Sediment-Transport Characteristics of Cane Creek, Lauderdale County, Tennessee

By W.P. CAREY

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
mile (mi)	1.609	kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
square mile (mi^2)	2.590	square kilometer
pound per square foot (lb/ft^2)	0.0479	kiloPascal

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

$$°F = 1.8\ (°C) + 32$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 – a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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By W.P. Carey

Abstract

An investigation of the sediment-transport characteristics of Cane Creek in Lauderdale County, West Tennessee, was conducted from 1985 to 1988. The study was designed to evaluate the potential for channel erosion induced by channel modifications (realignment and enlargement). The potential for different flows to move channel-stabilizing material also was investigated.

Incipient-motion analysis indicates that frequently occurring flows in Cane Creek are capable of moving sand-size material (0.0625 - 4.0 millimeters). This transport ability, coupled with a limited supply of coarse material in the basin, explains why limited deposits of alluvial material are present on the channel bed. During floods that equal or exceed the 2-year flood, Cane Creek is capable of moving coarse gravel (32 - 64 millimeters), indicating that Cane Creek is unlikely to undergo aggradation and channel-gradient reduction, which are common in post-modification stream channels in many areas.

Boundary-shear values at bridges where flow contractions occur correspond to critical diameters in excess of 100 millimeters. Thus, the areas near bridges, where channel stability is critical, are the areas where erosive power is greatest.

Deepening and widening of Cane Creek has exposed large areas of channel boundary that are a significant source of raindrop-detached sediment during the early stages of a storm before streamflow increases significantly. Erosion of these areas causes suspended-sediment concentration to peak while the discharge hydrograph is just beginning to rise. For basins like Cane Creek where runoff events often last less than a day and where variation in discharge and sediment concentrations are large, an estimate of sediment yield based on periodic observations of instantaneous values is subject to considerable uncertainty.

INTRODUCTION

The Cane Creek channel (fig. 1), located in Lauderdale County, West Tennessee, was realigned and enlarged in 1970-71 from old U.S. Highway 51 in Ripley to the confluence with the Hatchie River (fig. 1) to provide flood control and drainage for agricultural lands in the basin. The length of this channel was reduced from about 29 to 16.5 miles and the average slope increased from 0.00058 foot/foot (ft/ft) to about 0.00096 ft/ft. Additional water-carrying capacity also was provided by increasing the average cross-sectional area by about 15 percent (Charles R. Gamble, U.S. Geological Survey, written commun., 1990). Although the designed flood-control goals were achieved, the increased gradient and flow velocities associated with the channel modifications resulted in increased erosion and degradation throughout the channel length. From 1970 to 1985, erosion lowered the channel bed by as much as 30 feet in places and nearly doubled the channel width along most of the 16.5 mile reach.

The Cane Creek channel flows on deep, loess-derived, silty alluvium. Except in the uplands, depth to sand or gravel generally exceeds 40 feet in

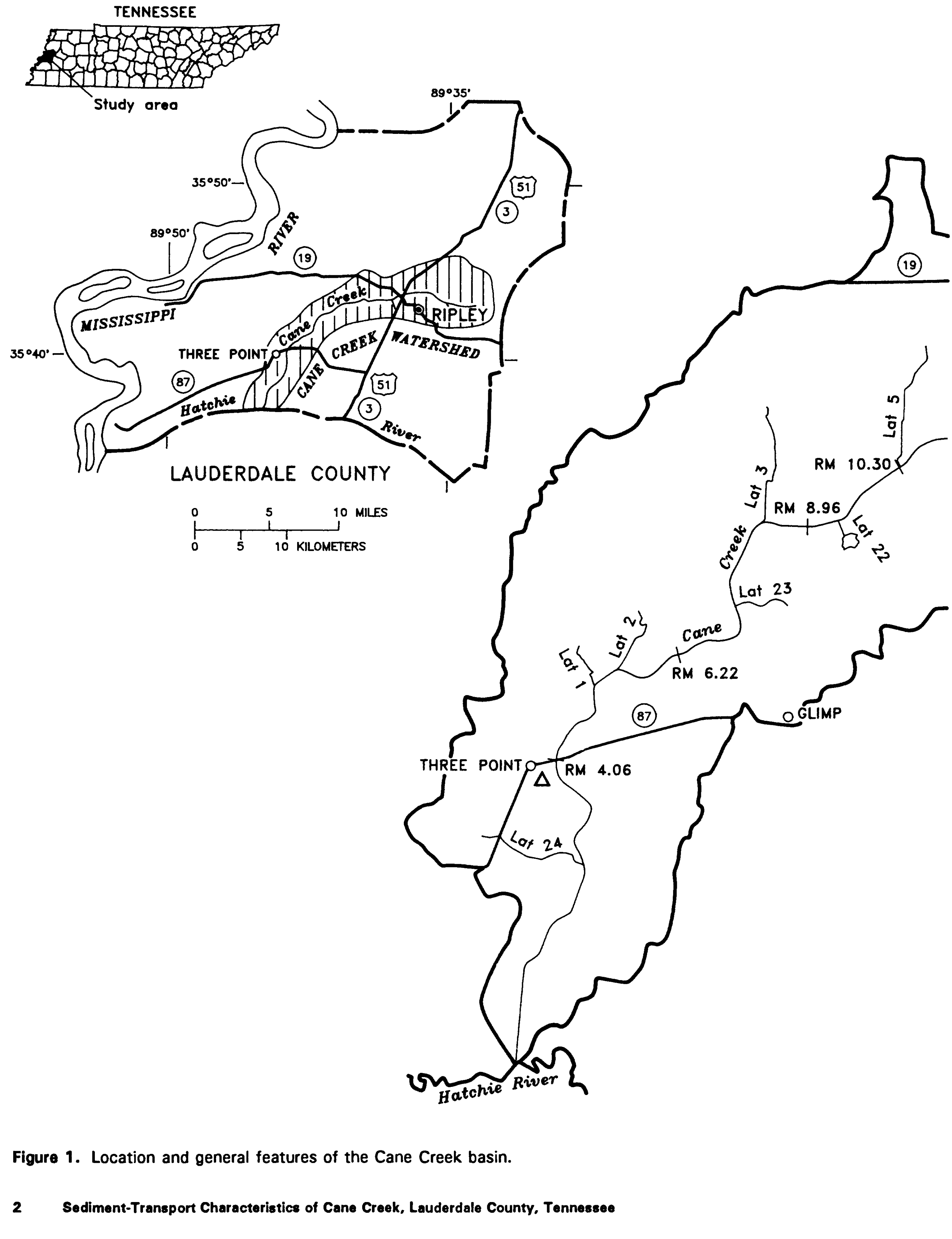
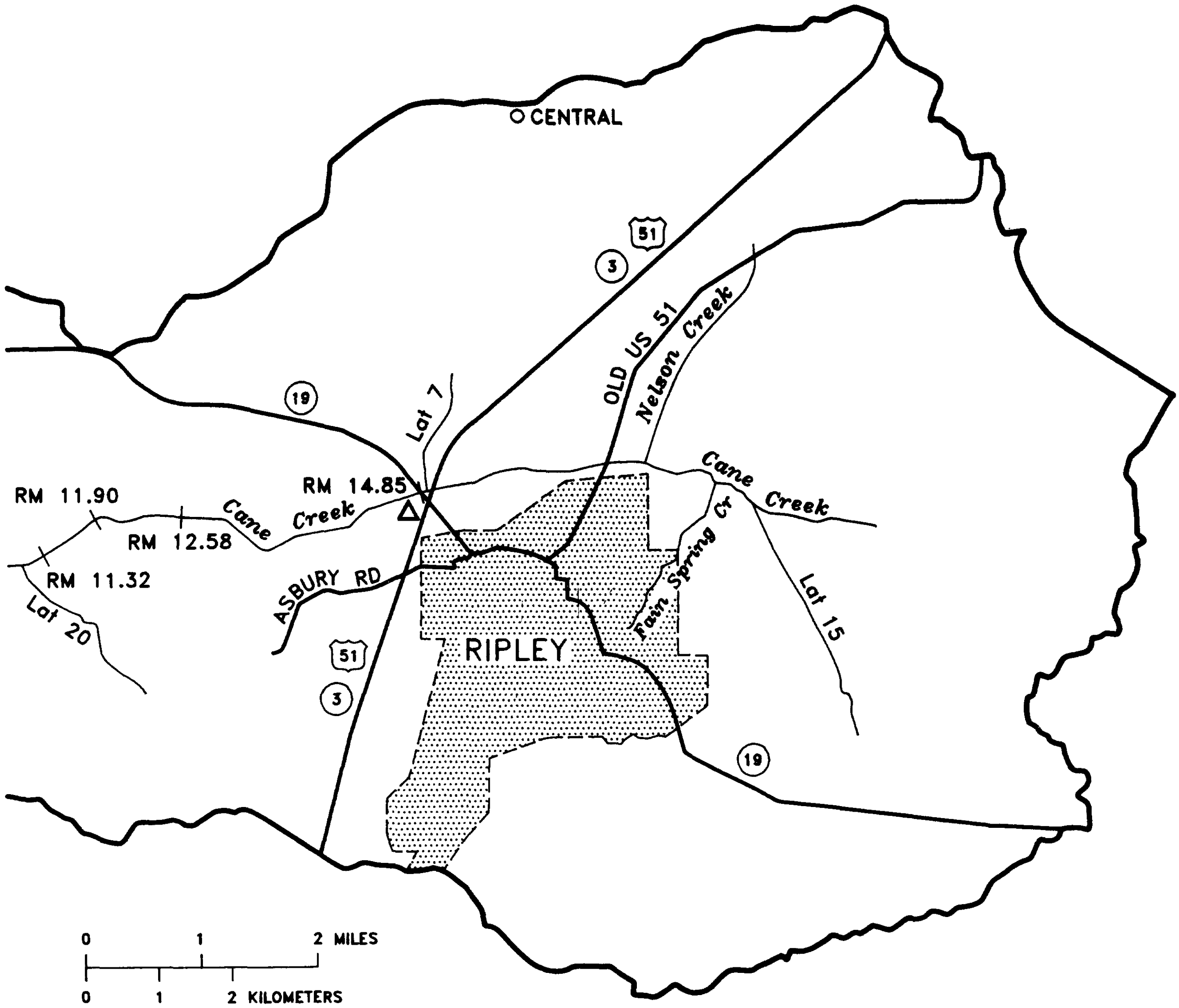


Figure 1. Location and general features of the Cane Creek basin.



EXPLANATION

Lat 15 LATERAL AND NUMBER

\ RM 14.85 RIVER MILE FROM MOUTH

△ GAGING STATION

Figure 1. Location and general features of the Cane Creek basin--Continued.

the Cane Creek basin (Miller, 1991), resulting in only limited amounts of sand-size or larger material being available for transport and armoring. Therefore, all of the sediment carrying capacity of Cane Creek flood flows is available for suspended-sediment transport and erosion of the silt-size material that forms the channel bed and banks.

Concerns about similar degradation of other channels in West Tennessee prompted an investigation to document the changes to Cane Creek channel morphology. The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Agriculture, Soil Conservation Service (SCS), initiated a multidisciplinary investigation of Cane Creek designed to study the geomorphic, geologic, and hydraulic history of the channel after the modifications. The transport of sediment in Cane Creek was among the processes studied during the project.

Purpose and Scope

The purposes of this report are to describe the hydraulic processes that control sediment transport in Cane Creek and to summarize sediment-transport characteristics of the creek. This report presents the results of an investigation, conducted between 1985 and 1988, of the Cane Creek channel from old U.S. 51 to the confluence with the Hatchie River (fig. 1). Hydraulic analyses of the Cane Creek main channel were used to determine the ability of selected discharges to move available sediment and material placed in the channel to stabilize bed and banks.

Description of the Study Area

Cane Creek is located in Lauderdale County, West Tennessee (fig. 1) in the Gulf Coastal Plain physiographic province (Fenneman, 1938). The channel, formed in deep, silty, erodible alluvium, flows from northeast to southwest and is tributary to the Hatchie River. The main channel and major tributaries have similar bed material (Miller, 1991) and have degraded and eroded headward extensively. Sand or gravel is generally greater than 40 feet beneath the layer of silty alluvium near the main channel (Miller, 1991). The hills that form the basin divide are highly dissected with relatively steep slopes. Upland soils are underlain by sand, gravel, and clay layers (Miller, 1991) that have not been exposed by the headward eroding channels, resulting in limited supply of sand-size or larger material for transport to downstream reaches (Miller, 1991). Isolated deposits of sand and gravel were observed in the main channel and probably originated from small lenses of sand and gravel in the flood-plain matrix.

Approach

Hydraulic characteristics of the Cane Creek main channel for post-modification and for conditions with drop structures in place (remedial conditions) were analyzed to evaluate the potential for sediment transport and for further channel degradation. Discharge and suspended-sediment data collected between October 1985 and September 1987 were used in this investigation to document sediment-transport characteristics.

DATA COLLECTION

Hydraulic characteristics for the main channel, including profiles, cross sections, and slopes, were documented from cross-sectional data collected by the SCS and USGS in 1970, 1980, and 1985 (Charles R. Gamble, U.S. Geological Survey, written commun., 1990). These sections represented channel conditions after modification. Potential changes in the water-surface profiles that might be induced by remedial measures were studied by analyzing the probable effects of proposed channel-stabilization structures on the 1985 cross-sections and profiles. Streamflow and suspended-sediment data collected at State Highway 19 at Ripley and State Highway 87 at Three Point (fig. 1) were used in conjunction with the channel hydraulics data to delineate changes in sediment-transport characteristics over time.

Hydraulic Data

For the 1970 condition, cross sections were developed from SCS channel modification plans.

Cross sections developed at the downstream end of each channel-width segment were propagated to the upstream end of that channel-width segment based on the design slope. Because the channel was uniform within that segment, uniform flow in the reach was assumed and only two sections were considered necessary (Charles R. Gamble, U.S. Geological Survey, written commun., 1990). For 1980, 101 cross sections surveyed by the SCS were available. For 1985, 73 cross sections surveyed by either the SCS or the USGS were available.

A step-backwater routing model developed and described by Shearman and others (1986) was used to compute water-surface profiles for selected discharges for 1970, 1980, and 1985 conditions. Hydraulic characteristics generated by the model were used to estimate potential for sediment transport.

Sediment Data

The data analyzed as part of this study included daily-mean suspended-sediment concentration, daily-mean discharge, and daily-mean suspended-sediment discharge, from October 21, 1985, to September 30, 1987, for the Ripley gaging station (drainage area 33.9 mi^2) and from October 21, 1985 to July 23, 1987, for the Three Point gaging station (drainage area 79.8 mi^2) (fig. 1). Suspended-sediment samples were collected with PS-69 automatic pumping samplers (U.S. Geological Survey, 1977) and manually by USGS personnel during regularly scheduled visits (at about 6-week intervals) and, whenever possible, during storm events using depth-integrating samplers (U.S. Geological Survey, 1977; Guy and Norman, 1970). The PS-69 pumping samplers were programmed to collect a sample every 45 minutes during storm events, and two samples per day between events. The samples were analyzed for suspended-sediment concentrations.

During the period of record, 34 flow events having peak discharges of 56 ft^3/s or higher occurred at Ripley. The discharge of 56 ft^3/s corresponds to a gage height of 6 feet and was selected arbitrarily to distinguish minor runoff events that do not require subdivided-day load computations from significant runoff events that were sampled by the PS-69 pumping sampler and required more complex computation methods. The PS-69 pumping sampler collected samples during all but 2 of the 34 events.

Thirty-one significant runoff events occurred at the Three Point gage and the PS-69 pumping sampler collected data on all but five of these events. A significant runoff event at Three Point is defined as an event having a peak discharge equal to or exceeding 141 ft^3/s. This discharge represents only a slightly larger runoff event than that represented by 56 ft^3/s at the Ripley station. On a per square mile basis, 56 ft^3/s at Ripley is 1.65 $(ft^3/s)/mi^2$, and 141 ft^3/s at Three Point is 1.77 $(ft^3/s)/mi^2$.

SEDIMENT-TRANSPORT CHARACTERISTICS

Sediment transport involves the processes of erosion, transport, and deposition. Sediment transport and deposition is dependent on the hydraulic characteristics of the flow of interest. Sediment detachment or erosion is dependent on the soil matrix characteristics and hydraulics at a given location. Quantity of sediment transported is dependent on hydraulics, soil matrix characteristics, and source characteristics such as land use or area of exposed channel banks.

Suspended-Sediment Transport

Data collected at Ripley and Three Point (fig. 1) were used to characterize suspended-sediment transport in the Cane Creek channel. Cross-section mean sediment concentrations were determined using the Equal Width Increment (EWI) sampling method (Guy and Norman, 1970) and were used to adjust point sediment concentrations from the PS-69 pumping samplers (Porterfield, 1972). Cross-section coefficients, the ratio of suspended-sediment concentration in a sample collected with a PS-69 automatic pumping sampler to the mean suspended-sediment concentration from an EWI sample taken at the same time, were determined at both stations for a range of flow conditions.

Ripley

The channel near the Ripley gage at State Highway 19 is straight for several hundred feet upstream and downstream of the bridge. The channel boundary near the gage is formed in loess-derived alluvium, which consists of silt and clay-size material.

Velocities at the Ripley gage usually range from 2 to 4 ft/s during runoff events. The highest measured velocity at the site was 4.96 ft/s. The maximum discharge for the period of record is 5,590 ft^3/s, which occurred on March 12, 1986, and equals the discharge of the computed 50-year flood for this site (Charles R. Gamble, U.S. Geological Survey, written commun., 1990). Discharge hydrographs at this site rise and fall rapidly, with stage changes of 4 to 7 feet per hour being common. The time between rapid rise and rapid fall of the flood hydrograph is usually less than 1 hour; entire runoff events usually last less than 24 hours.

These rapidly changing conditions required that the number of sampled verticals in the EWI sampling method be reduced from the recommended 10 or more, to 5. The sampling situation was further complicated by a tributary with a drainage area of 3.22 mi^2 that enters Cane Creek about 422 feet upstream from the gage. Mixing-length computations indicate that the required length to achieve 90-percent mixing exceeds the distance between the tributary and the Ripley gage for discharges in excess of 10 ft^3/s. For discharges above 100 ft^3/s, the mixing length exceeds the distance from the tributary to the gage by a factor of 4 to 5.

Cross-section coefficients determined at the Ripley gage range from 0.14 to 1.67 for 46 measurements. The mean of these 46 coefficients is 0.60, the standard deviation is 0.29, and the coefficient of variation is 48 percent. For 18 measurements made at a gage height of 6 feet or higher, the coefficients range from 0.46 to 1.00 with a mean of 0.69, a standard deviation of 0.16, and a coefficient of variation of 23 percent. Because no evidence of significant sand transport has been observed at this station, the variability in coefficients is believed to be caused by incomplete mixing of main-channel waters with those of the tributary entering 422 feet upstream. No apparent relation or correlation exists between these coefficients and stage or discharge. Therefore, coefficients were applied to the pumped sample concentrations only for the events for which they were determined. Interpolated coefficients were used for events between coefficient determinations.

Three Point

Downstream from the Three Point gage at State Highway 87 (fig.1), the channel is straight for a distance of about 800 feet. Upstream of the bridge, the channel is straight for about 200 feet and then curves such that the left bank forms the inside of the curve. The channel boundary near the gage is formed in loess-derived alluvium. Bank failures are much more prevalent at this station than at Ripley. Intermittent deposition of as much as 1.5 to 2 feet of alluvial material, consisting mostly of fine and medium sand, has been observed at this location. These accumulations occurred only during periods of backwater from the Hatchie River. This material is believed to have originated from sand lenses in the flood-plain matrix. The deposits, however, were later remobilized and transported out of the reach.

Velocities at the Three Point gage usually range from 2 to 4 ft/s during runoff events. The highest measured velocity at this site was 5.74 ft/s. The maximum discharge at this site during the period of record is 6,880 ft^3/s which occurred on March 12, 1986. This represents a flood with an average recurrence interval of 7 to 8 years (Charles R. Gamble, U.S. Geological Survey, written commun., 1990). Although this storm produced a discharge with an average recurrence interval of 50 years (a 50-year flood) at Ripley, relatively small discharges from intervening tributaries and hydrograph attenuation reduced it to about a 7- to 8-year flood at the Three Point gage. Stage changes at this site can be as rapid as 7 feet per hour; however, most hydrographs exhibit a rate of change of 2 to 4 feet per hour. Time between rise and fall of the hydrograph was usually less than 1 hour and entire events usually lasted less than 24 hours. Again, these rapidly changing discharge conditions required that the number of sampled verticals in the EWI sampling method be reduced from the recommended 10 or more, to 5.

Cross-section coefficients for estimating mean suspended-sediment concentrations from PS-69 data were determined for 40 measurements at the Three Point station. These coefficients range from 0.05 to 1.08, have a mean of 0.56, a standard deviation of 0.30, and a coefficient of variation of 54 percent. Coefficients for measurements when gage heights were 6 feet or higher and no backwater conditions existed, range from 0.20 to 1.08, have a mean of 0.74, a standard deviation of 0.33, and a coefficient of variation of 45 percent, based on 14 measurements. This large amount of variability is believed to result from the intermittent transport and deposition of sand in the reach during backwater from the Hatchie River and large areas of exposed bank material that cause locally high sediment concentrations near the PS-69 pumping sampler intake. No apparent relation or correlation exists between these coefficient values and stage or discharge. These coefficients were applied only to the events for which they were determined. Coefficients for periods between events were interpolated. Sediment data collected during periods of backwater were not used in the coefficient analysis.

Comparison of Sediment Transport at Ripley and Three Point

Summary statistics for daily-mean flow and sediment data at the Ripley and Three Point stations indicate that the data vary over a wide range and have high standard deviations relative to their means (table 1). Runoff per square mile is slightly higher at Ripley than at Three Point for all quartile values. Sediment discharge per square mile is about equal for values up to and including the median; but for the upper half of the distribution, values at Three Point exceed those at Ripley (fig. 2). The highly skewed nature of these distributions, and the importance of high-flow events is evident from the fact that the upper 25 percent of the distribution ranges over two orders of magnitude for discharge per square mile, and three orders of magnitude for sediment discharge per square mile (fig. 2). Also, the mean value for both of these quantities lies well within the upper 25 percent of their distributions.

The higher values of sediment discharge per square mile at Three Point are probably the result of channel-bed and bank erosion rather than a difference in upland erosion as the "per square mile" designation implies. The channel between Ripley and Three Point has deepened and widened to such an extent that large areas of the channel boundary, with little or no vegetation, are exposed to raindrop and rill erosion at the beginning of each storm. The length of channel between Ripley and Three Point represents a significant source of sediment during the early stages of a storm before streamflow begins to increase rapidly. This in-channel source of sediment causes sediment concentration to rise rapidly and peak while the discharge hydrograph is just beginning to rise (fig. 3).

At Three Point, the suspended-sediment concentration for a storm on March 11-13, 1986 (fig. 3), peaked 6 hours before the discharge peaked, and when discharge did peak, the suspended-sediment concentration had fallen to about 10 percent of its peak value. This is an extreme example in as much as the peak discharge on this date was the peak of record, but it illustrates that the initial stages of a storm can deliver a significant amount of sediment directly to the stream. The peak sediment discharge occurred 1 hour before the discharge peaked, and 5 hours after the peak sediment concentration.

For the same storm at the Ripley station, suspended-sediment concentration peaked 1.5 hours before the discharge peaked, and when discharge peaked, suspended-sediment concentration had fallen to 36 percent of its peak concentration (fig. 4). The fact that the peak sediment concentration preceded the peak discharge at Ripley indicates a nearby source of sediment, as was the case at the Three Point station. However, at the Ripley station, the primary source is more likely to have been upland agricultural areas than in-channel erosion. The upland source is indicated because the discharge corresponding to the peak sediment concentration was 53 percent of the peak discharge at the Ripley station (fig. 4), but only about 10 percent at the Three Point station (fig. 3). It seems

Table 1. Summary statistics for daily-mean flow and sediment data at Ripley and Three Point

[Q, water discharge in cubic feet per second; CONC, suspended-sediment concentration in milligrams per liter; QS, suspended-sediment discharge in tons per day; Q1, lower quartile value; Q3, upper quartile; CV, coefficient of variation; DA, drainage area in square miles]

Flow or sediment parameter	Number of samples	Mean	Median	Standard Deviation	Minimum	Maximum	Q1	Q3	CV
				Cane Creek at Ripley (Drainage area 33.9 mi²)					
Q	704	21.8	4.5	79.9	0.9	1,350	2.6	9.9	366
CONC	704	252	61	504	10	3,700	35	184	200
QS	704	113	.8	847.8	.1	19,100	.3	4.5	750
Q/DA	704	.6431	.1327	2.3569	.0265	39.82	.0767	.2920	366
QS/DA	704	3.33	.02	25.01	.003	563.42	.0088	.1327	751
				Cane Creek at Three Point (Drainage area 79.8 mi²)					
Q	635	50.2	9.5	185	1.4	2,490	5.8	22	369
CONC	635	636	100	1,673	10	17,300	40	400	263
QS	635	770	2.0	4,686	.0	56,000	1.0	20	609
Q/DA	635	.6291	.1190	2.3183	.0175	31.20	.0727	.2757	369
QS/DA	635	9.65	.03	58.72	.0	701.75	.0125	.2506	608

likely that water and sediment were supplied largely from beyond the channel boundary at Ripley, but largely from within the channel boundary at Three Point. Also, the channel upstream of Ripley had not undergone as much channel deepening and widening as was observed in the reach between Ripley and Three Point.

The time lag between peak suspended-sediment concentration and peak discharge for the event creates a hysteresis loop in the relation between discharge and suspended-sediment concentration (fig. 5). This means that almost every value of discharge has two observed values of sediment concentration associated with it. The larger the hysteresis loop, the more uncertain a mean-transport relation for the event. When a transport relation is constructed using instantaneous values, hysteresis can significantly increase estimation error. For basins like Cane Creek, where runoff events last less than a day, and where variance about the daily-mean discharge and sediment concentration is large, an estimate of sediment yield based on periodic observations of instantaneous values is subject to considerable uncertainty (table 1). Estimates of sediment yield using sediment transport curves should be made only after careful evaluation of all available data.

The suspended-sediment data collected at the Ripley and Three Point gages aid in understanding the transport characteristics of Cane Creek. However, caution should be used when interpreting these data. The effects of incomplete mixing are probably accounted for by the application of coefficients at the Ripley station, but the effects of backwater and bank failures near the PS-69 pumping sampler intake at the Three Point station are probably not accounted for. The sediment-discharge data at Ripley generally are more reliable than the data at Three Point as indicated by the smaller variations in cross-section coefficients. The data from the Three Point station seem to indicate that at times, particularly during periods of backwater, a large sediment concentration gradient develops near the channel boundary at this site. The cause of this

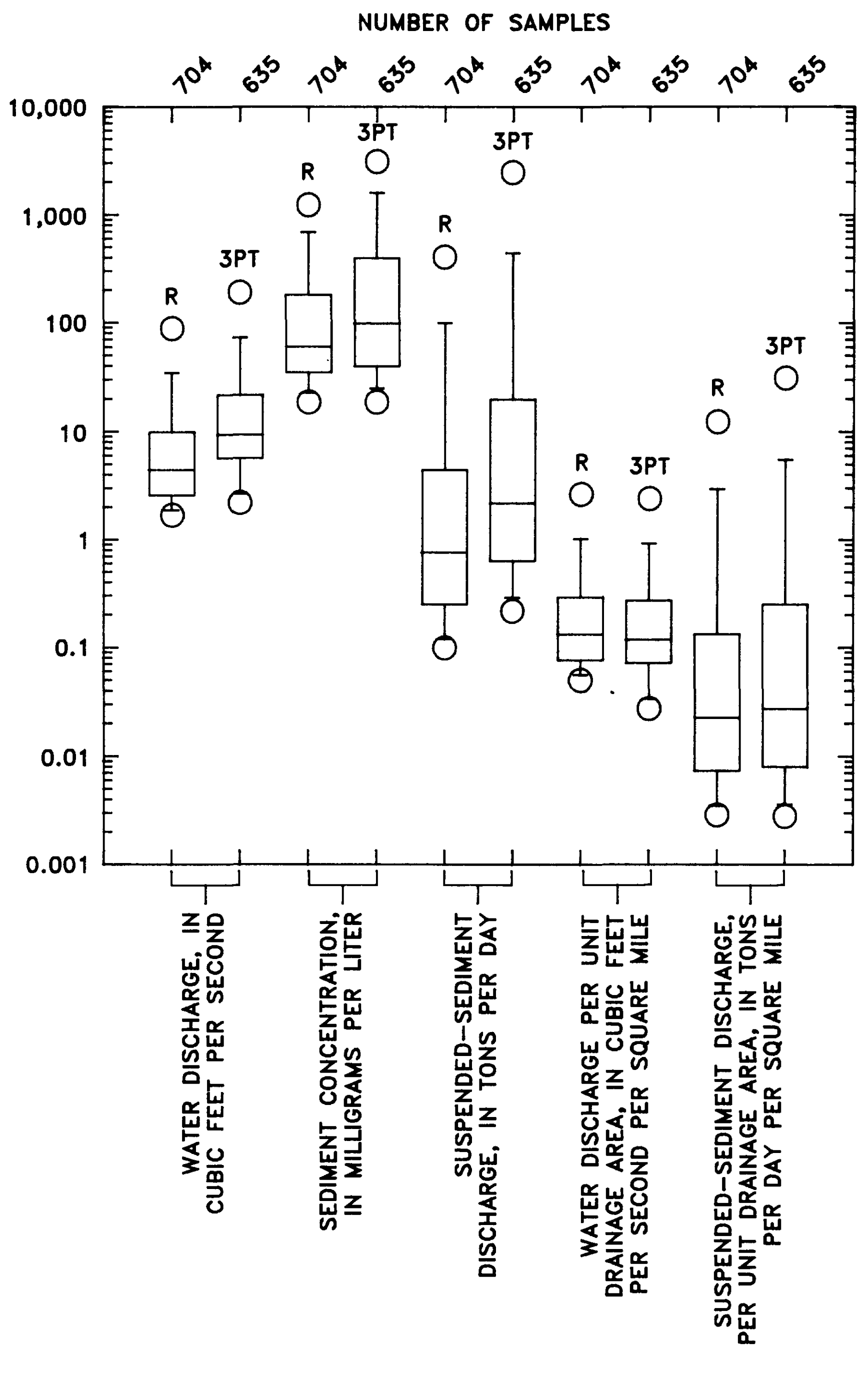


Figure 2. Boxplots summarizing statistics for daily-mean flow and sediment data at Ripley (R) and Three Point (3PT).

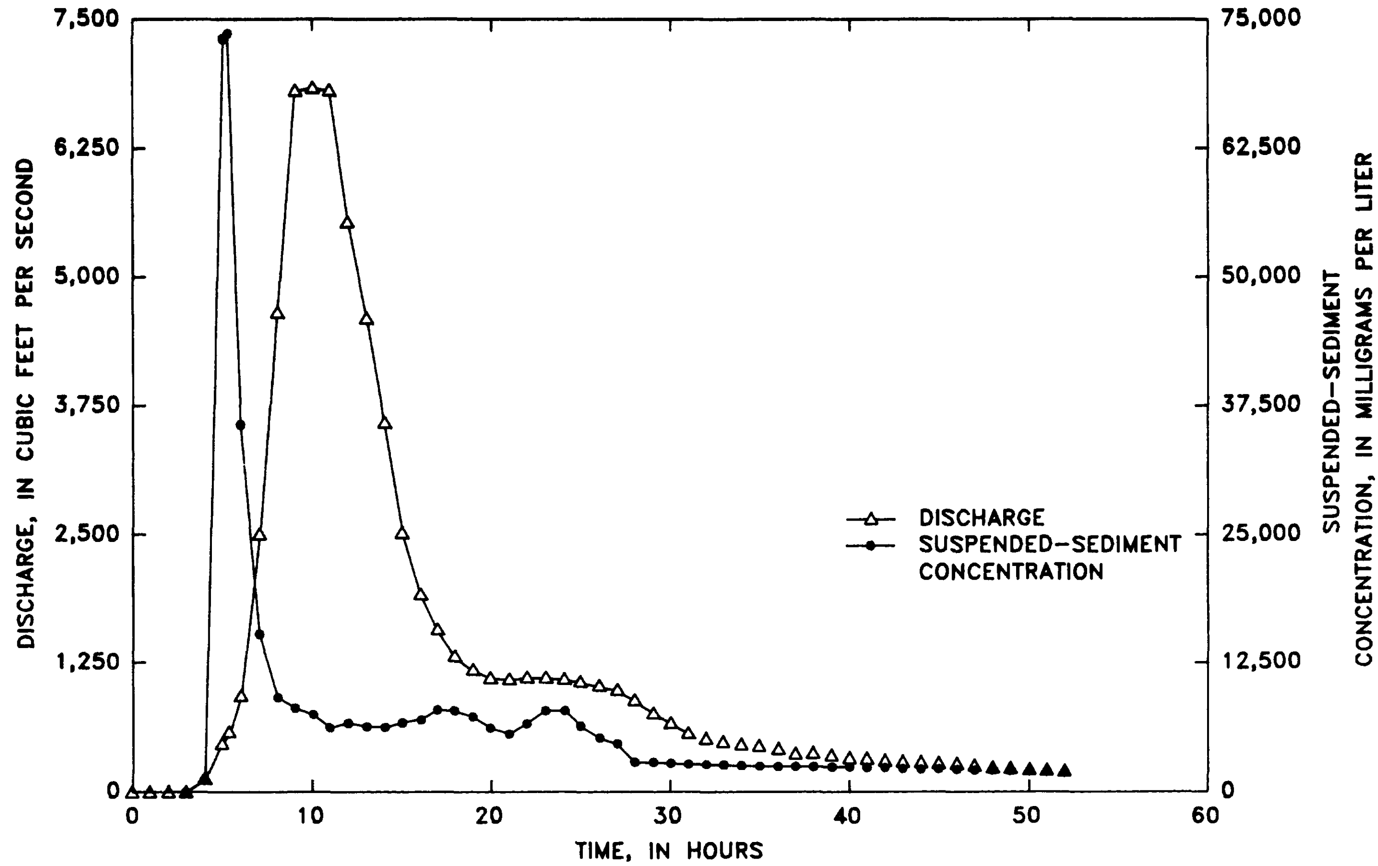


Figure 3. Discharge hydrograph and suspended-sediment concentration for Cane Creek at Three Point, storm of March 11-13, 1986.

gradient is believed to be incomplete mixing of fine-grained sediment derived from the channel boundary. The presence of this gradient and the extent to which mixing is incomplete are believed to be the causes for most of the variance observed in the coefficients at the Three Point station.

Suspended-sediment data are often used to compute the sediment yield for a basin and the basin yield is then compared to computed estimates of soil erosion. Problems with this comparison occur when the sediment data represent a short time period and when the relation between discharge and suspended-sediment concentration is complex. Soil erosion computations based on the Universal Soil Loss Equation (U.S. Department of Agriculture, 1978) are average annual values and as such represent the long-term mean. Comparisons of these values with sediment data representing less than a 2-year period on a highly disturbed basin would not be valid. Also, these computed soil erosion estimates apply strictly to upland areas; they would not include an estimate of the amount of material that might be eroded from the Cane Creek channel.

Potential for Mobilization of Bed and Bank Sediment

The potential for bed and bank sediment mobilization is dependent on the hydraulics of the stream and the sediment characteristics. An estimate for the slope of the energy grade line (EGL) is

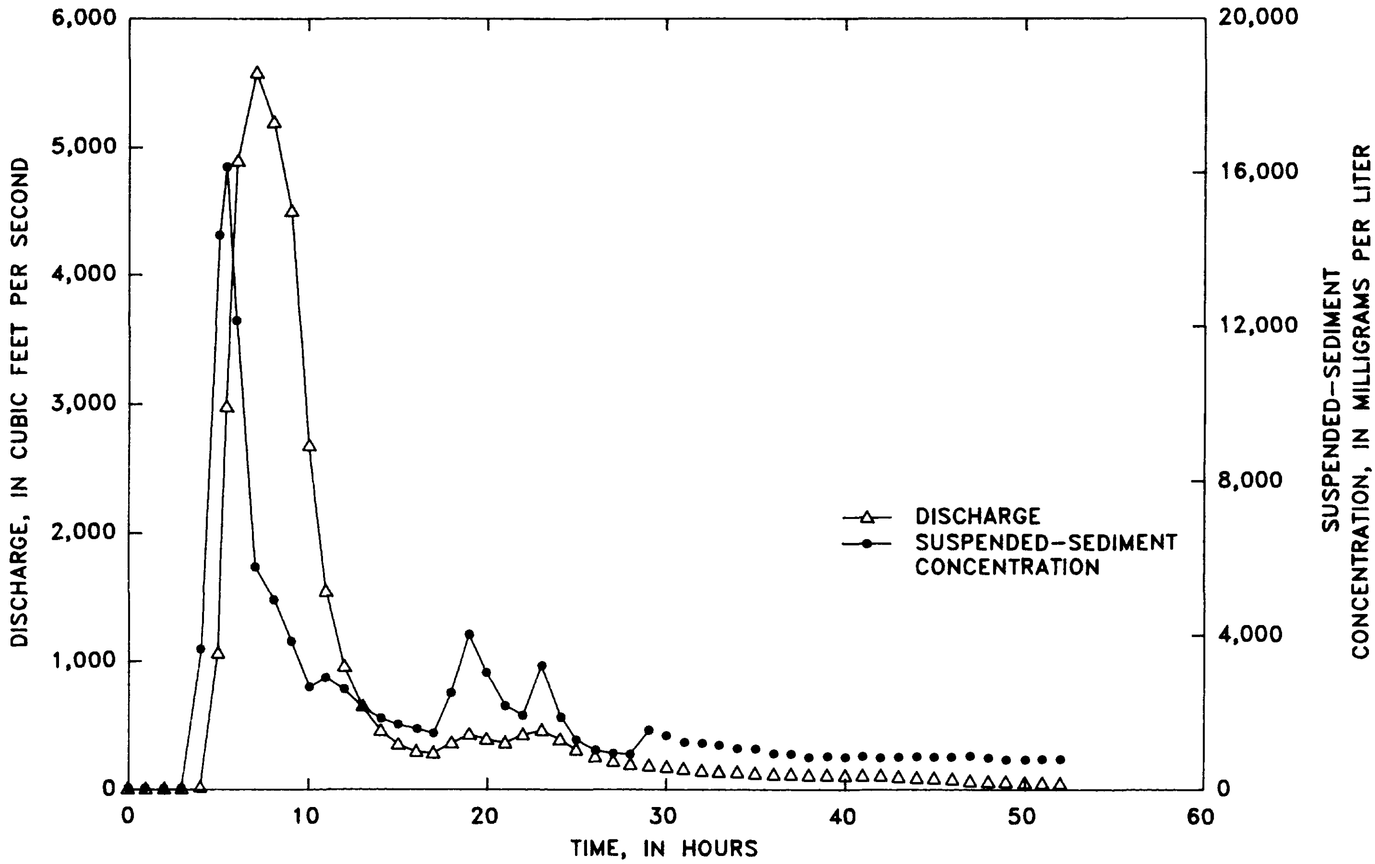


Figure 4. Discharge hydrograph and suspended-sediment concentration for Cane Creek at Ripley, storm of March 11-13, 1986.

required for almost all computations of sediment transport, boundary shear, stream power, and mixing length. For this study, values of the EGL were assumed to equal friction slope, which was derived from water-surface profile models (Charles R. Gamble, U.S. Geological Survey, written commun., 1990). Hydraulic conveyance was calculated at stream stage intervals of 1-foot from near base-flow stage to bank-full stage (Charles R. Gamble, U.S. Geological Survey, written commun., 1990).

The transport competence for a given flow is defined by the largest particle that is in a state of incipient motion. A particle is in a state of incipient motion when the hydrodynamic forces acting on the particle have reached a value such that an incremental increase will cause the particle to move. An evaluation of transport competence is usually undertaken to determine the stability of bed particles for various flow conditions. In the case of Cane Creek where the channel bed is composed of weakly cohesive silt, an analysis of transport competence also provides information on the potential ability of different flows to move material that might be placed in the channel to stabilize the channel boundary.

Analysis of incipient motion commonly is made by using methods described by Shields (1936). Shields expressed the critical condition for incipient motion as a graph of two dimensionless numbers: the shear stress and the boundary Reynolds number. The relation between particle size and some hydraulic parameters is not readily apparent from the Shields graph. However, if the viscosity of the fluid, and the density of the fluid and sediment particles are assumed to be constant, the Shields graph can be used to develop a relation between boundary shear and grain size.

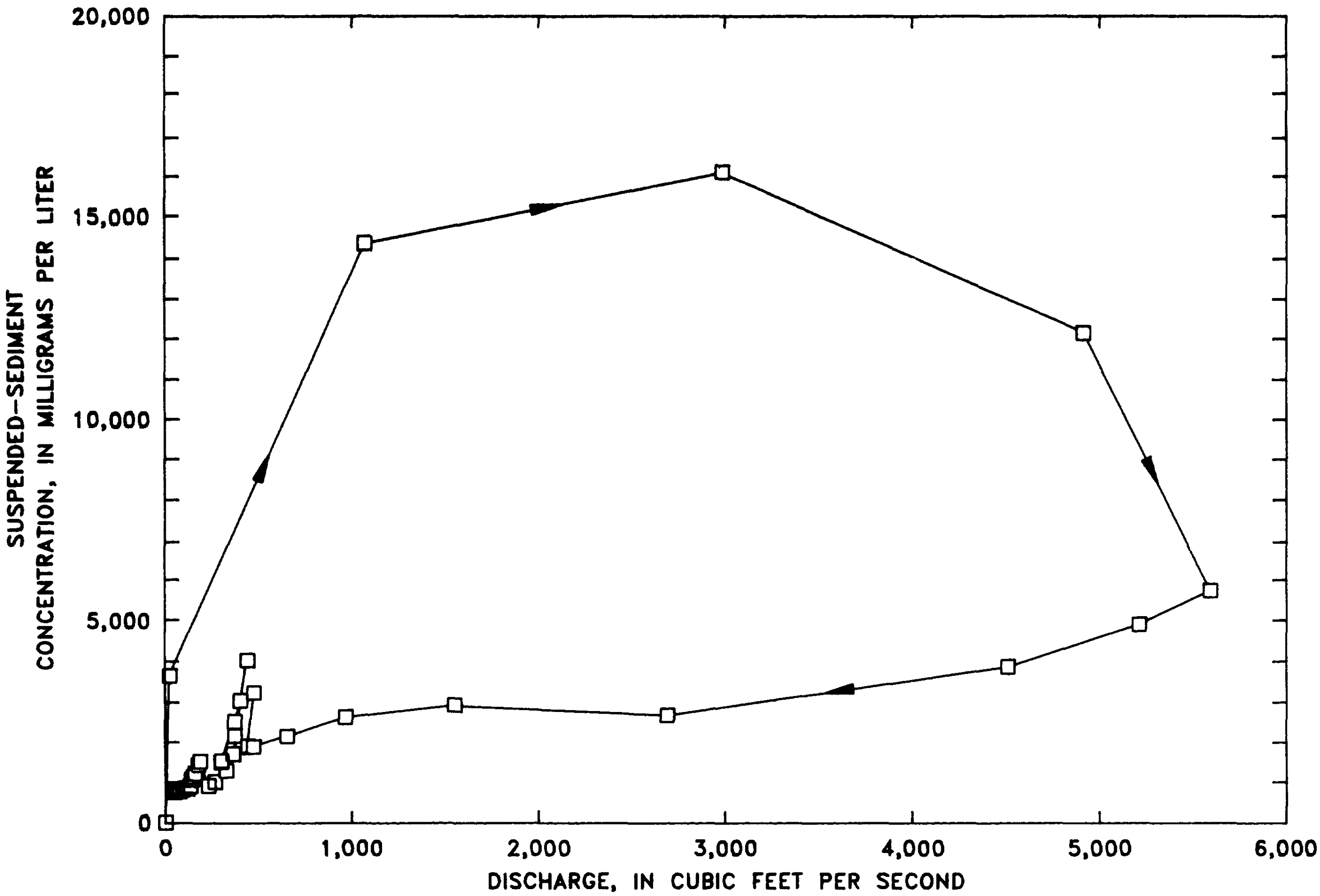


Figure 5. *Suspended-sediment transport relation for Cane Creek at Ripley, storm of March 11-13, 1986.*

Boundary shear stress is computed as:

$$\tau = \gamma RS \qquad (1)$$

where

τ is the average value of the shear stress, in pounds per square foot of wetted area;
γ is the specific weight of water, in pounds per cubic foot;
R is the hydraulic radius, in feet; and
S is the slope of the energy grade line, in feet per foot.

Boundary shear (τ) was computed for the complete range of measured flows at the two gaging stations for 1985 conditions (table 2). The critical particle diameter for each value of τ at the two gaging stations was determined from the Shields relation (Vanoni, 1975; table 2). As flow at Ripley increases by a factor of 5 from 56 to about 280 ft^3/s, the critical particle diameter increases by a factor of 2.6 from 6.5 to about 17 millimeters (mm). The next fivefold increase in flow (from 280 mm to about 1,400 ft^3/s) is accompanied by a twofold increase in critical diameter from 17 mm to about 34 mm.

Although a flow of 56 ft^3/s at Ripley is equivalent to a flow of 132 ft^3/s at Three Point on a per square mile basis, the overall relation between boundary shear and critical particle diameter at Three Point, is similar to that at Ripley. At Three Point, the critical diameter increases by a factor of 10 from 0.56 to 6.0 mm as discharge increases by a factor of 10, from 26.4 to 272 ft^3/s. For the next tenfold increase in discharge (from 272 to 2,820 ft^3/s), the critical diameter increases only by a factor of 3.3.

Table 2. Computed hydraulic data and critical diameters for 1985 conditions at Ripley and Three Point

[ft, feet; ft³/s, cubic feet per second; ft/ft, feet per foot; lbs/ft², pound per square foot; mm, millimeter]

Gage height (ft)	Discharge (ft^3/s)	Conveyance (ft^3/s)	Friction slope (ft/ft)	Hydraulic radius (ft)	Boundary shear (lbs/ft^2)	Critical diameter (mm)
			Ripley			
6.00	56		0.00137	1.64	0.14	6.5
7.00	137		.00142	2.59	.23	10.0
8.00	246		.00141	3.52	.31	16.0
9.00	385		.00141	4.42	.39	18.0
10.00	550		.00141	5.22	.46	23.0
11.00	751		.00142	5.98	.53	26.0
12.00	985		.00141	6.70	.59	28.0
13.00	1,260		.00140	7.32	.64	32.0
14.00	1,580		.00141	7.95	.70	35.0
			Three Point			
4.25	26.4	4,260	.000038	2.75	.01	.56
5.25	78.5	6,320	.000154	3.26	.03	2.1
6.25	166	8,670	.000366	3.53	.08	4.3
7.25	272	11,600	.000548	3.84	.13	6.0
8.25	386	15,500	.000618	4.38	.17	7.5
9.25	504	20,000	.000634	4.88	.19	9.0
10.25	641	25,100	.000652	5.37	.22	10.0
11.25	797	30,500	.000681	5.74	.24	12.0
12.25	976	36,500	.000715	6.11	.27	13.0
13.25	1,170	43,300	.000731	6.50	.30	15.0
14.25	1,380	51,000	.000736	6.79	.31	15.0
15.25	1,610	59,600	.000730	7.21	.33	16.0
16.25	1,870	69,300	.000731	7.53	.34	17.0
17.25	2,180	79,900	.000729	7.96	.36	18.0
18.25	2,480	91,600	.000732	8.40	.38	19.0
19.25	2,820	104,000	.000731	8.74	.40	20.0
20.25	3,200	118,000	.000739	9.08	.42	21.0
21.25	3,590	131,000	.000755	9.26	.44	22.0
22.25	4,020	145,000	.000765	9.40	.45	22.0
23.00	4,350	157,000	.000766	9.52	.46	23.0
23.25	4,470	161,000	.000765	9.58	.46	23.0
24.25	4,950	180,000	.000758	9.80	.46	24.0
25.25	5,450	200,000	.000744	10.05	.47	24.0
26.25	5,980	222,000	.000724	10.34	.47	24.0

The numbers given for boundary shear and critical diameter in table 2 should be considered as estimates because of uncertainties inherent in estimating EGL slope, computing hydraulic radius and hydraulic depth, and the Shields relation (Vanoni, 1975). Even though uncertainties are involved in the calculation of critical diameters (table 2), these diameters provide a useful indication of the relative changes in stream competence, and an estimate of the size of material that given flows should be capable of moving.

A comparison of the critical diameters in table 2 with particle sizes of bed and bank material which are generally less than 4 mm indicates that frequently occurring flows at both stations are capable of moving the bed and bank materials. This transport ability, coupled with a limited supply of coarse material in the basin, explains why only limited deposits of alluvial material are on the bed of the channel (Miller, 1991), and indicates that Cane Creek is unlikely to undergo gradient reduction through downstream aggradation. Measured flows at both stations have the ability to move material as large as coarse gravel (32 - 64 mm). Analyses of the transport characteristics of larger flood discharges are included in this section to provide an evaluation of the transport characteristics throughout the range of discharges.

The variations in boundary shear for a given discharge over time are primarily the result of channel gradient adjustments. To efficiently remove flood waters, drainage ditches and modified channels commonly are constructed with relatively uniform and steep channel gradients, which tend to result in relatively high stream power. Subsequent channel adjustments are toward reduced channel gradients and stream power. Stream power is the rate at which a stream loses energy per unit area of boundary (Bagnold, 1966), and is given by:

$$n = \tau \bar{v} \qquad (2)$$

where

n is stream power, in foot pounds per second per square foot;

τ is the average value of shear stress, in pounds per square foot; and

$\bar{v}$ is mean velocity, in feet per second.

The distribution of boundary shear with distance along the channel for the 2-year flood is shown for 1970, 1980, and 1985 channel conditions in figure 6. The plot for the 1985 channel condition (fig. 6) shows that extreme values tend to cluster together and primarily are at three of five existing bridge crossings, James Bridge, Lee Bridge, and Hendrix Bridge. Surveyed cross sections tend to be closer together at bridge sites so that the hydraulics of the bridge opening can be studied. However, the relative abundance of data does not explain the extreme values at these three sites, because there was also an abundance of data at Morris and Hunter Bridges where there were no extreme values. The variations in shear stress at James, Lee, and Hendrix Bridges are more likely the result of attempts to stabilize the channel near these bridges. These attempts at channel stabilization have caused the reaches near the bridges to function as grade controls and have resulted in channel constrictions with hydraulic drops. When these measures fail, as in 1983 at Hunter Bridge (fig. 1, river mile 10.30), the channel rapidly degrades, channel slope is decreased, and shear values are reduced (fig. 6). The 1980 plot of boundary shear (fig. 6b) shows outliers at the Hunter Bridge site, but the plot for 1985 (fig. 6c) conditions shows no extreme values at the site only 2 years after failure.

The magnitude of these outliers is indicative of the transport competence of flood flows near bridge crossings. The largest of the extreme values correspond to critical diameters in excess of 100 mm. Thus, the areas near bridges, where channel stability is of the greatest importance, are the areas at which erosive stream power is greatest. The magnitude of these spikes in boundary shear indicates that although armoring the channel near bridges can protect roadway embankments from erosion, it does not reduce the erosion and transport capability of the stream. Rock (6 to 12 inches in diameter) used to armor channel banks and beds, commonly referred to as rip-rap, was observed deposited in bar-type formations downstream from several bridges with contracted openings. Measures aimed

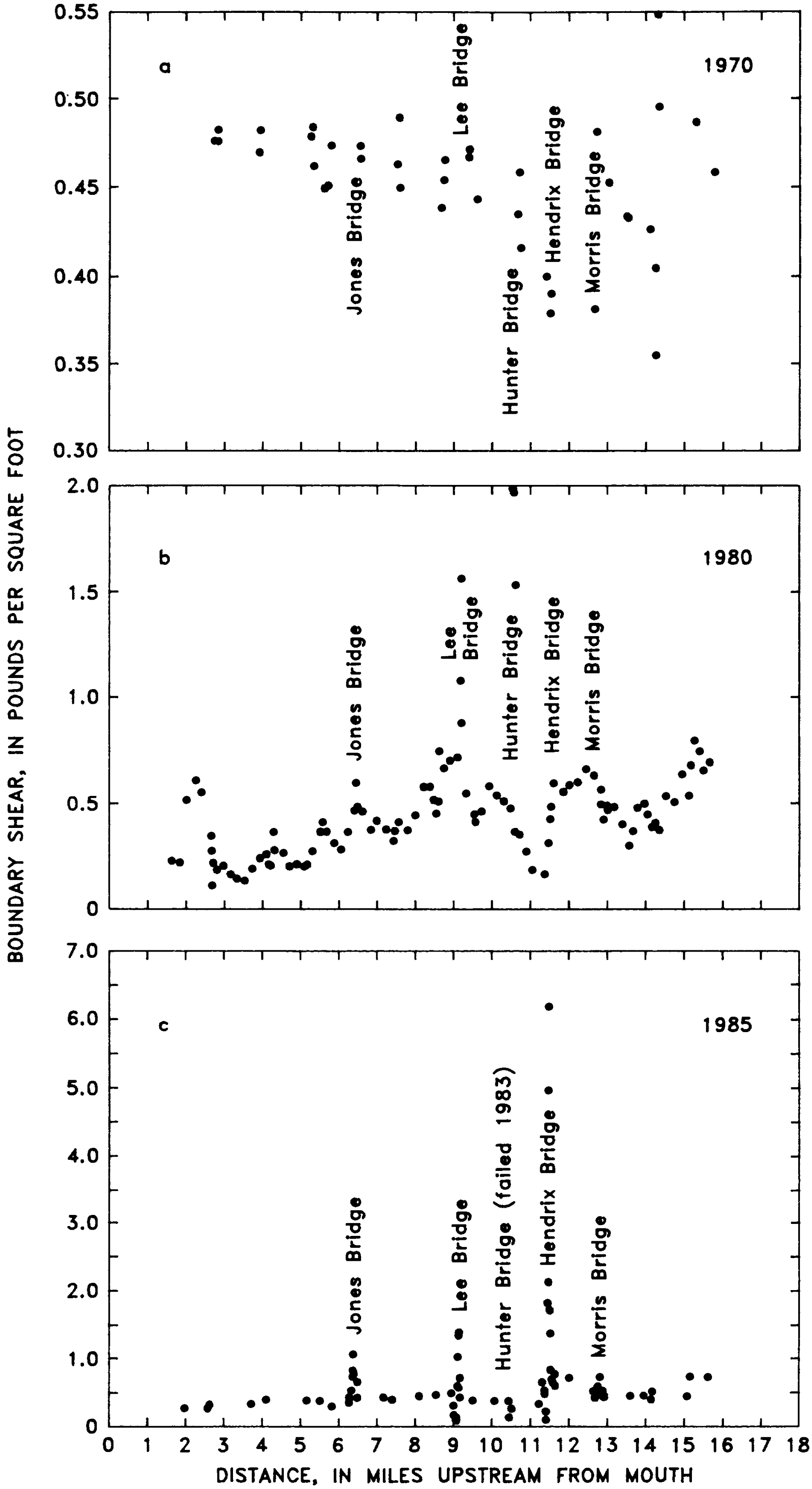


Figure 6. Distribution of boundary shear for (a) 1970, (b) 1980, and (c) 1985 for the 2-year discharge in Cane Creek, Lauderdale County, Tennessee.

at reducing the velocities and gradients, such as widening of the bridge opening or using a longer armored section with a smaller bed slope, would reduce the boundary shear forces and the sediment transport capability of the stream.

The historical development of the boundary-shear distribution shows how the channel has adjusted to the initial constructed condition, and illustrates the role of bridge sites in that development. Boundary shear for the constructed condition (1970) generally decreased in magnitude, but increased in variance in the upstream direction. The trend of decreasing values in the upstream direction was opposite the expected trend probably because the channel was constructed to a uniform slope. Under 1970 conditions, the downstream increase in hydraulic radius probably was responsible for the downstream increase in boundary shear. The maximum value of boundary shear for 1970 conditions was 0.55 pound per square foot.

Ten years later (1980), the channel had adjusted so that boundary shear increased in the upstream direction (fig. 6). As shown in figure 6b, for 1980 conditions, boundary-shear values in the downstream reaches, below Jones Bridge, were generally lower than those for 1970 conditions, and values in the upstream reaches were generally equal to or slightly higher than those for 1970 conditions. By 1980, distinct spikes in boundary shear had developed at Lee Bridge (fig. 1, river mile 8.96) and Hunter Bridge and to a lesser extent at Jones Bridge (fig. 1, river mile 6.22; fig. 6). Boundary shear values were somewhat elevated at Hendrix Bridge and Morris Bridge in 1980 (fig. 6; fig. 1, river mile 11.32 and 12.58), but these values did not stand out from the overall trend of the data.

By 1985, distinct spikes in boundary shear existed at Lee Bridge and at Jones Bridge, but by far the highest boundary shear values were at Hendrix Bridge. No abnormally high boundary shear values were noted at Morris Bridge (fig. 6). Apparently, prior to its failure in 1983, Hunter Bridge functioned as a channel control that impeded the upstream progress of channel adjustment. When Hunter Bridge failed, channel adjustments rapidly progressed upstream to Hendrix Bridge. Hendrix Bridge now appears to be functioning as the upstream control because no abnormally high boundary shear values have been noted at Morris Bridge (fig. 6). Should Hendrix Bridge fail, the channel adjustment would be expected to progress further upstream and Morris Bridge would become the upstream control.

Because bedload transport in Cane Creek is very limited and little energy is required to suspend silt and clay-size material, almost all of the increase in stream energy resulting from the increase in channel gradient associated with channelization was available to erode the channel boundary. The near absence of coarse material in the surficial geology of the Cane Creek basin (Miller, 1991) indicates that gradient adjustment is not likely to be accomplished by downstream aggradation. The only remaining processes for gradient adjustment (reduction) are headward channel erosion and lateral channel migration or widening. The observed geometry of Cane Creek and the associated problems are the direct result of these two processes operating on the channel, moving it toward a condition of reduced bed slope.

Effect of Proposed Grade-Control Structures

SCS proposed installing four drop structures on the main channel of Cane Creek in locations selected to provide maximum protection for existing bridges. Hydraulic analyses of six selected floods (Charles R. Gamble, U.S. Geological Survey, written commun., 1990) provided the data for a comparison between 1985 conditions and conditions with the drop structures in place.

Comparison of boundary-shear statistics for both conditions indicate that much of the power available for sediment transport and channel erosion is still available with the drop structures in place (table 3), even though the interquartile ranges show that, overall, boundary shear is somewhat lower with drop structures in place. When these boundary-shear values are entered into the Shields relation (Vanoni, 1975), it becomes apparent that even with drop structures in place, Cane Creek is still capable of moving sand and gravel-size material.

Table 3. Boundary-shear statistics for selected floods in Cane Creek, 1985 condition, and with remedial measures in place

[N, number of values in computation; Q1, boundary shear lower quartile value in pounds per square foot; Q2, boundary shear middle quartile value in pounds per square foot; Q3, boundary shear upper quartile value in pounds per square foot]

Flood recurrence interval	N	Mean	Standard deviation	Range		Quartiles		
				Low	High	Q1	Q2	Q3
2-year, 1985	85	0.71	0.85	0	6.21	0.40	0.52	0.74
2-year, remedial	113	3.27	11.78	.06	71.15	.32	.44	.65
5-year, 1985	85	.75	.78	0	5.62	.41	.61	.81
5-year, remedial	113	3.60	12.61	.08	79.72	.36	.49	.76
10-year, 1985	85	.78	.77	0	5.49	.41	.63	.87
10-year, remedial	113	3.88	13.39	.09	86.74	.39	.52	.80
25-year, 1985	85	.81	.75	0	5.35	.45	.68	.87
25-year, remedial	113	4.16	14.23	.10	95.37	.38	.54	.86
50-year, 1985	85	.84	.75	.13	5.36	.49	.71	.94
50-year, remedial	113	4.42	15.18	.10	104.81	.40	.54	.86
100-year, 1985	85	.87	.74	.13	5.36	.50	.74	.98
100-year, remedial	113	4.62	16.20	.09	115.42	.38	.53	.84

Under the 1985 condition, boundary-shear values were greatest at the bridges. With the drop structures in place, boundary shear is lowered slightly at bridges (fig. 7). However, at Hendrix Bridge (mile 11.32), which is a contracted opening, the 2-year flow is still capable of moving particles on the order of 50 mm in diameter.

SUMMARY AND CONCLUSIONS

Channelization of Cane Creek in 1970-71 reduced the main channel length by about 45 percent, increased the channel slope by 66 percent, and increased the average cross-sectional area by about 15 percent. Increased gradients and flow velocities associated with these modifications have resulted in channel deepening and widening. Deepening and widening of Cane Creek have exposed large areas of channel boundary that represent a significant source of sediment during the early stages of a storm before streamflow increases substantially. This causes sediment concentration to peak prior to the peak in the discharge hydrograph. An estimate of sediment yield based on periodic observations of instantaneous values is subject to considerable uncertainty for basins like Cane Creek where runoff events last less than a day and where variance of discharge and sediment concentrations about the daily-mean is large.

The increased velocities following channelization have resulted in increased boundary-shear values near most bridges where channels are commonly constricted. Near bridges where channel stability is critical, the erosive power of the stream is commonly larger than in less constricted reaches.

Frequently occurring floods in the Cane Creek basin have velocities sufficient to transport sand-size and smaller bed material. Floods in Cane Creek that equal or exceed the 2-year flood are capable of moving very coarse gravel.

Because bedload transport in Cane Creek is very limited, and little energy is required to suspend silt and clay-size material, almost all of the energy provided by increased stream gradients was available to erode the channel boundary following channel modification. The absence of coarse material in the surficial geology of the Cane Creek basin indicates that gradient adjustment by downstream aggradation is likely. The only remaining processes

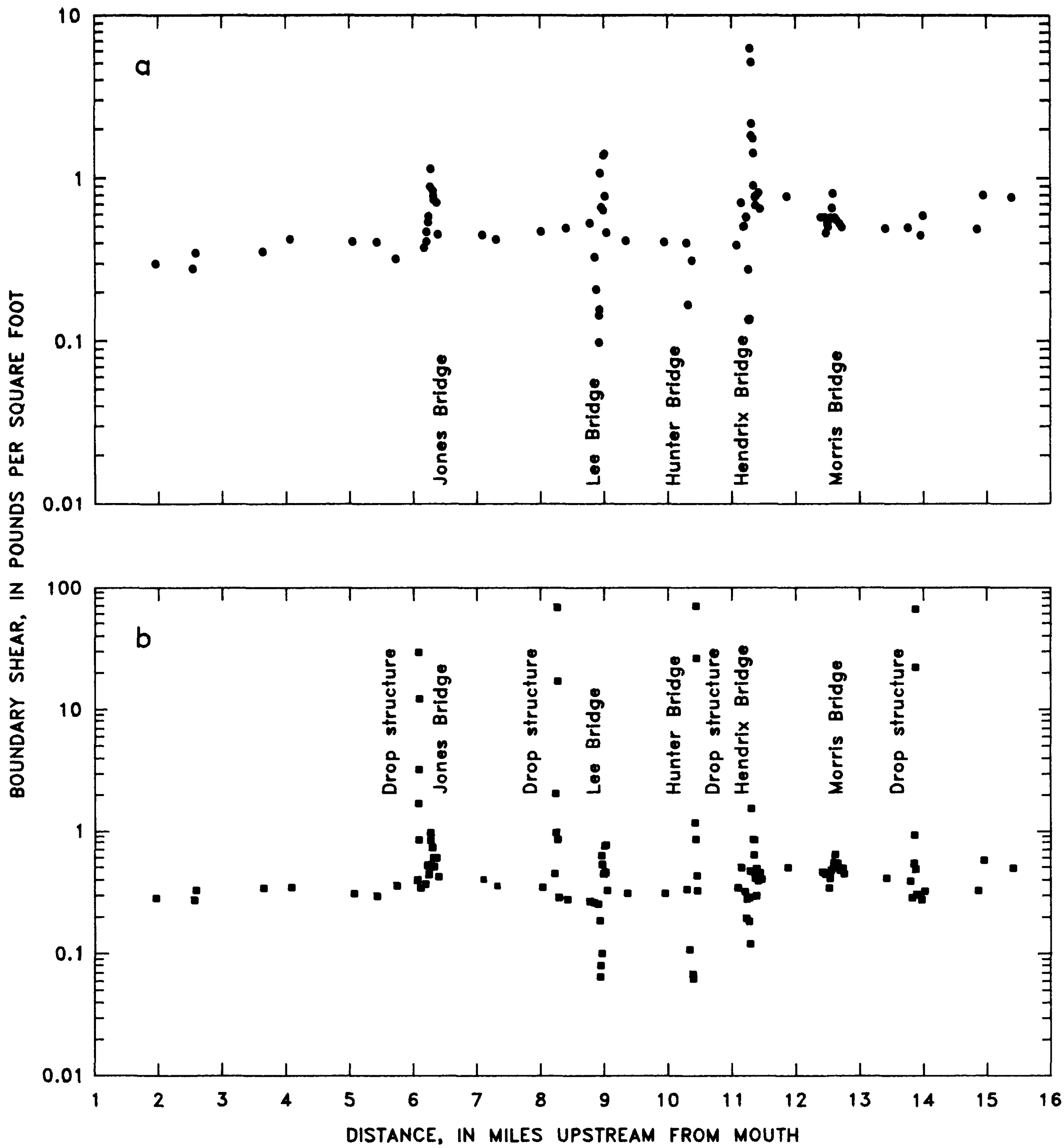


Figure 7. Plot of the 2-year flow boundary shear for (a) 1985 conditions and (b) with drop structures in place, Cane Creek, Lauderdale County, Tennessee.

for gradient adjustment (reduction) are headward channel erosion and lateral channel migration or widening. The deepening and widening of Cane Creek that has occurred since 1970 are the result of these two processes operating on the channel.

Boundary shear values were calculated for conditions with several proposed grade-control drop structures in place. Comparison of pre- and post-drop structure boundary shear indicates that even with the proposed drop structures in place, the stream will still have sufficient power to transport sand and gravel-size material. Boundary shear would be slightly lowered at the bridges, but even with the drop structures in place, the boundary shear forces would exceed the existing channel conditions, particularly near bridges and other channel constrictions, and the potential exists for continued channel bed and bank erosion.

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