the Obed River system have eroded gorges through the conglomerate and sandstone into the deeper shale. The largest gorges are up to 400 feet deep and are protected by the Wild and Scenic Rivers Act as part of the Obed Wild and Scenic River, which is managed by the National Park Service.

The growing communities of Crossville and Crab Orchard, Tennessee, are located upstream of the gorge areas of the Obed River watershed. The cities used about 5.8 million gallons of water per day for drinking water in 2010 from Lake Holiday and Stone Lake in the Obed River watershed and Meadow Park Lake in the Caney Fork River watershed. The city of Crossville operates a wastewater treatment plant that releases an annual average of about 2.2 million gallons per day of treated effluent to the Obed River, representing as much as 10 to 40 percent of the monthly average streamflow of the Obed River near Lancing about 35 miles downstream, during summer and fall. During the past 50 years (1960–2010), several dozen tributary impoundments and more than 2,000 small farm ponds have been constructed in the Obed River watershed. Synoptic streamflow measurements indicate a tendency towards dampened high flows and slightly increased low flows as the percentage of basin area controlled by impoundments increases.

Introduction

The Obed Wild and Scenic River (WSR), established in 1976 under the Wild and Scenic Rivers Act of 1968 (82 Statute 906, Public Law 90-542) and managed by the National Park Service (NPS), occupies about 14 square miles (mi^2) of rugged river gorge cut into the Cumberland Plateau of East Tennessee (fig. 1). The Obed WSR composes only about 3 percent of the drainage area (520 mi^2) of the Obed River at its confluence with the Emory River. The basin upstream of the WSR includes the rapidly growing communities of Crossville, Crab Orchard, and Fairfield Glade, Tennessee, all of which withdraw water from and release treated wastewater to the Obed River or its tributaries (fig. 1). After moderate population growth in the 1930s and 1940s, population stabilized at around 19,000 in the 1950s and 1960s (table 1). Beginning in the 1970s, the county entered a period of sustained population growth. Population growth has been accompanied by construction of more than 2,000 impoundments in the Obed River headwaters for water supply, recreation, livestock watering, and irrigation (table 2; Forester and others, 1998). Water withdrawals, wastewater releases, impoundments, and other human activities have potential to change the flow regime of the Obed River, possibly affecting the ecological, recreational, scenic, and other values and functions that helped justify the river's protection under the Wild and Scenic Rivers Act.

The Wild and Scenic Rivers Act requires the NPS to preserve rivers of the WSR system in "free-flowing condition to protect the water quality of such rivers and to fulfill other vital national conservation purposes." To meet this responsibility, the NPS must evaluate conditions or factors with potential to alter the natural flow of streams in the WSR system. The legal responsibility of the NPS to mitigate threats to the natural flow regime of the Obed WSR requires an evaluation of the hydrologic effects of human activities in the Obed River watershed. In 1999, the U.S. Geological Survey (USGS) began a cooperative effort with the NPS to assemble historical datasets and collect hydrologic data in the Obed River and its tributaries to support an assessment of the hydrologic effects of human activities in the basin.



Base from U.S. Geological Survey topographic quadrangles, 1:24,000
Lambert Conformal Conic projection
Standard parallels 35°15′ N and 36°25′ N, central meridian 86° W

Figure 1. Location of the rain gage (operated by the National Weather Service), streamgages, lakes, and other selected features in the Obed River watershed, Tennessee.

Table 1. Population estimates for Cumberland County, Tennessee, 1930–2010.

[n/a, not available; %, percent; population estimates from Center for Business and Economic Research, 2014]

	1930	1940	1950	1960	1970	1980	1990	2000	2010
population	11,440	15,592	18,877	19,135	20,733	28,676	34,736	46,802	54,251
net change by decade	n/a	4,152	4,152	258	1,598	7,943	6,060	12,066	7,449
percent change by decade	n/a	36%	21%	1%	8%	38%	21%	35%	16%

Table 2. Number of impoundments built in the Obed River watershed and Clear Creek and Daddys Creek subwatersheds, by time period.

[mi^2, square miles; –, not available]

Watershed	Drainage area, mi^2	Time period[a]	Total at end of time period		
			Cumulative number of impoundments	Surface area of impoundments, mi^2	Drainage area controlled by major impoundments, mi^2
Obed River	172	1943–1975	215	0.47	–
		1976–1987	438	1.17	–
		1988–1997	921	2.28	–
		1998–2002	929	2.28	28.3
Clear Creek	173	1943–1975	133	0.15	–
		1976–1987	380	0.54	–
		1988–1997	672	0.73	–
		1998–2002	695	0.75	8.64
Daddys Creek	175	1943–1975	40	0.19	–
		1976–1987	318	1.59	–
		1988–1997	830	2.43	–
		1998–2002	830	2.43	32
Total for study area	520	1943–1975	388	0.82	–
		1976–1987	1,136	3.3	–
		1988–1997	2,423	5.44	–
		1998–2002	2,454	5.46	68.9

[a]Data for period 1943 to 1987 supplied by National Park Service (Forester and others, 1998); data for period 1988 to 2002 supplied by National Park Service (Jacob Morgan, National Park Service, written commun., 2007).

Purpose and Scope

This report presents the findings of USGS hydrologic studies conducted in cooperation with the National Park Service in the Obed River watershed during 1999 through 2005. The report includes analysis of historical and contemporary streamflow and precipitation records from the Obed River watershed and a qualitative assessment of the influence of increased human alteration and climate on the flow regime of the Obed WSR.

The USGS conducts research to improve the understanding of the water resources of the Nation. A key science direction for the USGS Tennessee Water Science Center is the evaluation of changes to instream conditions and aquatic ecosystem health resulting from land-cover change, climate change, and management or mitigation measures. The results from this investigation will provide additional data and information to help meet that science goal. The investigation also provides information about the effects of the geology, climate, and human activities on the streamflow and water cycle of the area that will aid the USGS in advancing the understanding of the processes that determine water availability (Evenson and others, 2013).

Previous Studies

The first detailed studies of the Obed River watershed were conducted in the 1890s and early 1900s by the USGS and focused on producing general geologic folios (Keith, 1897) and topographic maps (U.S. Geological Survey, 1913) of the region. Geology and mineral resources of this part of Tennessee were studied by Stearns (1954), Luther (1959), Johnson and Luther (1972), and Wilson and others (1956). Wilson (1965) reported on the groundwater resources and hydrogeology of Cumberland County, Tenn., at a time when most of the population of the county obtained their water supply from domestic wells. Wilson (1965) revised the geologic naming conventions previously established by Stearns (1954) and Wilson and others (1956); the geologic names used in this report follow Wilson (1965) and conform to current usage by the USGS and the Tennessee Division of Geology. Brahana and others (1986) developed a preliminary description and delineation of the aquifers of the Cumberland Plateau.

Early studies of surface-water hydrology in the study area included general waterway surveys (U.S. Army Corps of Engineers, 1930; Tennessee Valley Authority, 1954, 1970) and studies of floods (Tennessee Valley Authority, 1960) and droughts (Tennessee Valley Authority, 1958). Many of these studies were conducted in the context of proposed impoundment of the Obed River, which was under consideration until about 1970 (National Park Service, 1993). More recently, the U.S. Army Corps of Engineers (1998) published a study of the Obed River watershed that includes a reconnaissance of water-supply sources of Cumberland County and assessment of water-supply alternatives for the county.

Following establishment of the Obed WSR in 1976, the focus of hydrologic studies shifted to the ecological implications of streamflow and water quality in the WSR (National Park Service, 1999). Initial reconnaissance and feasibility reports for the Obed WSR (Bureau of Outdoor Recreation, 1976a, b; National Park Service, 1978) included general discussions of hydrologic conditions in the proposed WSR and its drainage basin (J.C. Hughes, National Park Service, written commun., 2007). Reports by Minear and Tschantz (1976), Gaydos and others (1982), and Gottfried and others (1984) explored linkages between strip mining of coal and the aquatic environment of the Cumberland Plateau. Other studies documented the benthic fauna of streams on or adjacent to the Cumberland Plateau in Tennessee (Pennington and Estes, 1980; Gore and others, 1982; Bradfield, 1986a, b) and the proliferation of small dams and reservoirs constructed on creeks and rivers in Tennessee (Goodwin, 1981).

Recent studies have emphasized specific management questions or furthered the understanding of ecology and hydrology in the WSR and surrounding area. Forester and others (1998) produced a water-resources management plan for the Obed WSR describing decision-making and management processes for the conservation and management of water resources in the Obed WSR. The water-resources management plan is an extension of the general management plan for the park (National Park Service, 1995). In 2004, researchers from the University of Tennessee at Chattanooga developed a digital record of surface-water impoundments in the Obed River watershed (National Park Service, 2004). The impoundments range from farm ponds to small lakes having surface areas of several hundred acres. Arnwine and others (2006) reported on stream monitoring below small impoundments throughout Tennessee, including water-quality analyses for streams below several of the larger impoundments in the Obed River watershed. Recent academic theses from Tennessee Technological University examined current distribution and seasonal habitat use of the threatened spotfin chub (Russ, 2006) and benthic macroinvertebrate communities (Goodfred, 2006) within the Emory River watershed. Wolfe and others (2007) described the physical characteristics and spatial distribution of the Obed WSR alluvial bars, the role of hydrology in creating and maintaining them, patterns of plant distribution, and potential threats to alluvial-bar plant communities.

Description of the Study Area

The dominant landscape of the Obed River watershed is a gently rolling plateau covered by farms, pastures, and forest. Many of the forests are second growth, having been clear-cut in the early 1900s. The land has also been affected by localized strip-mining of coal prior to the 1970s (Johnson and Luther, 1972). The elevation of the plateau ranges generally between 1,200 and 2,000 feet (ft) above the National Geodetic Vertical Datum of 1929 (NGVD 29), with the Crab Orchard Mountains about 3,000 ft above NGVD 29 (Griffith and others, 1997). The Obed River watershed is about 1,000 ft higher in elevation than the Highland Rim physiographic region to the west and the Valley and Ridge physiographic region to the east. The Obed River is a tributary to the Emory River, and its 520-mi^2 basin composes 60 percent of the Emory River watershed at their confluence.

The Obed River watershed lies entirely within the Cumberland Plateau physiographic region (Griffith and others, 1997). The streams and rivers of this region are characterized by rapid runoff following storms and by low flow or no flow during the drier months in late summer and fall. Streams with drainage areas less than approximately 1 mi^2 are generally ephemeral in the study area, flowing only in direct response to local rainfall (Law and others, 2009). Streams in the study area with drainage areas between 1 and 100 mi^2 have flow regimes that range from ephemeral-intermittent to intermittent-perennial, commonly experiencing seasonal periods with little or no flow, even when some dry-season pools are maintained. Streams with drainage areas greater than 100 mi^2 generally are perennial and maintain flow throughout the year. The larger streams and rivers of the Obed River watershed have formed deeply incised gorges cut through sandstone and conglomerate layers down to and, in places, through underlying shale layers (Stearns, 1954; Wilson and others, 1956; Wilson, 1965; Milici, 1968).

Geology and Hydrogeology

Geologic strata in the study area generally are level or dip gently to the southeast (Stearns, 1954) (fig. 2). Local deformation due to thrust faulting and cross faulting (fig. 2) occurs primarily in strata that overlie the Mississippian-age limestone of the area (fig. 3). Additionally, several major geologic features, such as the Sequatchie Valley anticline, Crab Orchard Mountains anticline, and the Cumberland Plateau overthrust belt, interrupt the generally horizontal geologic structure (fig. 2; Stearns, 1954; Wilson and others, 1956; Milici, 1968). The overthrust belt is related to the faults in the underlying Mississippian and older formations (fig. 3), which are exposed primarily to the east and south in the Valley and Ridge physiographic region and Sequatchie Valley. Exposures of Mississippian-age limestone within the study area are found mainly at Crab Orchard Cove (fig. 3; Stearns, 1954; Wilson and others, 1956; Milici, 1968).

The Obed River watershed is underlain mainly by sandstones, siltstones, conglomerates, and shales of Pennsylvanian age with minor coal seams (fig. 3; Stearns, 1954; Wilson and others, 1956; Wilson, 1965). Major geologic units in the study area include the Crooked Fork Group, Rockcastle Conglomerate of the Crab Orchard Group, and the Vandever Formation and lower Crab Orchard Group. The Crooked Fork Group includes four units—a lower shale unit, the Crossville Sandstone member, an upper shale unit, and an upper sandstone unit. Throughout most of the study area, the upper sandstone and shale layers have been worn away by weathering and erosion. The lower shale unit and Crossville Sandstone have average thicknesses of about 50 ft and 100 ft, respectively. The Crossville Sandstone is the only member of the Crooked Fork Group that has substantial water-bearing capacity. The Crossville Sandstone, however, has low hydraulic conductivity, and yields of 5 to 10 gallons per minute (gal/min) are typical (Wilson, 1965).

The shaley Vandever Formation (fig. 3) transmits little groundwater flow, and few, if any, water-supply wells have been completed in this unit (Wilson, 1965). Exposed contacts between the Vandever Formation and the Rockcastle Conglomerate are sites of seeps and springs throughout the Obed River watershed. Seeps occurring on this geologic contact provide baseflow to perennial streams during dry periods (M.W. Bradley, U.S. Geological Survey, written commun., 2007). Some streams have cut through the Vandever Formation into the underlying Bonair sandstones in the Gizzard Group (Stearns, 1954; Wilson, 1965) and are likely to lose streamflow, especially during baseflow conditions.

The Rockcastle Conglomerate, positioned above the Vandever Formation and below the Crooked Fork Group (fig. 3), is the primary water-bearing geologic unit in the Obed River watershed. Most of the domestic wells in the watershed are completed in this unit, which has an average thickness of 150 ft (Stearns, 1954; Wilson, 1965). Groundwater occupies fracture systems within the massive cross-bedded sandstone, which is the principal component of the formation, and along bedding planes separated by thin stringers of shale (Wilson, 1965). Wells completed in the Rockcastle Conglomerate are mostly artesian, with water levels rising up to 100 ft above the water-bearing fracture systems. Reported yields of wells in the Rockcastle Conglomerate are up to 35 gal/min and average about 8 gal/min (Wilson, 1965).

Impoundments

Numerous small water-supply, recreational, and farm ponds have been constructed in headwater tributaries of the Obed River watershed and are collectively referred to as impoundments in this report. Recently, concern has risen over the potential effects of these impoundments on the hydrologic environment of the Obed WSR (Pringle, 2000). The water-resources management plan for the Obed WSR (Forester and others, 1998) notes that stream impoundment generally reduces natural physical and biological variability and promotes conditions of constancy within a stream system. In 1975, there were 388 impoundments in the Obed River watershed (Forester and others, 1998). By 1997, the number of impoundments had increased to 2,423 (table 2). After 1998, the rate of new impoundment construction slowed, probably reflecting a combination of economic conditions, increasing scarcity of suitable sites, greater public awareness of permitting requirements, and concerns about possible adverse environmental effects (R.D. Baker, Tennessee Department of Environment and Conservation, written commun., 2008). As of March 2002, impoundments in the Obed River watershed had a combined water-surface area of 5.46 mi^2 (table 2).

Aerial photographs and digital elevation models indicate that about 13 percent (69 mi^2) of the Obed River watershed drains to impoundments, primarily in the headwaters (Jacob Morgan, National Park Service, written commun., 2007). About 80 percent of the impoundments are for farm and private recreational purposes, with individual water-surface areas generally less than 1 acre and a combined water-surface area ranging from 1 to 1.5 mi^2, depending on weather conditions. These small ponds receive runoff from a combined watershed area of about 38 mi^2. About 15 percent of impoundments in the Obed River watershed have surface areas of 1 to 10 acres, with a combined surface area ranging from 1.5 to 2.5 mi^2, depending on weather conditions, and combined drainage areas represent 10 percent of the Obed River watershed (roughly 52 mi^2).

Impoundments with a surface area greater than 10 acres compose about 2 percent of the impoundments in the Obed River watershed. The largest of these impoundments is Lake Tansi near Crossville (fig. 1), which has a designed surface area of 425 acres (0.66 mi^2) and a design volume of 12,300 acre-feet (acre-ft; Lyle Bentley, Tennessee Department of Environment and Conservation, written commun., 2007). Larger impoundments in the Obed River watershed have a combined surface area ranging from 2.5 to 4 mi^2, depending on weather conditions, and receive runoff from about 76 mi^2. Many tributary watersheds have multiple impoundments.

Water Withdrawals and Sewage Discharges

The cities of Crossville and Crab Orchard collect and distribute drinking water for much of Cumberland County (Hutson and Morris, 1992; Hutson, 1999; Webbers, 2003; Bohac and McCall, 2008; J.L. Kerley, City of Crossville, written commun., 2010; W.L. Muirhead, Tennessee Department of Environment and Conservation, written commun., 2010). The sources of this drinking water are Meadow Park Lake, Lake Holiday, and Stone Lake in the headwaters of the Obed River and Caney Fork watersheds (fig. 1). Groundwater sources are not being used for public drinking water by municipal water systems in this area.

In 2010, Crossville and Crab Orchard withdrew, treated, and distributed 4.2 million gallons per day (Mgal/d) and

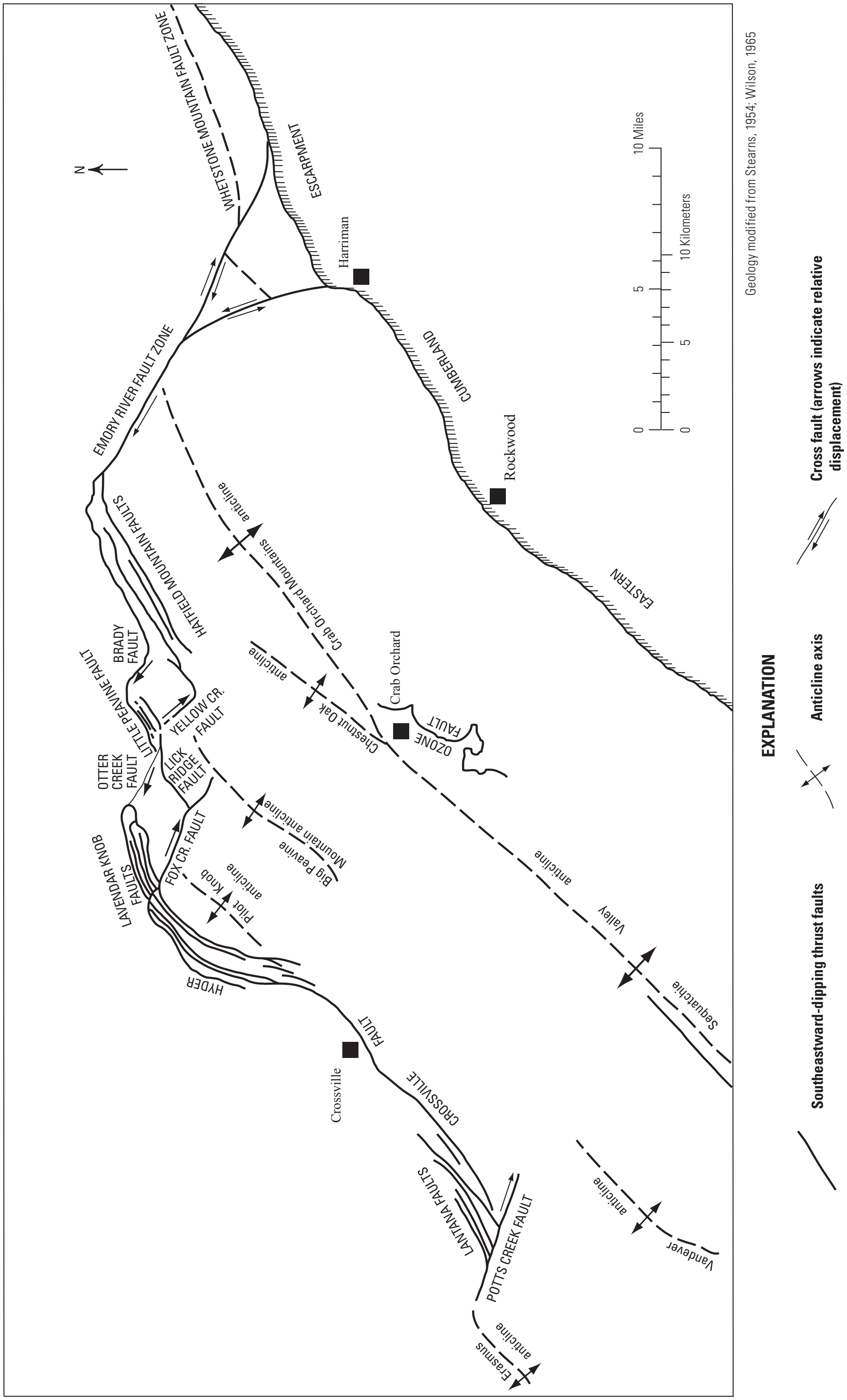


Figure 2. Major structural features of the geology of the Cumberland Plateau overthrust belt, Tennessee.

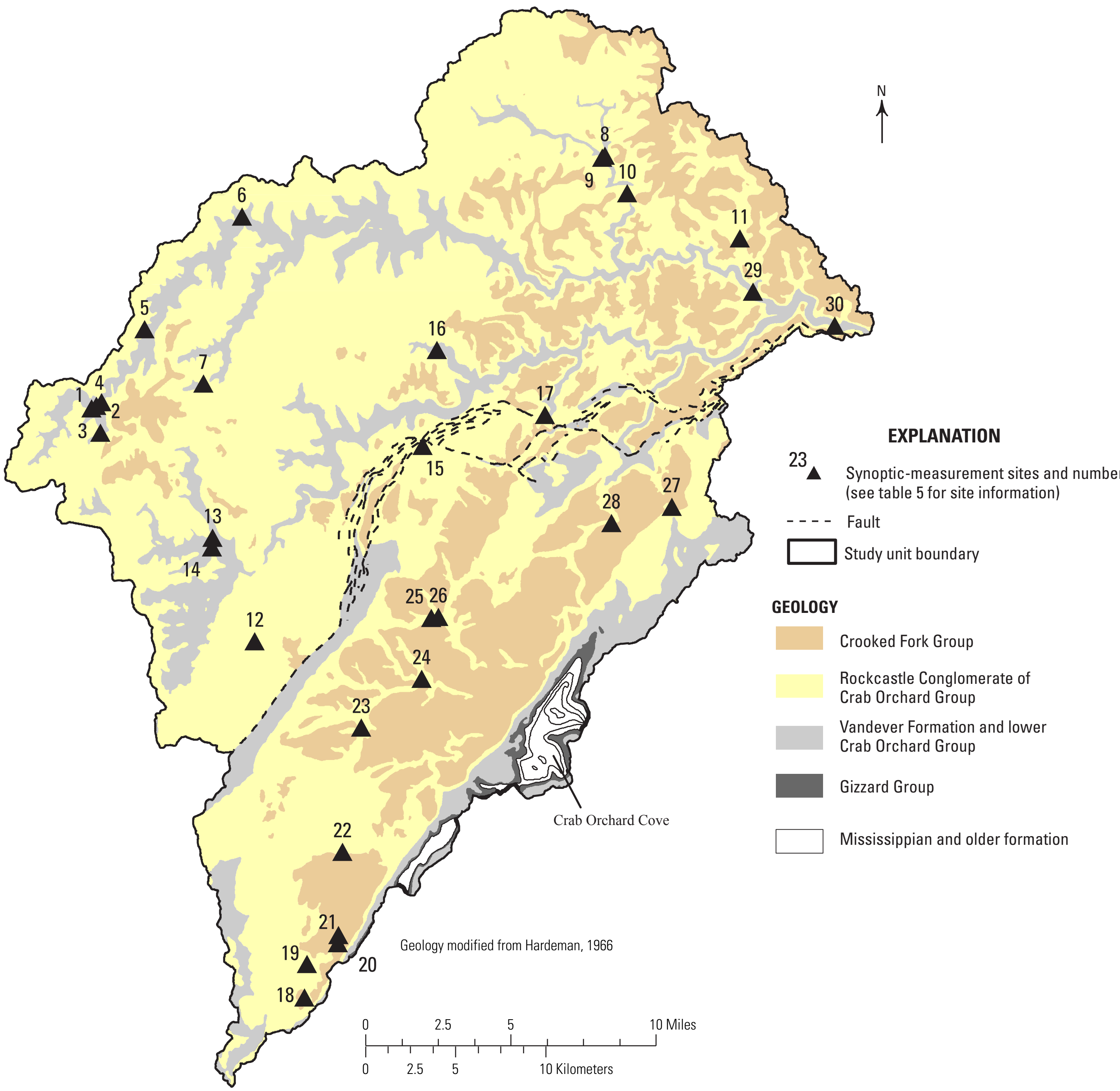


Figure 3. Geology and low-flow sites in the Obed River watershed, Tennessee.

1.6 Mgal/d of drinking water, respectively (table 3). As of 2010, the combined capacity of these drinking-water systems was about 8 Mgal/d (Robinson and Brooks, 2010). Analyses by the U.S. Army Corps of Engineers (1998) indicate that future water-supply needs for Crossville, Crab Orchard, and Cumberland County will exceed 10 Mgal/d by the year 2020.

The city of Crossville wastewater treatment plant (WWTP) is the only centralized wastewater system in the study area. The Crossville WWTP is located on the Obed River about 1 mile (mi) downstream of Lake Holiday and about 14 mi upstream of the Obed WSR boundary (fig. 1). In 2010, the Crossville WWTP discharged an average of 2.08 Mgal/d of treated effluent to the Obed River (R. Baker, Tennessee Department of Environment and Conservation, written commun., 2010). As of 2005, eight decentralized wastewater-treatment systems were applying a total of about 0.13 Mgal/d of treated effluent to land in the headwaters of the Obed River watershed. Five of these systems use spray irrigation, and three use drip irrigation.

About 52 percent of the public drinking water produced by Crossville is returned to the Obed River as treated effluent, which can account for a considerable proportion of flow in the river. During extended dry periods, filter backwash from the drinking-water plant, effluent discharged from Crossville WWTP, and limited groundwater discharge are the only flows into the Obed River at Crossville. Lake Holiday does not provide a guaranteed minimum flow for dilution of effluent from the Crossville WWTP (J.L. Kerley, City of Crossville, written commun., 2010). The most direct effect of WWTP effluent on flow conditions in the Obed WSR appears to occur during low-baseflow conditions from July through October of a typical year. During these periods, effluent released from the Crossville WWTP can constitute about 10 to more than 40 percent of the observed streamflow of the Obed River near Lancing, TN (03539800) (fig. 4*A*). The basin area at the Obed River near Lancing is about 40 times larger than the basin area at the location of the effluent discharge, indicating that effluent releases by the Crossville WWTP are greatly influencing downstream flow conditions. The effect of effluent releases on the low-flow variability of the Obed WSR has not been thoroughly evaluated; however, the wastewater discharge most likely increases the lowest flows expected along much of the

Table 3. Average daily water withdrawals by public water systems in the Cumberland County, Tennessee, area.

[See fig. 1 for general location of water-supply lakes in the study area; ft^3/s, cubic foot per second; Mgal/d, million gallons per day; –, prior to water withdrawal]

Public water system	Location of system intake	Calendar year	Average daily usage	
			ft^3/s	Mgal/d
Obed River watershed				
Crab Orchard	Stone Lake on Otter Creek	1988 [a]	–	–
		1995 [b]	1.38	0.89
		2000 [c]	2.18	1.41
		2005 [d]	2.40	1.55
		2010 [e]	2.48	1.6
Crossville	Lake Holiday on Obed River	1988 [a]	3.95	2.55
		1995 [b]	2.96	1.91
		2000 [c]	2.85	1.84
		2005 [d]	2.01	1.30
		2010 [e]	1.81	1.17
Caney Fork watershed				
Crossville	Meadow Park Lake on Meadow Creek[f]	1988 [a]	0.71	0.46
		1995 [b]	1.89	1.22
		2000 [c]	1.69	1.09
		2005 [d]	4.00	2.59
		2010 [e]	4.75	3.07

[a]Hutson and Morris, 1992; [b]Hutson, 1999; [c]Webbers, 2003; [d]Robinson and Brooks, 2010; [e]Tennessee Department of Environment and Conservation, Division of Water Supply, open-file records, provisional data, 2011; [f] interbasin transfer from Cumberland River Basin to Tennessee River Basin.

Obed River in any given year and decreases the low-flow variability. This brief analysis provides a conservative estimate for the effect of wastewater effluent on the flow of the Obed River and does not account for return flow from residential septic systems (fig. 4*B*).

Hydrologic Data

Data presented in this report include long-term streamflow and rainfall records, monthly average wastewater return flows, and synoptic discharge measurements. Historical and contemporary data from five streamgages in the Obed River watershed and one on the Emory River (table 4; fig. 1) were used to examine long-term changes in streamflow in the study area. Published rainfall records from the National Weather Service Crossville Experiment Station were used to study rainfall trends.

Synoptic discharge measurements were made at 27 stream sites on seven occasions (table 5; appendix 1). A typical range of high- to low-baseflow conditions was measured and compared with watershed characteristics and streamflow at the long-term gaging stations to assess anthropogenic effects. Watershed characteristics, including drainage area, geology, and watershed area controlled by impoundments upstream of the measurement sites, are listed for each site in table 5.

Synoptic-measurement sites were selected to represent the two dominant geologic formations underlying the Obed River watershed: the Rockcastle Conglomerate-Crooked Fork Group and the Vandever Formation (table 5). The majority

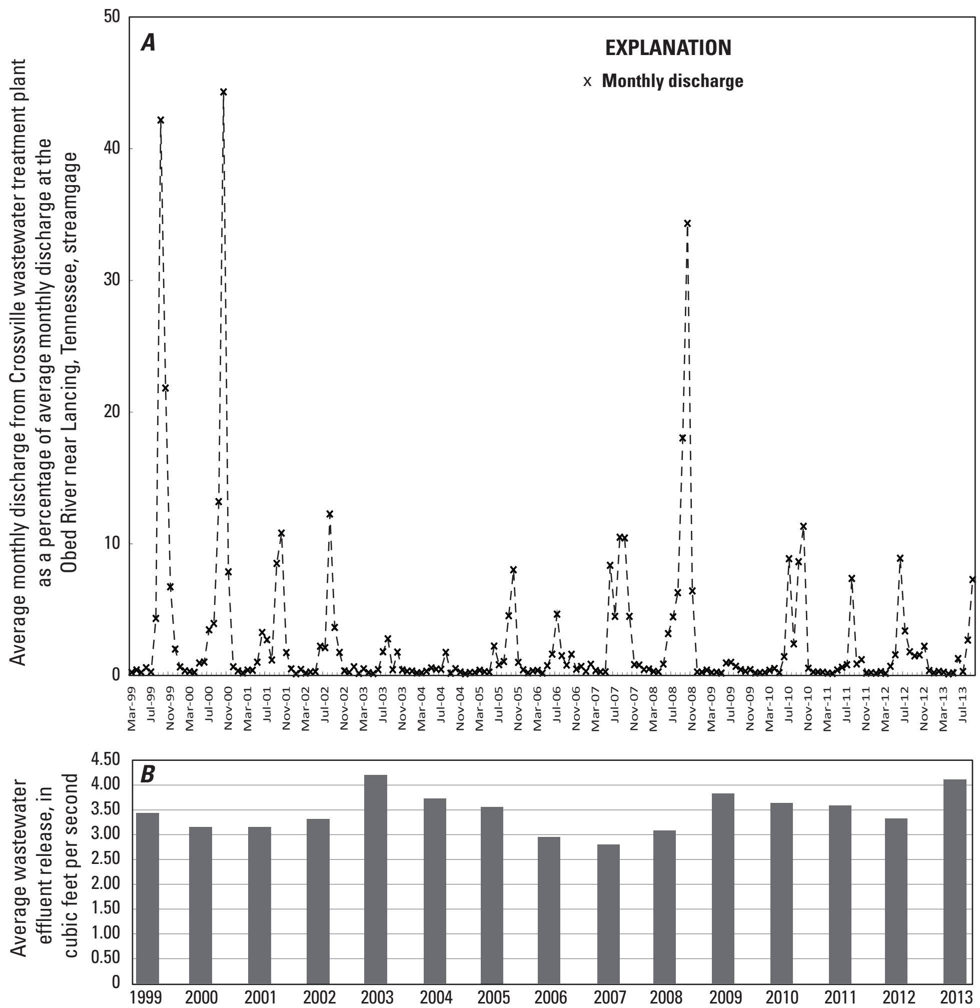


Figure 4. *A*, Monthly average discharge from the Crossville wastewater treatment plant as a percentage of monthly average discharge at the Obed River near Lancing streamgage, March 1999 through September 2013 and *B*, average wastewater effluent release by water year.

Table 4. Rain gages and streamgages used in the Obed River watershed study, Tennessee.

[mi², square miles; –, not applicable]

Site no. (fig. 1)	Station number	Station name (short name)	Latitude, in degrees, minutes, seconds	Longitude, in degrees, minutes, seconds	Drainage area, in mi²	Period of record
Rain gage						
1	COOP:402202	Crossville Experiment Station	36°01'00"	85°08'00"	–	1912–present
Streamgages						
1	03539600	Daddys Creek near Hebbertsburg	35°59'51"	84°49'21"	139	1957–68, 99–present
2	03539778	Clear Creek at Lilly Bridge	36°06'11"	84°43'06"	170	1997–present
3	03539800	Obed River near Lancing	36°04'53"	84°40'13"	518	1957–68, 73–87, 99–present
4	03540500	Emory River at Oakdale	35°58'59"	84°33'29"	764	1927–present
5	03538845	Fox Creek near Lavendar Knob	36°02'47"	84°56'00"	7.38	2001–2003
6	03538865	Elmore Creek near Genesis	36°05'34"	84°55'03"	7.82	2001–2003

Table 5. Synoptic-measurement and index sites in the Obed River watershed, Tennessee, 2003–2005.

[mi², square miles; Pcf, Crooked Fork Group; Pr, Rockcastle Conglomerate; Pv, Vandever Formation]

USGS station number	Site name (number on figure 3)	Latitude	Longitude	Total watershed drainage area, mi²	Number of tributary lakes	Impoundment surface area, mi²		Water-shed area controlled by tributary lakes, mi²	Total watershed area controlled		Geology at site
						tributary lakes	farm ponds		mi²	percent	
Obed River watershed synoptic sites											
03539701	Clear Creek above Panther Creek confluence (1)	36º05'05"	85º07'55"	6.52	0	0	0.029	0	0.29	4.4	Pv
03539703	Panther Creek below Lake Caryonah Dam (2)	36º04'16"	85º07'52"	1.61	1	0.047	0	1.61	1.61	100	Pv
03539704	Panther Creek at Pugh Cemetery (3)	36º05'00"	85º07'52"	3.05	1	0.047	0.016	1.61	1.77	57.9	Pv
03539705	Clear Creek below Panther Creek confluence (4)	36º05'07"	85º07'47"	9.57	1	0.047	0.044	1.61	2.05	21.4	Pv
03539708	Clear Creek at Clear Creek Road (5)	36º07'11"	85º05'48"	14.4	1	0.047	0.071	1.61	2.32	16.1	Pv
03539710	Clear Creek nr Rinnie (6)	36º10'10"	85º01'42"	23.4	1	0.047	0.123	1.61	2.84	12.1	Pv

Table 5. Synoptic-measurement and index sites in the Obed River watershed, Tennessee, 2003–2005.—Continued

[mi², square miles; Pcf, Crooked Fork Group; Pr, Rockcastle Conglomerate; Pv, Vandever Formation]

USGS station number	Site name (number on figure 3)	Latitude	Longitude	Total watershed drainage area, mi²	Number of tributary lakes	Impoundment surface area, mi²		Water-shed area controlled by tributary lakes, mi²	Total watershed area controlled		Geology at site
						tributary lakes	farm ponds		mi²	percent	
Obed River watershed synoptic sites—Continued											
03539715	No Business Creek at Isoline (7)	36º05'23"	85º03'51"	2.85	0	0	0.026	0	0.26	9	Pr
03539718	White Creek above Cook Creek confluence (8)	36º10'43"	84º47'59"	19.1	0	0	0.05	0	0.5	2.6	Pv
03539719	White Creek at Twin Bridges (9)	36º10'39"	84º48'01"	38.4	0	0	0.229	0	2.29	5.9	Pv
03539720	White Creek at Lavendar Bridge (10)	36º09'32"	84º47'20"	45.3	0	0	0.253	0	2.53	5.6	Pr
03539748	Little Clear Creek nr Howard Mill (11)	36º07'48"	84º43'21"	10.6	0	0	0.024	0	0.24	2.3	Pr
03538603	Obed River at US Hwy 70 (12)	35º57'36"	85º03'03"	12.5	1	0.344	0.119	8.49	9.68	77.5	Pr
03538813	Drowning Creek above Copeland Creek confluence (13)	36º00'48"	85º04'10"	10	0	0	0.123	0	1.23	12.3	Pv
03538814	Copeland Creek above Drowning Creek confluence (14)	36º00'31"	85º04'14"	10.7	0	0	0.1	0	1	9.4	Pv
03538845	Fox Creek near Lavendar Knob (03538845) (15)	36º02'47"	84º56'00"	7.38	3	0.294	0.03	2.08	2.38	32.2	Pr
03538865	Elmore Creek near Genesis (03538865) (16)	36º05'34"	84º55'03"	7.82	0	0	0.001	0	0.01	0.1	Pv
03538871	Otter Creek at Hebbertsburg (17)	36º03'16"	84º51'20"	16.9	2	0.477	0.051	5.35	5.86	34.7	Pv
03538890	Daddys Creek west of Brown Gap (18)	35º46'55"	85º02'44"	4.6	0	0	0.021	0	0.21	4.5	Pr
03538900	Self Creek nr Big Lick (19)	35º47'53"	85º02'30"	3.78	1	0.105	0	1.55	1.55	41	Pr
03538940	Daddys Creek at US Hwy 127 near Big Lick (20)	35º48"24"	85º01'16"	10.3	1	0.105	0.027	1.55	1.82	17.7	Pcf

Table 5. Synoptic-measurement and index sites in the Obed River watershed, Tennessee, 2003–2005.—Continued

[mi², square miles; Pcf, Crooked Fork Group; Pr, Rockcastle Conglomerate; Pv, Vandever Formation]

USGS station number	Site name (number on figure 3)	Latitude	Longitude	Total watershed drainage area, mi²	Number of tributary lakes	Impoundment surface area, mi²		Water-shed area controlled by tributary lakes, mi²	Total watershed area controlled		Geology at site
						tributary lakes	farm ponds		mi²	percent	
03538950	Lick Creek at Big Lick (21)	35º48"23"	85º12'13"	8.53	0	0	0.083	0	0.83	9.7	Pcf
03538990	Basses Creek below Lake Tansi at US Hwy 127 (22)	35º51'05"	85º00'43"	13.1	1	0.664	0.033	4.45	4.78	36.5	Pr
03539200	Byrd Creek at US Hwy 127 (23)	35º54'41"	84º59'29"	10.3	3	0.165	0.099	9.13	10.1	98.3	Pr
03539250	Byrd Creek below Ward Creek confluence (24)	35º55'55"	84º57'03"	24.8	3	0.165	0.193	9.13	11.1	44.6	Pr
03539502	North Creek above Brown Creek confluence (25)	35º57'41"	84º56'25"	5.19	1	0.164	0.051	1.24	1.75	33.7	Pr
03539503	Brown Creek above North Creek confluence (26)	35º57'41"	84º56'10"	6.44	1	0.33	0.035	2.5	2.85	44.2	Pr
03539680	Yellow Creek east of Cline School (27)	36º00'07"	84º47'03"	9.97	0	0	0.006	0	0.06	0.6	Pr
Obed River watershed index sites											
03539600	Daddys Creek near Hebbertsburg (28)	35º59'51"	84º49'21"	139	12	1.72	0.675	25.2	32	23	Pv
03539778	Clear Creek at Lilly Bridge (29)	36º06'11"	84º43'06"	170	1	0.047	0.703	1.61	8.64	5.1	Pv
03539800	Obed River near Lancing (30)	36º04'53"	84º40'13"	518	20	2.92	2.54	43.5	68.9	13.3	Pv

of impoundments in the Obed River watershed are located in areas that are underlain by the Rockcastle Conglomerate-Crooked Fork Group. The unit discharge of the Obed River near Lancing was used as an index to divide synoptic measurements into high- or low-baseflow categories. Measurements made when the unit discharge at the index site was greater than 0.1 cubic foot per second per square mile [(ft^3/s)/mi^2] were categorized as high baseflow, while all other synoptic measurements were categorized as low baseflow (appendix 1).

Precipitation and Streamflow

The average annual rainfall measured at the Crossville Experiment Station is about 57 inches for the 82-year period from 1930 through 2012 (National Climatic Data Center, 2014). Annual and cumulative departures from the 82-year average rainfall illustrate a pattern of generally higher rainfall since about 1970 (fig. 5). This pattern is consistent with results from numerous national and regional studies, which have documented a relatively abrupt increase in precipitation of 10 to 20 percent across the southeastern United States beginning about 1970 (Groisman and Easterling, 1994; Lettenmaier and others, 1994; Karl and others, 1996; Karl and Knight, 1998; Lins and Slack, 1999; Douglas and others, 2000; Easterling and others, 2000; Burkett and others, 2001; Groisman and others, 2001; McCabe and Wolock, 2002; Wolfe and others, 2003; Lins, 2005).

Annual flow-duration curves for the Emory River at Oakdale indicate recent historical change in hydrologic response at low flows, specifically an increase in the minimum values of the lowest flows since 1970 (fig. 6). Eighteen of 40 years between 1930 and 1970 had values for the 0.5th percentile flow of less than 3 cubic feet per second (ft^3/s). In contrast, the 42 years between 1970 and 2012 include only 2 years with values for the 0.5th percentile flow as low as 3 ft^3/s. This difference may partly reflect increases in regional rainfall after 1970 and evidenced by a general increase in average annual runoff post-1970 (fig. 5). However, increased average rainfall does not explain elevated low flows during periods of severe and sustained regional drought.

Comparison of the drought of 1952–54 with that of 2007–09 is instructive (table 6). Each drought was preceded by a similar wet period having about 600 inches of precipitation during the previous decade, and the first year of each drought had below average annual precipitation of about 40 inches. Moreover, both droughts produced discernible hydrologic effects during periods of about 3 years. The 1952–54 drought produced a minimum annual 0.5th percentile flow of 0.002 ft^3/s. By comparison, the 2007–09 drought produced minimum annual 0.5th percentile flow of 3 ft^3/s, which is more than 4 orders higher than that of the 1952–54 drought and equal to the 0.5th percentile flows after 1970 (fig. 6; table 6). Among known hydrologic changes in the Obed River watershed, increased wastewater return flows appear to be a likely explanatory factor in the sustainment of low flows during periods of severe drought.

Wastewater return flows for the 1950s are not readily available; however, census data show that the population of Cumberland County was relatively stable at about 19,000 to 21,000 persons between 1950 and 1970 (Center for Business and Economic Research, 2014). Beginning in 1970, the population of Cumberland County increased by 6,000 to 12,000 persons per decade, exceeding 54,000 by 2010 (table 1). Between 1995 and 2012, average return flows from the Crossville WWTP have ranged from 2.5 to 4.5 ft^3/s, with only 3 of 19 years falling below 3 ft^3/s (Robbie Baker, Tennessee Department of Environment and Conservation, written commun., 2010; City of Crossville, written commun., 2014; Veolia Water North America, written commun., 2014). It follows that wastewater return flows from Crossville are of sufficient magnitude to maintain low flows at or above 3 ft^3/s.

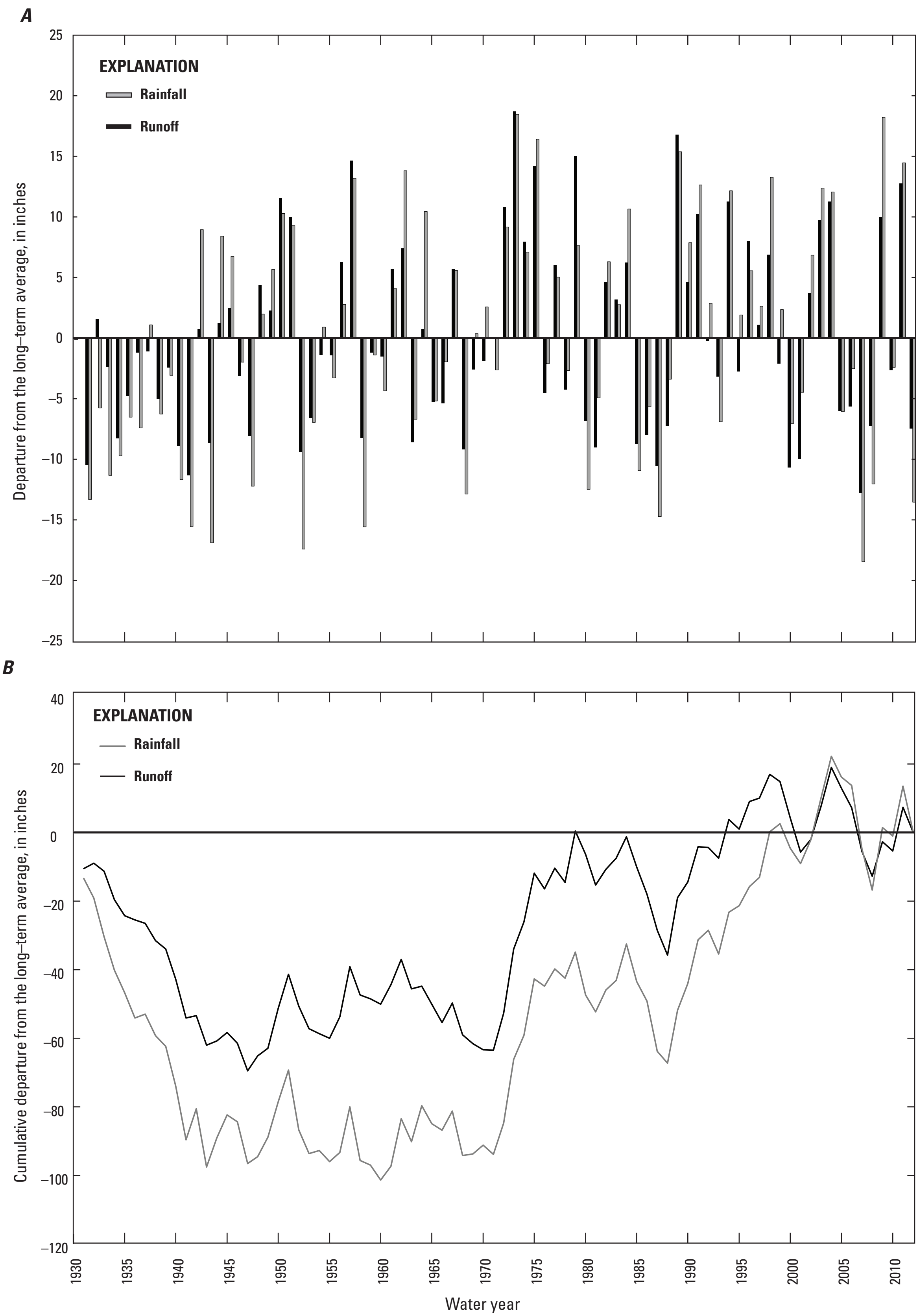


Figure 5. *A,* Annual and *B*, cumulative departures from average for annual rainfall at Crossville and annual runoff at the Emory River at Oakdale streamgage, 1930 through 2012.

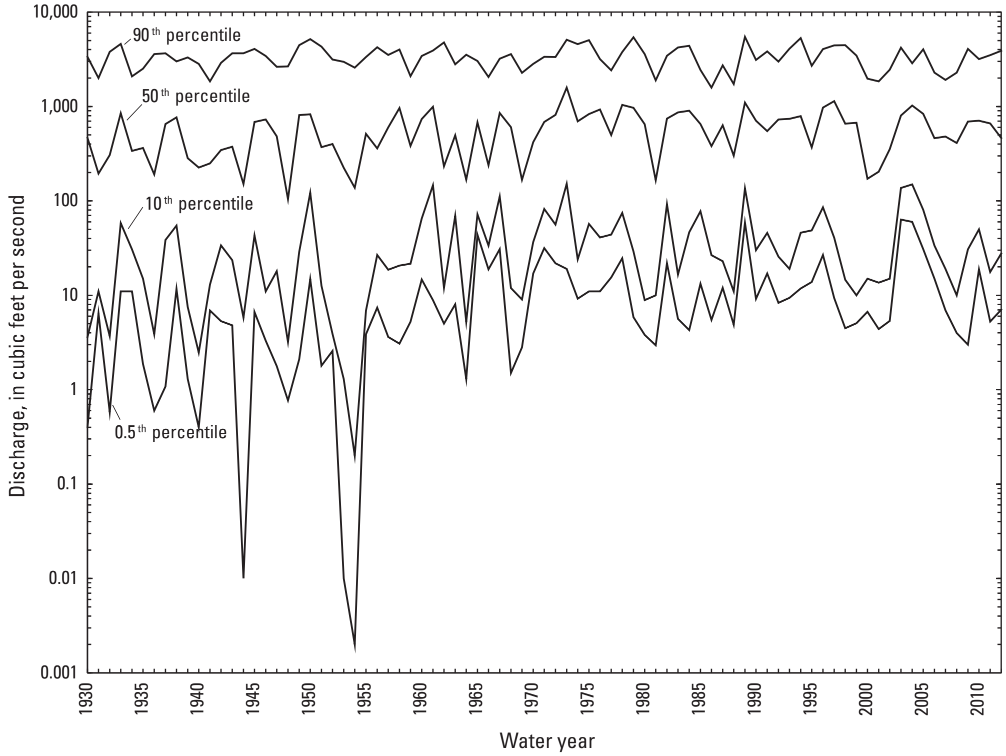


Figure 6. Annual flow-duration relations for Emory River at Oakdale, Tennessee, 1930 through 2012.

Table 6. Comparison of precipitation and resulting streamflows for two regional droughts in the Obed River Basin, 1952–2009.

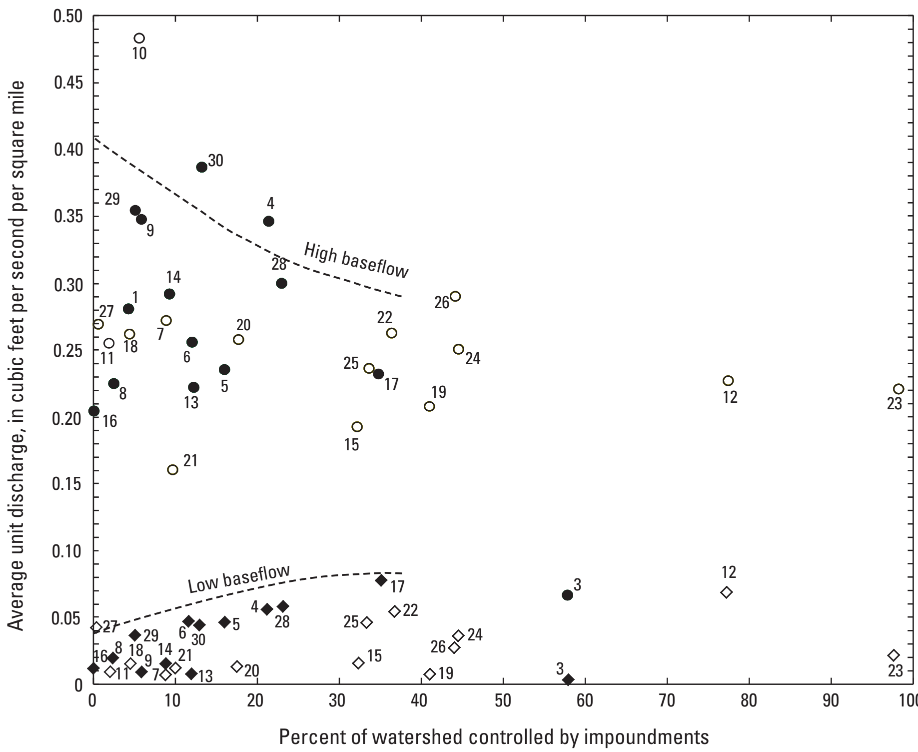
[Precipitation data for Crossville Experiment Station, National Climatic Data Center, 2014; 0.5th percentile flows based on Emory River at Oakdale, 1930–2012; average annual wastewater release based on written communication from Robbie Baker, Tennessee Department of Environment and Conservation, 2010 and City of Crossville, Veolia Water North America, 2014; ft³/s, cubic feet per second; –, data unavailable]

Drought period	Total precipitation (inches)		Annual precipitation for drought year (inches)	0.5th percentile flow (ft^3/s)	Average annual wastewater release (ft^3/s)
	Previous 10 years	Pervious 5 years			
1952	594	302	39.97	2.57	–
1953	567	296	50.43	0.01	–
1954	577	288	58.3	0.002	–
2007	603	309	40	6.932	2.8
2008	582	284	45.35	3.983	3.08
2009	557	260	75.61	3	3.8

Synoptic Analysis

Comparison of average unit discharge measured during high- and low-baseflow conditions with the percentage of watershed area controlled by impoundments shows that under high-baseflow conditions, unit discharge decreases as the percentage of watershed controlled by impoundments increases (table 7; fig. 7). Under low-baseflow conditions, unit discharge shows a weaker tendency to increase with increased percentage of drainage area controlled by impoundments (table 8; fig. 7). These observations are broadly consistent with the analysis of Smith and others (2002), who noted an increase in water retention, evapotranspiration, and groundwater recharge as effects of small impoundments. Under storm and high-baseflow conditions, impoundments retain water that would otherwise flow down the channel, thereby reducing streamflow magnitude downstream. Under low-baseflow conditions, some of the retained water seeps through, under, or around dams, thereby elevating downstream baseflow.

In the Obed River watershed, the relation between low baseflow and impoundments is most evident for basins primarily underlain by the Vandever Formation. Flow measurements from such basins define the upper envelope of the generally positive relation between low baseflow and percentage of drainage area controlled by impoundments (fig. 7). As previously noted, the Vandever Formation functions as a local confining unit, and outcrops of this formation commonly coincide with seeps and springs, except when breached by erosion. The low-baseflow effect of impoundments tends to further stabilize and elevate the low baseflows in the Obed WSR that are already augmented by effluent releases from the WWTP.



EXPLANATION

21 ○ High-baseflow measurement and site number, Rockcastle Conglomerate and Crooked Fork Group

19 ◇ Low-baseflow measurement and site number, Rockcastle Conglomerate and Crooked Fork Group

16 ● High-baseflow measurement and site number, Vandever Formation

3 ◆ Low-baseflow measurement and site number, Vandever Formation

See tables 5, 6, and 7 for site descriptions and data

Figure 7. Average high- and low-baseflow discharge measurements and the percentages of the Obed River watershed controlled by impoundments, 2003–2005.

Table 7. High-baseflow synoptic measurements for the Obed River watershed, Tennessee, 2003–2005.

[mi², square mile; (ft³/s)/mi², cubic feet per second per square mile; See appendix 1 for discharge measurement data]

Site number (on fig. 3)	Site name	Drainage area, mi²	Number of discharge measurements	Average unit discharge (ft³/s)/mi²	Drainage area controlled, percent	Selected impoundments in the watershed
			Rockcastle Conglomerate and Crooked Fork Group sites			
7	No Business Creek at US Hwy 127	2.85	3	0.271	9	farm ponds
10	White Creek at Lavendar Bridge at State Route 62	45.3	2	0.482	5.6	farm ponds
11	Little Clear Creek at State Route 62	10.6	3	0.255	2.3	farm ponds
12	Obed River at US Hwy 70	12.5	4	0.228	77.5	Lake Holiday
15	Fox Creek near Lavendar Knob	7.38	4	0.193	32.2	Fox Creek Lake, Frances Lake, Good Neighbor Lake
18	Daddys Creek west of Brown Gap	4.6	4	0.263	4.5	farm ponds
19	Self Creek at Big Lick Road near Big Lick	3.78	4	0.204	41	Lake Breckenridge #1 and #2
20	Daddys Creek at US Hwy 127 near Big Lick	10.3	4	0.257	17.7	Lake Breckenridge #1 and #2
21	Lick Creek at US Hwy 127	8.53	4	0.16	9.7	farm ponds
22	Basses Creek below Lake Tansi at US Hwy 127	13.1	4	0.261	36.5	Lake Tansi
23	Byrd Creek at US Hwy 127	10.3	4	0.22	98.3	Lake Mohawk, Lake Geronimo, Byrd Lake
24	Byrd Creek below Ward Creek confluence	24.8	4	0.251	44.6	Byrd Lake
25	North Creek above Brown Creek confluence	5.19	3	0.239	33.7	Lake Turner
26	Brown Creek above North Creek confluence	6.44	4	0.288	44.2	Lake St. George
27	Yellow Creek east of Cline School	9.97	3	0.264	0.6	farm ponds
			Vandever Formation sites			
1	Clear Creek above Panther Creek confluence	6.52	3	0.28	4.4	farm ponds
3	Panther Creek at Pugh Cemetery	3.05	2	0.066	57.9	Lake Caryonah
4	Clear Creek below Panther Creek confluence	9.57	2	0.345	21.4	farm ponds
5	Clear Creek at Clear Creek Road	14.4	3	0.236	16.1	farm ponds
6	Clear Creek at US Hwy 127	23.4	3	0.256	12.1	farm ponds
8	White Creek above Cook Creek confluence	19.1	3	0.227	2.6	farm ponds
9	White Creek below Cook Creek confluence	38.6	4	0.349	5.9	farm ponds
13	Drowning Creek above Copeland Creek confluence	10	3	0.223	12.3	farm ponds

Table 7. High-baseflow synoptic measurements for the Obed River watershed, Tennessee, 2003–2005.—Continued

[mi², square mile; (ft³/s)/mi², cubic feet per second per square mile; See appendix 1 for discharge measurement data]

Site number (on fig. 3)	Site name	Drainage area, mi²	Number of discharge measurements	Average unit discharge (ft³/s)/mi²	Drainage area controlled, percent	Selected impoundments in the watershed
			Vandever Formation sites—Continued			
14	Copeland Creek above Drowning Creek confluence	10.7	4	0.291	9.4	farm ponds
16	Elmore Creek near Genesis	7.82	4	0.206	0.1	farm ponds
17	Otter Creek at Catoosa Road	16.9	4	0.234	34.7	Stone Lake, Lake Dartmoor
28	Daddys Creek near Hebbertsburg	139	4	0.299	23	Lake Tansi, Lake Turner, Lake Glastowbury, others
29	Clear Creek at Lilly Bridge	170	3	0.353	5.1	farm ponds
30	Obed River near Lancing	518	4	0.387	13.3	Lake Holiday, Lake Dartmoor, Lake Tansi, others

Table 8. Low-baseflow synoptic measurements for the Obed River watershed, Tennessee, 2003–2005.

[mi², square mile; (ft³/s)/mi², cubic feet per second per square mile; See appendix 1 for discharge measurement data]

Site number (on fig. 3)	Site name	Drainage area, mi²	Number of discharge measurements	Average unit discharge (ft³/s)/mi²	Drainage area controlled, percent	Selected impoundments in the watershed
			Rockcastle Conglomerate and Crooked Fork Group sites			
7	No Business Creek at US Hwy 127	2.85	3	0.009	9	farm ponds
11	Little Clear Creek at State Route 62	10.6	3	0.013	2.3	farm ponds
12	Obed River at US Hwy 70	12.5	3	0.067	77.5	Lake Holiday
15	Fox Creek near Lavendar Knob	7.38	3	0.017	32.2	Fox Creek Lake, Frances Lake, Good Neighbor Lake
18	Daddys Creek west of Brown Gap	4.6	3	0.015	4.5	farm ponds
19	Self Creek at Big Lick Road near Big Lick	3.78	3	0.007	41	Lake Breckenridge #1 and #2
20	Daddys Creek at US Hwy 127 near Big Lick	10.3	3	0.015	17.7	Lake Breckenridge #1 and #2
21	Lick Creek at US Hwy 127	8.53	3	0.013	9.7	farm ponds
22	Basses Creek below Lake Tansi at US Hwy 127	13.1	3	0.052	36.5	Lake Tansi
23	Byrd Creek at US Hwy 127	10.3	3	0.022	98.3	Lake Mohawk, Lake Geronimo, Byrd Lake
24	Byrd Creek below Ward Creek confluence	24.8	2	0.031	44.6	Byrd Lake
25	North Creek above Brown Creek confluence	5.19	3	0.043	33.7	Lake Turner

Table 8. Low-baseflow synoptic measurements for the Obed River watershed, Tennessee, 2003–2005.—Continued

[mi^2, square mile; $(ft^3/s)/mi^2$, cubic feet per second per square mile; See appendix 1 for discharge measurement data]

Site number (on fig. 3)	Site name	Drainage area, mi^2	Number of discharge measurements	Average unit discharge $(ft^3/s)/mi^2$	Drainage area controlled, percent	Selected impoundments in the watershed
Rockcastle Conglomerate and Crooked Fork Group sites—Continued						
26	Brown Creek above North Creek confluence	6.44	3	0.029	44.2	Lake St. George
27	Yellow Creek east of Cline School	9.97	2	0.046	0.6	farm ponds
Vandever Formation sites						
3	Panther Creek at Pugh Cemetery	3.05	1	0	57.9	Lake Caryonah
4	Clear Creek below Panther Creek confluence	9.57	1	0.056	21.4	farm ponds
5	Clear Creek at Clear Creek Road	14.4	3	0.047	16.1	farm ponds
6	Clear Creek at US Hwy 127	23.4	3	0.049	12.1	farm ponds
8	White Creek above Cook Creek confluence	19.1	1	0.018	2.6	farm ponds
9	White Creek below Cook Creek confluence	38.6	3	0.013	5.9	farm ponds
13	Drowning Creek above Copeland Creek confluence	10	3	0.007	12.3	farm ponds
14	Copeland Creek above Drowning Creek confluence	10.7	3	0.013	9.4	farm ponds
16	Elmore Creek near Genesis	7.82	3	0.013	0.1	farm ponds
17	Otter Creek at Catoosa Road	16.9	3	0.077	34.7	Stone Lake, Lake Dartmoor
28	Daddys Creek near Hebbertsburg	139	3	0.059	23	Lake Tansi, Lake Turner, Lake Glastowbury, others
29	Clear Creek at Lilly Bridge	170	3	0.035	5.1	farm ponds
30	Obed River near Lancing	518	3	0.047	13.3	Lake Holiday, Lake Dartmoor, Lake Tansi, others

Summary and Conclusions

The data and observations presented in this report support the following conclusions:

1. Increased rainfall since 1970 has generally contributed to an increase in baseflows in the Obed WSR but does not fully explain increases in the lowest flow percentiles, which persist even during periods of historical drought;
2. The combination of headwater impoundments and wastewater treatment inflows appear to have generally stabilized and increased low baseflow in late summer and early fall; and
3. Climatic and human influences on streamflow conditions are either dampened or amplified by geologic controls on streamflow response, notably the tendency of the sandstones of the Rockcastle Conglomerate to accept infiltration and the tendency of the shales of the Vandever Formation to prevent infiltration and direct groundwater discharge to streams.

Acknowledgments

The authors thank Jeffrey C. Hughes and Steven Bakaletz of the National Park Service and W. Scott Gain and Michael W. Bradley of the U.S. Geological Survey for their support, assistance, and input to the study and this report. The National Park Service and the Tennessee Wildlife Resources Agency provided the support necessary to establish, reactivate, and maintain continuous-record gaging stations on the Obed River, Clear Creek, and Daddys Creek.

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Edited and prepared by:
USGS Science Publishing Network
Raleigh Publishing Service Center

Appendix 1. Synoptic data for the Obed River watershed, Tennessee, 2003–2005.

[See table 5 for site descriptions and locations; Q, discharge, in cubic feet per second; (D), month and day of observation; K, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; T, water temperature, in degrees Celsius; –, not observed]

Site no. (from figure 3)	Date and observation											
	High baseflow											
	7/14 –16/2003			5/10–12/2004			8/9–10/2004			6/6–7/2005		
	Q (D)	K	T	Q (D)	K	T	Q (D)	K	T	Q (D)	K	T
Obed River watershed synoptic sites												
1	0.87 (7/15)	66	21.9	–	–	–	1.1 (8/9)	46	18.8	–	–	–
2	0.26 (7/15)	73	17	–	–	–	–	–	–	–	–	–
3	0.38 (7/15)	64	25.3	–	–	–	0.02	–	–	–	–	–
4		–	–	5.4 (5/12)	43	15.6	1.2 (8/9)	47	19.1	–	–	–
5	1.93 (7/14)	64	12.7	6.4 (5/11)	51	17.4	1.9 (8/10)	61	16.9	–	–	–
6	4.4 (7/14)	80	21.1	9.4 (5/11)	59	16.5	4.2 (8/9)	75	18.8	–	–	–
7	1.2 (7/15)	114	16.7	0.83 (5/11)	74	18.1	0.29 (8/9)	107	18.6	–	–	–
8	22.1 (7/15)	32	18.3	7.7 (5/10)	30	16.3	2.9 (8/9)	34	16.7	2.4 (6/6)	32	18.4
9	23.4 (7/15)	49	20.4	17.8 (5/10)	30	17.5	7.5 (8/9)	38	17.3	5.2 (6/6)	35	19
10	24.4 (7/15)	35	20.4	19.3 (5/10)	32	17.8	–	–	–	–	–	–
11	22.4 (7/15)	25	18.1	4.8 (5/10)	27	16.6	2 (8/9)	31	17.7	1.3 (6/6)	32	20
12	2.3 (7/14)	162	21.4	5.5 (5/11)	141	18.3	1.4 (8/10)	191	20.5	2.2 (6/7)	220	19.4
13	2.4 (7/14)	68	13.6	3.5 (5/11)	69	18.2	0.78 (8/10)	91	18.9	–	–	–
14	3.3 (7/14)	66	13	–	–	–	0.76 (8/10)	73	18.3	3.7 (6/7)	63	19.6
15	1.1 (7/16)	32	20	3.2 (5/10)	24	14.9	0.21 (8/9)	31	16.3	1.2 (6/6)	25	19.3
16	0.73 (7/16)	26	19.6	3.9 (5/10)	24	14.3	0.8 (8/9)	30	16.5	1 (6/6)	23	17.7
17	3.7 (7/16)	83	23	8.4 (5/12)	56	17.3	0.74 (8/10)	–	–	3 (6/7)	62	19
18	2.2 (7/14)	43	20.1	1.5 (5/11)	41	17.2	0.57 (8/10)	54	18.2	0.57 (6/6)	–	–
19	1.2 (7/14)	30	21.5	1.4 (5/11)	28	16.7	0.22 (8/10)	33	18	0.26 (6/6)	–	–
20	4.1 (7/14)	38	21	4 (5/11)	36	17.9	1.4 (8/10)	48	19.5	1.1 (6/6)	–	–
21	1.5 (7/14)	66	21.3	2.4 (5/11)	50	17.7	1 (8/10)	66	18.9	0.57 (6/6)	–	–
22	4 (7/14)	80	23.7	6.5 (5/11)	63	19.5	1.8 (8/10)	74	20.9	1.4 (6/6)	–	–
23	4.5 (7/14)	75	23.2	3.3 (5/11)	76	19.5	0.77 (8/10)	88	22.4	0.48 (6/6)	–	–
24	7.5 (7/15)	109	22.5	12.2 (5/11)	106	18.2	2.6 (8/10)	143	21.6	2.6 (6/7)	–	–
25	1.2 (7/15)	100	22	5.1 (5/11)	97	18.1	0.72 (8/10)	106	19.5	1.8 (6/7)	–	–
26	2.3 (7/15)	109	21.1	4.1 (5/11)	87	17.4	0.3 (8/10)	132	18.3	0.73 (6/7)	–	–
27	10.4 (7/15)	54	19.8	5.3 (5/11)	251	15.3	1.1 (8/9)	148	18.8	1.5 (6/7)	184	18.7
Obed River watershed index sites												
28	59 (7/14)	–	–	72 (5/10)	–	–	26 (8/9)	–	–	27 (6/6)	–	–
	47 (7/15)	–	–	70 (5/11)	–	–	21 (8/10)	–	–	25 (6/7)	–	–
	38 (7/16)	–	–	62 (5/12)	–	–	–	–	–	–	–	–
29	252 (7/14)	–	–	84 (5/10)	–	–	36 (8/9)	–	–	36 (6/6)	–	–
	139 (7/15)	–	–	104 (5/11)	–	–	30 (8/10)	–	–	62 (6/7)	–	–
	98 (7/16)	–	–	106 (5/12)	–	–	–	–	–	–	–	–
30	420 (7/14)	–	–	306 (5/10)	–	–	90 (8/9)	–	–	137 (6/6)	–	–
	250 (7/15)	–	–	311 (5/11)	–	–	71 (8/10)	–	–	119 (6/7)	–	–
	179 (7/16)	–	–	315 (5/12)	–	–	–	–	–	–	–	–

Appendix 1. Synoptic data for the Obed River watershed, Tennessee, 2003–2005.—Continued

[See table 5 for site descriptions and locations; Q, discharge, in cubic feet per second; (D), month and day of observation; K, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; T, water temperature, in degrees Celsius; –, not observed]

Site no. (from figure 3)	Date and observation								
	Low baseflow								
	6/22–23/2005			9/12–13/2005			11/1/2005, 11/2/2005, 11/4/2005		
	Q (D)	K	T	Q (D)	K	T	Q (D)	K	T
Obed River watershed synoptic sites									
1	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–
3	0 (6/23)	–	–	–	–	–	–	–	–
4	0.54 (6/23)	50	21.8	–	–	–	–	–	–
5	1 (6/23)	–	–	0.1 (9/13)	99	20.3	0.93 (11/2)	94	10.9
6	2.5 (6/23)	75	20.2	0.5 (9/13)	97	18.9	0.46 (11/2)	107	11.3
7	0.02 (6/23)	144	18.1	0.03 (9/13)	–	–	0.03 (11/2)	173	10.2
8	0.35 (6/22)	34	18.4	–	–	–	–	–	–
9	1.2 (6/22)	41	19.2	0.14 (9/12)	42	19.5	0.12 (11/1)	84	7.2
10	–	–	–	–	–	–	–	–	–
11	0.3 (6/22)	38	19.6	0.09 (9/12)	52	19.8	0.02 (11/1)	69	8.2
12	1.2 (6/23)	–	–	0.84 (9/13)	186	18.5	0.48 (11/2)	369	11.8
13	0.14 (6/23)	118	19	0.04 (9/13)	209	19.1	0.04 (11/2)	177	10.8
14	0.39 (6/23)	70	21.2	–	–	–	0.02 (11/2)	144	12.8
15	0.26 (6/22)	30	19.1	0.07 (9/12)	46	19.7	0.04 (11/1)	52	9.1
16	0.29 (6/22)	26	17.4	0.001 (9/12)	–	–	0.001 (11/1)	–	–
17	1.9 (6/22)	65	19.3	1.1 (9/12)	79	18.8	0.89 (11/1)	88	9.4
18	0.13 (6/22)	–	–	0.02 (9/13)	–	–	0.06 (11/4)	62	9.1
19	0.01 (6/22)	–	–	0.01 (9/13)	–	–	0.06 (11/4)	40	10.2
20	0.39 (6/22)	–	–	0.04 (9/13)	–	–	0.04 (11/4)	59	10.9
21	0.11 (6/22)	–	–	0.04 (9/13)	–	–	0.18 (11/4)	74	9.7
22	0.74 (6/22)	–	–	0.59 (9/13)	–	–	0.73 (11/4)	92	10.4
23	0.32 (6/22)	–	–	0.22 (9/13)	–	–	0.15 (11/4)	111	10.5
24	1.1 (6/22)	–	–	0.46 (9/13)	–	–	–	–	–
25	0.27 (6/23)	–	–	0.26 (9/13)	83	19.1	0.14 (11/1)	124	9.7
26	0.22 (6/23)	–	–	0.2 (9/13)	139	18.2	0.14 (11/2)	140	7.8
27	0.78 (6/23)	–	–	1.1 (9/13)	–	–	0.14 (11/2)	227	8.6
Obed River watershed index sites									
28	11 (6/22)	–	–	11 (9/12)	–	–	5.7 (11/1)	–	–
	9.9 (6/23)	–	–	9.4 (9/13)	–	–	5.4 (11/2)	–	–
	–	–	–	–	–	–	4.8 (11/4)	–	–
29	14 (6/22)	–	–	4 (9/12)	–	–	1.6 (11/1)	–	–
	13 (6/23)	–	–	3.4 (9/13)	–	–	1.7 (11/2)	–	–
	–	–	–	–	–	–	1.4 (11/4)	–	–
30	45 (6/22)	–	–	22 (9/12)	–	–	12 (11/1)	–	–
	40 (6/23)	–	–	21 (9/13)	–	–	11 (11/2)	–	–
	–	–	–	–	–	–	11 (11/4)	–	–

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Knight, Wolfe, and Law—**Hydrologic Data for the Obed River Watershed, Tennessee**—Open-File Report 2014–1102

ISBN 978-1-4113-3795-4

9 781411 337954

Printed on recycled paper

ISSN 0196-1497 (print)
ISSN 2331-1258 (online)
http://dx.doi.org/10.3133/ofr20141102