

Prepared in cooperation with Macon County, North Carolina

Suspended Sediment and Bed Load in Three Tributaries to Lake Emory in the Upper Little Tennessee River Basin, North Carolina, 2000–02

U.S. Geological Survey
Water-Resources Investigations Report 03–4194

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

Suspended Sediment and Bed Load in Three Tributaries to Lake Emory in the Upper Little Tennessee River Basin, North Carolina, 2000–02

By Carolyn J. Oblinger

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 03–4194

Prepared in cooperation with
Macon County, North Carolina

Raleigh, North Carolina
2003



U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

The use of firm, trade, and brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Government.

Additional information about U.S. Geological Survey programs and products in North Carolina can be obtained from the Web site: <http://nc.water.usgs.gov>

For additional information write to:

District Chief
U.S. Geological Survey
3916 Sunset Ridge Road
Raleigh, NC 27607

dc_nc@usgs.gov

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286, Federal Center
Denver, CO 80225

1-888-ASK-USGS

CONTENTS

Abstract	1
Introduction	1
Purpose and scope	3
Study area	3
Acknowledgments	3
Data-collection methods	4
Streamflow data	5
Suspended-sediment data	6
Bed-load data	6
Particle size	6
Streamflow	6
Estimation of streamflow in the Cullasaja River	9
Estimation of Porter's Bend dam releases	13
Suspended sediment	13
Load	13
Particle size	19
Bed material	21
Bed load	21
Particle size	23
Summary	23
References	24

FIGURES

1–2. Maps showing:	
1. Location of the upper Little Tennessee River basin, North Carolina	2
2. Locations of streamgages and sediment-sampling sites in the upper Little Tennessee River basin, North Carolina	4
3. Photograph of a Helley-Smith bed-load sampler	6
4–13. Graphs showing:	
4. Total annual precipitation at the Franklin, North Carolina, Weather Station for 1990–2001, and the long-term average annual rainfall	7
5. Long-term minimum and median daily-mean streamflow and daily-mean streamflow for water year 2001 at (A) the Little Tennessee River near Prentiss and (B) Cartoogechaye Creek near Franklin, North Carolina	7
6. Departure from mean-monthly streamflow at (A) the Little Tennessee River near Prentiss and (B) Cartoogechaye Creek near Franklin, North Carolina, and (C) monthly rainfall at the Franklin Weather Station	8
7. Distributions of sampled streamflows at (A) the Little Tennessee River and (B) Cartoogechaye Creek in relation to long-term streamflow durations from streamgages at the Little Tennessee River near Prentiss and Cartoogechaye Creek near Franklin, North Carolina	9
8. Relation of daily-mean streamflow in the Cullasaja River to daily-mean streamflows at Cartoogechaye Creek near Franklin and the Little Tennessee River near Prentiss, North Carolina, for water years 1970–71	10

9. Relation of instantaneous and daily-mean streamflows at the Cullasaja River near Franklin, North Carolina, to instantaneous (2001–02) and daily-mean (1970–71) streamflows at the Little Tennessee River near Prentiss and Cartoogechaye Creek near Franklin	12
10. Distribution of suspended-sediment concentrations at the four Little Tennessee River basin study sites in North Carolina	16
11. Relation of daily sediment load to instantaneous streamflow at (A) the Cullasaja River near Franklin, (B) Cartoogechaye Creek near Franklin, and (C) the Little Tennessee River at Riverside, North Carolina	17
12. Relation of daily suspended-sediment load and instantaneous streamflow at Cartoogechaye Creek near Franklin, North Carolina, for 1977–79 and 2001	19
13. Distribution of percentages of suspended-sediment particles finer than 0.062 millimeter at the four Little Tennessee River basin study sites in North Carolina	21

TABLES

1. Selected U.S. Geological Survey streamgaging stations in the upper Little Tennessee River basin, North Carolina	5
2. Regression equations relating streamflow at the two Little Tennessee River basin index sites to streamflow in the Cullasaja River, North Carolina	11
3. Relation of streamflow measured at the Cullasaja River to streamflow at Cartoogechaye Creek near Franklin and the Little Tennessee River near Prentiss, North Carolina, during water years 2001 and 2002	11
4. Streamflow statistics for the Little Tennessee River basin, North Carolina, study sites for the 2001 water year	13
5. Suspended-sediment concentrations at the four Little Tennessee River basin study sites in North Carolina and measured or estimated streamflow at three of the study sites.....	14
6. Results of regression analyses relating the natural log of instantaneous suspended-sediment load to the natural log of instantaneous streamflow at three Little Tennessee River basin study sites in North Carolina	18
7. Estimated suspended-sediment loads and yields at the three study sites and at sites sampled in 1970–79 in the Little Tennessee River basin, North Carolina	18
8. Streamflow and suspended-sediment concentration and particle-size distributions in samples from the four Little Tennessee River basin study sites in North Carolina	20
9. Bed load and suspended-sediment load during three runoff events at three sites in the Little Tennessee River basin in North Carolina	22
10. Particle-size distribution in bed-load samples from three sites in the Little Tennessee River basin in North Carolina	23

CONVERSION FACTORS, ABBREVIATIONS, and ACRONYMS

	Multiply	By	To obtain
Length			
	millimeter (mm)	0.03937	inch
	centimeter (cm)	0.3937	inch
	meter (m)	3.281	foot
		1.094	yard
	kilometer (km)	0.6214	mile
Area			
	hectare (ha)	2.471	acre
	square kilometer (km ²)	0.3861	square mile
Volume			
	cubic meter (m ³)	35.31	cubic foot
		1.308	cubic yard
Flow			
	meter per second (m/s)	3.281	foot per second
	cubic meter per second (m ³ /s)	35.31	cubic foot per second
	cubic meter per second per square kilometer [(m ³ /s)/km ²]	91.49	cubic foot per second per square mile
Mass			
	kilogram (kg)	2.205	pound
	metric ton (t)	1.102	short ton (2,000 pounds)
	metric ton per day (t/d)	1.102	short ton (2,000 pounds)
	metric ton per square kilometer (t/km ²)	2.855	short ton (2,000 pounds) per square mile

Abbreviated water-quality units: mg/L, milligram per liter
L, liter (a unit of volume equal to approximately 1.056 quarts)

Acronyms:

EWI	equal-width integrated
FISP	Federal Interagency Sedimentation Project
MEWI	multiple equal-width increment
NOAA	National Oceanic and Atmospheric Administration
NWIS	National Water Information System
USGS	U.S. Geological Survey
VA	visual accumulation

GLOSSARY

Daily-mean streamflow—The mean streamflow for any one day. For example, the daily-mean streamflow for October 10, 2002.

Annual-mean streamflow—The arithmetic mean of the daily-mean streamflows for the year noted or for the designated period. For example, the annual-mean streamflow for 1944 to 2001 is the arithmetic mean of all daily-mean streamflow for that period.

Mean-monthly streamflow—The arithmetic mean of the means of record for a specific month during a specific period of years. For example, the mean-monthly streamflow for October is the arithmetic mean of all October means during 1944 to 2001.

Suspended Sediment and Bed Load in Three Tributaries to Lake Emory in the Upper Little Tennessee River Basin, North Carolina, 2000–02

By Carolyn J. Oblinger

ABSTRACT

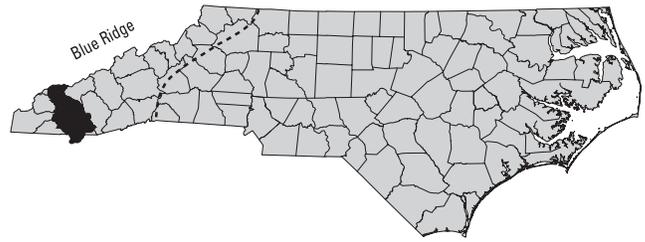
A study was conducted in the upper Little Tennessee River basin to characterize suspended-sediment and bed-load sediment transport into Lake Emory from the main stem and two major tributaries—Cartoogechaye Creek and the Cullasaja River. Suspended-sediment concentrations in the discharge from Lake Emory also were measured. Weekly samples for suspended-sediment concentration were collected between November 2000 and November 2001, and periodic samples were collected during targeted high-flow events. Suspended-sediment samples were collected during stormwater runoff conditions for analysis of particle-size distribution. Three bed-load samples were collected at each stream site.

The greatest annual load (5,700 metric tons) and yield (18 metric tons per square kilometer) of suspended sediment during the study period were in the Little Tennessee River near Riverside, North Carolina. Much smaller annual yields were calculated for Lake Emory, the Cullasaja River, and Cartoogechaye Creek (5, 5, and 7 metric tons per square kilometer, respectively). Drought conditions during the study period appear to have been a factor in the small loads compared to loads measured in the same area in the 1970's. The annual-mean streamflow at the Little Tennessee River at Prentiss during 2001 was about 50 percent of the long-term annual-mean streamflow (1944–2001). High-flow events carry most of the annual sediment load.

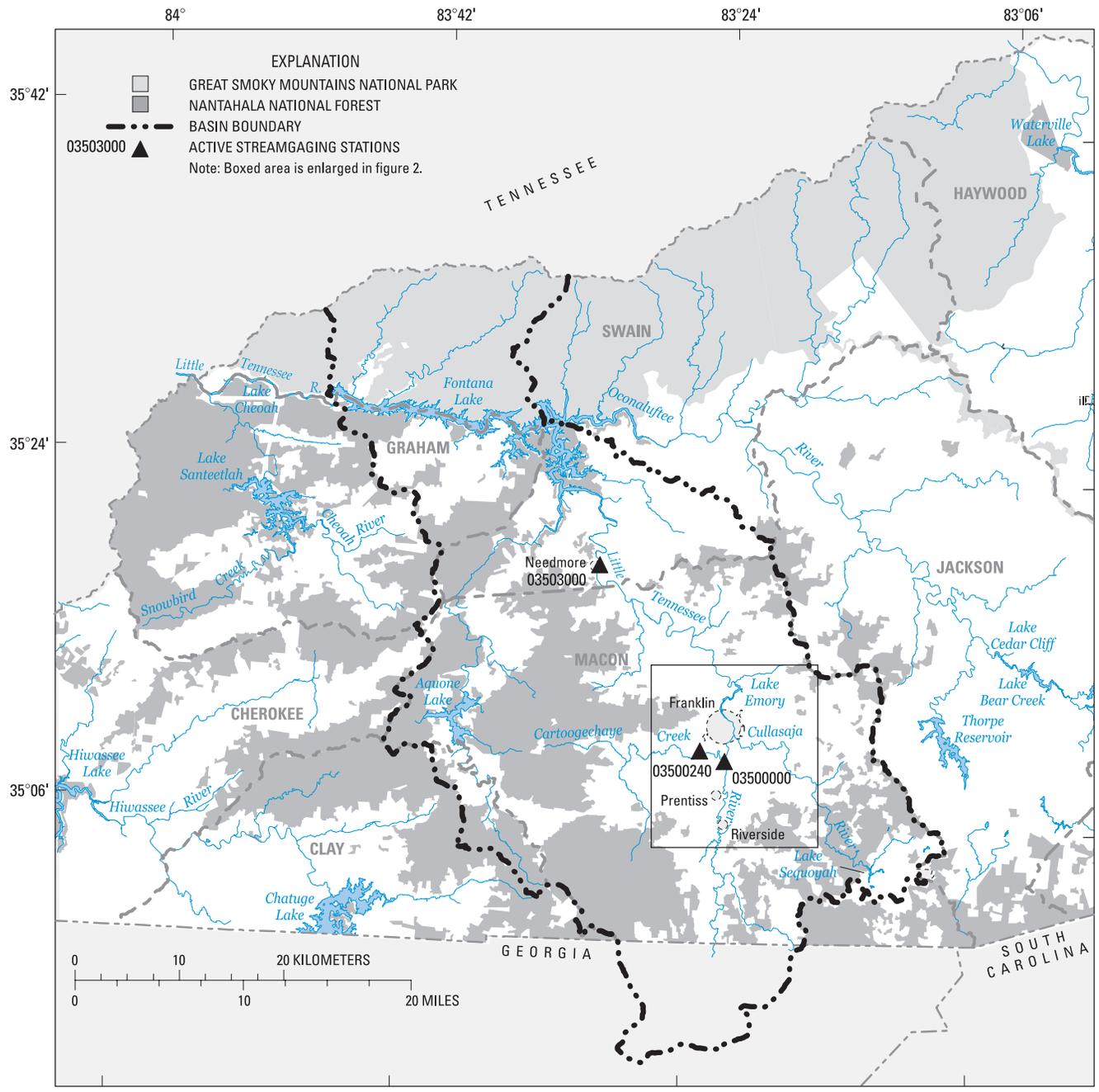
INTRODUCTION

The upper Little Tennessee River basin in western North Carolina is part of the Little Tennessee River basin upstream from Fontana Lake (fig. 1). The upper basin is mountainous and rural—less than 5 percent of the land use in the basin is classified as urban and 89 percent is forested. Parts of the basin lie within the Great Smoky Mountains National Park and Nantahala National Forest. Because the Little Tennessee River is a mountain river, its tributaries typically have relatively steep gradients and riffle habitats capable of supporting trout populations (North Carolina Division of Water Quality, 2000). The Little Tennessee River also supports a large variety of other aquatic species, including three rare species on the Federal endangered species list—the Appalachian elktoe mussel (*Alasmidonta raveneliana*), the little-wing pearly mussel (*Pegias fabula*), and the Spotfin chub (*Cyprinella monacha*). The Little Tennessee River basin is the only basin in North Carolina where the slippershell mussel (*Alasmidonta viridis*) and Tennessee pigtoe mussel (*Fusconaia barnesiana*) can be found.

A major water-quality issue in the rural setting of the Little Tennessee River basin is sedimentation—both historic and recent (North Carolina Division of Water Quality, 2002). Sedimentation is the primary factor affecting ecological communities in the basin (Harding and others, 1998), resulting in loss of in-stream microhabitats and aquatic-habitat degradation. Sedimentation is caused primarily by land-clearing



LOCATION OF LITTLE TENNESSEE RIVER BASIN AND BLUE RIDGE PHYSIOGRAPHIC PROVINCE IN NORTH CAROLINA



Base from digital files of:
 U.S. Department of Commerce, Bureau of Census,
 1990 Precensus TIGER/Line Files-Political boundaries, 1991
 Environmental Protection Agency, River File 3
 U.S. Geological Survey, 1:100,000 scale

Figure 1. Location of the upper Little Tennessee River basin, North Carolina.

activities, rural roads, loss of riparian vegetation to agriculture and silviculture, and urban runoff. In addition, landscape features, such as high stream-channel gradients, are important factors contributing to sedimentation rates (Scott and others, 2002). Harding and others (1998) reported that the conditions of current aquatic communities are related more to past land use than to current land use.

Historically, sediment has clogged the channel of the upper Little Tennessee River and has deposited sediment in Lake Emory (fig. 1; North Carolina Department of Environment, Health, and Natural Resources, 1992, p. 155). Riparian agricultural practices, such as stock watering and growing specialty vegetable crops, and more recently, increasing urbanization in the upper portion of the watershed in the towns of Highlands and Franklin have increased the river's suspended-sediment load and bed load. Thus, by trapping sediments, Lake Emory has protected important natural resources downstream, particularly in respect to several federally listed species of freshwater mussel.

Suspended-sediment data are available from the 1970's for the Little Tennessee River at Needmore and Cartoogechaye Creek near Franklin (Simmons, 1993). Average annual suspended-sediment loads were calculated to be 100,000 metric tons (t) for the Little Tennessee River at Needmore and 10,000 t for Cartoogechaye Creek near Franklin for the 1970's. Average annual suspended-sediment yields at these sites were 110 and 81 metric tons per square kilometer (t/km^2), respectively. By comparison, an average yield of 68 t/km^2 was calculated for rural, agricultural sites in the upper Tennessee River basin (Simmons, 1993).

Federal, State, and local agencies and organizations are working to restore degraded aquatic resources in the upper Little Tennessee River and some of its tributaries, including protection and enhancement of threatened and endangered species populations and wetland restoration. Key to developing restoration strategies is a better understanding of the amount of sediment that is transported in the upper Little Tennessee River, the sediment sources and particle-size characteristics, and the amount of sediment that is transported past Porter's Bend dam at Lake Emory. The data collected during this investigation begin to address these issues.

Purpose and Scope

This report describes the results of a study to characterize suspended-sediment and bed-load sediment transport into Lake Emory from the main stem of the Little Tennessee River and two major tributaries—Cartoogechaye Creek and the Cullasaja River. Suspended-sediment concentration in discharge from Lake Emory also was measured. Sediment samples were collected weekly over a 12-month period from November 2000 to November 2001. In addition, three bed-load measurements were made between October 2001 and September 2002.

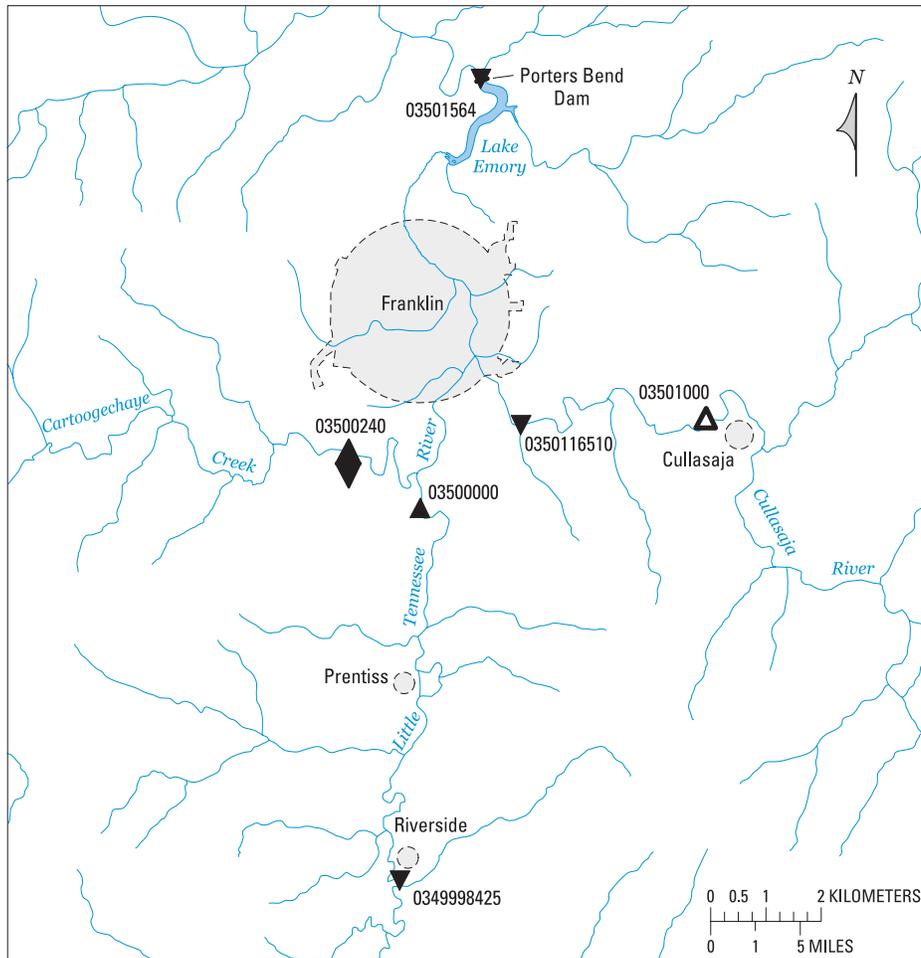
Study Area

The Little Tennessee River basin is in the Blue Ridge Physiographic Province. The river rises in Georgia near the North Carolina border and flows north through North Carolina into Tennessee (fig. 1) where it joins the Tennessee River. The upper Little Tennessee River basin is the area of the Little Tennessee River basin that is upstream from Fontana Lake. The study area includes the portion of the upper Tennessee River basin upstream from Porter's Bend dam at Lake Emory (fig. 2). The study area is drained by the Little Tennessee River, the Cullasaja River, and Cartoogechaye Creek. The Cullasaja River and Cartoogechaye Creek join the Little Tennessee River near Franklin, N.C. (fig. 2).

Lake Emory is a 76-hectare (ha) reservoir built in the 1920's as a source of hydropower. Nantahala Power and Light Company has owned and operated the lake since 1933 (North Carolina Department of Environment, Health, and Natural Resources, 1992). Based on lake samples collected in July 1988, the lake has been described as eutrophic and shallow and having a short retention time (North Carolina Department of Environment, Health, and Natural Resources, 1992). Suspended-solids concentrations at each of three sites sampled in the lake were at least 18 milligrams per liter (mg/L).

Acknowledgments

This investigation was cooperatively funded by the U.S. Geological Survey (USGS) and Macon County, N.C. The author wishes to thank Eugene Gonzales of Macon County for collecting weekly



EXPLANATION

SITES AND USGS SITE NUMBER

- 03501000  DISCONTINUED STREAMGAGE
- 03500000  STREAMGAGE ONLY
- 0349998425  SEDIMENT ONLY
- 03500240  STREAMGAGE AND SEDIMENT

Figure 2. Locations of streamgages and sediment-sampling sites in the upper Little Tennessee River basin, North Carolina.

suspended-sediment samples regardless of weather conditions. The author also wishes to acknowledge the assistance of Gene Barker and his staff from the USGS Field Office in Asheville, N.C. Leadership in bringing together the partners who supported this investigation was provided by Linda Adcock of the U.S. Army Corps of Engineers in Nashville, Tenn.

DATA-COLLECTION METHODS

The data-collection methods used during this investigation are consistent with published USGS protocols (Rantz and others, 1982; U.S. Geological Survey, 1997–present; Edwards and Glysson, 1999). Results of all sediment analyses are stored in the USGS

National Water Information System (NWIS) water-quality database.

Streamflow Data

Streamflow in the upper Little Tennessee River basin was determined from measurements from available streamgauge records (Rantz and others, 1982) or from estimates based on record from a nearby streamgauge. The streamgages in the study area are operated and maintained by the USGS in cooperation with the North Carolina Department of Environment and Natural Resources.

Of the four study sites (table 1), streamflow is recorded continuously only at Cartoogechaye Creek near Franklin. Streamflow at the Little Tennessee River at Riverside was estimated from streamflow record at the Little Tennessee River near Prentiss, about 4.8 kilometers (km) downstream. Streamflow near Prentiss was reduced by multiplying by a factor determined by the ratio of the drainage areas ($311 \text{ km}^2 / 363 \text{ km}^2 = 0.857$) to obtain an estimate of the streamflow at Riverside.

Estimating the streamflow at Cullasaja River near Franklin was more complex, however, because no streamgauge was in operation on the Cullasaja River during the study period. A location just upstream from

the Cullasaja study site was operated from 1921 to 1971—Cullasaja River at Cullasaja, N.C. (03501000). Although the difference in the drainage areas of the two sites is only 12 km^2 , a stage-streamflow relation from this gage was too dated to be useful. In addition, a 60-ha drinking-water reservoir, Lake Sequoyah, impounds the upper 23 km^2 of the watershed and potentially affects streamflow downstream (fig. 1).

As a result, two nearby streamgages were selected as potential index sites for estimating streamflow at the Cullasaja River near Franklin—the Little Tennessee River near Prentiss (03500000) and Cartoogechaye Creek near Franklin (03500240). Historic streamflow records were retrieved from the NWIS surface-water database and analyzed to determine which of the two sites was the better index site.

Discharge below the dam at Lake Emory also had to be estimated. Although water is released through the turbines at the Porter's Bend dam for power generation, no records of the releases are maintained by Nantahala Power and Light Company (Richard Conley, Duke Power Lake Management, oral commun., December 20, 2001). In addition, leakage occurs through the dam structure, and when lake levels are high, water also may be released over the spillway. An annual-mean streamflow was estimated for 2001 based

Table 1. Selected U.S. Geological Survey streamgaging stations in the upper Little Tennessee River basin, North Carolina

[USGS, U.S. Geological Survey; km^2 , square kilometer; m^3/s , cubic meter per second; t, metric ton; t/km^2 , metric ton per square kilometer; **bold**/shaded station numbers and names identify sites sampled for this study; —, no data]

USGS station number ^a (fig. 2)	Station name	Period of streamflow record (water years ^b)	Drainage area (km^2)	Annual-mean streamflow (m^3/s)		Annual suspended sediment	
				Period of record	2001 water year	Load (t)	Yield (t/km^2)
0349998425	Little Tennessee River at Riverside	—	311	—	—	—	—
03500000	Little Tennessee River near Prentiss	1943–present	363	11	5.44	—	—
03500240	Cartoogechaye Creek near Franklin	1944, 1947, 1953–55, 1958, 1960, 1961–present	148	4.1	2.09	10,000	81
0350116510	Cullasaja River near Franklin	—	236	—	—	—	—
03501000	Cullasaja River at Cullasaja	1907–09, 1921–71	224	—	—	—	—
03501564	Lake Emory at the dam near Franklin	—	804	—	—	—	—
03503000	Little Tennessee River at Needmore	1943–81, 1983–present	1,130	29.9	15.2	100,000	110

^a Station number is assigned by the U.S. Geological Survey on the basis of geographic location. The downstream order number system is used for surface-water sites.

^b Water year is the period October 1 through September 30 and is identified by the year in which the period ends.

on record from the streamgage at the Little Tennessee River at Needmore about 32 km below the dam (fig. 1).

Suspended-Sediment Data

Stream samples for analysis of suspended-sediment concentration were collected once per week at each of the four study sites. In addition, several samples were collected during targeted high-flow events. At each data-collection stream site, a box enclosure containing a US-D-74 suspended-sediment sampler was mounted to a bridge rail at the approximate center of streamflow (Edwards and Glysson, 1999). Macon County staff used this equipment to collect single, vertical, suspended-sediment samples (box samples) once per week. The US-D-74 sampler is one of a number of samplers designed by the Federal Interagency Sedimentation Project (FISP) for use in collecting a depth-integrated suspended-sediment sample. USGS staff used a US-DH-81 or US-DH-59 sampler periodically to collect equal-width integrated (EWI) suspended-sediment samples that could be used to validate the single, vertical samples as being representative of the average suspended-sediment concentration in the stream cross section. Suspended-sediment concentrations in samples collected using the EWI method were compared to concentrations measured in the box samples. The samples were shipped to the USGS sediment laboratory in Louisville, Ky., and analyzed for suspended-sediment concentration. Samples were analyzed by using the filtration method described by Guy (1977).

Bed-Load Data

A Helley-Smith type sampler was used to sample bed load (fig. 3). The sampler is designed to collect particles less than 76 millimeters (mm) at mean velocities up to 3.0 meters per second (m/s). The sampler has a 76-mm by 76-mm opening to a 0.25-mm mesh sampling bag that is supported by a metal frame. The sampler weighs 29.9 kilograms (kg). The nozzle-expansion ratio is 3.1.

Bed-load samples were analyzed for total weight by the USGS sediment laboratory in Iowa City, Iowa, using methods described by Guy (1977). Two samples were collected from each stream site using the multiple equal-width-increment (MEWI) method (Edwards and Glysson, 1999, p. 75). Each stream cross section was



Figure 3. Helley-Smith bed-load sampler.

sampled at five equally spaced locations. The sampler was positioned on the streambed at each location for 20 minutes in October 2001 when streamflow was low, and for 5 minutes in January and September 2002 when streamflow was much greater. Two transects were collected for a total of 10 subsamples for each sample. Subsamples were combined into one composite sample that was analyzed for total weight and particle-size distribution. The number of subsections, width of each subsection, time the sampler rested on the streambed, number of transects, and average streamflow during the sampling period were recorded.

Particle Size

Selected suspended-sediment samples were analyzed for the distribution of particle sizes. The quantity of material collected was, for most samples, insufficient for a full particle-size analysis. Therefore, samples were sieved according to Guy (1977) to determine the percentage of particles finer than sand—less than (<) 0.062 mm. However, at least one suspended-sediment sample from each stream site was analyzed for a more complete range of particle sizes by using the visual accumulation (VA) tube method (Guy, 1977). Each bed-load sample was analyzed for particle-size distribution by the USGS sediment laboratory in Iowa City using methods described by Guy (1977).

STREAMFLOW

A severe drought was occurring in western North Carolina during the study period. Rainfall at the National Oceanic and Atmospheric Administration's

(NOAA) Franklin, N.C., weather station typically averages 134 centimeters (cm) per year based on data collected from 1949 through 2000 (Southeast Regional Climate Center, 2003). Rainfall amounts at the Franklin weather station are seasonally variable but declined steadily overall from about July 1998 (fig. 4). Ninety percent of the daily-mean streamflows in 2001 were less than the median daily-mean streamflow at the Little Tennessee River near Prentiss and Cartoogechaye Creek near Franklin (fig. 5), and the annual-mean streamflow for 2001 was 50 percent of the long-term annual-mean streamflow (table 1). Moreover, new minimum values for daily-mean streamflow were established for 12 and 18 percent of the days in 2001 at the Little Tennessee River near Prentiss and Cartoogechaye Creek near Franklin, respectively. Monthly departures from the long-term mean-monthly streamflows were almost entirely negative at these two sites beginning in July 1998 (fig. 6).

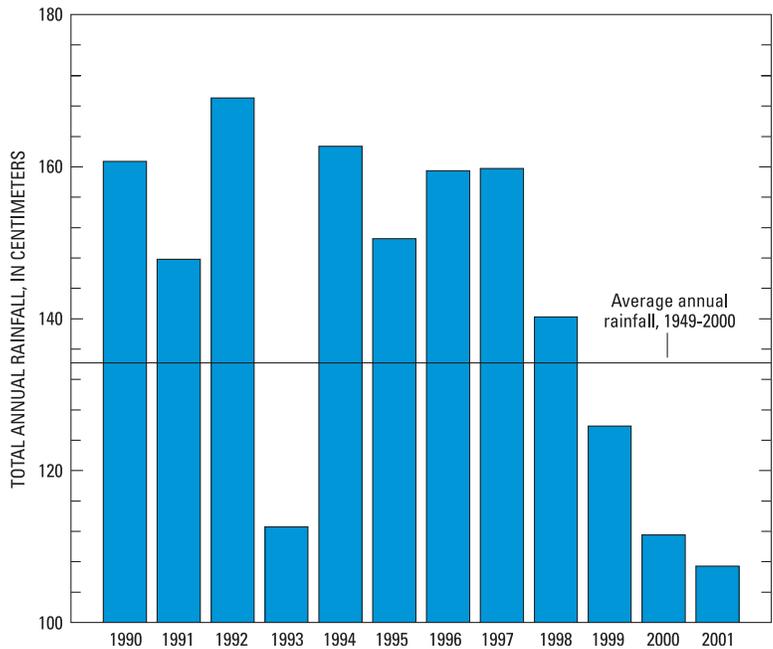


Figure 4. Total annual precipitation at the Franklin, North Carolina, Weather Station for 1990–2001, and the long-term average annual rainfall.

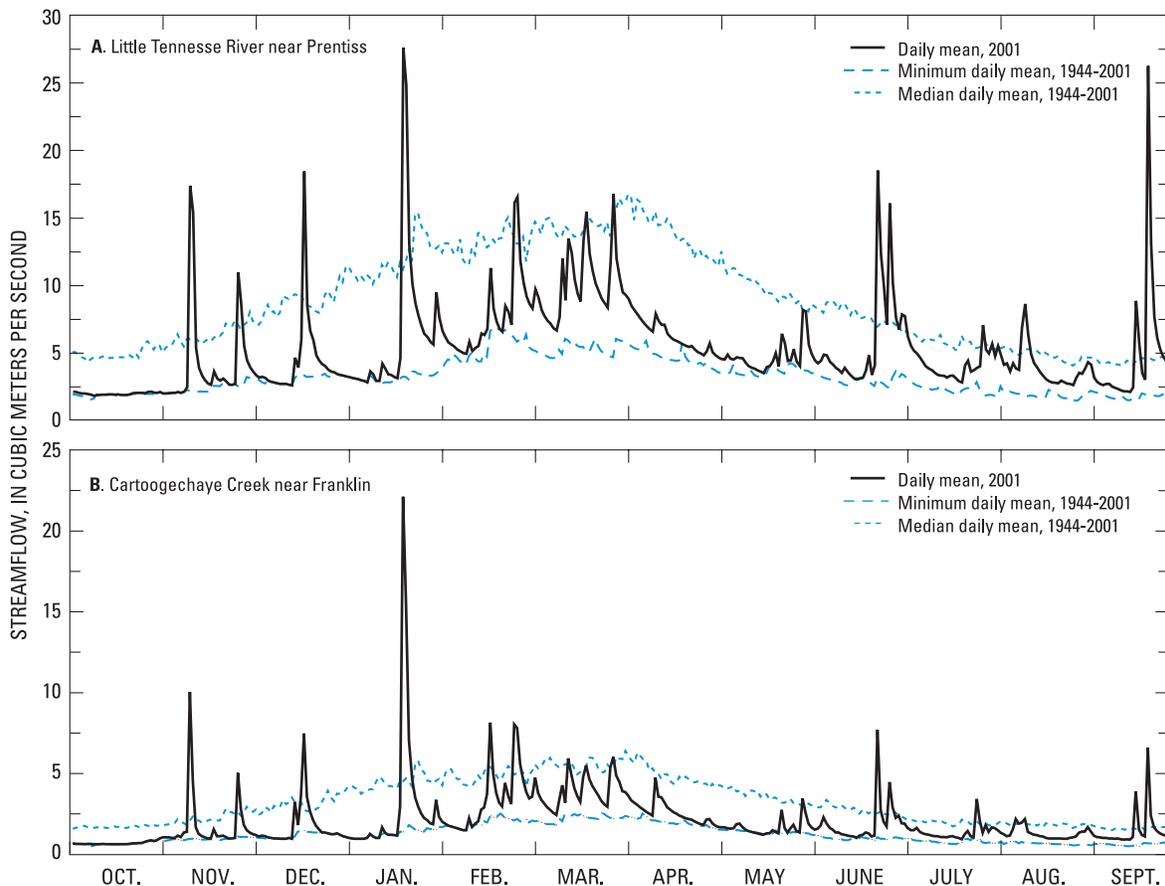


Figure 5. Long-term minimum and median daily-mean streamflow and daily-mean streamflow for water year 2001 at (A) the Little Tennessee River near Prentiss and (B) Cartoogechaye Creek near Franklin, North Carolina.

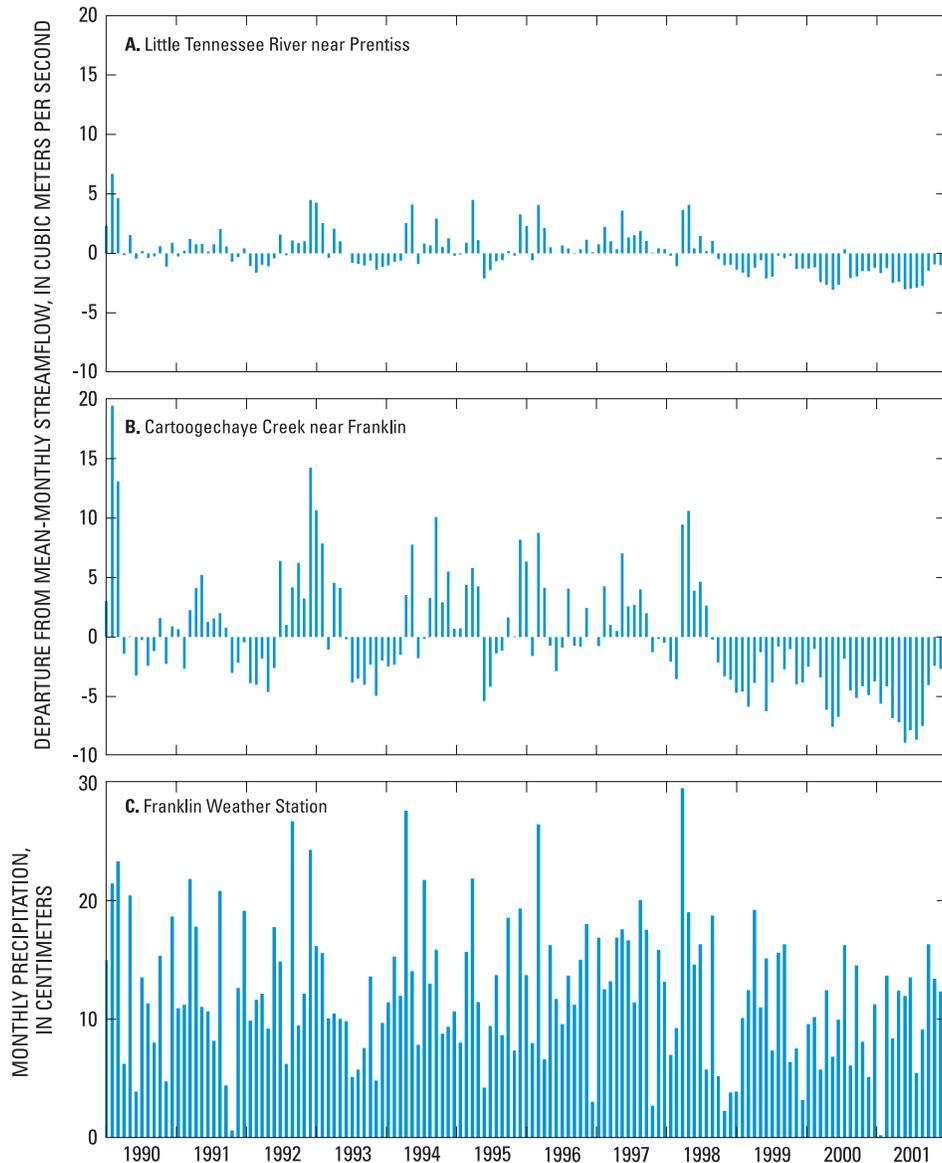


Figure 6. Departure from mean-monthly streamflow at (A) the Little Tennessee River near Prentiss and (B) Cartoogechaye Creek near Franklin, North Carolina, and (C) monthly rainfall at the Franklin Weather Station.

Because streamflows generally were very low during the period of study, few of the sampled streamflows represent high-flow conditions. This is important to note because most suspended sediment is transported under high-flow conditions. In figure 7, the distributions of sampled streamflows at Cartoogechaye Creek and the Little Tennessee River are shown in relation to long-term streamflow durations from streamgages at Cartoogechaye Creek near Franklin and the Little Tennessee River near Prentiss. At both sites, 75 percent of the suspended-sediment samples were collected at streamflows that were approximately equal to the long-term 70th to 75th percentile streamflow

duration. That is, most of the samples were collected at streamflows that, when compared to long-term streamflow record, are equaled or exceeded 70 to 75 percent of the time. However, the maximum streamflow sampled at Cartoogechaye Creek was quite high—near the long-term 1st percentile streamflow duration (fig. 7B). Likewise, the maximum streamflow sampled at the Little Tennessee River was between the long-term 15th and 20th percentile streamflow duration (fig. 7A). Suspended-sediment concentrations collected during these high streamflow events are crucial to adequately define the relation between streamflow and sediment concentration.

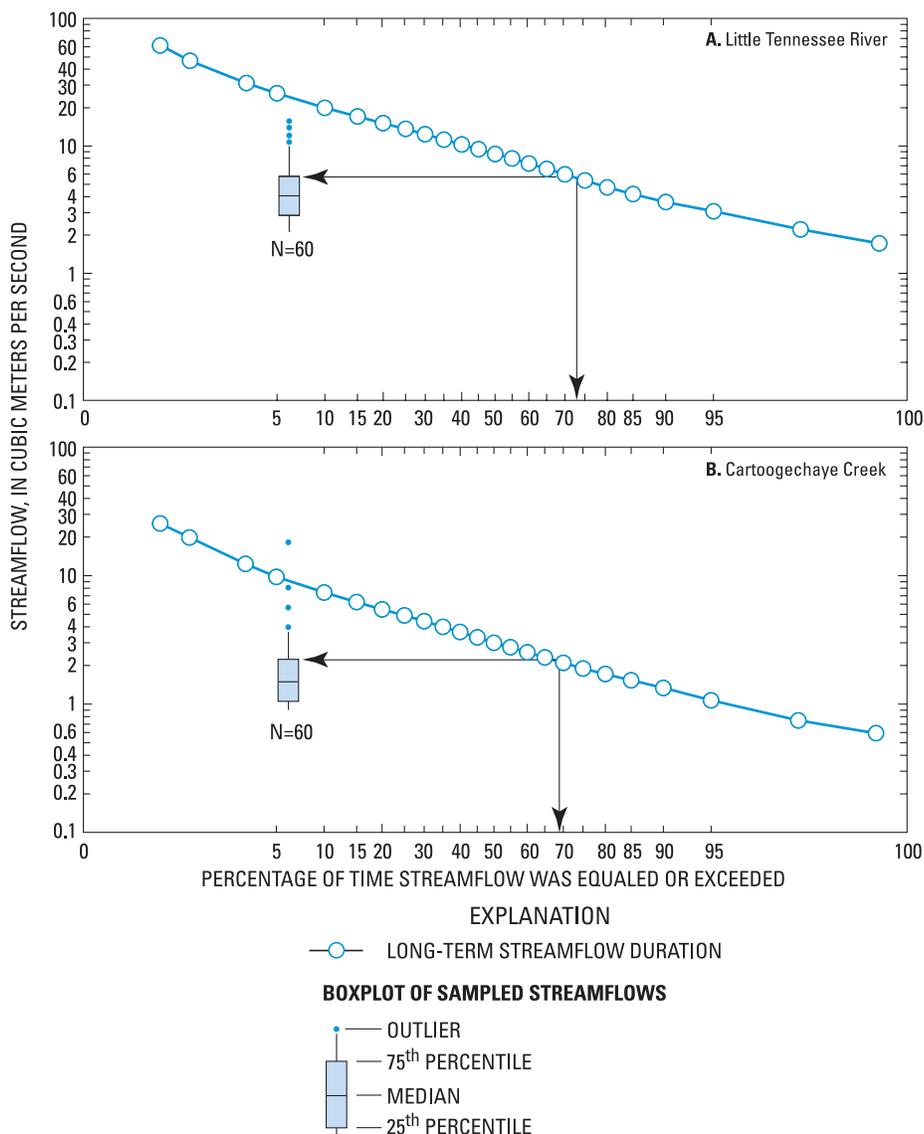


Figure 7. Distributions of sampled streamflows at (A) the Little Tennessee River and (B) Cartoogechaye Creek in relation to long-term streamflow durations from streamgages at the Little Tennessee River near Prentiss and Cartoogechaye Creek near Franklin, North Carolina.

Estimation of Streamflow in the Cullasaja River

Record from a discontinued streamgage at Cullasaja River at Cullasaja, which has a drainage area 12 km² less than the drainage area near Franklin (table 1), provided daily-mean streamflow that was compared to coincidental daily-mean streamflow at streamgages at Cartoogechaye Creek near Franklin and the Little Tennessee River near Prentiss to assess whether either of these streamgages could be used as an index gage. An index gage was needed to estimate streamflow during the study period for the Cullasaja River near Franklin. The most recent year for which

coincident daily-mean streamflow data were available for these three sites was water year¹ 1971. Streamflow was compared for water years 1970–71 (fig. 8).

Equations relating daily-mean streamflow at the index sites to daily-mean streamflow at the Cullasaja River at Cullasaja were determined by means of ordinary least-squares linear regression (table 2). The greater scatter about the regression line and the lower coefficient of determination (R^2) for Cartoogechaye Creek near

¹ Water year is the period October 1 through September 30 and is identified by the year in which the period ends.

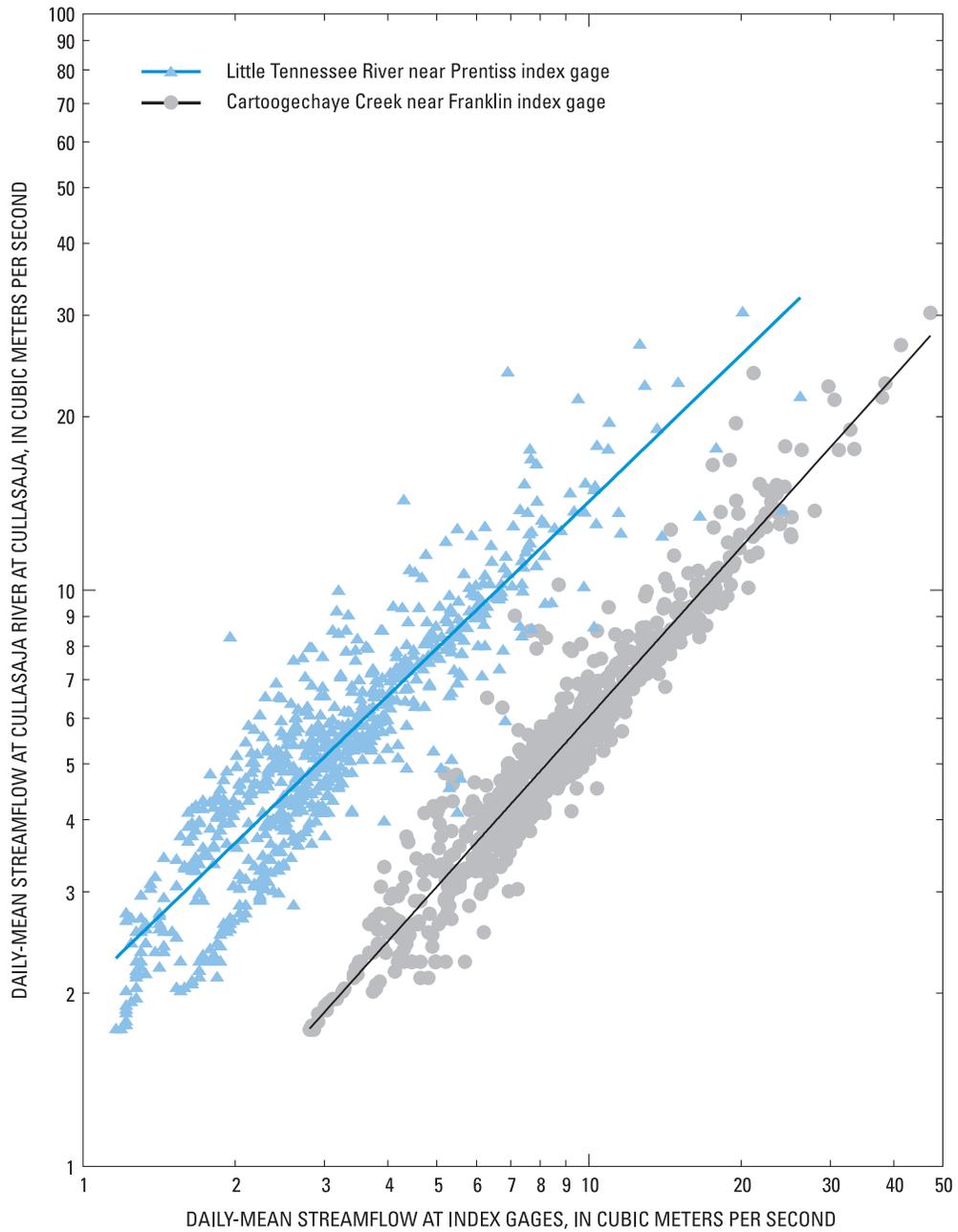


Figure 8. Relation of daily-mean streamflow in the Cullasaja River to daily-mean streamflows at Cartoogechaye Creek near Franklin and the Little Tennessee River near Prentiss, North Carolina, for water years 1970–71.

Table 2. Regression equations relating streamflow at the two Little Tennessee River basin index sites to streamflow in the Cullasaja River, North Carolina

[N, number of observations; R^2 , coefficient of determination; P value, probability that the slope is equal to zero; Q_{cc} , streamflow, in meters per second, at the Cullasaja River at Cullasaja; Q_{cf} , streamflow, in meters per second, at the Cullasaja River near Franklin; $\ln Q_i$, natural log of streamflow, in meters per second, at the index gage]

Type of streamflow record	N	Regression equation	R^2	P value for the slope
Little Tennessee River near Prentiss				
Daily mean, 1970–71	730	$Q_{cc} = e^{0.98(\ln Q_i) - 0.46}$	0.9242	0.0000
Instantaneous, 2001–02	7	$Q_{cf} = e^{1.014(\ln Q_i) - 0.45}$	0.9886	0.0000
Cartoogechaye Creek near Franklin				
Daily mean, 1970–71	730	$Q_{cc} = e^{0.85(\ln Q_i) - 0.70}$	0.8159	0.0000
Instantaneous, 2001–02	7	$Q_{cf} = e^{0.83(\ln Q_i) - 0.75}$	0.8834	0.0016

Franklin indicate that Cartoogechaye Creek is a poorer index gage for the Cullasaja River than is the Little Tennessee River near Prentiss.

During the study, instantaneous streamflow was measured seven times at the Cullasaja River near Franklin at streamflows ranging from 1.77 to 21.0 cubic meters per second (m^3/s ; table 3). These instantaneous streamflow measurements were compared to simultaneous instantaneous streamflow determined from the streamgage record at the potential index sites (table 3; fig. 9). Instantaneous streamflows at the index sites were related to instantaneous streamflow at the Cullasaja River near Franklin using ordinary least-squares linear regression (table 2).

As in the 1970–71 relations (fig. 8; table 2), the greater scatter about the regression line and the lower R^2 value for Cartoogechaye Creek near Franklin indicate that Cartoogechaye Creek is a poorer index gage for the Cullasaja River than is the Little Tennessee River near Prentiss. The slope and intercept of the 2001–02 relation for the Little Tennessee River near Prentiss are very similar to the slope and intercept of the 1970–71 relation. The slight offset of the 2001–02 regression relation compared with the 1970–71 relation is due, in part, to the difference in the drainage areas of the Cullasaja River at Cullasaja (1970–71 relation) and the Cullasaja River near Franklin (2001–02 relation; table 1). For example, when

Table 3. Relation of streamflow measured at the Cullasaja River to streamflow at Cartoogechaye Creek near Franklin and the Little Tennessee River near Prentiss, North Carolina, during water years 2001 and 2002 [Water year is the period October 1 through September 30 and is identified by the year in which the period ends; %, percent]

Date	Time	Instantaneous streamflow, in cubic meters per second			Predicted streamflow at Cullasaja River based on comparison of data for the study period with data from the index gage (percent error)	
		Cartoogechaye Creek	Little Tennessee River near Prentiss	Cullasaja River	Cartoogechaye Creek	Little Tennessee River near Prentiss
03-14-2001	1030	3.20	9.03	6.00	5.56 (7%)	5.48 (9%)
05-02-2001	1050	1.90	5.12	3.88	3.60 (7%)	3.73 (4%)
06-22-2001	1220	1.13	3.06	1.77	2.35 (-33%)	1.97 (-11%)
08-31-2001	1030	1.05	3.06	1.86	2.20 (-18%)	2.19 (-18%)
09-25-2001	1130	2.32	12.32	7.70	4.26 (45%)	8.05 (-5%)
10-25-2001	1055	2.07	4.62	3.31	3.65 (-10%)	3.03 (9%)
01-23-2002	1523	19.7	32.0	21.0	25.1 (-20%)	21.1 (-1%)

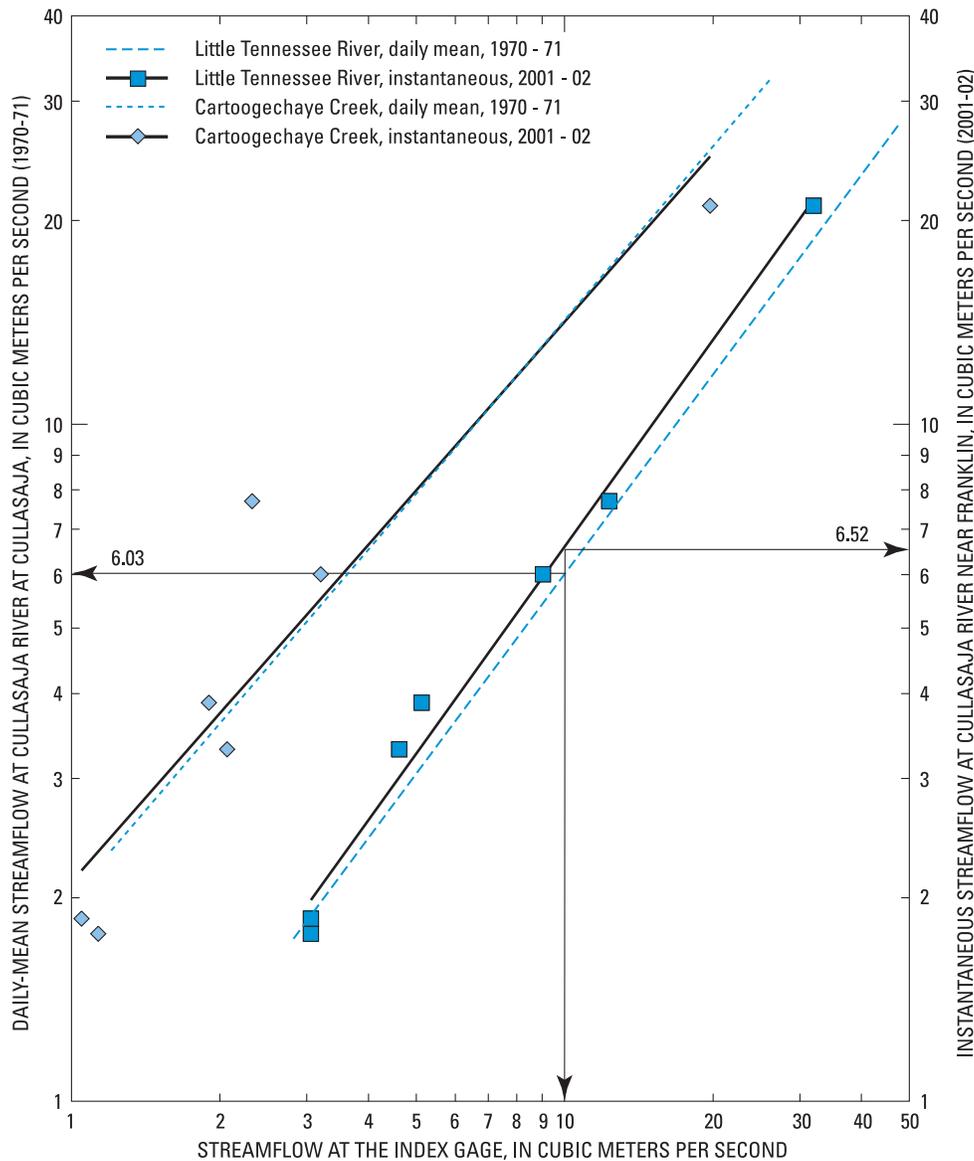


Figure 9. Relation of instantaneous and daily-mean streamflows at the Cullasaja River near Franklin, North Carolina, to instantaneous (2001–02) and daily-mean (1970–71) streamflows at the Little Tennessee River near Prentiss and Cartoogechaye Creek near Franklin.

streamflow at the Little Tennessee River near Prentiss is $10 \text{ m}^3/\text{s}$, the calculated streamflow using the relation for 2001–02 data from the Cullasaja River near Franklin is $6.52 \text{ m}^3/\text{s}$, whereas the calculated streamflow using the relation for 1970–71 data from the Cullasaja River at Cullasaja is $6.03 \text{ m}^3/\text{s}$ (fig. 9). When divided by the drainage area, the resulting runoff values are nearly the same— 0.028 and 0.027 cubic meter per second per square kilometer [$(\text{m}^3/\text{s})/\text{km}^2$] near Franklin and at Cullasaja, respectively.

The Little Tennessee River near Prentiss was selected as the best index site for estimating streamflow at the Cullasaja River near Franklin based on the better closeness of fit (table 3) and higher coefficient of determination (92 to 98 percent, table 2) for the regression equation compared with the equation for the other potential index site. The equation based on 2001–02 data was selected even though it was based on only seven measurements, because the data were more current and the relation was verified by the large amount of data collected during 1970–71.

Estimation of Porter's Bend Dam Releases

No records exist of releases through the Porter's Bend dam at Lake Emory, so the quantity of water discharged from the lake had to be estimated in order to estimate sediment load from the lake. Two methods were used to estimate an annual-mean water discharge from the dam. In the first method, streamflows in the Little Tennessee River near Prentiss, Cartoogechaye Creek near Franklin, and the Cullasaja River near Franklin were measured or estimated at 15-minute intervals for the study period, and the values were summed. The result was 396,800,000 m³ of streamflow for the study period (1.25 years), or an annual-mean streamflow of 10.0 m³/s, which was the assumed discharge through the dam. In the second method, the measured annual-mean streamflow at the Little Tennessee River at Needmore for 2001 (15.3 m³/s, table 4) was reduced by multiplying by a factor determined by the ratio of drainage areas (804 / 1,130 = 0.71) to estimate an annual-mean streamflow of 11 m³/s, which was the assumed discharge through Porter's Bend dam.

Using the two estimated values, the annual runoff, in centimeters, was calculated and compared with annual runoff at the other sites (table 4). The estimated annual runoff for the dam obtained by using

Table 4. Streamflow statistics for the Little Tennessee River basin, North Carolina, study sites for the 2001 water year

[Water year is the period October 1 through September 30 and is identified by the year in which the period ends; km², square kilometer; m³/s, cubic meter per second; cm, centimeter]

Site	Drainage area, in km ²	Annual-mean streamflow, in m ³ /s	Runoff, in cm
Little Tennessee River at Riverside	311	4.58	46.4
Little Tennessee River at Needmore	1,130	15.3	42.7
Cartoogechaye Creek near Franklin	148	2.09	44.5
Cullasaja River near Franklin	236	3.4	45.4
Porter's Bend dam at Lake Emory	804	^a 10/ ^b 11	^c 39/ ^d 43

^a Estimated annual-mean streamflow by using method one.

^b Estimated annual-mean streamflow by using method two.

^c Calculated runoff by using estimated annual-mean streamflow from method one.

^d Calculated runoff by using estimated annual-mean streamflow from method two.

the second method was reasonably close to runoff at other sites in the study area, so the annual-mean streamflow of 11 m³/s was judged to be a reasonable estimate for calculating suspended-sediment load.

SUSPENDED SEDIMENT

Samples for analysis of suspended-sediment concentration were collected once per week at each site from November 2000 to November 2001 (table 5). In addition, several samples were collected during targeted high-flow events. The distribution of measured concentrations at each site is shown in figure 10. The greatest median suspended-sediment concentration was measured at Porter's Bend dam at Lake Emory (12 mg/L). Lowest median concentrations were measured at the Cullasaja and Cartoogechaye sites (5 and 4.9 mg/L, respectively), although the range of concentrations was large.

Load

Instantaneous suspended-sediment loads, in metric tons per day, were calculated from instantaneous streamflow and measured suspended-sediment concentration. A regression equation was developed for each site—the Little Tennessee River at Riverside, Cartoogechaye Creek, and the Cullasaja River—relating the natural log of streamflow to the natural log of suspended-sediment load at each site (fig. 11; table 6). The regression equations were used to calculate suspended-sediment loads for each 15-minute (unit value) interval at each site by using continuous streamflow record (Cartoogechaye Creek and the Little Tennessee River at Riverside) or estimates of streamflow (Cullasaja River). These unit-value load data were summed for each site. Each sum was adjusted by multiplying by the mean of the antilog of the regression residuals (Duan's smearing estimator) to account for retransformation bias (Duan, 1983; Koltun and others, 1994) to determine the total load for the study period (1.25 years). The total load for the period of study, annual load, and annual yield are shown in table 7.

As noted previously, suspended-sediment load could not be calculated for water discharged from Lake Emory because there was no record of streamflow out of the dam. Instead, suspended-sediment load was estimated by using the 11-m³/s estimate for average

Table 5. Suspended-sediment concentrations at the four Little Tennessee River basin study sites in North Carolina and measured or estimated streamflow at three of the study sites[m³/s, cubic meter per second; mg/L, milligram per liter; **bold** values represent the average of multiple vertical samples; —, no data]

Date	Little Tennessee River at Riverside			Cartoogechaye Creek near Franklin			Cullasaja River near Franklin			Lake Emory at Porter's Bend dam near Franklin	
	Time	^a Instantaneous streamflow, in m ³ /s	Suspended-sediment concentration, in mg/L	Time	Instantaneous streamflow, in m ³ /s	Suspended-sediment concentration, in mg/L	Time	^a Instantaneous streamflow, in m ³ /s	Suspended-sediment concentration, in mg/L	Time	Suspended-sediment concentration, in mg/L
06–21–2000	1440	4.0	17	1240	1.5	14	1540	3.03	17	1030	24
11–14–2000	1215	2.6	4.5	1105	1.0	3.0	1404	1.90	3.3	1525	7.5
11–14–2000	1230	2.6	3.9	1110	1.0	1.5	1420	1.90	4.0	—	—
11–21–2000	1200	2.5	4.9	1100	1.0	7.0	1315	1.90	25	1415	5.4
11–27–2000	0925	4.9	7.6	0830	1.8	3.7	1400	3.49	4.5	1100	5.6
12–05–2000	1200	2.6	5.2	1100	1.0	2.5	1345	1.93	2.0	1300	2.2
12–12–2000	1050	2.3	4.1	1115	1.0	2.3	1220	1.75	.6	1320	15
12–19–2000	1130	5.7	13	1100	2.7	4.4	1200	4.35	5.3	1200	5.5
12–26–2000	1100	3.1	5.4	1000	1.2	.6	1200	2.32	.8	1300	3.2
01–02–2001	1100	2.7	7.2	1200	.9	3.0	1215	1.93	5.6	1300	3.4
01–09–2001	1306	2.9	5.0	1330	1.0	3.0	1410	2.12	6.4	1500	3.6
01–16–2001	1100	2.8	4.1	1130	1.1	3.5	—	—	—	1230	3.3
01–23–2001	1100	7.4	13	1200	3.5	7.2	1300	5.68	4.9	1430	4.2
01–30–2001	1115	9.6	72	1145	4.0	25	1230	7.58	16	1400	7.0
02–06–2001	1030	4.5	3.0	1100	1.6	3.8	1130	3.40	3.5	1300	2.0
02–13–2001	1100	4.7	4.1	1145	1.9	2.6	1245	3.55	.8	1300	5.5
02–20–2001	1200	5.9	6.9	1100	3.2	3.3	1245	4.41	4.1	1300	6.3
02–26–2001	1100	14.0	97	1020	8.0	23	1145	10.57	19	1235	20
02–27–2001	1245	10.0	32	1145	5.6	12	1345	7.66	12	1440	12
03–06–2001	1000	7.1	9.7	1100	3.3	2.8	1200	5.35	2.9	1300	5.1
03–13–2001	1000	10.7	56	1100	4.0	12	1200	7.73	6.9	1300	16
03–20–2001	1000	8.0	24	1100	4.0	9.7	1200	7.17	6.0	1300	6.9
03–27–2001	1000	7.4	9.1	1100	3.1	2.7	1200	5.68	3.5	1300	5.5
04–03–2001	1000	7.9	12	1100	3.7	6.2	1200	6.02	3.4	1300	6.2
04–10–2001	1000	6.1	11	1100	2.6	5.8	1200	4.62	19	1200	7.6
04–17–2001	1100	5.5	12	1200	2.9	5.0	1230	4.15	2.9	1300	20
04–24–2001	1000	4.7	11	1100	2.2	8.0	1200	3.55	6.0	1300	8.0
05–01–2001	1000	4.9	13	1100	2.0	7.7	1200	3.68	5.9	1300	43
05–02–2001	1025	4.4	9.7	1135	1.9	7.0	1335	3.27	2.6	1420	5.1
05–02–2001	1110	4.4	7.5	1200	1.9	4.7	1350	3.27	3.2	—	—
05–08–2001	1000	3.9	8.0	1100	1.6	6.0	1000	2.95	5.0	1300	9.0
05–15–2001	1100	3.4	7.0	1100	1.4	5.8	1000	2.51	3.0	1300	17
05–22–2001	0900	3.7	24	1000	1.4	8.0	1100	2.81	9.0	1200	35
05–29–2001	1100	4.6	26	1200	1.9	10	1300	3.49	12	1400	17

Table 5. Suspended-sediment concentrations at the four Little Tennessee River basin study sites in North Carolina and measured or estimated streamflow at three of the study sites—Continued

[m³/s, cubic meter per second; mg/L, milligram per liter; **bold** values represent the average of multiple vertical samples; —, no data]

Date	Little Tennessee River at Riverside			Cartoogechaye Creek near Franklin			Cullasaja River near Franklin			Lake Emory at Porter's Bend dam near Franklin	
	Time	^a Instantaneous streamflow, in m ³ /s	Suspended-sediment concentration, in mg/L	Time	Instantaneous streamflow, in m ³ /s	Suspended-sediment concentration, in mg/L	Time	^a Instantaneous streamflow, in m ³ /s	Suspended-sediment concentration, in mg/L	Time	Suspended-sediment concentration, in mg/L
06-05-2001	1100	3.8	18	1200	1.5	7.1	1300	2.92	8.5	1400	8.8
06-12-2001	1100	3.3	13	1200	1.3	6.0	1300	2.55	9.0	1400	12
06-19-2001	1200	2.6	8.7	1300	1.0	2.5	1400	1.97	4.9	1500	10
06-26-2001	1200	15.7	554	1300	18.2	933	1400	17.64	75	1500	46
07-03-2001	1100	5.6	26	1200	2.0	14	1300	4.35	19	1400	15
07-10-2001	1100	4.1	12	1200	1.4	6.1	1300	3.07	7.1	1400	14
07-17-2001	1100	2.9	11	1200	1.1	3.6	1300	2.16	2.8	1400	20
07-24-2001	1100	2.4	17	1200	.9	5.4	1300	1.79	2.0	1400	23
07-31-2001	1100	5.4	497	1200	1.3	7.8	1300	8.53	9.0	1020	10
07-31-2001	—	—	—	—	—	—	—	—	—	1400	27
08-07-2001	1100	3.5	23	1200	1.2	5.3	1300	2.68	9.4	1400	60
08-14-2001	1100	7.9	79	1200	2.0	27	1300	5.52	38	1400	49
08-21-2001	1100	2.7	7.2	1200	1.0	2.5	1300	2.01	3.8	1400	24
08-28-2001	1100	2.3	7.1	1200	1.0	2.6	1300	1.75	2.3	1400	18
09-04-2001	1100	4.3	12	1200	1.5	4.2	1300	2.81	9.4	1400	19
09-11-2001	1200	2.7	5.2	1300	1.0	1.7	1400	1.75	7.5	1500	68
09-18-2001	1200	2.1	4.2	1300	.9	1.9	1400	1.40	1.4	1500	16
09-25-2001	1200	12.1	67	1300	2.3	20	1400	7.70	21	1500	25
09-26-2001	1055	6.5	19	1151	1.6	2.0	1351	4.88	3.0	1325	9.0
10-02-2001	1100	4.0	4.0	1200	1.0	1.1	1100	2.55	1.3	1400	12
10-09-2001	1100	3.5	2.2	1200	1.0	.6	1300	2.27	.8	1400	15
10-16-2001	1100	5.9	12	1200	1.5	3.5	1300	4.41	8.2	1400	13
10-23-2001	1100	3.8	4.1	1200	1.2	3.0	1300	2.84	2.9	1400	8.9
10-24-2001	1400	3.6	4.0	1500	1.2	1.4	—	—	—	—	—
10-25-2001	—	—	—	—	—	—	1200	3.31	2.5	1500	2.9
10-30-2001	1100	3.5	3.0	1200	1.1	2.2	1300	2.60	3.8	1400	12
11-06-2001	1100	3.1	1.8	1200	1.1	.8	1300	2.36	1.5	1400	28
11-13-2001	1100	2.9	2.9	1200	1.0	1.3	1300	2.19	.5	1400	17
11-20-2001	1100	2.8	2.1	1200	1.0	2.5	1300	2.12	.8	1400	31
11-27-2001	1100	4.3	6.5	1200	1.5	3.2	1300	3.23	2.8	1400	18
01-20-2002	1130	13.4	87	—	—	—	1040	—	9.0	1225	31
01-23-2002	1325	28.2	369	1110	21.7	324	1215	21.0	114	1417	93
01-23-2002	1327	28.2	289	1112	21.7	302	1216	—	169	—	—
01-24-2002	1421	19.5	47	1015	10.6	5.9	1224	12.4	2.8	—	—

^a Estimated from the streamgage record at the Little Tennessee River near Prentiss.

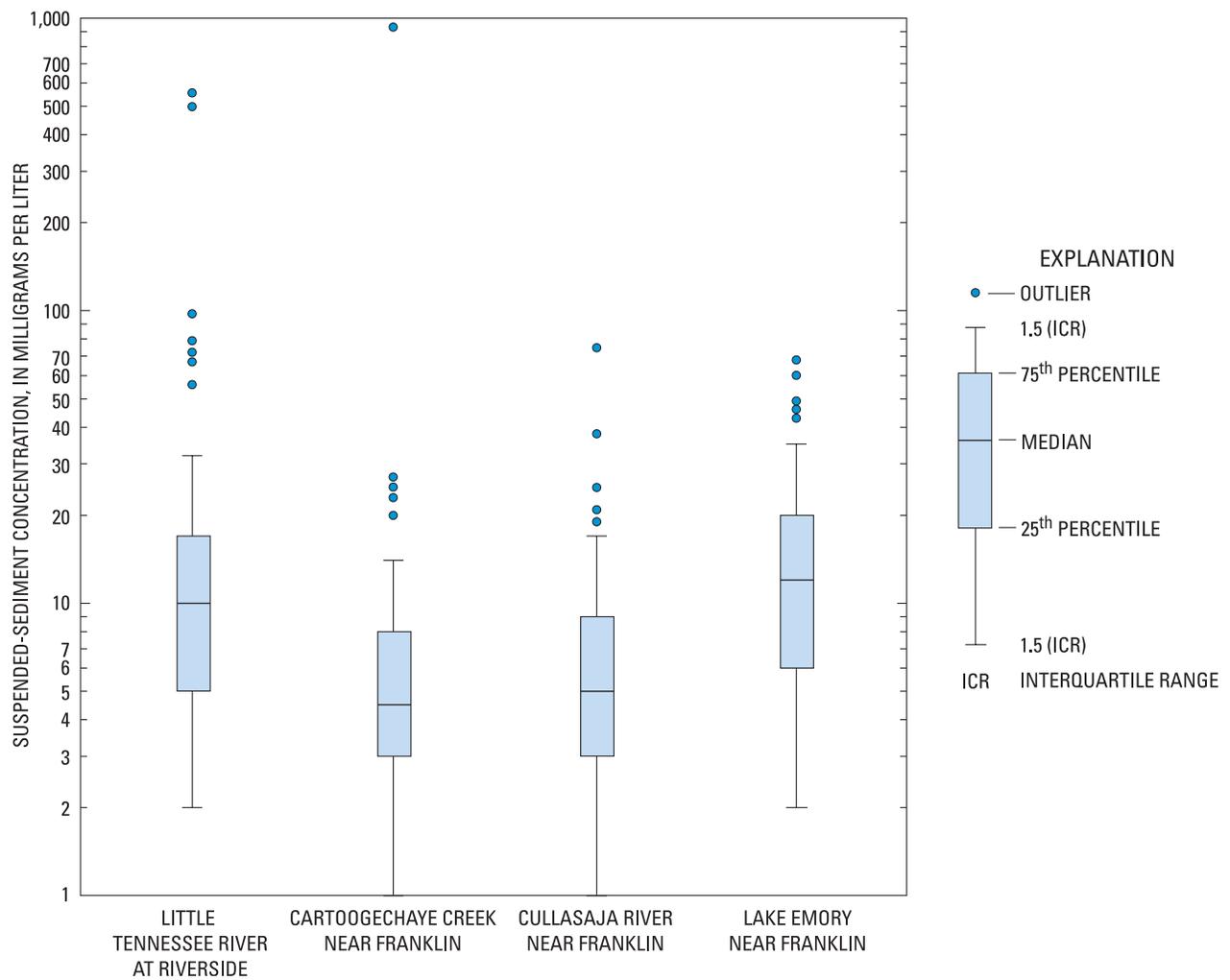


Figure 10. Distribution of suspended-sediment concentrations at the four Little Tennessee River basin study sites in North Carolina.

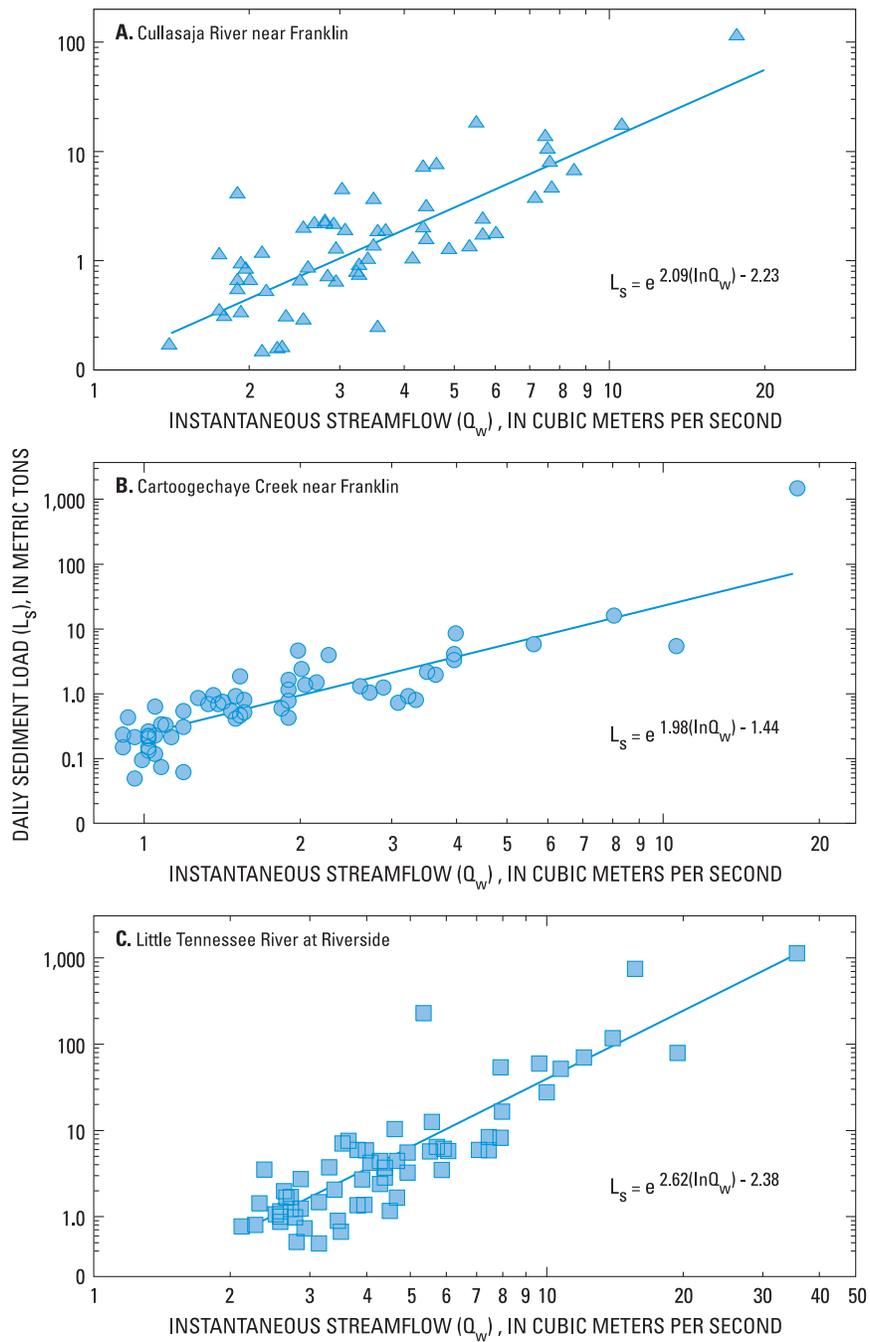


Figure 11. Relation of daily sediment load to instantaneous streamflow at (A) the Cullasaja River near Franklin, (B) Cartoogechaye Creek near Franklin, and (C) the Little Tennessee River at Riverside, North Carolina.

Table 6. Results of regression analyses relating the natural log of instantaneous suspended-sediment load to the natural log of instantaneous streamflow at three Little Tennessee River basin study sites in North Carolina [R^2 , coefficient of determination; P value, probability that the slope is equal to zero]

Site	Intercept	Slope coefficient	R^2	P value	Mean of the antilog of the residuals
Cartoogechaye Creek	-1.44	1.98	0.72	0.00	1.57
Cullasaja River	-2.23	2.09	.62	.00	1.44
Little Tennessee River at Riverside	-2.38	2.62	.80	.00	1.24

daily discharge from the dam (table 4) and a median measured suspended-sediment concentration of 12 mg/L (fig. 10). This resulted in an estimated annual suspended-sediment load of 4,200 t and yield of 5 t/km² (table 7).

The greatest annual load and yield in 2001 (5,700 t and 18 t/km², respectively) was in the Little Tennessee River at Riverside (table 7). The yield at Riverside far exceeded the yields at Cartoogechaye Creek, the Cullasaja River, and out of Lake Emory. By comparison, Simmons (1993) calculated mean-annual suspended-sediment yields, based on data from the 1970's, of 20 t/km² for the Nantahala River near Rainbow Springs and 15 t/km² for Cataloochee Creek near Cataloochee—two relatively pristine, forested

basins in the Blue Ridge Province of North Carolina.

In order to assess the significance of drought conditions during the study period on suspended-sediment loads, the 2001 data were compared with estimates of suspended-sediment load and yield, and the annual-mean streamflows at Cartoogechaye Creek near Franklin and the Little Tennessee River at Needmore between 1970 and 1979 (Simmons, 1993; table 7). Annual load and yield were an order of magnitude less during the study period compared to estimates from the 1970's. This may be, in part, due to the higher streamflows during the period 1970–79 when annual-mean streamflows were more than twice as high as those during the study period (table 7).

The decrease in suspended-sediment load compared to the 1970's also may be a result of long-term change in the relation between suspended-sediment load and streamflow as a result of changes in land-use conditions in the basin. Annual suspended-sediment loads are highly variable and difficult to assess with only 1 year of recent data. The relation of suspended-sediment load to instantaneous streamflow for the period 1977–79 (when streamflow and suspended-sediment data are available) was compared to the relation of suspended-sediment load to instantaneous streamflow for the study period at Cartoogechaye Creek (fig. 12). During 1977–79, more

Table 7. Estimated suspended-sediment loads and yields at the three study sites and at sites sampled in 1970–79 in the Little Tennessee River basin, North Carolina

[m³/s, cubic meter per second; t, metric ton; t/km², metric ton per square kilometer; —, no data]

Site	Annual-mean streamflow, in m ³ /s	Suspended sediment, 2000–01			Annual-mean streamflow, in m ³ /s	Suspended sediment, 1970–79 ^a	
		Load, in t, 10–01–00 to 12–31–01	Annual load, in t	Annual yield, in t/km ²		Annual load, in t	Annual yield, in t/km ²
Little Tennessee River at Riverside	^b 4.58	7,200	5,700	18	—	—	—
Cartoogechaye Creek near Franklin	2.09	1,300	1,000	7	4.39	10,000	81
Cullasaja River near Franklin	^c 3.4	1,500	1,200	5	—	—	—
Porter's Bend dam at Lake Emory	^c 11	—	4,200	5	—	—	—
Little Tennessee River at Needmore	15.3	—	—	—	33.7	100,000	110

^a From Simmons (1993).

^b Streamflow at the Prentiss, North Carolina, streamgage.

^c Estimated.

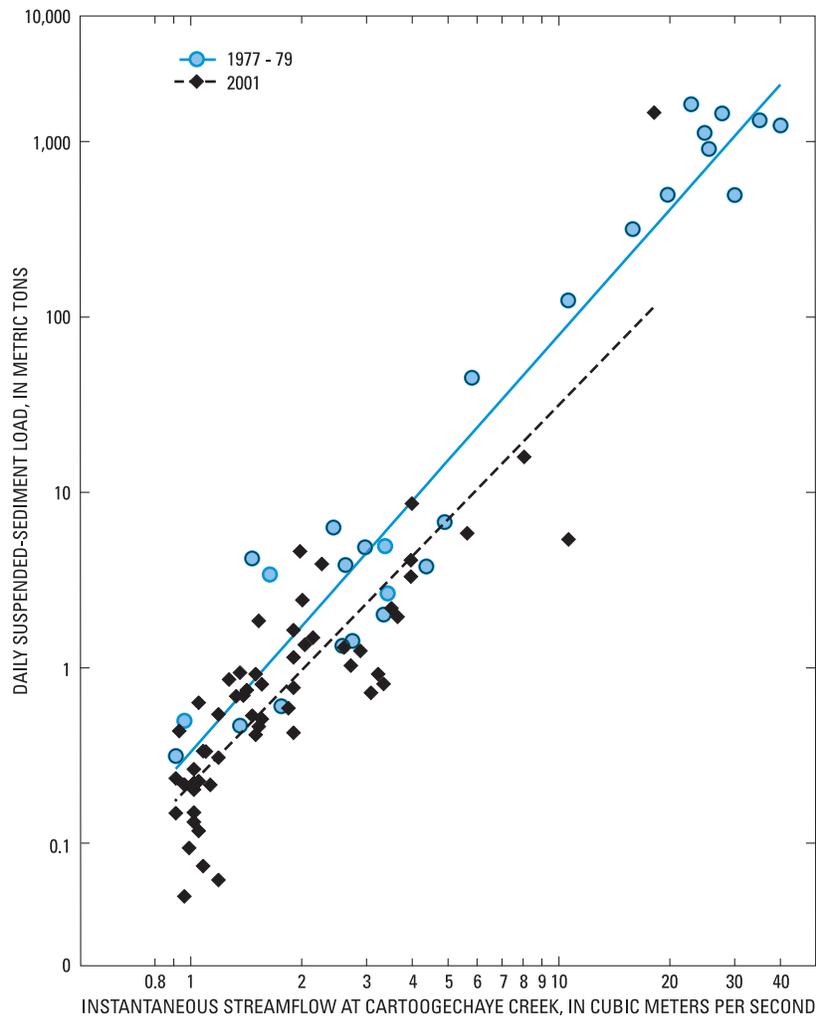


Figure 12. Relation of daily suspended-sediment load and instantaneous streamflow at Cartoogechaye Creek near Franklin, North Carolina, for 1977–79 and 2001.

samples were collected at high streamflow than during the study period when nearly 75 percent of the samples were collected at streamflows less than 2 m³/s because of drought conditions (fig. 12). Figure 12 indicates a decrease in the slope and intercept of the line determined by regressing streamflow on instantaneous load in 2001 compared with 1977–79. However, more samples are needed at streamflows greater than 10 m³/s to adequately define the suspended-sediment load and streamflow relation for the 2001 water year.

Particle Size

Selected suspended-sediment samples were analyzed for particle size (table 8). Based on the small number of samples collected during this study, particle sizes were predominately finer than sand (finer than 0.062 mm) at all of the sites (fig. 13). This, too, probably is an effect of low streamflows during the study. There was little variation in the median percentage of particles finer than 0.062 mm among the sites; however, as would be expected, the median

Table 8. Streamflow and suspended-sediment concentration and particle-size distributions in samples from the four Little Tennessee River basin study sites in North Carolina

[m³/s, cubic meter per second; mg/L, milligram per liter; mm, millimeter; —, no data]

Site	Date	Time	Instantaneous discharge, in m ³ /s	Suspended-sediment concentration, in mg/L	Percentage of suspended-sediment particles finer than the indicated size				
					0.062 mm	0.125 mm	0.250 mm	0.500 mm	1.00 mm
^a Little Tennessee River at Riverside	04-24-01	1000	4.7	11	70	—	—	—	—
	05-08-01	1000	3.9	8	81	—	—	—	—
	05-22-01	0900	3.6	24	85	—	—	—	—
	07-31-01	1240	11.1	441	86	92	97	100	100
	09-26-01	1055	7.6	19	85	88	100	100	100
	01-20-02	1130	13.4	87	64	68	100	100	100
	01-23-02	1325	35.7	369	64	72	82	100	100
Cartoogechaye Creek near Franklin	04-24-01	1100	2.2	8	75	—	—	—	—
	05-08-01	1100	1.6	6	64	—	—	—	—
	05-22-01	1000	1.4	8	81	—	—	—	—
	07-31-01	1120	1.3	^b 3	95	—	—	—	—
	09-26-01	1151	1.6	^b 2	100	—	—	—	—
	01-20-02	0952	8.6	79	70	70	89	100	100
	01-23-02	1110	21.7	324	80	87	97	100	100
^a Cullasaja River near Franklin	04-24-01	1200	3.8	6	71	—	—	—	—
	05-08-01	1000	3.1	5	70	—	—	—	—
	05-22-01	1100	2.6	9	60	—	—	—	—
	07-31-01	1350	8.5	5	90	—	—	—	—
	09-26-01	1351	4.9	^b 3	100	—	—	—	—
	01-20-02	1040	—	^b 15	100	—	—	—	—
	01-23-02	1215	22.4	114	79	85	100	100	100
Lake Emory at Porter's Bend dam near Franklin	04-24-01	1300	—	8	93	—	—	—	—
	05-08-01	1300	—	9	93	—	—	—	—
	05-22-01	1200	—	35	77	—	—	—	—
	07-31-01	1020	—	^b 10	100	—	—	—	—
	09-26-01	1325	—	^b 9	100	—	—	—	—

^a Streamflows are estimated for the Little Tennessee River at Riverside and Cullasaja River near Franklin.

^b Concentration was too low for full particle-size analysis.

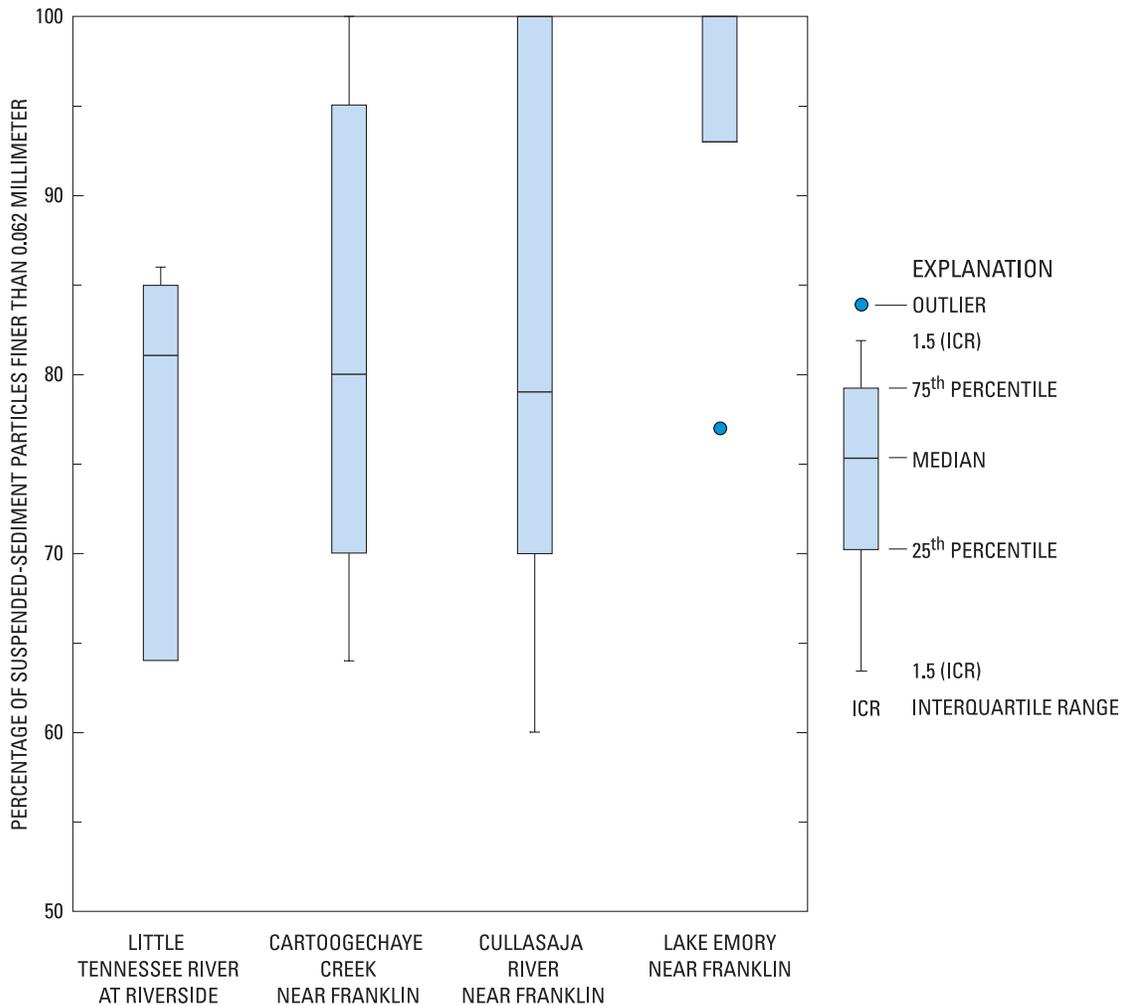


Figure 13. Distribution of percentages of suspended-sediment particles finer than 0.062 millimeter at the four Little Tennessee River basin study sites in North Carolina.

percentage of fine suspended-sediment particles (<0.062 mm) was greatest at Porter’s Bend dam.

BED MATERIAL

Sediment that is deposited on the streambed is bed material. Small particles can be resuspended during periods of elevated streamflow to produce suspended-sediment load (discussed previously). Larger particles that are too heavy to be suspended in the water column during elevated streamflows may move along the streambed as bed load.

Bed Load

Bed load is sediment that moves by sliding, rolling, or bouncing along on or near the streambed

(Edwards and Glysson, 1999). Bed load is difficult to accurately measure because (1) any sampling device placed on the bed may disturb bed-load flow and rate of movement and (2) bed load is highly temporally and spatially variable. The material collected with the bed-load sampler generally consists of material that is not collected by suspended-sediment sampling equipment.

Drought conditions during the study period limited opportunities for collecting bed-load samples because most bed load is carried during high-streamflow events. Three bed-load samples were collected at each stream site to estimate the amount of material that was being transported near the streambed and that was unaccounted for by the suspended-sediment sampler (tables 9, 10). Bed load was added to the suspended-sediment load calculated for a particular day to determine a total load.

Table 9. Bed load and suspended-sediment load during three runoff events at three sites in the Little Tennessee River basin in North Carolina

[Samples were collected and composited at two cross sections from five or six equally spaced locations in the cross section; —, no data; <, less than]

Date	Time	Discharge, in cubic meters per second	Stream width, in meters	Width of each section, in meters	Sampling time at each section, in seconds	Daily-mean suspended- sediment load		Daily-mean bed load		Daily-mean total sediment load, in metric tons
						Metric tons	Metric tons per square kilometer	Metric tons	Metric tons per square kilometer	
Little Tennessee River at Riverside (0349998425)										
10–24–01	1305	4.3	6.7	1.34	1200	1.5	0.005	0.5	0.002	2.0
01–24–02	1421	19.4	5.8	3.81	180	79	.25	47	0.15	126
09–26–02	1538	29.4	19.2	1.16	300	—	—	42	0.14	—
Cartoogechaye Creek near Franklin (03500240)										
10–24–01	1530	1.05	3.3	0.64	1200	0.13	0.001	0.004	<0.001	0.13
01–24–02	1015	10.6	4.4	2.89	180	5.5	.037	3.3	.012	8.8
09–26–02	1106	15.5	15.8	.88	300	—	—	5.1	.034	—
Cullasaja River near Franklin (0350116510)										
10–25–01	1500	3.3	4.8	0.98	1200	0.72	0.003	0.07	<0.001	0.79
01–24–02	1224	12.4	5.8	1.16	180	3.2	.014	2.5	.010	5.7
09–26–02	1312	18.4	20.7	3.44	300	—	—	5.3	.022	—

Table 10. Particle-size distribution in bed-load samples from three sites in the Little Tennessee River basin in North Carolina [m³/s, cubic meter per second; mm, millimeter]

Date	Discharge, in m ³ /s	Percentage of bed-load particles finer than size indicated								
		0.062 mm	0.125 mm	0.250 mm	0.500 mm	1.00 mm	2.00 mm	4.00 mm	8.00 mm	16.0 mm
Little Tennessee River at Riverside (0349998425)										
10-24-01	4.3	0.2	0.4	8.5	59	90	97	99	100	100
01-24-02	19.4	0	0	4	29	74	96	99	100	100
09-26-02	29.4	.3	.7	4.6	38	91	100	100	100	100
Cartoogechaye Creek near Franklin (03500240)										
10-24-01	1.05	2.2	2.2	16	58	71	76	78	84	100
01-24-02	10.6	0	1	12	70	92	97	99	100	100
09-26-02	15.5	.5	1.5	17	80	93	95	96	97	100
Cullasaja River near Franklin (0350116510)										
10-24-01	3.3	.2	.8	13	66	79	85	90	93	100
01-24-02	12.4	0	0	10	73	94	98	99	100	100
09-26-02	18.4	.6	1.7	17	60	86	97	99	100	100

Not surprisingly, total load was significantly less during low flow than during high flow. Bed load was negligible at all three sites during low-flow conditions. Greatest daily bed load, in metric tons, and bed-load yield, in metric tons per square kilometer, was in the Little Tennessee River at Riverside during runoff events. Bed loads in Cartoogechaye Creek and the Cullasaja River were not substantially different from each other and were less than one-fifth the bed load and yield in the Little Tennessee River on the same day. Bed load accounted for 25 to 44 percent of the total sediment load in January 2002 when both bed and suspended-sediment loads were measured (table 9).

Particle Size

The bed-sediment particle-size distributions were similar at the two tributary sites for the dates sampled (table 10). The Little Tennessee River at Riverside transports slightly greater particle sizes than the tributaries. For the high-flow samples in January 2002 and September 2002, more than 60 percent of the particles were finer than 0.5 mm in the tributaries, whereas less than 38 percent of the particles were finer than 0.5 mm in the Little Tennessee River at Riverside.

SUMMARY

A study of sediment transport in the upper Little Tennessee River basin was begun in June 2000 in cooperation with Macon County. The purpose of the study was to characterize bed and suspended-sediment loads into Lake Emory from the main stem and major tributaries—Cartoogechaye Creek and the Cullasaja River. The study was designed to be completed in 1 year; however, because of extreme drought conditions in western North Carolina, some sampling continued into September 2002 in order to collect samples during high-flow conditions.

Weekly samples for suspended-sediment concentration were collected at the Little Tennessee River near Riverside, Cartoogechaye Creek near Franklin, the Cullasaja River near Franklin, and Lake Emory at the Porter's Bend dam between November 2000 and November 2001. In addition, some samples were collected during targeted high-flow events and analyzed for particle-size distribution of suspended sediment. Three bed-load samples were collected at each stream site and analyzed to determine mass and particle-size distribution.

Annual suspended-sediment load was calculated based, in part, on continuous record of discharge for Cartoogechaye Creek near Franklin. Streamflow data

for the Little Tennessee River at Prentiss were used to estimate instantaneous streamflow record and suspended-sediment load at the Little Tennessee River at Riverside and Cullasaja River near Franklin. Streamflow at the Little Tennessee River at Needmore was used to estimate an annual-mean discharge for 2001 for releases from Lake Emory. Equations relating estimated streamflow to suspended-sediment concentration were developed and used to compute estimates of annual suspended-sediment loads.

Bed-load samples were collected in October 2001 during low-flow conditions and in January and September 2002 during stormwater-runoff conditions. Bed-load samples were analyzed for weight and particle-size distribution. Selected suspended-sediment samples were analyzed for particle-size distribution.

For the study period, the greatest annual load and yield of suspended sediment (5,700 t and 18 t/km², respectively) was at the Little Tennessee River near Riverside. Much smaller annual yields were calculated for Lake Emory, the Cullasaja River, and Cartoogechaye Creek—5, 5, and 7 t/km², respectively.

In an earlier study in the 1970's, the mean-annual suspended-sediment yield at Cartoogechaye Creek was 81 t/km² and 110 t/km² at the Little Tennessee River at Needmore, which indicates a decline in sediment loads. The mean-annual suspended-sediment yield for relatively pristine, forested sites in the North Carolina Blue Ridge Province was 20 t/km² for the Nantahala River near Rainbow Springs and 15 t/km² for Cataloochee Creek near Cataloochee. Drought conditions during the more recent study period probably were a factor in the small loads at these sites in 2001 compared to those in the 1970's and to forested reference sites. The annual-mean streamflow for the 2001 water year was about 50 percent of the long-term annual-mean streamflow (1944–2001), and high-flow events carry most of the annual sediment load.

REFERENCES

- Duan, N., 1983, Smearing estimate—a nonparametric retransformation method: *Journal of the American Statistical Association*, v. 78, no. 383, p. 605–610.
- Edwards, T.K., and Glysson, G.D., 1999, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C2, 89 p.
- Guy, H.P., 1977, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. C1, 58 p.
- Harding, J.S., Benfield, E.F., Bolstad, P.V., Helfman, G.S., and Jones, E.B.D., III, 1998, Stream biodiversity—The ghost of land use past: *Proceedings of the National Academy of Sciences USA*, v. 95, no. 25, p. 14843–14847.
- Koltun, G.F., Gray, J.R., and McElhone, T.J., 1994, User's manual for SEDCALC, a computer program for computation of suspended-sediment discharge: U.S. Geological Survey Open-File Report 94–459, 46 p.
- North Carolina Department of Environment, Health, and Natural Resources, Division of Environmental Management, 1992, North Carolina lake assessment report: Raleigh, N.C., North Carolina Department of Environment, Health, and Natural Resources, Report 92–02, 353 p.
- North Carolina Division of Water Quality, 2000, Basinwide assessment report—Little Tennessee River: Raleigh, N.C., North Carolina Department of Environment and Natural Resources, 83 p.
- 2002, Little Tennessee River basinwide water quality plan: Raleigh, N.C., North Carolina Department of Environment and Natural Resources, 129 p.
- Rantz, S.E., and others, 1982, Measurement and computation of streamflow: U.S. Geological Survey Water-Supply Paper 2175, v. 1 and 2, 631 p.
- Scott, M.C., Helfman, G.S., McTammany, M.E., Benfield, E.F., and Bolstad, P.V., 2002, Multiscale influences on physical and chemical stream conditions across Blue Ridge landscapes: *Journal of the American Water Resources Association*, v. 38, no. 5, p. 1379–1392.
- Simmons, C.E., 1993, Sediment characteristics of North Carolina streams, 1970–79: U.S. Geological Survey Water-Supply Paper 2364, 84 p.
- Southeast Regional Climate Center, 2003, Historical climate summaries for North Carolina: accessed on Jan. 16, 2003, at <http://cirrus.dnr.state.sc.us/cgi-bin/sercc/cliMAIN.pl?nc3228>
- U.S. Geological Survey, 1997 to present, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A1–A9, 2 v. [variously paged].