SEDIMENT YIELD ESTIMATES BASED ON FLOODWATER MEASUREMENTS AND SAMPLES[1/]

by

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INTRODUCTION

This study was conducted on Coles Creek and on the Buffalo River in southwestern Mississippi for which diversion channels will be necessary if proposed levees along the Mississippi River are constructed. A knowledge of the sediment quantities and sizes delivered to the sites by the streams was considered to be desirable. The study was requested and supported by the Soil Conservation Service. A progress report was presented in 1969 by Willis, et al. (1).

A data collection program was followed that gave the information needed to estimate average annual sediment yields, using the sediment-rating curve-flow duration method. Noteworthy precedents in the use of this method have been described by Campbell and Bauder (2), Miller (3), and Wark and Keller (4). Bed material sizes, suspended sediment sizes, channel geometries, and water surface elevations in selected channel reaches, and for selected floods, were also measured in order to compare the sediment rating curves derived from flood water sampling with those derived by other techniques.

Numerous equations have been proposed to relate the sediment transport quantity of a stream to the flow variables under the assumption that a unique relationship exists. Then the sediment concentrations for a given discharge can be determined by measurement or computation of the controlling flow variables and application of an equation rather than by sampling the flood flows for sediment content. Unfortunately, application of various transport relationships to the same channel have given estimates of the transport quantity that vary as much as 500 percent according to Shulits and Hill (5). Thus, flow measurements and a sampling program for each channel in question are required to develop sediment yield estimates with an acceptable degree of reliability.

THE STREAM CHANNELS

Coles Creek drains a watershed of 257 square miles which is predominantly in Jefferson County, Mississippi. It consists of two main forks

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(North and South Forks) with their confluence located about 8 miles west of Fayette, Mississippi, near Church Hill. The two main forks drain watersheds of about equal areas. The gaging station for this study was established at a county bridge about 0.7 mile below the confluence. The gage zero was at elevation 66.79 feet. The channel reach encompassing the bridge section has a sand bed and an average bottom width of about 110 feet. The low water slope was about 0.00050.

Buffalo River is located in Wilkinson County, Mississippi. Its watershed is typical of the classical drainage pattern with one main channel and many small tributaries. The channel drains an area of 182 square miles at the location of the study. It also has a sand bed and is quite wide -- about 225 feet. The gage zero was at elevation 94.52 feet. The measured low water slope was 0.00127.

The bed materials of the two streams are similar. Median particle diameters are 0.30 and 0.33 mm and geometric standard deviations of the particle size distributions are 1.46 and 1.69 for Buffalo River and Coles Creek, respectively. Both streams are in the same general climatic area and drain watersheds along the bluff line of the Mississippi River.

DATA COLLECTION

The U. S. Geological Survey has maintained water stage records and has made flow measurements in Buffalo River at the U. S. Highway 61 bridge, 8-1/2 miles north of Woodville, Mississippi, since 1942. These records provide the means for defining the stage discharge relation and flow duration curve for this channel. The U.S.G.S. water stage recorder on the bridge was used to provide gage height information for the present study.

Channel surveys of two study reaches on Buffalo River and one on Coles Creek were made by Soil Conservation Service personnel at the beginning of the study. Five ranges along each test reach, plus the bridge section, were surveyed to describe the channel geometry and low water slopes. Mean cross sections are shown in Figure 1. Crest gages were installed along both banks of each reach in an attempt to describe the high water surface profiles. The crest gage records were adequate for only a few floods.

Flood water samples were collected at each stream with a 200-pound P-63 sampler. Depth-integrated samples were collected at five to eight verticals across the channel. The samples were weighed by the collection crews soon after procurement to avoid errors due to evaporation. The samples were analyzed for the sediment concentrations and particle size distributions at the USDA Sedimentation Laboratory.

In addition to the flood water samples, 23 sets of flow velocity measurements were made at the Coles Creek station at a point 0.6 of the depth from the surface. Five to eight measurements were taken across the channel. The stream discharge value was the summation of the flows through the several segments of the cross section in which velocity measurements were made. The gage heights just before and after the set of velocity measurements were made were recorded and the average of these two values was used in establishing the stage-discharge curve for Coles Creek. Stream gage records were obtained during the period August 1967 to February 1970. Current meter measurements and flood water sampling ended in April 1969. The sampling and stream gaging were done by local residents who were paid at a rate per measurement or per sample according to a schedule of rates that increased with increasing stage. Also utilized were 9 sets of current meter measurements by the U. S. Geological Survey, obtained during 1961-62.

DATA INTERPRETATIONS

The sediment samples collected from the two streams were analyzed for the fine (less than 0.062 mm) and coarse sediment concentrations. Theory and the results of laboratory experiments indicate that the coarse sediment load, or bed material load, will exhibit some general relation to the flow variables. But a relationship between the flow and fine sediment load ("wash" load) exists only insofar as the flow at the measuring site reflects the erosivity of the flood runoff in the watershed. Although the separation of the load into the fraction in equilibrium with the flow and the fraction consisting of the finer sediments does not actually occur at just one sediment size for all water discharge rates, the lower limit of the sand sizes (0.062 mm) was chosen to approximate this distinction between the transport mechanisms.

The fine and coarse sediment concentrations were determined for each sample to depict any lateral variation in the concentrations across the channel. As expected, the fine sediment (wash load) concentration was nearly uniform across the channel for every set of samples, but the coarse sediment concentrations varied considerably. Some samples contained exceedingly high sand concentrations which probably resulted from the sampler nozzle striking a dune face or being allowed to rest too long near the channel bed. These obviously inaccurate sand samples were deleted from the average coarse sediment determinations.

The average concentration for the channel cross section was taken as that of a "composite sample" formed by combining the weights of sediment and water from all the samples of a set taken across the channel. From the average of the gage heights immediately before and after the set of samples was collected, the corresponding water discharge was determined from the stage-discharge rating curves. The sediment transport rate at the time of sampling was then determined as the product of the water discharge rate, the unit weight of water, and the sediment concentration of the composite sample. Thus Q_s, the sediment transport rate in lbs/sec, is the product of γ_w, the unit weight of water equal to 62.3 lbs/ft^3, times Q, the water discharge in cubic feet per second, times the sample concentration in grams per gram.

Many investigators relate average concentrations of sediments in transport to the rate of water flow; concentrations usually increasing as flow increases at a stream site. But this relationship is not unique, since things other than the rate of flow, Q, affect the concentration. These include water temperature, seasonal changes in watershed erodibility, changes in land use, and variations in flood water sources within the watershed. Consequently, the variation of sediment concentration data is quite large for a given rate of flow. Nevertheless comparisons are made and average relationships between sediment discharges and rates of water discharge are established for use in the sediment discharge computations as shown in Figures 2 through 5. Trend lines are drawn by eye to represent the data. The data for Coles Creek deviate more from the trend lines than those for Buffalo River. This could be due to the proximity of the Coles Creek gaging station to the confluence of the two forks of the stream. Each fork may possess a different load relation and cause some of the variability of the data.

Also included in Figures 2 and 4 are computed sand transport relationships based on laboratory flume data by Willis and Coleman (6) and on Colby's (7) diagram for 0.3-mm sand. In Colby's diagram the bed material transport rate is defined as a function of velocity and depth of flow. For the flume model analysis the total sand concentration is defined as a function of the flow Froude number, $V/(gy_T)^{1/2}$, and the median diameter of the bed material. The average of the predicted concentrations for 0.2-mm and 0.4-mm sands in reference (6) for a given Froude number was used in applying the flume model data to the natural channels because the available flume data for 0.3-mm sand in that study gave unreasonably low sediment concentrations.

Tables 1 and 2 for Buffalo River and Coles Creek, respectively, give the mean parameters for the flood flows for which crest gage data were obtained in the several surveyed channel reaches. Tables 3 and 4 show information for selected gage heights needed for the applications of the Colby and Froude number techniques to the construction of the sediment rating curves shown in Figures 2 and 4. If crest gage data had not been obtained, it would have been necessary to assume channel retardance factors and make water surface profile computations to obtain estimates of the values shown in Tables 3 and 4.

The observed sand transport rates in Buffalo River are somewhat higher than those predicted by either the flume model data or Colby's diagram for 0.3-mm sand. This finding would suggest that the sand load in Buffalo River is higher than the uniform flow capacity load for the same flow, and hence, a portion of the sand load should be considered as "wash load" rather than "bed material load." In fact an average of 20 percent of the measured suspended sand load was finer than 1/8 mm, whereas less than one percent of the bed material was finer than 1/8 mm. However, this only accounts for a small portion of the differences.

Another condition of the sampling site, conducive of non-uniformity in the flow, may have been a factor. The helicoidal flow patterns and additional turbulence generated by the sharp channel bend upstream from the measuring section could certainly suspend more sediment than the same flow under uniform conditions. However, for channel design involving straight reaches of uniform section in which uniform flow may be established, the entire sand load may need to be considered as the equilibrium load. Therefore, the sand and fine load distinctions are maintained in making the yield estimates for these channels.

Two study reaches were established on the Buffalo River as a check because completely satisfactory conditions could not be found. The preferred location, the upper reach, encompassing the gaging station was too short and was flanked by sharp bends both upstream and downstream. The plan geometry of the lower reach was quite satisfactory, but the banks on one side were too low to contain the largest floods. Predicted bed material discharge rates at the crests of measured floods for the two reaches, using the Colby method of computation, are given in Table 5 to give an idea of variability with this method. Differences for the two comparable floods are about 20% and 10%.

The flow duration relationships that are used for these streams are summarized in Table 6. Here P is the fraction of time that the discharge Q is exceeded. The relationship for Buffalo River for flows less than 30 cubic feet per second per square mile of drainage area was derived from daily discharge tables in U. S. Geological Survey Water Supply Papers. The high flow portion of the curve is based upon the estimated (8) occurrences of rare floods. And, the intermediate values were adjusted by trial to give the 23-year average runoff rate of 252 cubic feet per second as shown in USGS Water Supply Paper No. 1920 (9).

Peak flood flows for the Buffalo River, based upon a 24-year record, are represented by

$$Q_p = -(1/c)\ln p = -19{,}900 \log (r/R) \tag{1}$$

where Q_p = peak flood flow, cfs

c = a constant inversely related to flood magnitude

p = the probability that Q_p will be exceeded in the next flood

r = the number of past flood peaks that exceed Q_p during the period of record

R = the total number of observed floods = $\overline{m}Y$; $\overline{m}$ = 8.5 = average number of floods per year.

Whereas Q_p is a flow rate at the peak of a flood, rates only slightly smaller prevail for about an hour for these channels. Then eq. (1) may be used to represent flood volumes, for that small portion of the time that the rate of flow is essentially equal to the peak rate, by multiplying by an increment of time. Also, $r/R = r\Delta T/\Delta TR = (r\Delta T/Y)/\overline{m}\Delta T = P/\overline{m}\Delta T)$, where: $P = r\Delta T/Y$ = proportion of the time that flood flows exceed Q_p, (with Y and ΔT in years). Then the proportion of the time that flood flows exceed Q_p is

$$P = (\bar{m}\Delta T)e^{-cQ_p} \tag{2}$$

where: $c = 2.3/19{,}900$

ΔT = time in years.

Using one hour, $\Delta T = 1/8760$ year, and Q_p is found to be 56,500 cfs and 39,570 cfs for $P = 10^{-6}$ and 10^{-5}, respectively, as shown in the table. These flows occur so rarely that even though very large they contribute an almost negligible proportion of the total runoff.

Since flow measurements on Coles Creek were so few, it is necessary to correlate the existing flow data for nearby streams with their watershed areas and geographical positions in order to derive suitable c, $\bar{m}$, and average runoff values for the creek. Thus for Coles Creek

$$Q_p = -k\log(r/R) = -23000\log\,(P/10\Delta T) \tag{3}$$

and the average runoff is 365 cfs, or 1.42 cfs/sq. mi. The average number of floods per year is estimated to be 10, and ΔT is assumed again to be one hour = (1/8760) year. Then the flows are 70,300 cfs and 47,300 cfs for $P = 10^{-6}$ and 10^{-5}, respectively.

The low flows in the range of P = 1 to 0.3 are assumed to have the same runoff rate per square mile of drainage area for a given P value as for Buffalo River. And, the flows for intermediate values of P are adjusted by trial to give a total mean runoff rate of 1.42 cfs/sq. mi.

The probable peak flows in a year, derived from equations (1) and (3) are 22,000 cfs and 27,000 cfs for Buffalo River and Coles Creek, respectively.

The final step in developing the sediment yield estimates involves combining the flow duration information of Table 6 with the flow-sediment transport relations of Figures 2 through 5 to generate transport-time relations between the rates of sediment transport q_s and the proportions of the total time during which they occur. The areas under the resulting curves then give the expected sediment yield per unit time, G_s as:

$$G_s = \int_o^1 q_s dP \tag{4}$$

The indicated integration is performed on an incremental basis in Tables 7 and 8. The columns headed $\sum q_s \Delta P$ indicate the sediment yield contributed by water discharges less than the flow value that is given in the first column. Final values in these summation columns are the fine sediment yield G_{sf} and sand yield G_{sc}, respectively. A summary of the average, measured sediment discharges for Coles Creek and the Buffalo River is given in Table 9.

The outstanding difference in the sediment yields is for the fine sediments. The yield for Coles Creek is much higher than that from Buffalo River, being 0.19 lbs/sec/sq. mi. vs. 0.07 lbs/sec/sq. mi.

Although estimates of the total sediment yield per unit of watershed area for the two channels differ by a factor of two, the fraction of the total yield that is delivered by a given discharge per unit of watershed area is approximately the same for both streams. This is illustrated in Figure 6 by the close correspondence of the two sets of data of relative yield versus water discharge per unit watershed area. An interesting observation from Figure 6 is that the discharge per unit area giving the median sediment yield is about 30 cfs/sq. mi. Thus half of the sediment yield is apparently contributed by flows that persist for only 0.5 percent of the time. This is equivalent to slightly less than two days per year. Thus the infrequent large floods, as noted by Piest (10), are major contributors to the sediment yield.

Another method of comparison that relates the proportion of total sediment yields to flood size is shown in Figure 7 where the flows are expressed in terms of the probable annual peak flow. It shows that half the sediment yield is delivered by flows less than a fourth of the probable maximum in a year and 94 percent at flows less than the expected maximum in a year.

Flood water sampling techniques are known to be deficient because the sampler intake usually does not reach the bed of the stream, thus missing a bottom layer that has a high concentration of suspended coarse material. The measured sand delivery rates of Table 9 may therefore be lower than the actual yields. However, as previously discussed, sharp bends immediately upstream from the sampling stations on both streams undoubtedly create greater turbulence and a more uniform distribution of the suspended sand than would prevail in a long straight reach wherein the flows would approach uniform conditions. The unmeasured sand load would therefore be less than normal. No attempt is made to estimate it.

SUMMARY

An investigation was conducted in southwest Mississippi in cooperation with the Soil Conservation Service to determine the sediment yields of Coles Creek and Buffalo River. The watershed areas are 257 sq. mi. and 182 sq. mi., respectively. The floodwater sampling and water discharge measurements were made during August 1967 to April 1969. The sediment contents of flood water samples were related to water flow rates to give sediment-water discharge ratings for both sands and fine sediments. Flow-duration relationships were established which defined the relation between water flow rate and the proportion of the time that the rate was exceeded. The flow-duration relationships were then combined with the flow-sediment discharge information to give sediment discharge-time association in the form of curves and tables of rates of sediment discharge against the proportion of the total time during which they occur.

The measured sand yields were at about the same rate for the two watersheds, being 1.00 ton/acre/year and 1.21 tons/acre/year for Coles Creek and Buffalo River, respectively. The big difference was in the yield of fines: 4.56 tons/acre/year for Coles Creek and 1.71 tons/acre/year for Buffalo River.

The datashow that about half the sediment discharge occurs in about 0.5 percent of the time, suggesting that the larger floods are major contributors. On the other hand, the data show that half the sediment yield occurs during flows that are less than one-fourth the probable annual peak flow; and that 94 percent of the sediment discharge occurs at water flows less than the probable annual maximum.

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Table 1.--Buffalo River Flood Data (Peak Flow Rates)

Gage Height ft.	Date	Flow Q cfs	Area A ft^2	Velocity V ft/sec	Wetted Perimeter ω ft	Hyd. Radius R ft	Slope S ft/ft	Shear Stress T_o lbs/ft^2	Froude No. F	Manning n $n_{1/6}$ ft
UPPER REACH (L=1545')*										
9.66	12/01/68	4200	1219	3.45	246	4.96	0.001068	0.331	0.273	0.0412
11.97	2/22/69	9800	1733	5.65	263	6.47	0.000932	0.376	0.392	0.0286
12.81	3/17/69	12200	1884	6.48	271	6.95	0.001417	0.615	0.433	0.0306
LOWER REACH (L=5360' for flood of 2/22/69; 4103' for 3/17/69)*										
11.97	2/22/69	9800	1647	5.95	283	5.82	0.000382	0.139	0.435	0.0160
12.81	3/17/69	12200	1840	6.63	310	6.06	0.000568	0.215	0.475	0.0177

* L = length of study reach

Table 2.--Coles Creek Flood Data (Peak Flow Rates)

Gage Height ft	Date	Peak Flow cfs	Area ft^2	Velocity ft/sec	Wetted Perimeter ft	Hyd. Radius ft	Slope ft/ft	Shear Stress lbs/sq ft	Froude No.	Manning "n" ft
13.90	12/18/68 and 5/08/69	8075	1530	5.28	164	9.33	0.000276	0.161	0.305	0.0207
18.55	4/10/69	18300	2198	8.33	189	11.63	0.000591	0.428	0.431	0.0222

Table 3.--Buffalo River Channel Geometry and Hydraulics Near the Gaging Station

Gage Height ft	Flow Q cfs	Area A ft^2	Hyd. Radius R ft	Velocity V ft/sec	Froude No. $F = V/(gR)^{1/2}$
4.5	116	103	0.82	1.13	0.219
5.5	410	263	1.51	1.56	0.224
7.5	1720	679	2.99	2.53	0.258
10.5	6300	1381	5.51	4.56	0.343
13.5	14400	2106	7.90	6.84	0.429
14.5	17900	2371	8.80	7.55	0.449

Table 4.--Coles Creek Channel Geometry and Hydraulics Near the Gaging Station

Gage Height ft	Flow Q cfs	Area A ft^2	Hyd. Radius R ft	Velocity V ft/sec	Froude No. $F = V/(gR)^{1/2}$
4	185	203	1.86	0.91	0.118
5	390	303	2.48	1.29	0.144
8	1660	670	5.02	2.48	0.195
11	4170	1076	7.27	3.88	0.253
14	8230	1524	9.42	5.40	0.310
17	14080	1974	11.03	7.13	0.379
20	22000	2537	12.41	8.67	0.434
22	28400	2910	13.38	9.76	0.470

Table 5.--Predicted Buffalo River Bed Material Discharge, Using Colby's Diagram

Gage Height ft	Date mo/d/yr	Flow Q cfs	Width W_{ws} ft	Bed Sediment Discharge Q_s/W t/d/ft	lbs/sec/ft	Total Qs lbs/sec
UPPER REACH						
9.66	12/01/68	4200	242	28	0.65	157
11.97	2/22/69	9800	259	104	2.41	624
12.81	3/17/69	12200	266	146	3.38	898
LOWER REACH						
11.97	2/22/69	9800	278	120	2.78	772
12.81	3/17/69	12200	305	142	3.29	1003

Table 6.--Flow Duration Relationships

Proportion of Time that the Flow is Larger P	Buffalo River Flow cfs	Buffalo River Accumulated Mean Flow cfs	Coles Creek Flow cfs	Coles Creek Accumulated Mean Flow cfs
8×10^{-1}	38	6	53	8
3×10^{-1}	120	39	169	55
1×10^{-1}	396	91	558	128
3×10^{-2}	1200	146	1800	210
1×10^{-2}	2930	188	4440	273
3×10^{-3}	6250	220	8950	320
1×10^{-3}	10200	236	14800	343
3×10^{-4}	16000	246	22200	356
1×10^{-4}	22000	249	29400	361
3×10^{-5}	30000	251	38000	364
1×10^{-5}	39600	252	47300	365

TABLE 7.--Coles Creek Sediment Discharge Computations

Flow Q cfs	Proportion of Time That Q is Exceeded P	$\overline{Q}$ cfs	ΔP	Fine Sed. Transport Rate q_{sf} lbs/sec	Sand Transport Rate q_{sc} lbs/sec	$q_{sf}\Delta P$ lbs/sec	$\sum q_{sf}\Delta P$ lbs/sec	$q_{sc}\Delta P$ lbs/sec	$\sum q_{sc}\Delta P$ lbs/sec
125	.385								
		149	.100						
177	.285								
		210	.075	2.0	.18	0.150		.014	
250	.210						0.150		.014
		297	.059	4.9	.58	0.289		.034	
354	.151						0.439		.048
		421	.042	12.2	1.71	0.512		.072	
500	.109						0.952		.120
		595	.031	28.5	6.45	0.884		.200	
707	.078						1.835		.319
		841	.0228	63.5	10.3	1.448		.235	
1000	.0552						3.283		.554
		1190	.0167	118	22.8	1.971		.381	
1414	.0385						5.253		.935
		1680	.0118	202	45.5	2.384		.537	
2000	.0267						7.637		1.472
		2380	.0087	355	81.0	3.089		.705	
2830	.0180						10.726		2.177
		3360	.0066	605	145	3.993		0.957	
4000	.0114						14.719		3.134
		4760	.00440	1040	252	4.576		1.109	
5660	.0070						19.295		4.242
		6730	.00327	1820	440	5.951		1.439	
8000	.00373						25.246		5.681
		9510	.00190	3220	750	6.118		1.425	
11300	.00183						31.364		7.106
		13400	.00101	5500	1240	5.555		1.252	
16000	.00082						36.919		8.359
		19300	.000536	9800	1980	5.253		1.061	
22600	.000284						42.172		9.420
		27300	.000215	16700	2940	3.591		.632	
32000	.000069						45,762		10.052
		38600	.000057	25000	4250	1.425		.242	
45200	.000012						47.187		10.294
		54600	.000010	35800	5960	0.358		.060	
64000	.000002						47.545		10.354
						.08			

TABLE 8.--Buffalo River Sediment Discharge Computations

Flow Q cfs	Proportion of Time That Q is Exceeded P	$\overline{Q}$ cfs	ΔP	Fine Sed. Transport Rate q_{sf} lbs/sec	Sand Transport Rate q_{sc} lbs/sec	$q_{sf}\Delta P$ lbs/sec	$\sum q_{sf}\Delta P$ lbs/sec	$q_{sc}\Delta P$ lbs/sec	$\sum q_{sc}\Delta P$ lbs/sec
125	.285								
		149	.076	0.84		.064			
177	.209						.064		
		210	.059	1 1.60		.094			
250	.150						.158		
		297	.042	3.20		.134			
354	.108						.293		
		421	.030	6.60	.086	.198		.003	
500	.078						.491		.003
		595	.023	11.8	1.17	.271		.027	
707	.055						.762		.029
		841	.017	23.0	8.8	.391		.150	
1000	.0380						1.153		.179
		1190	.0124	44.2	30.0	.548		.372	
1414	.0256						1.701		.551
		1680	.0088	86.0	76.0	.757		.669	
2000	.0168						2.458		1.220
		2380	.0066	160	158	1.056		1.043	
2830	.0102						3.514		2.263
		3360	.0041	312	295	1.279		1.210	
4000	.0061						4.793		3.473
		4760	.00260	570	490	1.482		1.274	
5660	.00350						6.275		4.747
		6730	.00171	1070	770	1.830		1.317	
8000	.00179						8.105		6.063
		9510	.00101	1820	1160	1.838		1.172	
11300	.00078						9.943		7.235
		13400	.000485	2750	1700	1.334		0.825	
16000	.000295						11.277		8.059
		19300	.000203	3850	2460	0.782		0.499	
22600	.000092						12.058		8.559
		27300	.000059	5000	3500	0.295		0.207	
32000	.000033						12.353		8.765
		38600	.000029	7000	4950	0.203		0.144	
45200	.000004						12.556		8.909
		55000	.000004	7000	7000	0.028		0.028	
							12.58		8.937

Table 9.--Average, Measured Sediment Discharges

	lbs/sec	lbs/sec/sq mi	tons/acre/yr
	Coles Creek		
Fine Sediment	47.5	0.185	4.56
Measured Sand	10.4	0.041	1.00
Total Measured Sediment	57.9	0.226	5.56
	Buffalo River		
Fine Sediment	12.6	0.069	1.71
Measured Sand	8.9	0.049	1.21
Total Measured Sediment	21.5	0.108	2.91

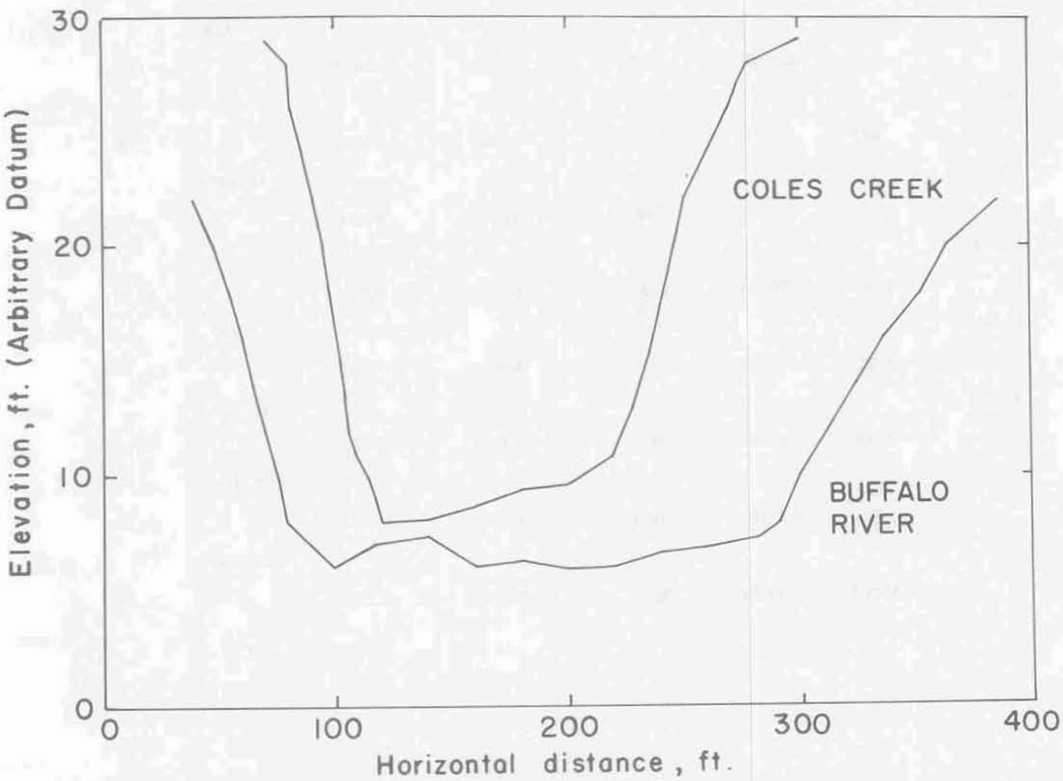

Figure 1.__ Average cross sections

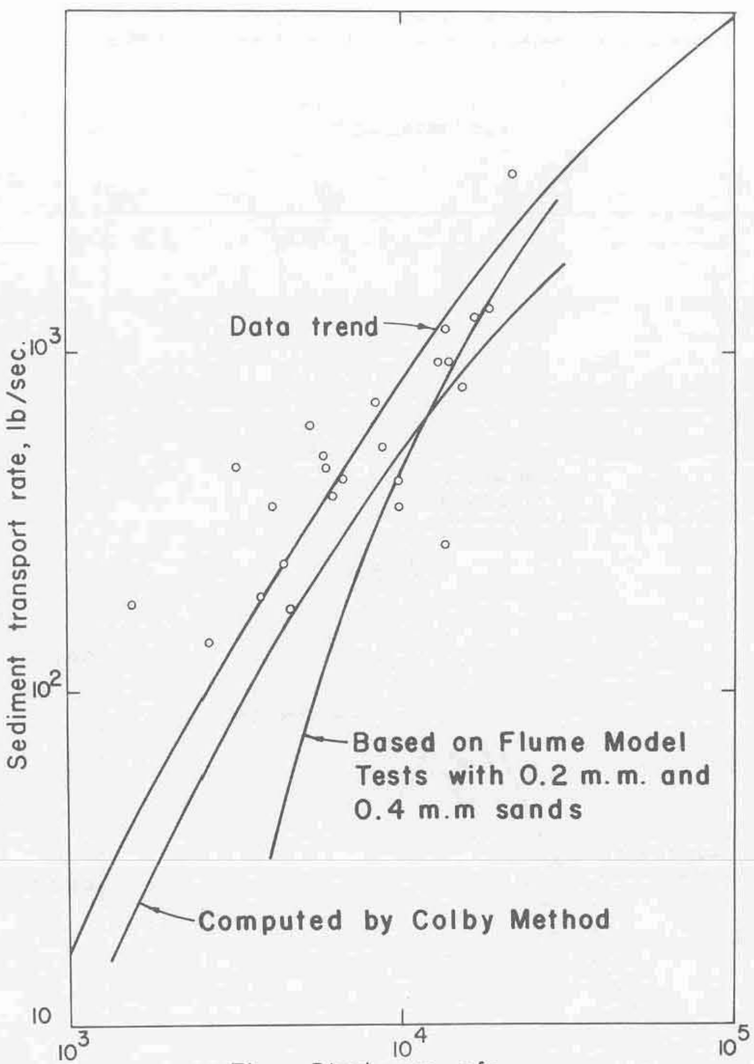

Figure 2. Sand transport rates for Coles Creek near Church Hill, Mississippi

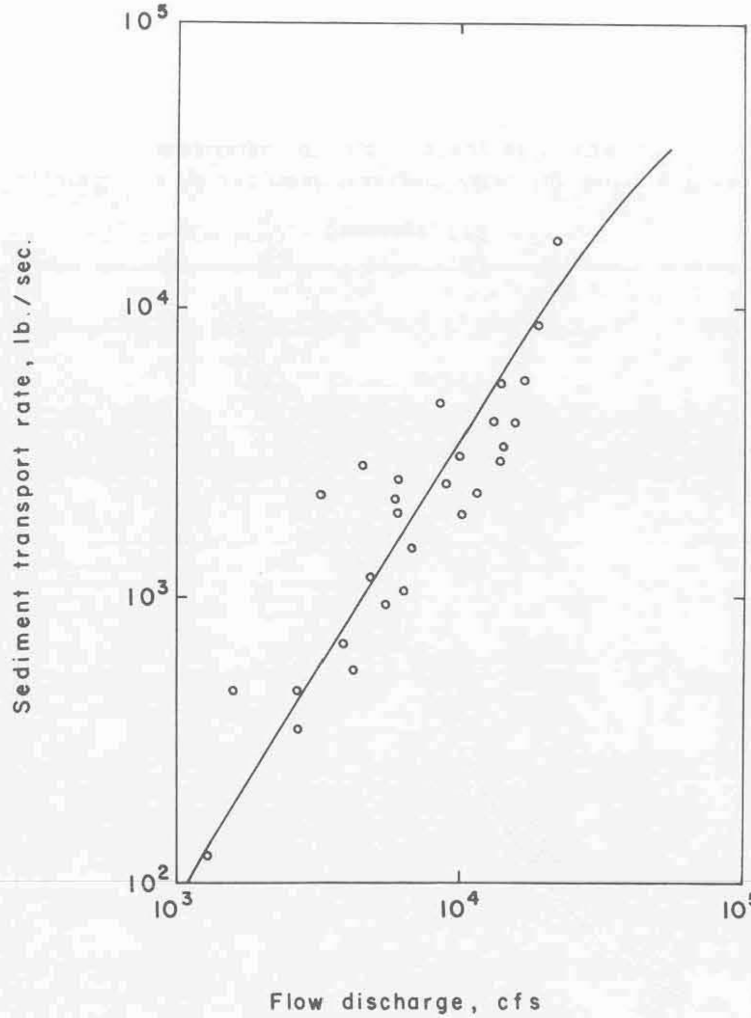

Figure 3.--Fine sediment transport rates (D<.062 mm) Coles Creek near Church Hill, Mississippi

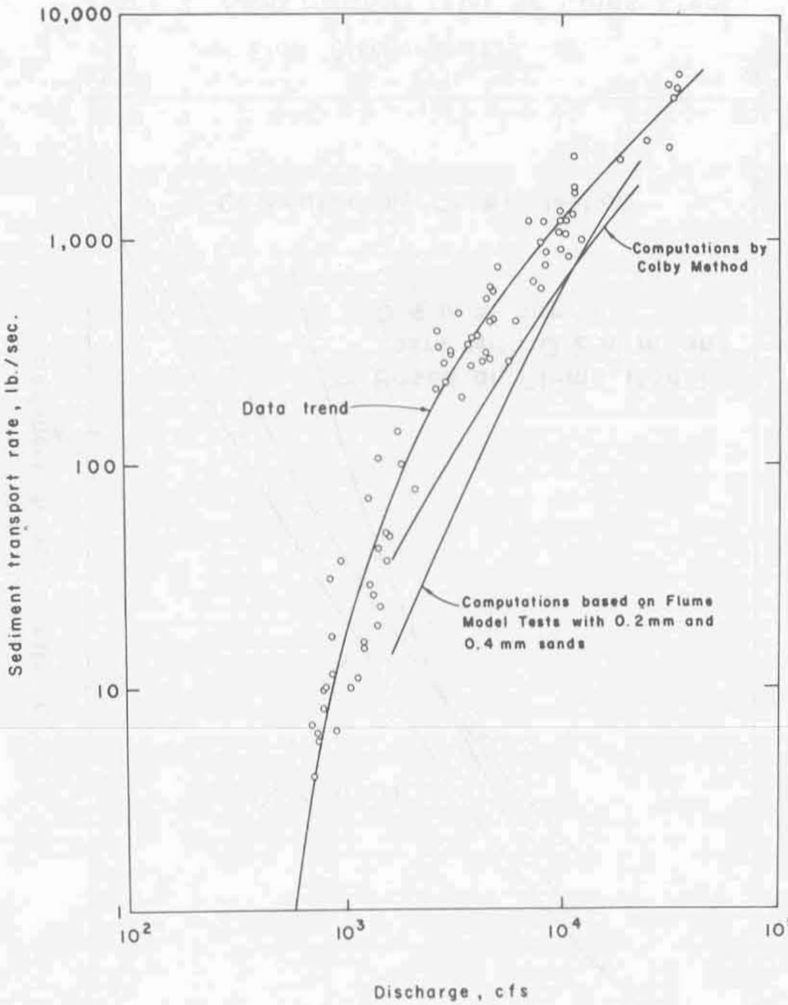

Figure 4.-- Measured sand transport rates and computed transport capacity for Buffalo River at U.S. Highway No. 61 Bridge.

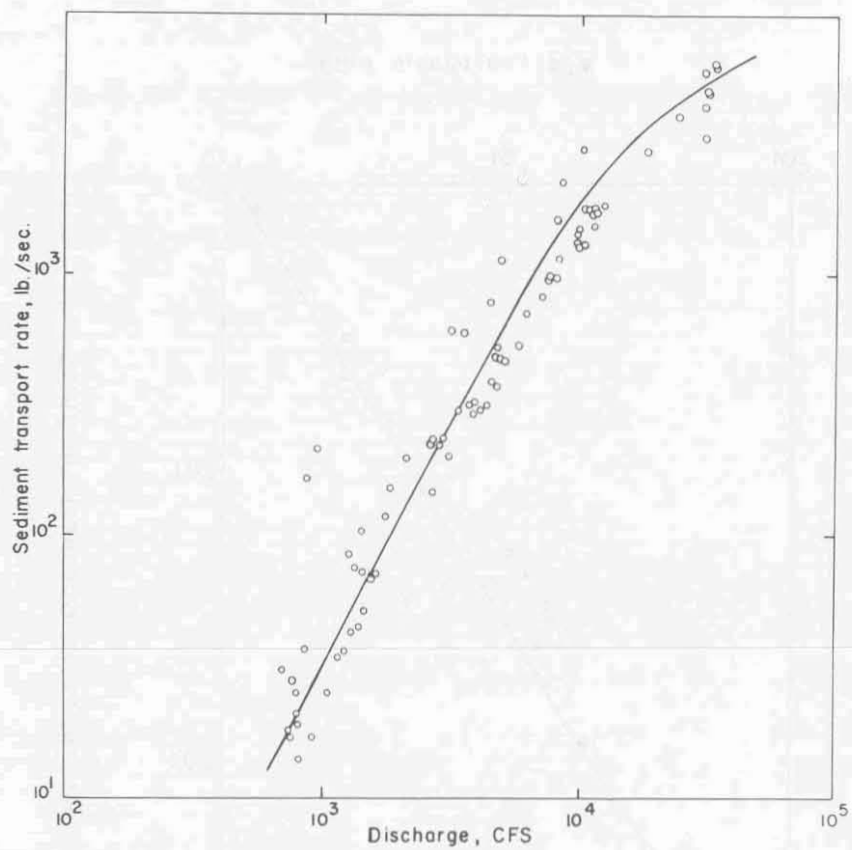

Figure 5.--Fine sediment transport rates for Buffalo River Mississippi at U.S. Highway 61 bridge

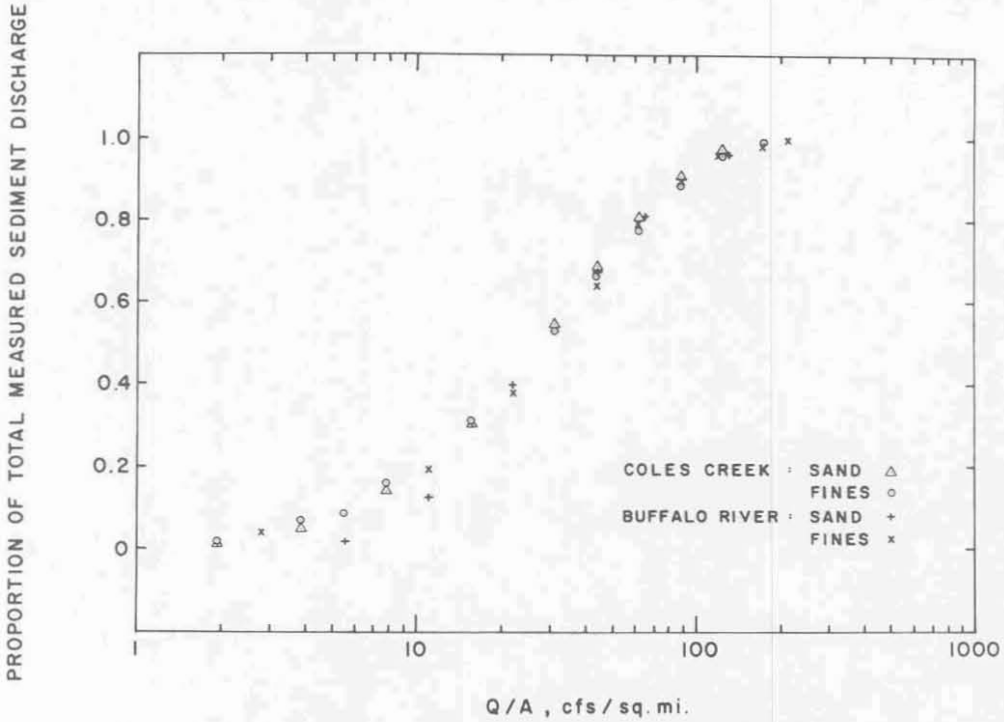

Figure 6.--The Distribution of Sediment Discharge Relative to the Water Discharge per Unit Watershed Area

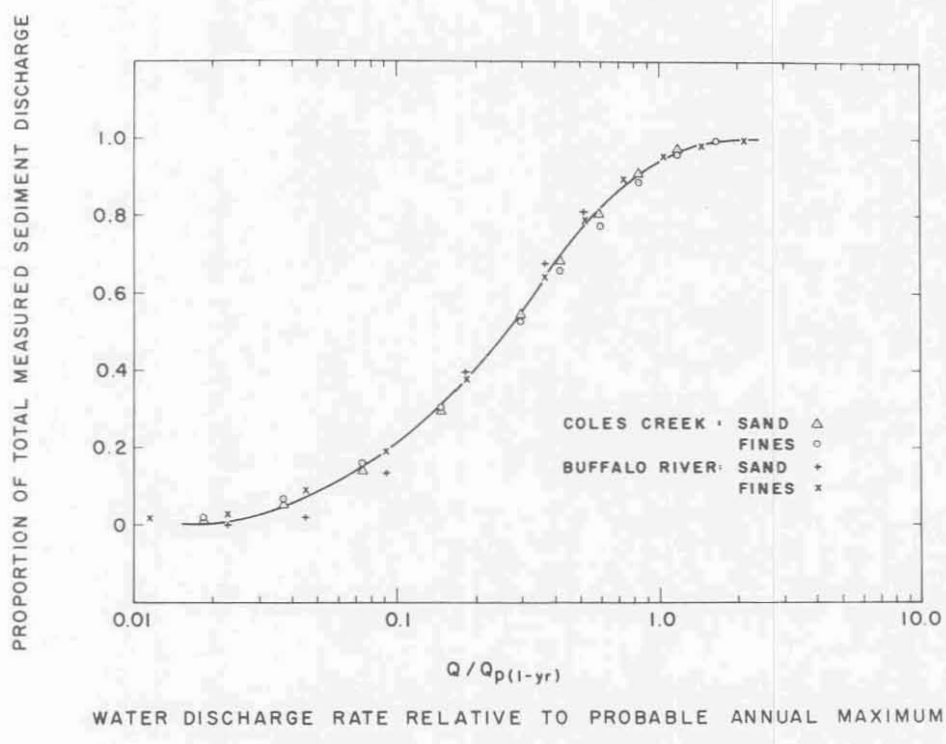

Figure 7.--The Distribution of Sediment Discharge Relative to the Water Discharge as Related to the Probable Annual Peak Flow