STREAM CHANNEL EROSION CONTRIBUTION TO SEDIMENT YIELDS IN COMPLEX WATERSHEDS

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INTRODUCTION

The greatest quantity of pollutants in surface waters is sediment produced by erosion of the land and stream channels. It is a misconception to think that the only significant eroded material that is transported in a stream channel originates entirely from land surfaces within the drainage area. The erosion that occurs within the channel system, which includes streambank and streambed, can be very significant under many circumstances. This is especially true if the channel bank and bed are composed largely of unconsolidated material.

In a report by the Chief of Engineers to the Secretary of the Army (1969) it was estimated that out of 3-1/2 million miles of streams in the United States, approximately 9 percent or some 300,000 miles of channels are experiencing a considerable degree of erosion. Approximately ½ or 150,000 miles of these channels are located in watersheds of 1,000 sq. miles or less and are classified as severely eroded. It has been further estimated that streambank erosion alone from the 300,000 miles of eroded channels produces 500 million tons of sediment each year (Barnes, 1968). This is equivalent to 1,670 tons per mile of eroding channel.

Streambank erosion, in itself, is an extremely complex subject from the point of view of its genesis, its effects, and its prevention. Whether or not erosion occurs depends upon the composition and condition of the soil composing the bank, and the erosive action of the stream. Why some banks erode and similar ones do not is not fully known. A number of variables are involved in the process and may exert their influence individually. More often, however, streambank erosion is the result of a complex combination of variables, making it extremely difficult to understand, predict, and to treat.

The problem of channel erosion is one for which there is pressing need for quantitative answers. Quantitative analysis and evaluation of data relative to channel erosion, and more especially streambank erosion, are very difficult, and in some cases, almost impossible to obtain. Research is continuing on the subject of both streambank and streambed erosion with increased emphasis on estimating erosion quantities, predicting the effects of erosion on channel characteristics, and identifying control factors.

DESCRIPTION OF STUDY AREA

Measurements of channel erosion were made for several years at permanent established channel cross sections in the 117 sq. mile Pigeon Roost Creek Experiment Watershed in North Mississippi. The watershed lies in the North Central Hills region of the East Gulf Coast physiographic section of the Coastal plain province (Bowie, 1970). The drainage network in the watershed consists of approximately 57 miles of dredged and undredged channels (Figure 1). Pigeon Roost Creek between gaging stations 12 and 34, and Cuffawa Creek between Gaging Station 35 and the confluence with Pigeon Roost Creek, were dredged during the early 1940's. The remaining 39 miles of streams in the watershed are natural well-defined channels with very few straight reaches. All of the channels are composed of largely unconsolidated material that erodes readily. Channel slopes are fairly uniform ranging from 6 to 12 ft. per mile for the large streams. Smaller streams, in the upper portion of the watershed, are much steeper with slopes varying from 18 to 29 ft. per mile.

The main channel, Pigeon Roost Creek between Gaging Stations 12 and 34, a distance of approximately 10 miles, is a perennial stream. There is some intermittent base flow in the lower reach of Cuffawa Creek below Gaging Station 32. Flow in other channels is limited to surface runoff.

RESULTS AND DISCUSSION

Relatively accurate estimates of channel erosion or deposition processes can be made if a system of channel and valley profiles is established in the valley under study (Coldwell, 1957). These range profiles should be surveyed so that they cross at right angles and are perpendicular to the stream channel when first established. Theoretically, the problem would then consist of re-surveying the ranges; multiplying the average change in area by the distance between ranges; and after allowing for the bulk density, compute the volume of channel material involved.

Quantitative estimates of erosion and deposition were made for approximately 57 miles of well-defined channels in the Pigeon Roost Creek Watershed. These estimates were based on changes in the channel cross sections as revealed by periodic detailed surveys of pre-established channel ranges spaced about 500 feet apart. Generally, surveys were made on an average of every 5 years. The number of surveys, dates of the original and last survey, and miles of channel surveyed for each subwatershed are given in Table 1.

Table 1. Channel Surveys of Pigeon Roost Creek Watershed

Watershed Number	Number of Surveys	Miles of Channel Surveyed
4	4 (1957-1976)	3.6
5	4 (1957-1976)	2.5
10	4 (1958-1976)	2.9
12	5 (1957-1976)	26.0
17	5 (1957-1976)	29.0
17A	4 (1958-1976)	3.1
32	5 (1958-1976)	14.0
34*	5 (1958-1976)	6.8
34**	6 (1958-1977)	3.9
35	4 (1958-1976)	4.6

* Above confluence Cuffawa and Pigeon Roost Creek
** Dredged reach below confluence Cuffawa Creek to Station 34

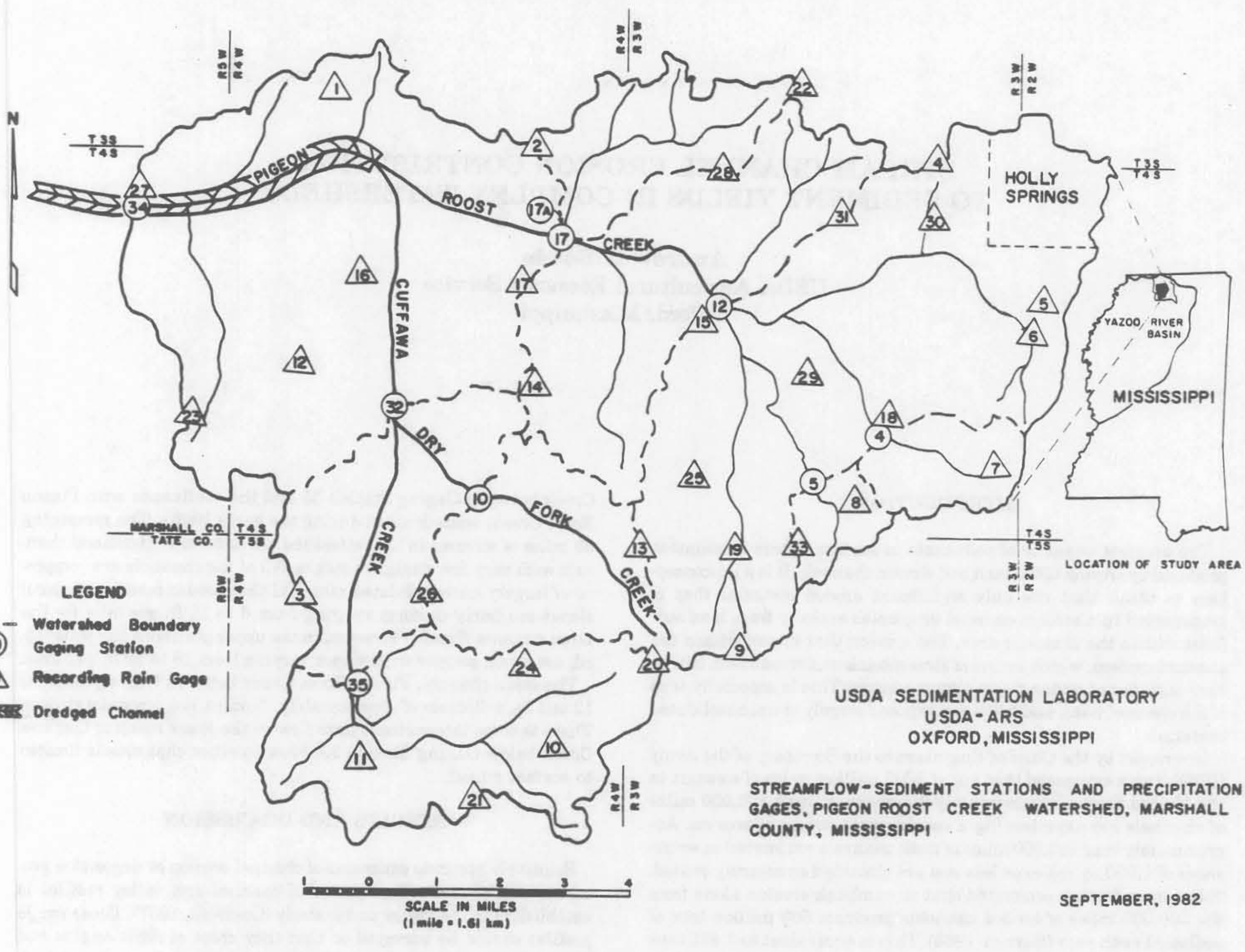

Figure 1. Location map of experimental watershed

The bulk density ranged from 85 to 102 pounds per cubic foot for channel bed material and from 82 to 104 pounds per cubic foot for channel bank material. Average unit weights of 90 pounds per cubic foot for the bank material and 91 pounds per cubic foot for the bed material were used to compute the volume of material changes between surveys.

Numerous samples of bed and bank material were collected from all channels in the study area and analyzed for particle sizes. Bed material was predominantly sand, with less than 1 percent larger than 2.0 mm. Only a very small amount of silt or particles less than .053 mm was found in the bed material. On the average, bank material was composed of approximately 13 percent clay, 55 percent silt, and 32 percent sand.

The magnitude of channel contribution to sediment yield is easily recognized when compared to the total measured sediment shown in Table 2. The total sediment discharge for each watershed was determined from measurements made at streamflow gaging stations. The proportion of the total sediment discharge attributed to channel erosion ranged from 12 percent of the total measured sediment for Watershed 17-A to 55 percent from Watershed 4. Most of the channels in the study area degraded quite rapidly. The change in profile for Cuffawa Creek, the largest tributary in the Pigeon Roost Watershed, is shown in Figure 2. The average depth of this channel increased 3.0 to 4.0 feet during the 19-year period of record.

Table 2. Channel Erosion for Pigeon Roost Creek Watershed, 10-1-57 to 9-30-76

Watershed Number	Channel length (miles)	Total Sediment discharge (tons)	Channel erosion (tons)	Channel erosion (tons/mile/year)	Channel erosion in percent of sediment yield
4	3.6	100,900	55,200	800	55
5	2.5	134,900	28,600	600	21
10	2.9	776,500	142,300	2,600	18
12	26	1,853,300	478,900	1,000	26
17	29	2,632,500	441,800	800	17
17A	3.1	279,300	32,900	600	12
32	14	3,342,200	864,600	3,300	26
35	4.6	1,210,700	403,000	4,600	33
34*	6.8	–	537,500	4,200	–

* Above confluence Cuffawa and Pigeon Roost Creek to stations 17 and 32. These reaches of channel were not gaged for sediment yield.

In considering the problems associated with total channel erosion, it may become desirable or even necessary to compute the bank and bed contribution and treat each as a separate entity. This is especially true when different methods of treatment for control purposes are to be evaluated. An analysis of the data for the Pigeon Roost Creek

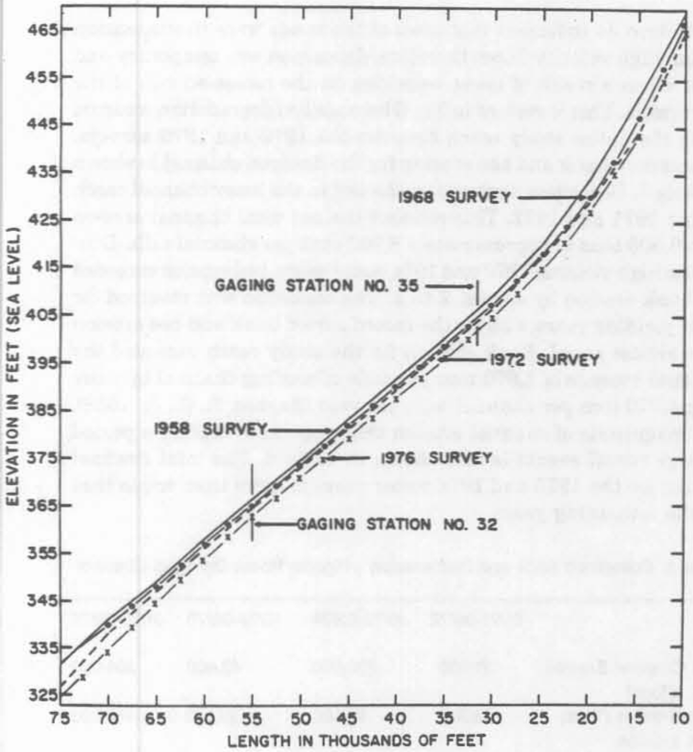

Figure 2. Profile of Cuffawa Creek

Watershed revealed that most of the channel beds eroded at a rate of more than double, and in some cases triple, that of bank erosion for the same stream (Table 3). Bank erosion exceeded bed erosion in only one stream, Cuffawa Creek above Gaging Station 35. Within Watershed 17-A, there was one small natural channel, approximately 3 miles in length, with a net result of 400 tons of bank aggradation. The reason for this is not fully explained since the same channel had bed scour on a per-mile basis that was equivalent to other channels of the same size.

Table 3. Computed Bank and Bed Erosion-Percent of Total

	Channel Erosion 10-1-57 to 9-30-76				
Watershed	Total Channel (Tons)	Bank (Tons)	Bank % of Total	Bed (Tons)	Bed % of Total
4	55,200	19,100	35	36,100	65
5	28,600	9,500	33	19,100	67
10	142,300	39,900	28	102,400	72
12	478,900	119,000	25	360,000	75
17	441,800	95,100	22	346,700	78
17A	32,900	400**	—	33,300	100
32	864,600	332,700	38	531,800	62
34*	537,500	181,900	34	355,600	66
35	403,000	240,900	60	162,100	40

* Above confluence Cuffawa and Pigeon Roost Creek to stations 17 and 32

** Aggradation

Since record periods were not concurrent, channel erosion rates were converted to tons per channel mile per inch of runoff to provide a more valid comparison of the various subwatersheds. As shown in Table 4, the streambank erosion ranged from "zero" for Watershed 17- A to 233 tons per channel mile per inch of runoff for Watershed 35. The bed erosion ranged from 30 tons per channel mile per inch of runoff for Watershed 5 to 186 tons per channel mile per inch of runoff for Watershed 10. Table 4 also identifies Cuffawa Creek Watersheds 32 and 35 and the channels in Watershed 10 as the most erosive.

Table 4. Total Watershed and Channel Erosion - Tons/Inch Runoff From 10-1-57 to 9-30-76

Watershed Number	Total Storm Runoff (inches)	Total Sediment discharge tons/inch runoff	Channel Erosion tons/inch runoff	Channel erosion tons/channel mile 1 inch runoff	
				Bank	Bed
4	113	893	488	47	89
5	256	527	112	15	30
10	190	4,087	749	72	186
12	149	12,438	3,214	31	93
17	218	12,076	2,027	15	55
17A	174	1,605	189	0	62
32	224	14,921	3,860	106	170
35	225	5,381	1,791	233	157

There was also a significant difference in the channel erosion rates between Watersheds 4 and 5. The channels in Watershed 4 eroded at a rate more than double that of the channels in Watershed 5. However, non-channel erosion per inch of runoff was essentially the same for both watersheds. In order to better evaluate some of the factors contributing to the difference in channel erosion, more detailed studies were conducted in the two watersheds.

Comparison of Watersheds 4 and 5

Watersheds 4 and 5 are joined by a common boundary of approximately 1.0 mile (Figure 1). Watershed 4 has a drainage area of 2.47 square miles (1,580 acres) and Watershed 5 has 1.56 square miles or 998 acres. Both watersheds have rather narrow flat flood plains with natural channels and rolling dissected upland areas. The average annual precipitation, runoff, and sediment yield for the 19-year period of record is as follows:

Rainfall (inches) Watershed		Runoff (inches) Watershed		Sediment Yield Ton per acre Watershed		Sediment Yield T/A per in. runoff Watershed	
4	5	4	5	4	5	4	5
51.34	51.44	5.95	13.47	3.35	7.11	0.56	0.53

Although the weighted precipitation was nearly equal for the two watersheds, a comparison of the average runoff shows watershed 5 to exceed that of Watershed 4 by more than 100 percent. Average sediment yields for the two areas are in the same proportion.

Some factors that could affect runoff and channel erosion are considered to occur under natural conditions, while others are influenced by man. An investigation of several of the natural factors indicates that geology and soils are major contributors to the difference in runoff between the two watersheds (Bowie and Bolton, 1972). A relatively impermeable clay lens underlies the valley fill in Watershed 5. A small amount of clay is also present at some locations beneath Watershed 4, but it is not continuous. There is a smaller percentage of recent deposits or valley fill in Watershed 5, a higher percentage of the Kosciusko formation, and a small percentage of the Tallahatta formation (Asmussen and Dendy, 1963). Compared with the Tallahatta, the Kosciusko has a much lower permeability due to a more even dissemination of clay throughout the formation. Consequently, channels in Watershed 5 are composed of materials that, as a general rule, are less susceptible to erosion than the more permeable materials found in Watershed 4.

Stream-channel erosion rates are related to the total quantity of sediment in transport. An increase in the sediment load of streamflow results in a decrease in the flow capacity for entrainment of additional material, and thus can result in a reduced stream-channel erosion rate. Conversely, any reduction in sediment inflow into the channel system can increase the ability of streamflow to erode the channel boundary. It is possible, therefore, that a conservation land use program would be one of the factors contributing to this condition. The data indicate that differences in channel erosion rates between channels 4 and 5 may be attributed partially to land use difference in the watersheds. There was a reduction in cultivated land combined with a large increase in good to excellent cover conditions in Watershed 4 that helped to reduce the amount of eroded material reaching the channel system; whereas, an increase in cultivated land with a reduction in permanent cover contributed to conditions in Watershed 5 that provided for more eroded material reaching the channel system. The increased amount of overland eroded material reaching the channel system in Watershed 5 decreased proportionally the capacity of the flowing water to transport streambank and streambed material (Bowie, et al., 1972).

Effects of Dredging

Studies have shown that man's activities have influenced, and in some cases accelerated channel erosion. Channel dredging is one example of man's activities that has had a profound effect. As a result of frequent out of bank flooding along the lower reach of the Pigeon Roost Creek, a dredging operation was initiated in 1969 to increase the capacity of the channel to transport the flood waters. The channel was dredged from the confluence of Cuffawa Creek downstream to the Coldwater River, a distance of approximately 14.8 miles. Detailed studies were conducted on 3.9 miles of the dredged channel contained within the drainage area of the experimental watershed (Figure 1). Dredging of the channel was completed in the Spring of 1970 with the spoil placed along both banks. Removal of natural vegetation along the channel banks left the banks unprotected. The average bottom width was increased from 75 feet to 100 feet with an increase in the cross section area of approximately 1200 square feet (Bowie; 1983).

Prior to dredging, out of bank flow occurred at approximately 5,000 cfs. After dredging, peak discharge rates in excess of 20,000 cfs were contained in the channel. Measurements at gaging station 34 showed an increase in mean velocity for peak stages from 8.0 ft/sec prior to dredging to more than 12.0 ft/sec after dredging (Fig. 3). These higher velocities caused excessive bank erosion. Increased velocities along the banks also resulted in undercutting of the bank toe along most of the dredged reach. Occasional high stages for long periods increased the moisture content of the near vertical banks to saturation. This caused a reduction in shear strength, and the increased weight of the saturated bank caused large sections to slide into the channel.

Cross section surveys were made in 1968 prior to dredging and immediately after dredging in 1970 (Fig. 4). Resurveys were completed in 1972, 1974 and 1976. The 1976 survey shows that in some sections the channel width increased as much as 40 ft. (Fig. 5). Between the time the dredging was completed in 1970 and the 1976 survey, bed degradation in the upper channel reached a depth of approximately 4.0 ft. As shown in Fig. 6, there was some bed aggradation in the lower section of the study reach between 1970 and 1972. This was caused by large sand loads entering the channel from four rather large tributaries between ranges 750 and 830. Measurements at gaging station 34 indicated that most of the sands were in suspension during high velocity flows; therefore, deposition was temporary and occurred as a result of lower velocities on the recession side of the hydrograph. This is evident in Fig. 6 because bed degradation occurred along the entire study reach between the 1972 and 1976 surveys.

Computed bank and bed erosion for the dredged channel is shown in Table 5. Deposition occurred on the bed in the lower channel reach during 1971 and 1972. This reduced the net total channel erosion from 8,500 tons to approximately 6,900 tons per channel mile. During the high yielding 1973 and 1974 water years, bed erosion exceeded the bank erosion by almost 2 to 1. The condition was reversed for lower yielding years, and for the record period bank and bed erosion were almost equal. Bank erosion for the study reach exceeded the national average of 1,670 tons per mile of eroding channel by more than 4,770 tons per channel mile per year (Barnes, R. C., Jr. 1968). The magnitude of channel erosion that may occur during a period of large runoff events is also shown in Table 5. The total channel erosion for the 1973 and 1974 water years is more than triple that for the remaining years.

Table 5. Computed bank and bed erosion - Pigeon Roost Dredged Channel

	01/71-09/72	10/72-09/74	10/74-09/76	01/71-09/76
Total Channel Erosion (Tons)	27,000	233,600	43,400	304,000
Bank Erosion (Tons)	33,000	90,500	27,100	150,600
Bank Erosion % of Total	100	39	62	50
Bed Erosion (Tons)	6,000*	143,100	16,300	153,400
Bed Erosion % of Total	—	61	38	50

* Aggradation

From 1958 through 1969, prior to dredging, approximately 3.75 million tons of sediment discharge was measured for the 117 sq. mile watershed at gaging station 34. This compares with almost an equal amount during the 6 year period following dredging (Table 6). Of the total measured sediment discharge from the 117 sq. mile watershed following dredging, over 8 percent was channel erosion from the 3.9 mile dredged channel.

Table 6. Total Sediment Yield - Pigeon Roost Dredged Channel

Length of Dredged Channel - 3.9 Miles
Drainage Area at Gaging Station 34 - 117 Sq. Miles

	1958 - 1969*	1971 - 1976**
Total Measured Sediment (Tons)	3,796,000	3,790,400
Total Channel Erosion (Tons)	—	304,000
Channel Erosion - Tons/Channel Mile		77,900
Channel Erosion - % of Measured Sediment		8

* Prior to Dredging
** After Dredging

Watershed sediment yield in tons per inch of runoff is shown in Table 7. Sediment concentrations at gaging station 34 increased by 33 percent after dredging. When channel erosion is deducted, measured sediment shows an increase of approximately 23 percent, or 29,800 tons per inch of runoff. Mean annual storm runoff after dredging increased 60 percent.

During the period of record from October 1, 1957 to September 30, 1976, over 7,580,000 tons of sediment was measured at station 34 for the 117 sq. mile watershed. During this same period of time, over 2,180,800 tons of eroded material was computed from channel cross section surveys throughout the watershed. This amounts to approx-

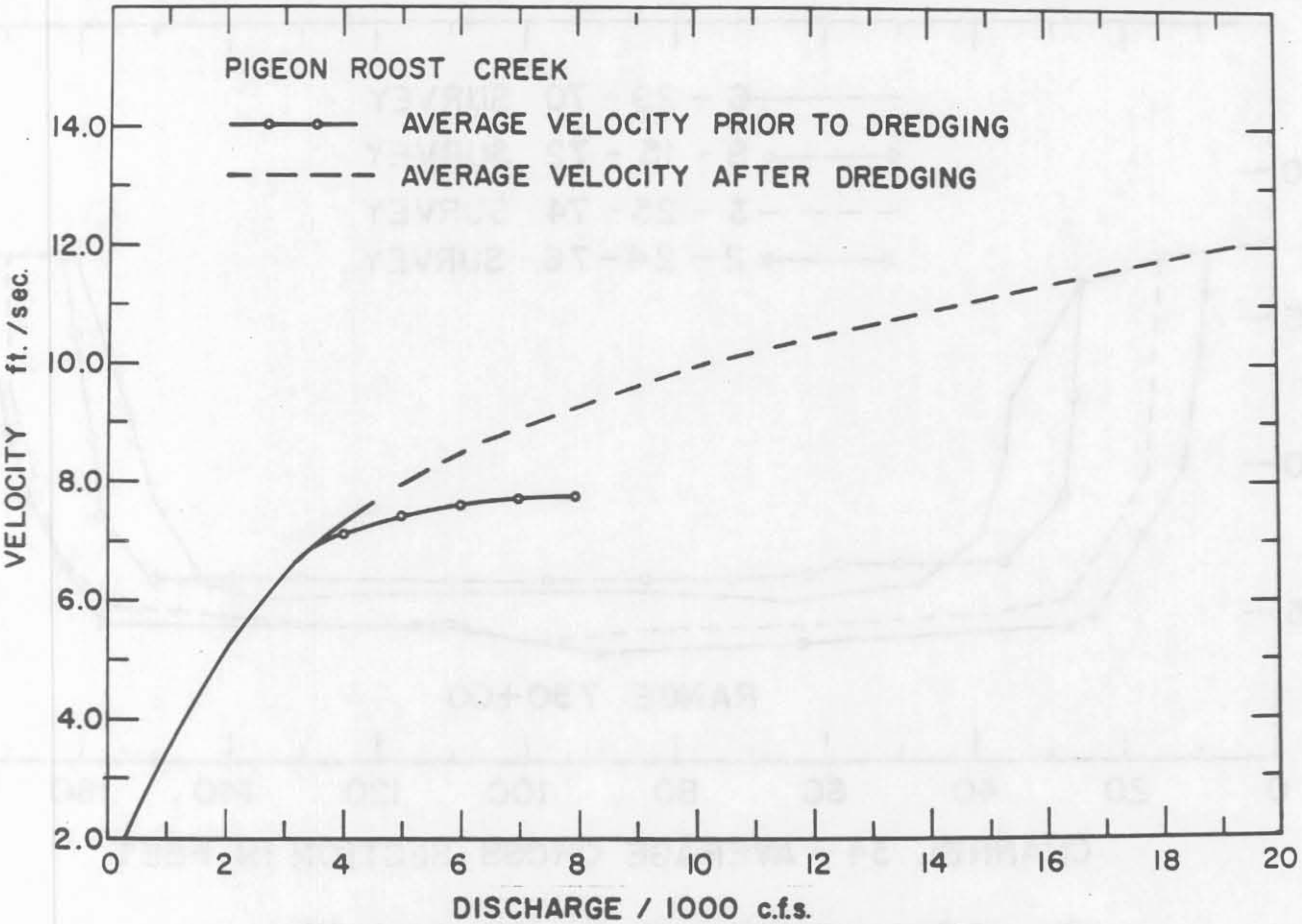

Figure 3. Increase in velocity following dredging

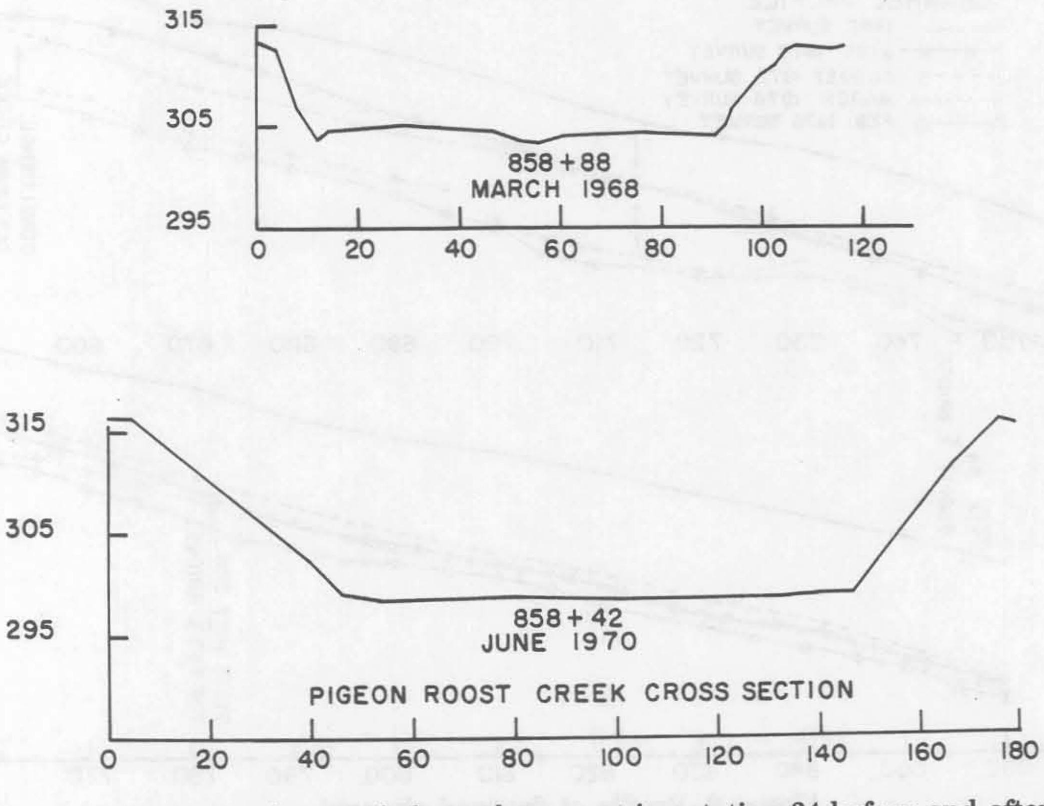

Figure 4. Cross sectional area of channel near gaging station 34 before and after dredging

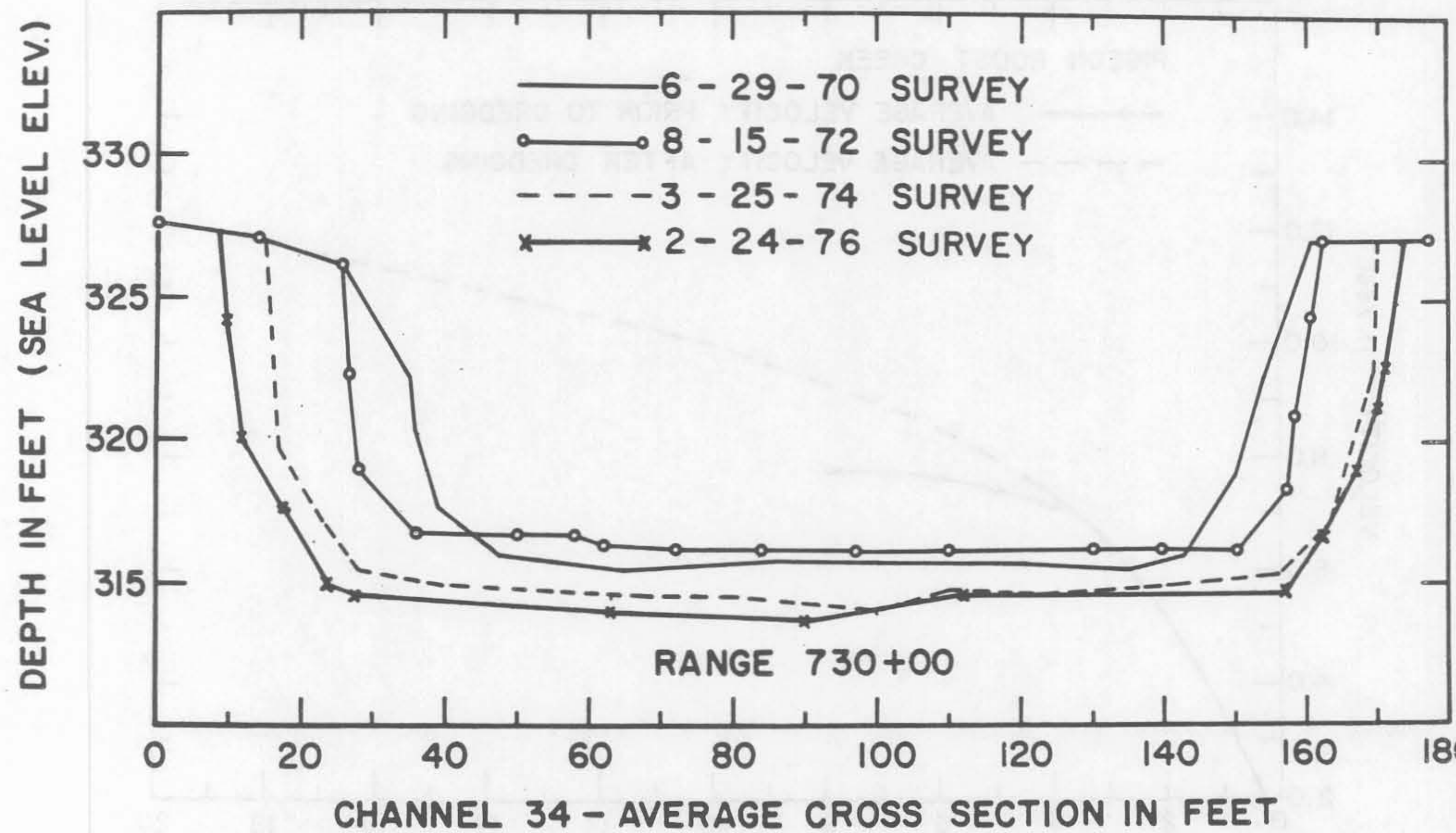

Figure 5. Increase in cross section area following dredging

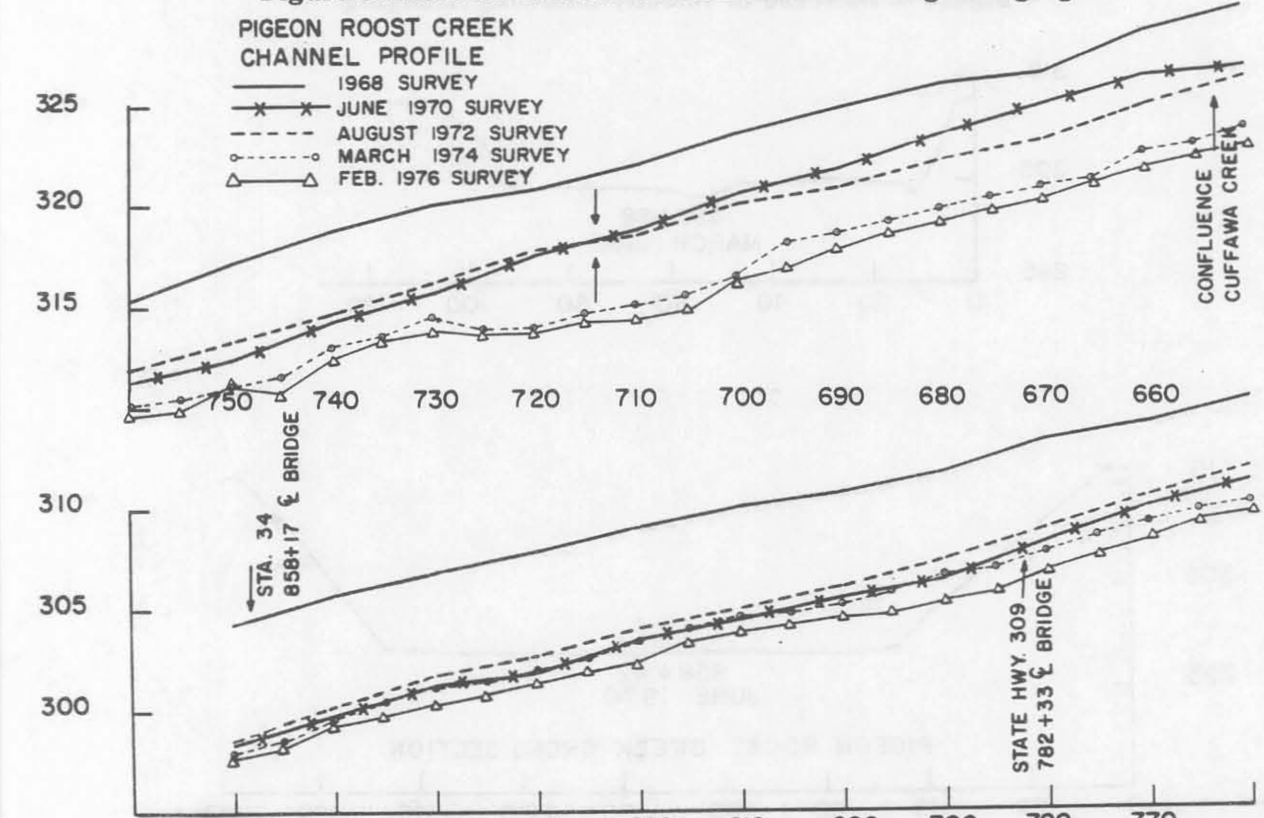

Figure 6. Profile of dredged channel

imately 2,000 tons per channel mile per year, or 29 percent of the total measured sediment discharge from the 117 sq. mile watershed that was attributable to channel erosion.

Table 7. Total Sediment Yield and Runoff - Pigeon Roost Dredged Channel

	1958 - 1969*	1971 - 1976**
Total Storm Runoff (Inches)	156	117
Measured Sediment - Tons/in Runoff	24,300	32,400
Channel Erosion - Tons/in Runoff	—	2,600

* Prior to Dredging
** After Dredging

SUMMARY

Surveys were made over a 19 year period on approximately 57 miles of permanent well-defined channels in a north Mississippi watershed. These surveys were made in order to determine the extent of channel contribution to sediment yield. Surveys indicated erosion rates for natural undredged channels ranged from 12 to 55 percent of the total watershed sediment yield. With the exception of one subwatershed, channel bed erosion was twice as much as bank erosion.

The studies revealed that soil conditions, land use changes, and channel dredging have a profound effect on channel erosion. Because deposition usually occurs in most of the downstream drainageways, they must be dredged periodically, and as a result, a high rate of erosion may occur. Channel erosion rates for a recently dredged channel were exceedingly high. A change in the flow regime resulted in greatly increased velocities, which caused excessive erosive action along unprotected channel banks. During high stages and prolonged periods of storm flow, the moisture content of the channel banks increased to the point of saturation. Soil resistance to shear was overcome by its own weight causing large sections of the bank to slide into the stream. Channel erosion rates as high as 430 tons per inch of runoff per year were computed for the dredged channel. This is equivalent to 13,000 tons per channel mile per year.

Combined channel erosion for the 19 year period of record averaged 29 percent of the total measured sediment discharge for the 117 sq. mile watershed.

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