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Berry H. (Nick) Tew, Jr.
State Geologist

WATER INVESTIGATIONS PROGRAM

AN ANALYSIS OF SEDIMENTATION LOADING RATES IN CEDAR CREEK, FRANKLIN COUNTY, ALABAMA, 2005-06
OPEN-FILE REPORT 0602

by

Stuart W. McGregor, Patrick E. O'Neil, and Neil E. Moss

With field and laboratory assistance from Mirza A. Beg, Lifo Chen,
Marlon R. Cook, and Robert E. Meintzer

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TABLE OF CONTENTS

Abstract 1
Introduction 2
Acknowledgments 3
Description of the study area 4
Methods 4
Results 8
Streamflow conditions 8
Suspended sediment 10
Bedload sediment 10
Conclusions and recommendations 16
Literature cited 22

ILLUSTRATIONS

Figure 1. Location of sampling stations in the Bear Creek system 5
Figure 2. Measured discharge and total suspended sediment at station CC2, Cedar Creek near Pogo, Franklin County, Alabama 11
Figure 3. Estimated total suspended sediment loads for Bear Creek and selected tributaries (total watershed area) 13
Figure 4. Estimated total suspended sediment loads for Bear Creek and selected tributaries (specified drainage areas) 13
Figure 5. Measured discharge, average streamflow velocity, and bedload sediment at Cedar Creek near Pogo, Franklin County, Alabama 15
Figure 6. Estimated bedload sediment for Bear Creek and selected tributaries (total drainage area) 17
Figure 7. Estimated bedload sediment for Bear Creek and selected tributaries (specified drainage area) 17
Figure 8. Estimated total sediment loads for Bear Creek sampling stations 18
Figure 9. Estimated total sediment loads for Bear Creek sampling stations 18

TABLES

Table 1. Streamflow characteristics for selected stations in the Bear Creek system 9
Table 2. Total suspended sediment (TSS) and TSS loads for sampling stations in the Bear Creek system 12
Table 3. Measured daily bedload and estimated annual bedload for sampling stations in the Bear Creek system 14

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ABSTRACT

A short stream reach of Bear Creek harbors a diverse population of freshwater mussels, which is a rare occurrence in post-impoundment Tennessee River tributaries. Results of this study and a previous study in Bear Creek (McGregor and Cook, 2004) indicate that significant and, in some cases, excessive sedimentation is occurring in the Bear Creek system, primarily in the Bear Creek floodway, threatening mussel populations in lower Bear Creek. Most stations evaluated during these studies showed potential for continued habitat degradation due to sedimentation. However, the reach of Bear Creek from Red Bay, Alabama, to Tishomingo County, Mississippi, County Road 86, including the floodway, consistently yielded very high sediment loading rates, which are of most concern to mussel habitat. The floodway stations (BC1 and BC2) consistently had (a) the largest volume of gravel bed material mobilized, (b) the highest mean streamflow velocity, (c) the largest suspended sediment load in total weight and in mass per unit area, and (d) the largest bedload in total weight and in mass per unit area. The gravel bed material moving through the floodway is composed of materials eroded from ridges in the middle and downstream reaches of the watershed (Tuscaloosa Group) and from the headwaters (Pottsville Formation). This suggests that land disturbance activities in those areas introduce a large volume of sediment that enters tributaries and is transported to Bear Creek and the floodway, and eventually to the Tennessee River.

INTRODUCTION

Freshwater mussels are considered one of the most imperiled faunal groups in North America based on their rapid extinction rate and preponderance of imperiled species (Master, 1993; Williams and others, 1993; Lydeard and Mayden, 1995). Historic records of 91 percent of the recognized North American mussel fauna exist from the southeastern United States and 60 percent from Alabama (Neves and others, 1997). Of particular importance is the Tennessee River system, considered to be the most biologically diverse system for mussels in the world (Ortmann, 1918, 1924, 1925; Remington and Clench, 1925; Dennis, 1984; Garner and McGregor, 2001).

The Bear Creek system mussel fauna has experienced extreme changes due to the effects of habitat alterations (such as impoundment, channelization, wastewater discharge and possibly other point-source pollution, and agricultural and silvicultural practices) or in the potential fish host composition. However, a diverse and viable fauna still remains in a short reach of the main channel. The population of the Cumberlandian combshell, *Epioblasma brevidens* (Lea, 1831), in Bear Creek is the only known population of this species in the lower Tennessee River system, and only two populations of the slabside pearlymussel, *Lexingtonia dolabelloides* (Lea, 1840), remain downstream of Paint Rock River, one in Bear Creek and one in Duck River of middle Tennessee (Ahlstedt, 1991; McGregor and Garner, 2004). With concerted effort to identify and mitigate sources of impairment, it is possible the existing fauna in Bear Creek could eventually repopulate other areas of the system.

Impoundments are significant impairments to native mussel populations (Ortmann, 1924; Scruggs, 1960; Isom, 1969; Fuller, 1974; Benke, 1990; Williams and others, 1993; Yeager, 1993). However, the downstream effects of impoundment are equally important. There may appear to be sufficient streamflow to support mussels on casual observation. However, changes in seasonality, intensity and duration of flow along with altered patterns of scour and deposition of sediment and altered suspended sediment regimes often renders downstream habitats unsuitable as well (Vaughn and Taylor, 1999). Furthermore, fragmenting of populations by impoundments may diminish

the survival of mussel populations by interrupting gene flow and possibly reducing the availability of host fishes (Bogan, 1993). Powell (1999) found that, although many water-quality and habitat variables were covariant with the density of cropland in streams in the Eastern Highland Rim Ecoregion of the lower Tennessee River basin, fish communities (and therefore mussel communities) primarily responded to the cumulative effects of sedimentation. Roy and others (2003) found that riffle habitats exhibited the strongest relations with environmental variables among riffle, pool, and bank habitats studied and were negatively affected by both physical (*e.g*. bed mobility) and chemical (*e.g*. specific conductance, nutrient concentrations) variables.

The objective of this study was to quantify the relative sedimentation loading rates in Cedar Creek. Previous research (McGregor and Cook, 2004) determined the relative rates of sedimentation loading in other streams within the Bear Creek system. The information gathered during these studies will assist regulatory agencies and other responsible parties to determine specific problem areas where remediation efforts should be implemented to best protect the stream's fauna.

ACKNOWLEDGMENTS

Phillip Henderson of the Geological Survey of Alabama (GSA) created the original version of the map used in this report. Marlon R. Cook of the Office of Water Resources, Alabama Department of Economic and Community Affairs, formerly of GSA, designed the sampling protocol for this study and assisted with field work. Personnel of the Tennessee Valley Authority (TVA) supplied stream discharge data. This project was supported by funds from the Alabama Department of Conservation and Natural Resources, Wildlife and Freshwater Fisheries Division. Sampling outside Alabama was supported by funds from the National Fish and Wildlife Foundation.

DESCRIPTION OF THE WATERSHED

Bear Creek (fig. 1) is a 136-mile long southern tributary of the Tennessee River. The system drains 942 square miles (mi^2) in Colbert, Franklin, Lawrence, and Winston Counties, Alabama, and Itawamba and Tishomingo Counties, Mississippi, with about 85 percent of the watershed in Alabama (Mettee and others, 1996). According to Taylor and Hall (1974), in the early 1970s approximately 70 percent of the watershed was in forest, 20 percent was in miscellaneous use such as commercial enterprise, roads, towns, etc., and 10 percent was in agricultural use. The Forest Riparian Habitat Survey conducted by the U.S. Environmental Protection Agency (USEPA) (1990) reported over 75 percent of the watershed to be forest. Conservation assessment worksheets compiled by local U.S. Department of Agriculture, Soil and Water Conservation Districts (SWCDs) reported the following percentages of land use: forestland (72 percent), pastureland (12 percent), cropland (6 percent), urban land (3 percent), open water (3 percent), mining (2 percent), and other (2 percent) (Alabama Department of Environmental Management, 2000). Phillips (2001) reported that land use within the watershed showed little change between 1972 and 1992.

Pickwick Reservoir of the Tennessee River has inundated the lowermost 20 miles of Bear Creek since 1938. Four dams built within the Bear Creek system between 1969 and 1979 inundated several thousand acres and changed long reaches of free-flowing streams into large pools. Two of these dams were on the main channel, at Bear Creek mile (BCM) 75 (1969) and BCM 116 (1978), and one each on Little Bear Creek at mile 11.6 (1975), and Cedar Creek at mile 23.3 (1979). Other human alterations to habitat associated with flood control include channelization of selected reaches and a 9-mile floodway along an 18-mile stretch of the stream designed to limit flooding of about 15,000 acres of floodplain during high water events (TVA, 2001).

METHODS

Sedimentation is a process by which eroded particles of rock are transported primarily by moving water from areas of relatively high elevation to areas of relatively low elevation, where the particles are deposited. Upland sediment transport is

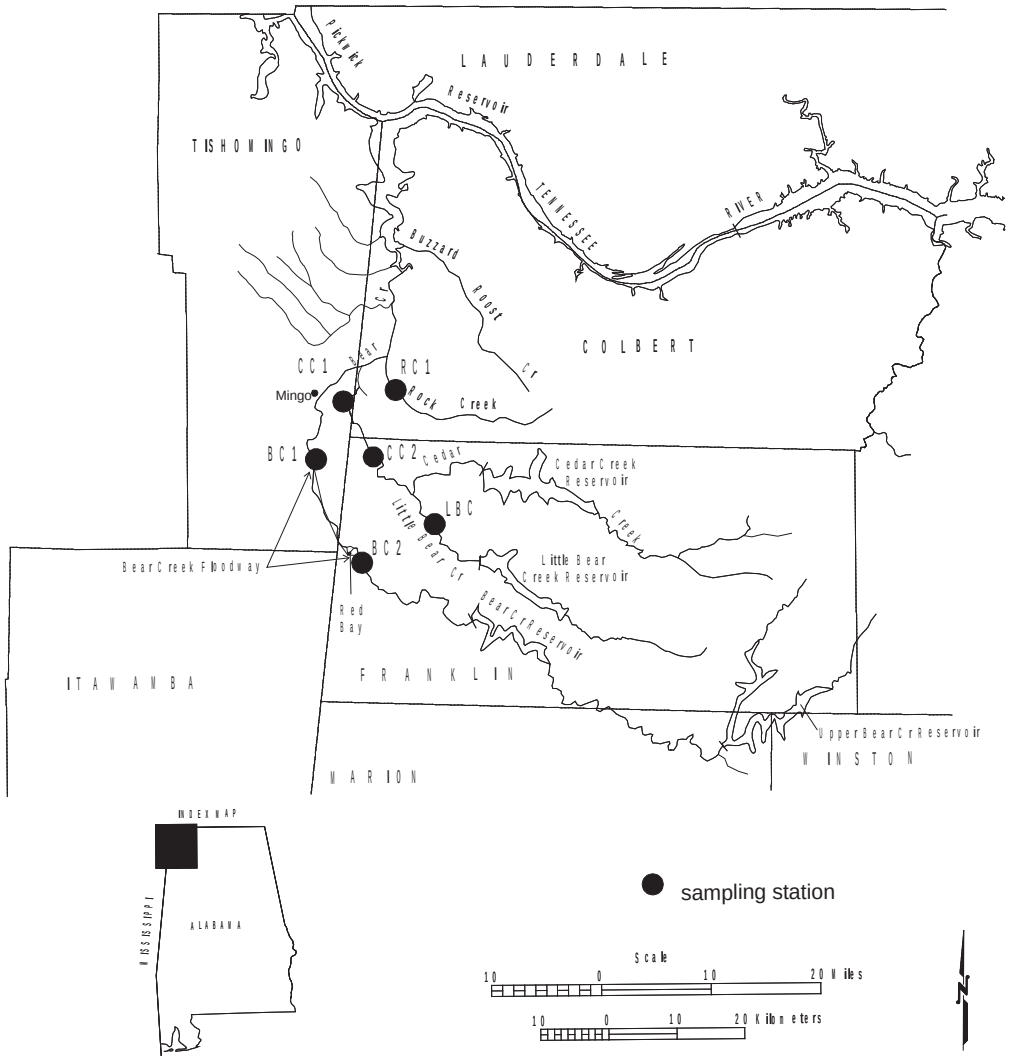

Figure 1. Location of sampling stations in the Bear Creek system.

accomplished by overland flow and rill and gully development. Lowland or floodplain transport occurs in streams of varying order, where upland sediment joins sediment eroded from floodplains, stream banks, and streambeds. Erosion rates are accelerated by human activity related to agriculture, construction, timber harvesting, unimproved roadways, or any activity where soils or geologic units are exposed or disturbed. Excessive sedimentation is detrimental to water quality, destroys habitat, reduces storage volume of water impoundments, impedes the usability of aquatic recreational areas, and causes damage to instream man made structures. Sediment loads in streams are primarily composed of relatively small particles suspended in the water column (suspended sediment) and larger particles that move on or periodically near the streambed (bedload).

During a previous study (McGregor and Cook, 2004) five monitoring stations were established in the Bear Creek system to measure total suspended and bed sediment loads, streamflow conditions, and water quality. In addition, a limited number of bank pins were installed to measure stream bank erosion. The stations were on three tributaries to Bear Creek (Rock Creek at Colbert County Road 1 near Maud (RC1); Cedar Creek at Mingo Road, Tishomingo County, Mississippi (CC1); and Little Bear Creek downstream from Alabama Highway 247, Franklin County, Alabama (LBC)) and two sites on Bear Creek (Tishomingo County Road 86 at the downstream end of the floodway (BC1) and at Alabama Highway 24 near Red Bay, Franklin County (BC2)) (fig. 1). Due to morphology of the stream channel at site CC1, insufficient data were collected for an assessment of bed sediment loads in the Cedar Creek watershed. Station CC2, located at the Franklin County Highway 90 bridge near Pogo, was selected as a replacement station for CC1 due to its more desirable morphology.

Twelve samples were collected at CC2 from June, 2005 until January, 2006, and analyzed for total suspended sediment (TSS). Field parameters were also measured for each sample using a Horiba water sampler model U10 and included dissolved oxygen (milligrams per liter, mg/L), temperature (degrees Celsius, °C) turbidity (nephlometric turbidity units, NTU), pH, and specific conductance (micro Siemens per centimeter, μS/cm). Stream gauge height was measured for each sample from a fixed reference

point on the bridge. Discharge was measured on four sampling trips and stream bedload was measured on two sampling trips.

Discharge at site CC2 is determined in large part by regulated flows from Cedar Creek and Little Bear Creek dams in response to flooding or expected flooding. Reservoir levels are systematically lowered in the fall which results in high streamflow rates that may increase or decrease rapidly and may continue at high levels for extended periods several times each year. The TVA provided daily flow information at the dams. The values for each day were added together and corrected for area yielding average daily discharge at site CC2 which was used for calculating loading rates of TSS and bedload.

The TSS load is the weight of suspended sediment that passes a cross-section of a stream in a specific amount of time. Loads are generally expressed in mass units (*e.g.*, tons (t) or kilograms (kg)) and are considered for time intervals that are relative to the type of pollutant and the watershed area for which the loads are calculated (per day (d), per year (yr)). The computer model, Regr_Cntr.xls (*Regression with Centering*), was selected to calculate TSS loads for this project. The program is an EXCEL adaptation of the U.S. Geological Survey seven-parameter regression model for load estimation (Cohn and others, 1992). It estimates constituent loads in a manner very similar to that used most often by the Estimatr.exe (*USGS Estimator*) program. The Regr_Cntr.xls program was adapted by R. Peter Richards at the Water Quality Laboratory of Heidelberg College (Richards, 1999) and establishes a regression model using a calibration set of data composed of constituent concentrations and discharge values measured at the time of water sampling.

The Geological Survey of Alabama has developed a portable bedload sedimentation rate monitoring device that was designed to measure instantaneous bedload sediment rates in shallow sand or gravel bed streams. Daily bedload rates were then calculated from these measurements, and a relationship between discharge and daily bedload rate was determined. Average daily discharge was then used with the relationship to estimate daily bedload rates for site CC2.

RESULTS

STREAMFLOW CONDITIONS

Sediment transport in the Bear Creek system was evaluated within particular stream segments in relation to the tributary impoundments. Rock Creek (drainage area upstream from monitoring site RC1 to headwaters, 50 mi^2) was the only unregulated stream in the investigation and exhibited flashy flow conditions typical of most natural upland streams in the Upper Coastal Plain Paleozoic Complex Province (Cook and Kopaska-Merkel, 1997). Cedar Creek (drainage area upstream from site CC1 to headwaters, 331 mi^2; drainage area upstream of site CC2 to headwaters, 303 mi^2) (drainage area upstream from monitoring site CC2 to Cedar Creek Dam, 33.2 mi^2) is highly regulated with periodic rapid changes in flow conditions. Little Bear Creek (drainage area upstream from site LBC, 83 mi^2) (drainage area upstream from site LBC to Little Bear Creek Dam, 32 mi^2) exhibits flashy flow conditions and may experience periodic rapid changes in discharge in response to releases of water from Little Bear Creek Reservoir. Bear Creek at Alabama Highway 24 (drainage area upstream from site BC2 to headwaters, 267 mi^2) (drainage area upstream from site BC2 to Bear Creek Dam, 36 mi^2) exhibits less flashy discharge due to the proximity of the monitoring site to Bear Creek Reservoir. However, this stream may experience periodic rapid changes in discharge in response to releases of water from Bear Creek Reservoir. Bear Creek at Tishomingo County Road 86 near the downstream end of the floodway (drainage area upstream from site BC1 to headwaters, 313 mi^2) (drainage area upstream from site BC1 to Bear Creek Dam, 83 mi^2) (drainage area upstream from site BC1 to site BC2, 46 mi^2) is subject to rapid increases in flow in response to large precipitation events and releases of water from Bear Creek Reservoir. Streamflow characteristics for these stations are shown in table 1.

Table 1. Stream flow characteristics for selected stations in the Bear Creek system.

Sampling station	Discharge (ft^3/s)[1]			Flow velocity (ft/s)[2]		
	Avg	Max	Min	Avg	Max	Min
Rock Creek (RC1)	61	311	3	1.2	1.42	0.89
Cedar Creek (CC1)	538	2749	25	2.02	3.22	1.33
Cedar Creek (CC2)	456	2641	53.9	2.2	3.97	1.23
Little Bear Creek (LBC1)	144	741	7	2	2.8	1.12
Bear Creek at Co. Hwy 86 (BC1)	655	3346	31	2.25	2.8	1.6
Bear Creek at Ala. Hwy. 24 (BC2)	467	2390	22	1.45	2.02	1.02

[1](ft^3/s)-cubic feet per second
[2](ft/s)-feet per second

SUSPENDED SEDIMENT

The relationship between measured TSS concentrations and stream discharge for station CC2 depicts a significant correlation between these parameters (fig. 2). Calculated TSS loads for stations CC2 and the other monitoring stations in the Bear Creek system are compared in table 2. Suspended sediment loads were calculated two ways: first by total watershed area (fig. 3) and second by TSS loads contributed by the watershed downstream of tributary impoundments (fig. 4). The amount of suspended sediment retained in the Bear Creek, Little Bear Creek, and Cedar Creek reservoirs was estimated from a limited amount of data collected from the impoundments (McGregor and Cook, 2004). These data indicated that approximately 36 percent of the suspended sediment entering impoundments is potentially retained and 64 percent passes through. This estimate was considered in the calculation of TSS loads for the partial watershed areas downstream of impoundments (table 2). Rock Creek (site RC1) is the only suspended sediment load calculated for an unregulated stream.

During the previous study (McGregor and Cook, 2004) the greatest TSS load, both in total mass (41,458 t/yr) and in mass per unit area (498 t/mi^2/yr), was transported by the segment of Bear Creek between sites BC2 and BC1. The smallest loads were transported by Rock Creek (1,502 t/yr and 30 t/mi^2/yr) and Little Bear Creek (4,881 t/yr and 127 t/mi^2/yr). The calculated TSS loads for station CC2 were 11,701 t/yr and 97 t/mi^2/yr.

BEDLOAD SEDIMENT

The bedload-discharge relationship was applied to estimated mean daily discharge for station CC2, and values of mean daily bedload mass were calculated from these data. Table 3 includes measured daily bedload rates and estimated annual bedload rates for all stations examined in the Bear Creek system. Figure 5 depicts measured bedload sedimentation rates, stream discharge, and mean stream velocity for station CC2. Correlations of measured mean flow velocity and bedload mass for stations BC1 and BC2 (McGregor and Cook, 2004) indicate that once a critical threshold of flow velocity is achieved, the bed material is mobilized and bedload

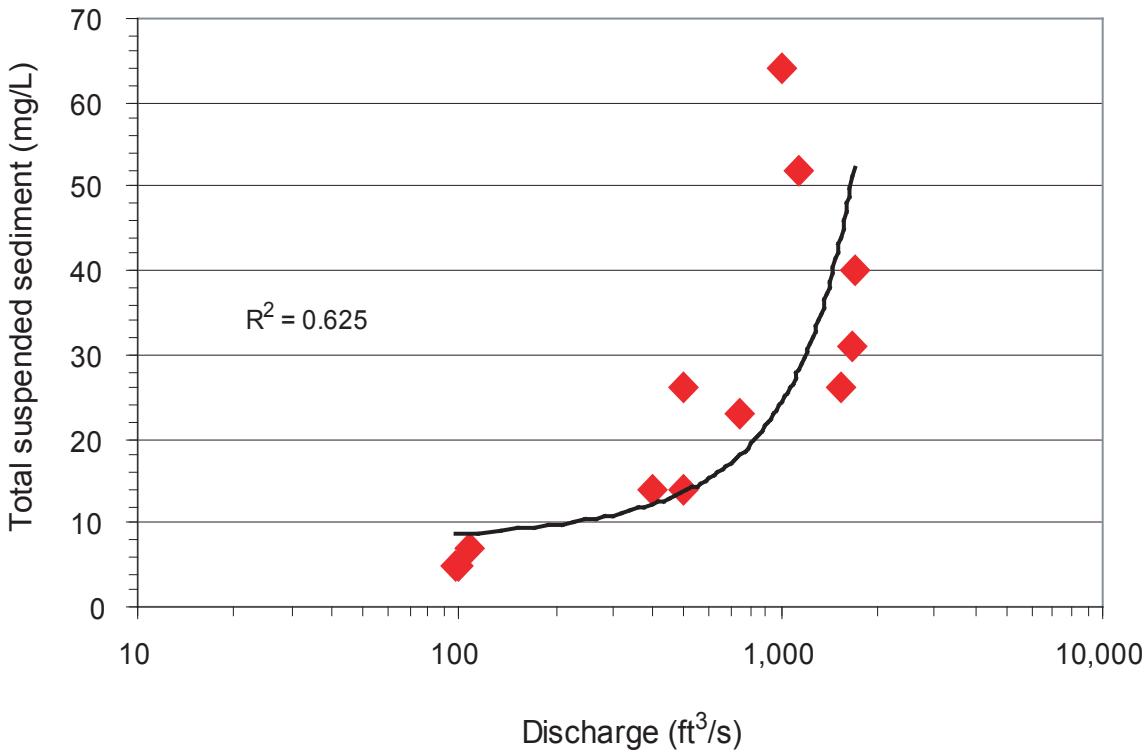

Figure 2. Measured discharge and total suspended sediment at station CC2, Cedar Creek near Pogo, Franklin County, Alabama.

Table 2. Total suspended sediment (TSS) and TSS loads for sampling stations in the Bear Creek system.

Sampling station	Total suspended sediment (mg/L)			Suspended sediment load	
	Avg	Max	Min	t/yr	$t/mi^2/yr$
Rock Creek (RC1)	20	94	<4	1,502	30
Cedar Creek (CC1)	15	73	4	22,146	199[a]
Cedar Creek (CC2)	26	64	5	11,701	97[a]
Little Bear Creek (LBC1)	19	73	<4	4,881	127[a]
Bear Creek at Co. Hwy 86 (BC1)	44	172	<4	41,458	498[b]
Bear Creek at Ala. Hwy. 24 (BC2)	22	63	<4	18,572	230[a]

[a] Effects of impoundments on suspended sediment transport were considered in calculating normalized loads.
[b] Drainage area used for calculation of normalized suspended sediment load from station BC1 to BC2.

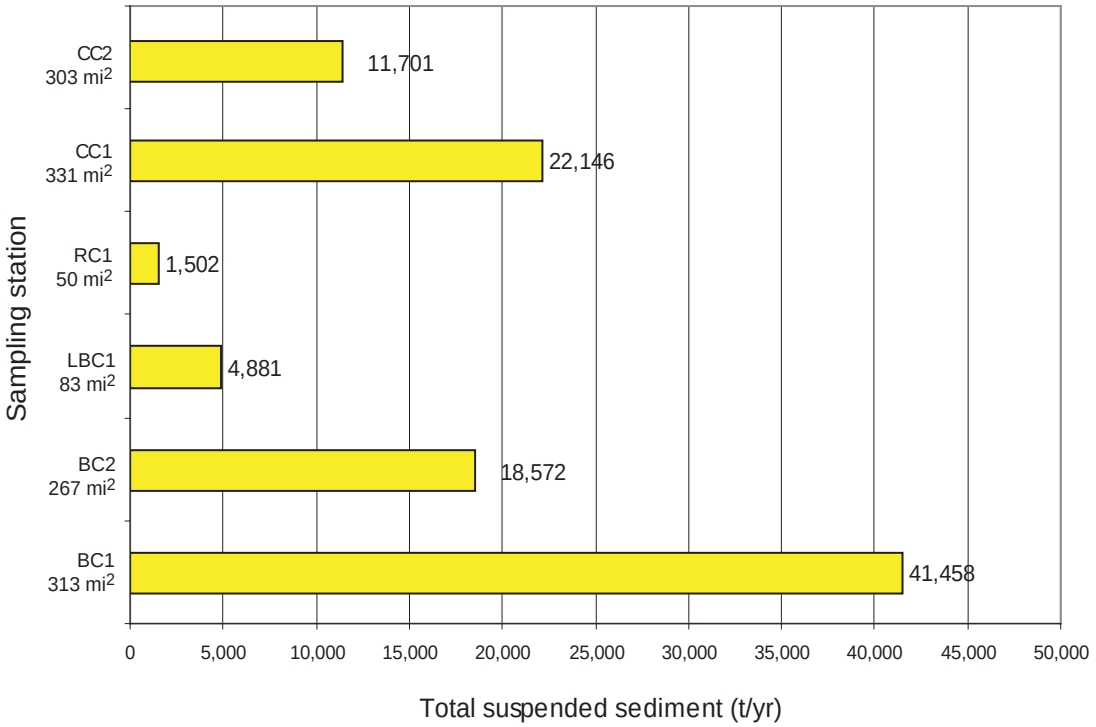

Figure 3. Estimated total suspended sediment loads for Bear Creek and selected tributaries (total watershed area).

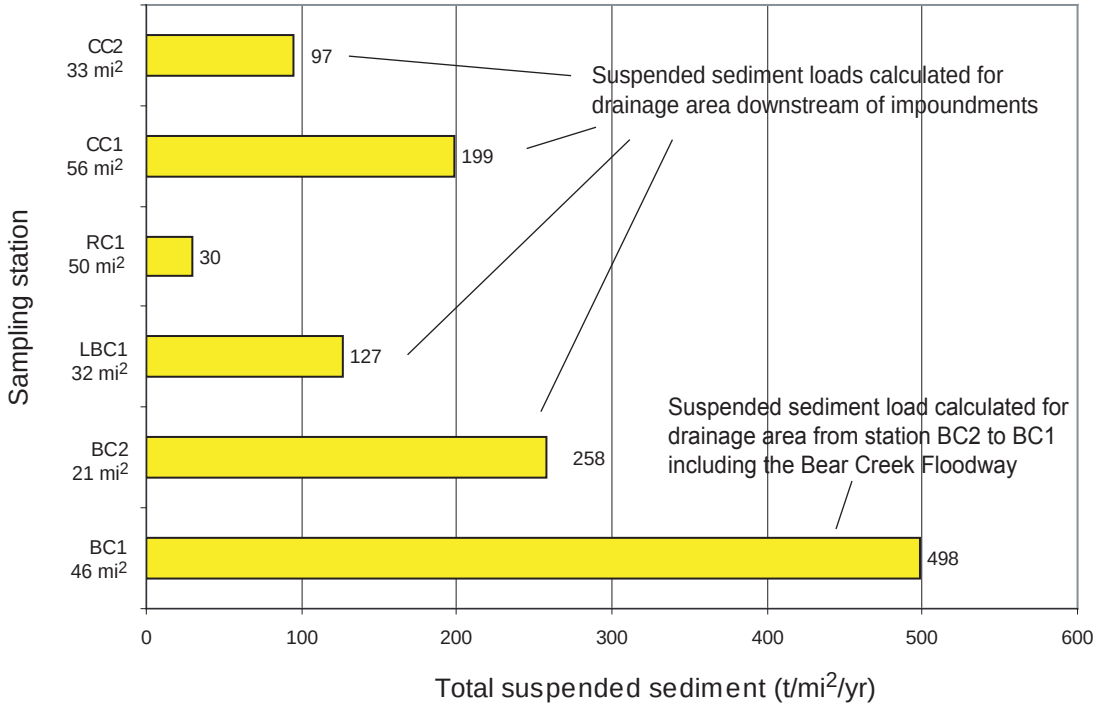

Figure 4. Estimated total suspended sediment loads for Bear Creek and selected tributaries (specified drainage area).

Table 3. Measured daily bedload and estimated annual bedload for sampling stations in the Bear Creek system.

Sampling station	Bedload sediment				
	Avg (t/d)	Max (t/d)	Min (t/d)	t/yr	$t/mi^2/yr$
Rock Creek (RC1)	1.3	2.9	0.02	241	4.8
Cedar Creek (CC1)	–-[a]	0.22	0	--	
Cedar Creek (CC2)	0.68	1.26	0.10	652	20
Little Bear Creek (LBC1)	19	73	BDL[b]	1,346	43
Bear Creek at Co. Hwy 86 (BC1)	21	76	0.16	12,491	272[c]
Bear Creek at Ala. Hwy. 24 (BC2)	22	63	BDL	464	22[d]

[a] Insufficient data to calculate average measured bedload or annual sediment loads.
[b] Below detection limit.
[c] Drainage area used for calculation of normalized suspended sediment load from station BC1 to BC2.
[d] Drainage area utilized for calculation of normalized suspended sediment load extends from impoundment to monitoring station.

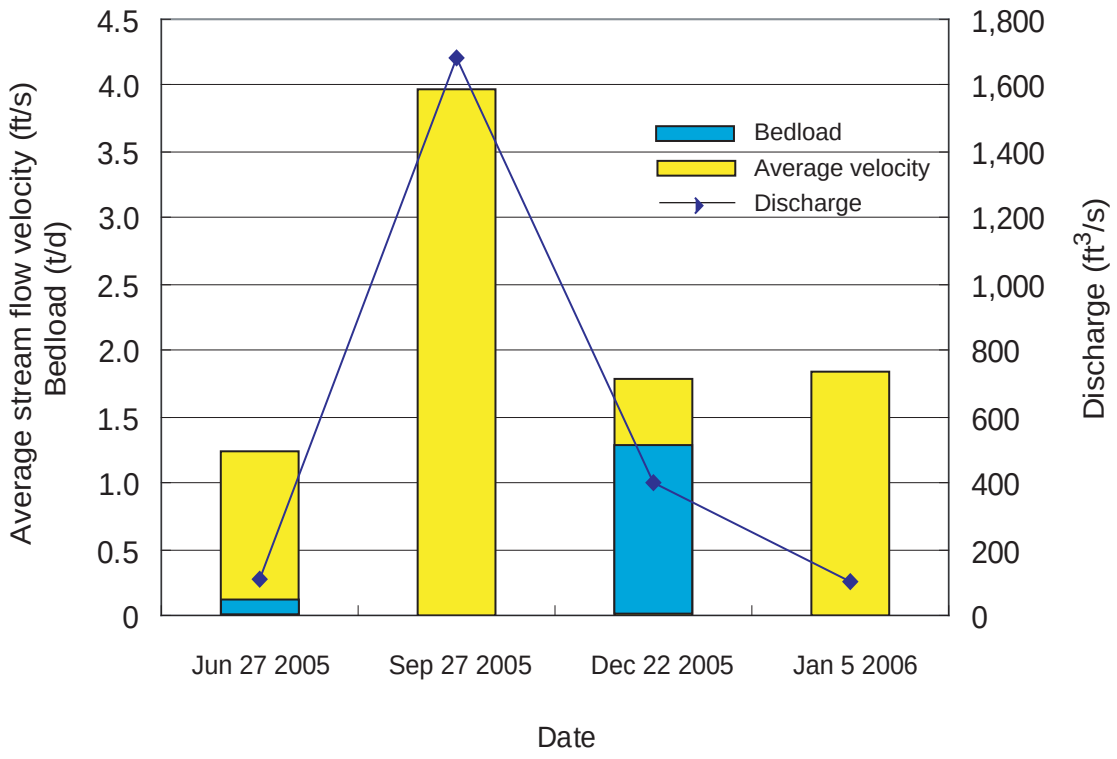

Figure 5. Measured discharge, average stream flow velocity, and bedload at Cedar Creek near Pogo, Franklin County, Alabama.

transport rates increase significantly. This velocity threshold is dependent on sediment supply and bedload grain size and is stream or stream segment specific. The critical velocity was estimated at 2.2 ft/s for site BC1, 1.36 ft/s for site BC2, and 1.25 ft/s for site RC1. A critical velocity could not be determined from the data collected at station LBC. Critical velocity at station CC2 was estimated at 1.5 ft/s. Once bed material is mobilized during a high streamflow event, it will continue to move at increased rates until the stream approaches base flow or until the stream bed achieves equilibrium.

The largest bedload, both in total mass (12,491 t/yr) and in mass per unit area (272 t/mi^2/yr), was transported by the segment of Bear Creek between sites BC2 and BC1. The smallest bedload was transported by Rock Creek (241 t/yr and 4.8 t/mi^2/yr). Like TSS loads, bed sediment loads were calculated two ways: first by total watershed area (fig. 6) and second by bed sediment loads contributed by the watershed downstream of tributary impoundments (fig. 7). The total sediment loads (suspended plus bed) for all stations are depicted in figures 8 and 9.

CONCLUSIONS AND RECOMMENDATIONS

The rate of sediment transport is a complex process controlled by a number of factors related to land use, precipitation runoff, erosion, stream discharge and flow velocity, stream base level, and physical properties of the sediment. One of the major land uses in the Bear Creek watershed is row crop agriculture at lower elevations. These soils were formed by deposition of sediment from upland areas and by weathering of the Bangor Limestone that underlies the floodplain. Timbering and construction occur at higher elevations on areas underlain by unconsolidated sands and gravels of the Eutaw Formation and Tuscaloosa Group. These and other land uses cause erosion that supplies sediment to Bear Creek and its tributaries. Excessive sedimentation causes changes in base-level elevation of stream beds and triggers downstream movement of the material as streams attempt to regain base-level equilibrium. The movement of this material is accelerated by periodic extreme precipitation events and releases of impounded water that cause increased streamflow and streamflow velocity.

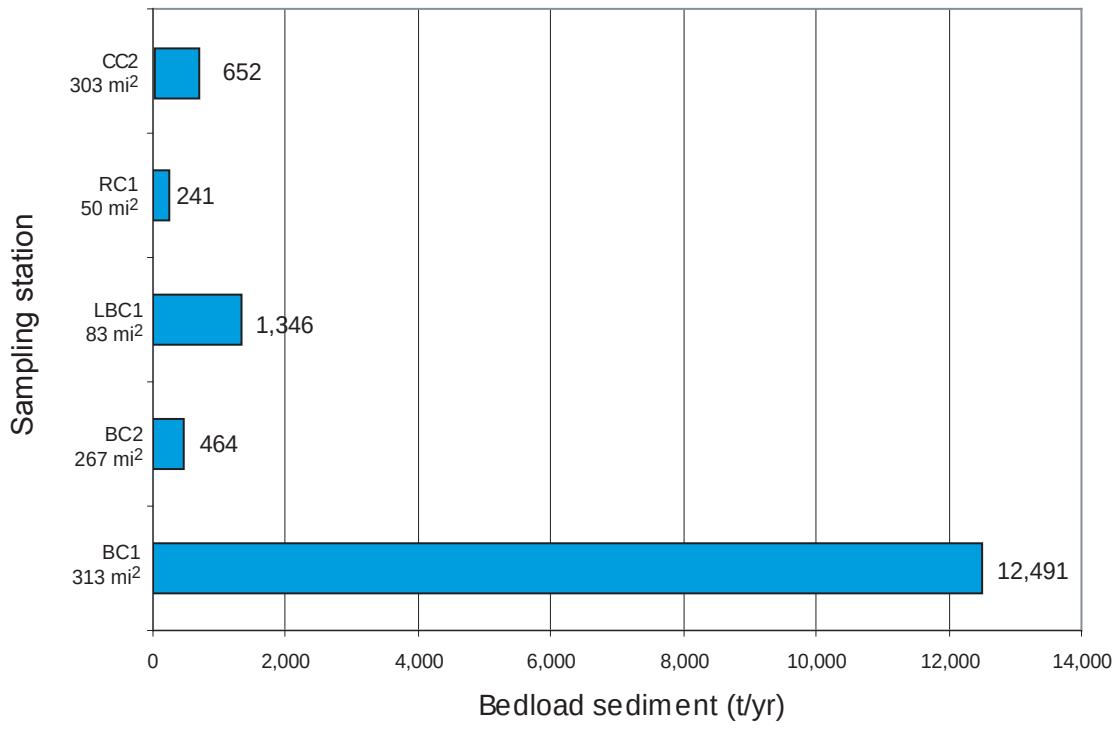

Figure 6. Estimated bedload sediment for Bear Creek and selected tributaries (total drainage areas).

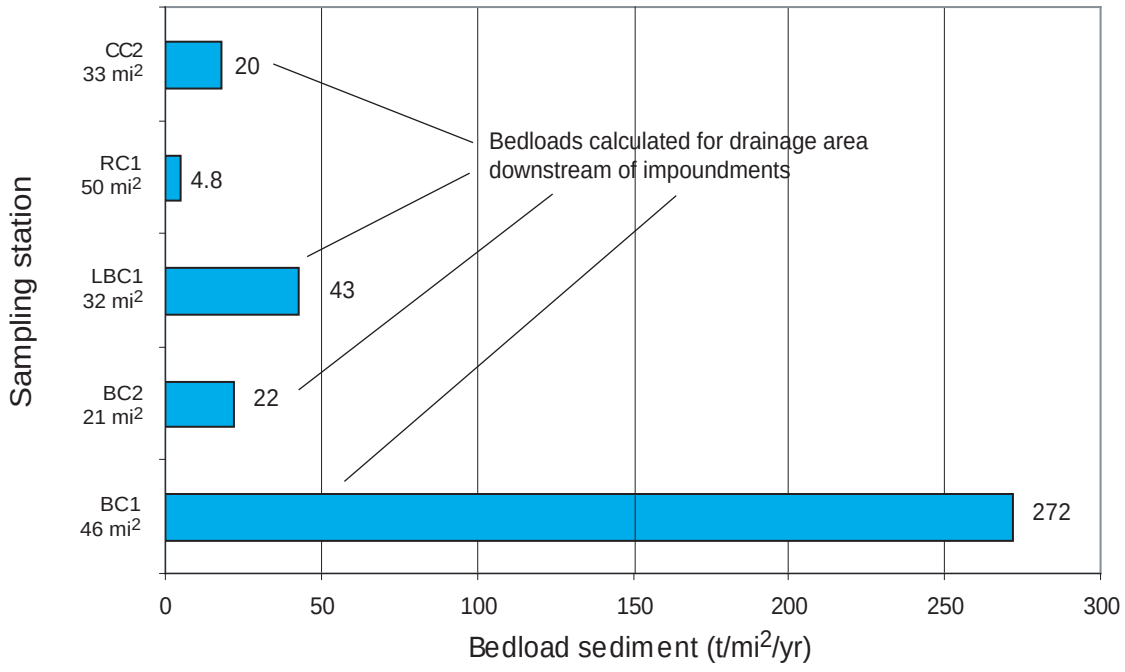

Figure 7. Estimated bedload sediment for Bear Creek and selected tributaries (specified drainage areas).

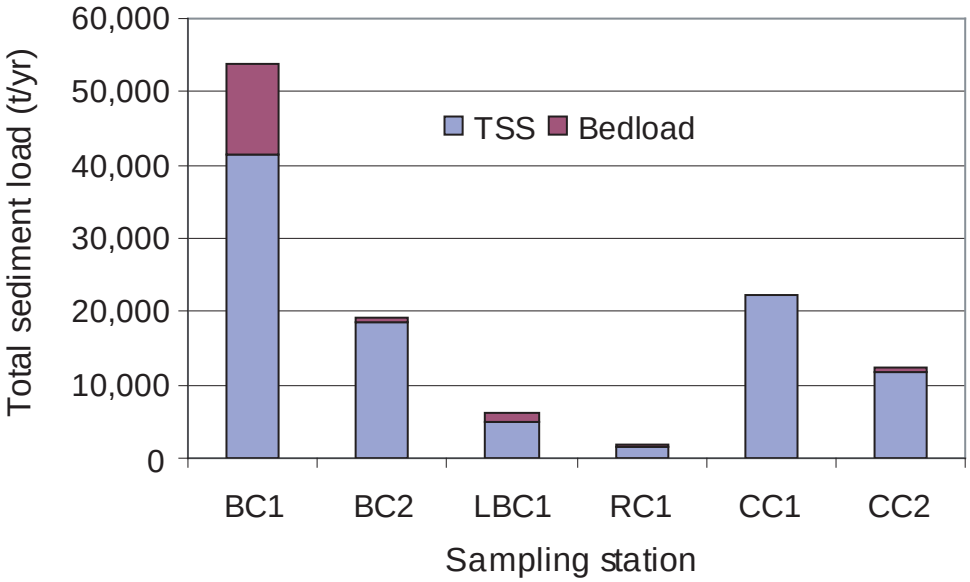

Figure 8. Estimated total sediment loads for Bear Creek sampling stations.

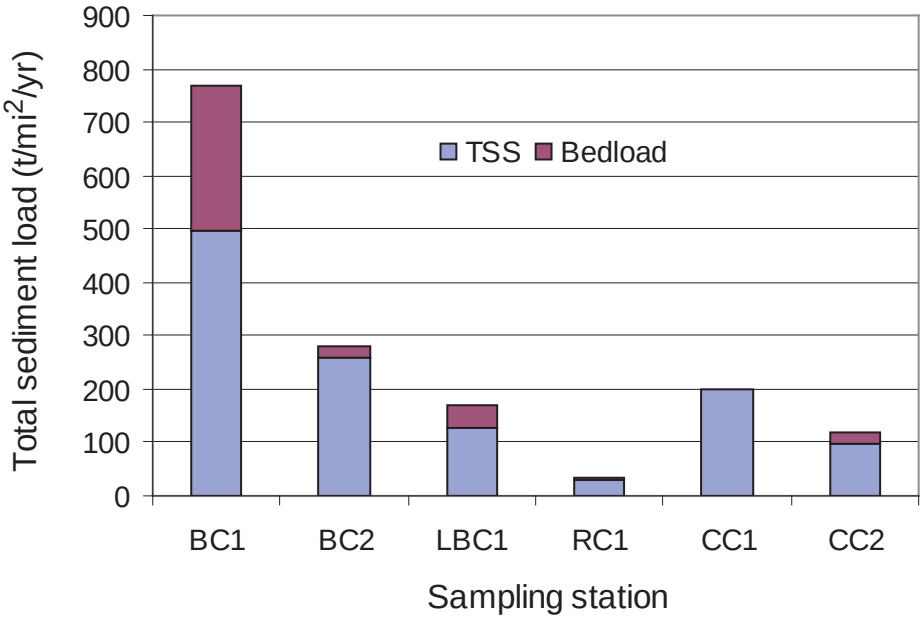

Figure 9. Estimated total sediment loads for Bear Creek sampling stations.

Due to the grain size composition of sediment in the Bear Creek watershed, movement of sediment material is controlled primarily by streamflow velocity. Large amounts of clay and silt may be suspended in the water column and transported at relatively low velocities during any discharge event greater than base flow. However, much of the bedload material in Bear Creek consists of heavier coarse sand and gravel eroded from the Tuscaloosa Group (Cretaceous age fluvial sediments) that forms ridge tops in the middle and downstream portions of the watershed, and silt, sand, and cobbles eroded from the Pottsville Formation (Pennsylvanian age sandstone and shale) that underlies the headwaters of the watershed. In order for the bedload material to be transported, a critical flow velocity threshold must be exceeded. This occurs during large precipitation events or during regulated releases of water from impoundments in the Bear Creek watershed. The duration of each pulse of bedload migration is dependent on the magnitude and duration of the discharge event. However, observations made at selected stations in the Bear Creek system during a previous study (McGregor and Cook, 2004) indicated that the downstream migration of bedload continues for three to seven days after the peak discharge and is not necessarily correlated to large discharge or the critical streamflow velocity threshold. Once the streambed material is mobilized, the level of energy required to keep the material moving on the falling limb of the hydrograph is generally much less. Therefore, large amounts of bedload will continue to be transported even as the stream approaches baseflow conditions. That was particularly evident at the downstream end of the Bear Creek floodway (BC1), where base level is profoundly affected by large volumes of gravel bed material that forms longitudinal bars in the stream channel.

Transport of streambed material is controlled by a number of factors primarily related to stream discharge and flow velocity, erosion and sediment supply, stream base level, and physical properties of the streambed material. Most streambeds are in a state of constant flux in order to maintain a stable base level elevation. The energy of flowing water in a stream is constantly changing to supply the required power for erosion or deposition of bedload to maintain equilibrium with the local water table and regional or global sea level. Stream base level may be affected by regional or global

events including fluctuations of sea level or tectonic movement. Local factors affecting base level include fluctuations in the water table elevation, changes in the supply of sediment to the stream caused by changing precipitation rates, and /or land use practices that promote excessive erosion in the floodplain or upland areas of the watershed.

Sources of sediment are related to land-use practices employed in the watershed and erosion from high flow events that occur frequently each year. As previously discussed, the primary land uses in the Bear Creek watershed are row crop agriculture at lower elevations and timbering and construction that occur at higher elevations. The largest concentration of row crop agriculture occurs in the Bear Creek floodplain along the floodway that extends 18 miles from near Red Bay, Alabama, downstream to County Road 86 in Tishomingo County, Mississippi. The largest area of silviculture is in the Cedar and Rock Creek watersheds in Colbert County, Alabama, and Tishomingo County, Mississippi. In areas where land-use practices have caused the land surface to erode, sediment is transported by overland flow to relatively small tributary streams where it is transported to the major streams. The floodway appears to be a major conduit for sediment transport and area for sediment deposition. Based on the results of this study and our qualitative observations throughout the Bear Creek system, we make the following recommendations:

- Evaluations of current land-use practices should be completed and areas of greatest potential sediment contribution determined. The results of these evaluations should be used to formulate best management practices (BMPs) for the watershed. These BMPs should be implemented throughout the watershed, not just along major streams, and should include areas near small headwater tributaries and ephemeral streams.
- Areas of denuded streambanks or with minimal riparian buffer should be identified and addressed.
- After sediment supply sources in the tributary headwaters are reduced, streamflow velocities in regulated streams should be maintained below the critical

thresholds required to mobilize bedload and erode stream banks and channels. The critical threshold velocity of Little Bear Creek should be determined.

- Further evaluation of sediment entrapment in Bear Creek impoundments should be completed. This would aid in refining the calculation of TSS loads normalized to watershed areas in respective tributaries.

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GEOLOGICAL SURVEY OF ALABAMA
P.O. Box 869999
420 Hackberry Lane
Tuscaloosa, Alabama 35486-6999
205/349-2852

Berry H. (Nick) Tew, Jr., State Geologist

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