Sediment Sources and Yields from Upland Watersheds in North Mississippi

F. E. Dendy
Research Hydraulic Engineer
USDA Sedimentation Laboratory
USDA-SEA-AR
Oxford, Mississippi

S. J. Ursic
Principal Hydrologist
USDA Forest Service
Southern Forest Experiment Station
Forest Hydrology Laboratory
Oxford, Mississippi

A. J. Bowie
Research Hydraulic Engineer
USDA Sedimentation Laboratory
USDA-SEA-AR
Oxford, Mississippi

INTRODUCTION

While information is available on erosion rates from various sediment source areas, a satisfactory method for accurately predicting sediment yields for large mixed-cover drainage basins is not. The method most commonly used for agricultural watersheds is to compute erosion rates for various categories of land use. Normally the universal soil loss equation is used to compute sheet and rill erosion, and gully and channel erosion rates are estimated or based on local field measurements (11). A sediment delivery ratio is then applied to the computed erosion rates to obtain estimated sediment yields at some location downstream (4) (6) (7).

The sediment delivery ratio, often the weakest link in the estimation process, is influenced by many watershed and hydrologic parameters, and it is extremely difficult to determine accurately. As sediment moves downslope, or downstream, deposition may occur at any point. However, unless channel aggradation or overbank flooding occurs, all of the sediment delivered to the watershed channel network is transported downstream. Therefore, in the absence of flooding and channel aggradation, watershed sediment yield should equal, approximately, the quantity of sediment delivered to the channels; i.e., the sediment delivery ratio would equal one. In this paper sediment yields from small, upland, single-cover watersheds, all with defined channels, are examined and compared with sediment yields from larger mixed cover watersheds in the vicinity.

METHODS AND CONCEPTS

Nineteen small unit source watersheds and five large mixed-cover watersheds provided the basic sediment data for this study. They represent the soils, past erosion, land use, and forest cover prevailing on several million acres of hilly uplands in the upper Coastal Plain in north Mississippi and west Tennessee.

Key physical characteristics of the small, unit-source watersheds are given in Table 1. They include one in pasture, two in cultivation, and 16 in abandoned fields and forest. The pasture watershed, typical of unimproved pasture in the area, was poorly managed and heavily grazed. Although cover was generally poor, most of the sediment eroding from this watershed came from small rills which developed along cow trails. The cultivated watersheds were planted in corn each year, cultivated on the approximate contour, with no conservation practices applied. Farming operations were typical of those used by farmers with large multirow equipment.

The forest land catchments included three replications each of abandoned fields, depleted stands of upland hardwoods, and mature pine and hardwoods, and seven replications of loblolly pine plantations. The abandoned field watersheds had a dense grass-herbaceous cover dominated by broomsedge (Andropogon spp.). The upland hardwood catchments had sparse stands of poor quality blackjack oak, post oak and hickory. The stands of short-leaf pine-hardwoods were mature and well stocked. The pole-size loblolly pine plantations had established severely eroded lands with a heavy forest floor.

Soils represented by the small watersheds include: Memphis (Thermic Typic Hapludalfs), Loring (Thermic Typic Fragiudalf), Providence (Thermic Typic Fragiudalfs) and Lexington (Thermic Typic Paleudalfs) series derived from wind deposited loess; and Ruston (Thermic Typic Paleudalts) and closely allied series developed from Coastal Plain materials. Additional details on the soils, topography, plant cover, land use, instrumentation, and data-collection procedures were given by Ursic and Dendy (9) and Ursic and Duffy (10).

The five large, mixed-cover watersheds are located in the Pigeon Roost Creek basin in Marshall County, Mississippi. They range in size from 1000 to 22,800 acres. About 20 to 25% of the land area is cultivated, 40 to 50% is pasture or idle land, and 30 to 40% is forest land.

Table 1—Physical characteristics and period of record for the single-cover watersheds.

Land Use or Cover	Drainage Area (acres)	Soils		Range in Elevation (feet)	Period of Record (years)
		Loessial (a) (percent)	Coastal Plain (b) (percent)		
Cultivated (corn)	3.88	100	0	27	8
	1.61	100	0	18	8
Pasture	3.01	62	38	28	3
Old Fields	2.65	100	0	37	5
	2.62	64	36	44	12
	2.43	25	75	49	5
Depleted Hardwoods	2.56	65	35	49	12
	2.12	34	66	58	5
	2.13	100	0	44	5
Pine-Hardwoods	3.31	16	84	74	10
	4.56	6	94	99	10
	4.01	4	96	95	10
Pine Plantations	3.35	29	71	68	14
	3.58	46	54	60	14
	2.60	100	0	40	14
	6.95	100	0	43	4
	4.77	100	0	59	4
	5.91	36	64	63	4
	3.67	7	93	62	4

(a) Memphis, Loring, Providence and Lexington series
(b) Principally Ruston soils

While many factors influence erosion rates and sediment yields, runoff volume usually has the greatest effect. Over long-time periods, sediment yield from unit source areas tends to correlate closely with runoff volume. Data reported by McGregor, *et al.* (2) for a 0.022-acre bare-fallow plots on loessial soils in North Mississippi showed a good linear relationship between annual soil loss and annual runoff (Figure 1). Similarly, annual sediment yields reported by Bowie, *et al.* (1) for large mixed-cover watersheds with relatively constant land use patterns also were correlated closely with annual runoff (Figure 2). This indicates that long-term sediment yield in the upper Mississippi Coastal Plain is primarily a function of runoff volume.

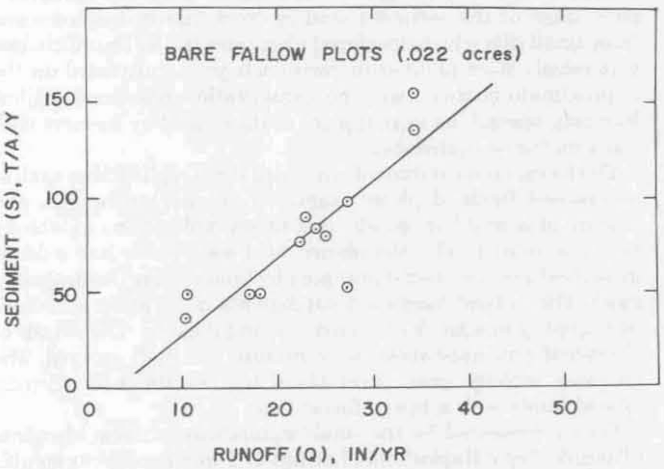

Figure 1. Annual runoff-sediment relationship for bare, fallow, 0.022-acre plots (from McGregor, et al., 1969).

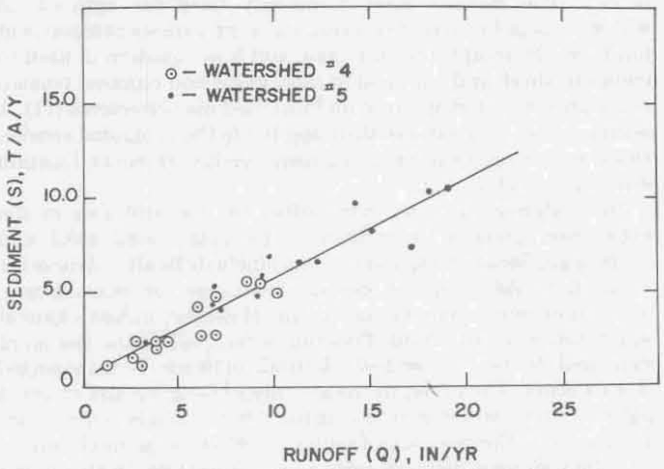

Figure 2. Annual runoff-sediment relationship for large, mixed-cover watersheds (from Bowie, et al., 1975).

RESULTS AND DISCUSSION

Annual rainfall, runoff, and sediment yields for the small, single-cover watersheds used in this study are summarized in Table 2. Table entries are average values for all watersheds in each land use category. The range in values provides some indication of the yearly variability of the data. Large differences among land uses are evident. Runoff from the cultivated and pasture watersheds averaged twice as much as that from the forest land watersheds, and sediment yields from the cultivated watersheds were almost 300 times greater than those from forest lands.

The annual runoff-annual sediment yield relationship for the cultivated (corn) watersheds is poor as shown in Figure 3. While rainfall intensity and runoff rates exert some influence, much of the variability in annual sediment yield is caused by varying amounts of runoff during the spring and early summer. During the planting and early growth period, the fields are usually

Table 2—Annual rainfall, runoff and sediment yields for the single-cover watersheds.

Land Use or Cover Type	Annual Rainfall (b) Average (a) (inches)	Annual Rainfall (b) Range (inches)	Annual Runoff (b) Average (a) (inches)	Annual Runoff (b) Range (inches)	Annual Sediment Yield (c) Average (a) (Tons/acre)	Annual Sediment Yield (c) Range (tons/acre)
Open land:						
Cultivated	48.9	47.1-61.1	15.39	6.2-24.0	23.85	6.7 -43.1
Pasture	52.2	47.1-61.0	16.52	12.9-23.4	1.61	1.21- 2.03
Forest Land:						
Abandoned Fields	51.4	42.3-61.1	6.65	1.2-20.7	0.141	0.013-0.544
Depleted Hardwoods	51.2	42.6-60.0	5.94	1.2-13.1	.118	.018- .316
Pine and Hardwoods	50.5	38.4-62.4	8.74	0.4-19.8	.051	.001- .206
Pine Plantations	54.7	43.4-70.7	1.49	<.1- 9.7	.011	<.001- .079

(a) Table entries are average values for each land use or cover type for which concomitant records were available.
(b) Eight years of concomitant data for forest land covers.
(c) Four years of concomitant data for forest land covers.

freshly plowed, have little or no vegetative cover, and are highly erodible. When a high proportion of annual runoff or intense rains occur during this period, sediment yields are high. However, there is a positive linear trend between annual sediment yields and annual runoff (Figure 3). A best fit curve forced through the origin indicates a mean annual sediment yield rate of 1.5 tons per acre per inch (T/AI) of runoff:

$$S_{cd} = 1.5\ Q \qquad [1]$$

where

S_{cd} = annual sediment yield (tons/acre/year)

Q = annual runoff (inches)

The pasture watershed data were limited, but indicated a similar relationship; i.e., the average sediment concentration per unit of runoff was relatively constant. A linear relationship was assumed (Figure 3) and the following equation derived:

$$S_p = 0.09\ Q \qquad [2]$$

Sediment yields from each of the four undisturbed forest land covers were also direct functions of runoff volumes. Slopes of regressions of sediment concentration in (T/AI) over annual runoff for each of the four cover types did not differ significantly from zero. However, statistical comparison of the forest land cover types revealed two discrete populations of erosion potential. Sediment concentrations for the pine plantations and pine-hardwoods were significantly lower than those of the abandoned field and depleted-hardwood covers.

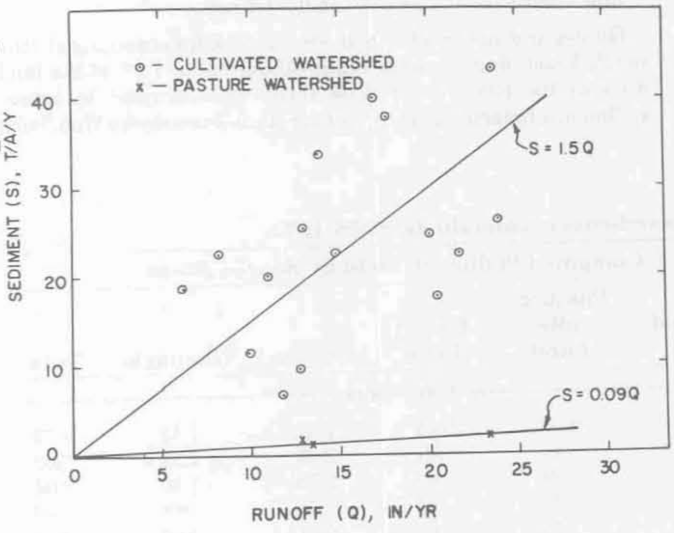

Figure 3. Annual runoff-sediment relationship for small, cultivated and pasture watersheds.

Annual sediment concentrations for the loblolly pine plantations (n = 58) averaged 0.0077 T/AI of runoff. This compared favorably with the 0.0066 T/AI previously reported for a smaller sample (10). Concentrations for the pine-hardwood types averaged 0.0065 T/AI (n = 30) and did not differ significantly from the pine plantations. Thus, the mean (0.007 T/AI) adequately represents the pine-cover types.

Annual sediment concentrations for the abandoned fields (0.0283 T/AI, n = 22) and depleted upland hardwoods (0.0239 T/AI, n = 22) did not differ significantly. Although the mean for these two cover types (0.0261 T/AI) was significantly different from the average for the pine types, the relatively small contribution of sediment from forest lands did not warrant the additional effort required to separate forest types. Hence, for this paper, we assumed that the average sediment concentration of the two categories represented all forest land:

$$S_f = 0.017\ Q \qquad [3]$$

This equation is for undisturbed forest lands. Neither the area subjected to forestry activities nor the impacts of disturbances was known. However, the contributions of sediment resulting from forestry activities would be slight compared with those from other sources.

A well defined channel existed at, or immediately below, the sediment gaging station on all of the small watersheds. Thus, it may be assumed that all of the sediment discharge from these small, single-cover areas was delivered to the channel network of a larger drainage basin. Reductions in sediment yield as the material moved downstream only occurred as channel deposits or as flood plain deposits when overbank flow (flooding) occurred.

Annual runoff from the cultivated and pasture watersheds was much greater than that from the forest watersheds (Table 2). Annual rainfall (R) plotted vs. annual runoff (Q_{NF}), for these nonforest watersheds (Figure 4) showed a reasonably good linear relationship. The following equation, derived for a best fit curve, explained 77% of the variation (r^2 = 0.77) in annual runoff.

$$Q_{NF} = -14.57 + 0.61\ R \qquad [4]$$

A general rainfall-runoff relationship for forest lands was established by plotting average annual forest runoff (Q_f) vs. average annual rainfall for all forest watersheds with concomitant data. Eight years of concomitant data were available (Figure 5). The regression equation

$$Q_f = -11.43 + 0.33\ R \qquad [5]$$

explained 78% of the variation (r^2 = 0.78). Previous studies (10) showed that soil characteristics have a strong influence on the rainfall-runoff relationship for forest watersheds. Therefore, the accuracy of equation 5 could be improved with detailed soils information.

Drainage areas, average annual runoff, and sediment yields for the five large, mixed-cover watersheds are given in Table 3.

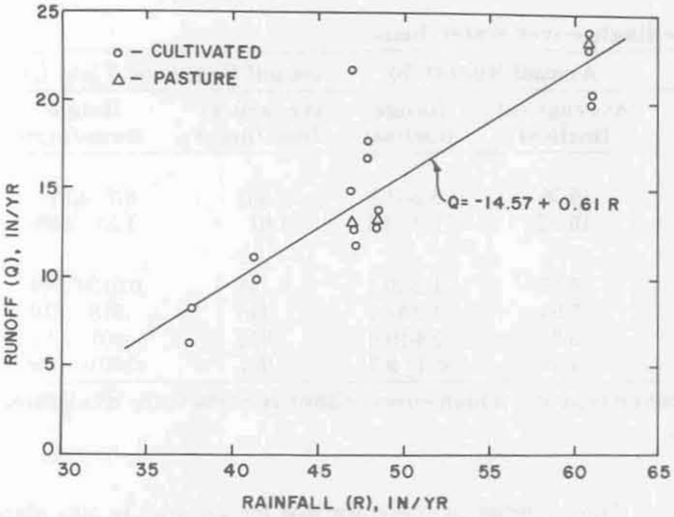

Figure 4. Annual rainfall-runoff relationship for non-forest watersheds.

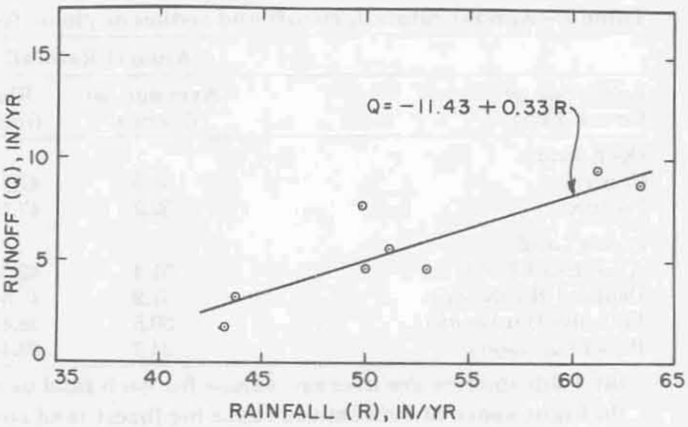

Figure 5. Annual rainfall-runoff relationships for forest watersheds.

For the 14-year (1958-1971) period of record annual rainfall was relatively uniform on all of these watersheds but runoff and sediment varied greatly (1) (8).

Periodic field surveys provided information on land-use and vegetative cover changes in mixed-cover watersheds. Generally, the proportion of pasture-idle land and land in cultivation decreased and forest land increased between 1958 and 1971.

Many small ponds and gully plugs existed before or were constructed in these watersheds during the record period. These structures effectively trapped sediment, and drainage areas above them contributed only relatively small amounts of sediment to the channel network. Therefore, the sediment contributing area decreased annually, and was always less than the total drainage area. In 1971, sediment contributing areas ranged from 70 to 80% of the total drainage areas. Land use changes and changes in the sediment contributing area were taken into account in the computations of annual sediment yields described below. Land classified as idle in the land use surveys was treated as pasture.

Assuming that equations [1], [2], [3], [4], and [5] represent long-term runoff and sediment yields for cultivated, pasture, and forest cover categories, they were used to compute annual sediment yields for the mixed-cover watersheds. First, the measured annual runoff (Q) was apportioned to forest runoff and non-forest runoff. Using equations [4] and [5], the relationship between Q_F and Q_{NF} was established as follows:

$$\frac{Q_{NF} + 14.57}{0.61} = R = \frac{Q_F + 11.43}{0.33} \quad [6]$$

and

$$Q_F = -3.54 + 0.54\, Q_{NF} \quad [7]$$

then assume

$$Q = a\, Q_{NF} + b\, Q_F \quad [8]$$

where

a = the proportion of watershed area with nonforest cover

b = the proportion of watershed area with forest cover.

Computed runoff values, Q_F and Q_{NF}, were then used in equations [1], [2], and [3] to calculate annual watershed sediment yield, S_c, for cultivated, pasture-idle, and forest land as follows:

$$S_c = \frac{1[1.5\, Q_{NF} A_1 + 0.09\, Q_{NF} A_2 + 0.017\, Q_F A_3]}{A} \quad [9]$$

where

A = total watershed area

A_1 = cultivated land area

A_2 = pasture-idle land area

A_3 = forest land area

and other symbols as previously defined.

Gullies and stream channels are major sediment sources in the north Mississippi Coastal Plain. About 1.0 to 1.4% of the land area in the mixed-cover watersheds was occupied by active sediment-producing gullies. Earlier studies nearby by Woodburn

Table 3—Average annual runoff and sediment data for the mixed-cover watersheds, 1958-1971.

				Computed Sediment Yield by Source Areas					
Watershed	Drainage Area	Runoff	Measured Sediment Yield	Cultivated Land	Pasture-Idle Land	Forest Land	Gullies	Channels	Total
	(acres)	(inches)	(tons/acre)	tons/acre					
W-4	2,000 [a]	5.41	3.13	1.51	0.20	0.01	1.41	1.19	4.32
W-5	1,130 [b]	11.43	6.70	2.93	.43	.01	2.41	1.25	7.03
W-10	5,530	9.41	6.86	3.48	.39	.02	3.75	1.30	8.94
W-12	22,800	6.53	3.62	2.14	.24	.01	1.58	.86	4.83
W-35	7,550	11.08	7.90	4.27	.48	.02	2.11	2.69	9.57

a Drainage area reduced from 2000 to 1580 acres Jan. 1, 1965.
b Drainage area reduced from 1130 to 1000 acres Oct. 1, 1969.

(12) and Miller, *et al.* (3) showed an average annual gully erosion rate of approximately 300 tons per surface acre of gully. Annual sediment yields from gullies in the mixed-cover watersheds for the 1958-1971 record period were estimated by adjusting this average yield by the same proportion that annual runoff varied from the mean. Symbolically:

$$S_{Gi} = A_{Gi} \overline{S_G} \frac{Q_i}{\overline{Q}} \quad [10]$$

where

S_{Gi} = annual sediment yield from gullies
A_{Gi} = area in gullies
$\overline{S_G}$ = mean annual sediment yield from gullies per unit area
Q_i = annual runoff
$\overline{Q}$ = mean annual runoff

Channel erosion rates in the mixed-cover watersheds were determined from periodic channel surveys (1) (4) (5). Detailed channel cross-section surveys, at 500-foot intervals, of well defined channels showed mean annual channel (bed and bank) erosion rates ranging from 0.9 to 2.7 tons per acre of drainage area. Annual sediment yields from channels (S_{Ci}) were determined by adjusting the average rate for each watershed by the same proportion that annual runoff varied from the mean. Symbolically:

$$S_{Ci} = \overline{S_C} \frac{Q_i}{\overline{Q}} \quad [11]$$

where

$\overline{S_C}$ = mean annual sediment yield from watershed channels.

Computed yields from the various sources; i.e., channels, gullies, cultivated land, pasture-idle land, and forest, were converted to tons per watershed acre and added to obtain total watershed sediment yields. The relationship between computed sediment yields, S_c, and measured sediment, S_m, is shown in Figure 6. At the 95% confidence level, about 80% of variation in sediment yield was explained. The slope of the best fit curve did not differ significantly from one. Furthermore, slopes, computed individually for each of the five watersheds, were not significantly different from one. Intercept values of the five regressions ranged from 0.33 to 1.6 and correlation coefficients from 0.82 to 0.92.

Most of the data points are above the line of equal values. This indicates that all of the sediment did not reach downstream gaging stations. Even though defined channels normally exist below small natural drainage basins, local flooding often occurs and sediment is deposited in small upland valleys and depressions. The proportion of the computed mean annual sediment yield reaching the gaging stations ranged from 72 to 95%.

Sediment yield predictions could be improved by better estimates of erosion from the major sediment sources. For example, erosion on cultivated fields and gullies is influenced by topography, soil type, vegetation, conservation practices, and

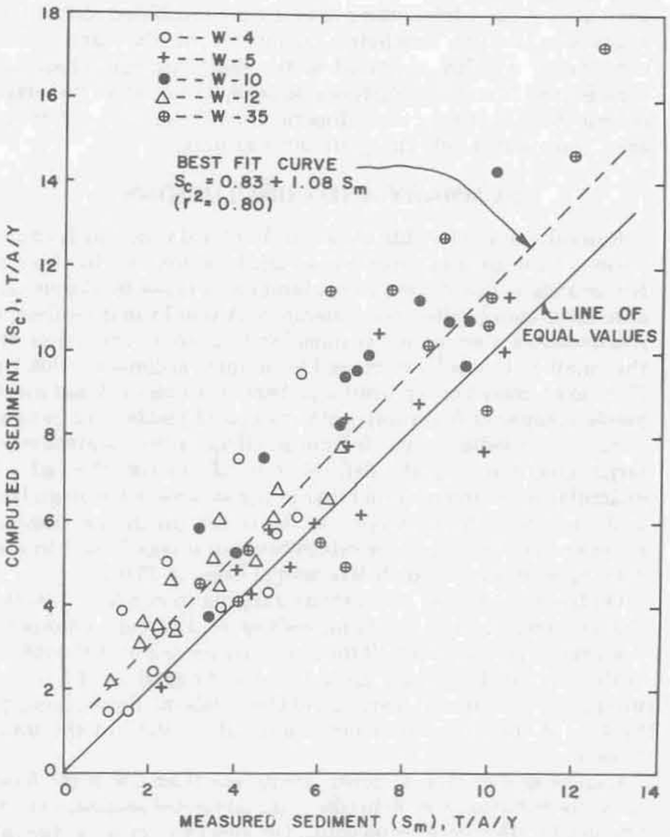

Figure 6. Measured vs. computed sediment for mixed-cover watersheds.

rainfall intensity, but none of these were considered in the present study. Even greater improvement could be obtained by more accurate predictions of runoff volumes from the various land-use categories. Since both runoff volume and sediment concentration from the various sediment sources varied greatly, the accuracy of sediment yield predictions is highly dependent upon the accuracy of runoff estimates from the different source areas.

Equally important is the relative magnitude of the sediment coming from the various sources. Table 3 gives mean annual runoff, measured sediment yield, and computed sediment yield for each sediment source area in the mixed-cover watersheds. Table 4 gives the proportion of sediment contributed and land area represented by each sediment source.

Most of the sediment comes from cultivated land, gullies and channels. These three major sediment sources, comprising less

Table 4—Mean proportion of contributing area and computed sediment yield for the various land use categories, 1948-1971.

	Cultivated Land		Pasture-Idle		Forest		Gullies		Channels	
Watershed	Area	Sediment	Area	Sediment	Area	Sediment	Area	Sediment	Area	Sediment
	----------	----------	----------	----------	Percent of Total	----------	----------	----------		
W-4	18	35	38	5	43	0.2	1	33	1	27
W-5	21	42	47	6	31	.1	1	34	1	18
W-10	22	44	44	4	33	.2	1.4	42	1	15
W-12	19	44	38	5	42	.2	1	33	1	18
W-35	24	45	50	5	25	.2	1	22	1	28

than 25% of the contributing land area, contributed 95% of the sediment. Gullies, occupying about 1% of the land area, contributed roughly one-third of the sediment, and channels contributed 18 to 28%. Pasture-idle land, 38 to 50% of the area, contributed about 5% of the sediment. Forest land, 25 to 43% of the area, contributed only insignificant amounts.

SUMMARY AND CONCLUSIONS

Annual sediment yields from small natural watersheds under various land use and cover types varied widely, ranging from a few pounds per acre from forest land cover types to 43 tons per acre for a small cultivated watershed. Annual runoff-sediment relationships, derived for various land use-cover categories on the small watersheds, were used to compute sediment yields for five large mixed-cover drainage basins. Computed sediment yields compared favorably with measured yields. The results suggest that sediment yields from small unit source watersheds, large enough to support a defined channel, and runoff-weighted estimates of sediment from other major sources, such as gullies and channels, may provide a basis for predicting annual sediment yields from large mixed-cover drainage basins in the hilly uplands of the north Mississippi Coastal Plain.

On five mixed-cover watersheds, ranging in size from 1,000 to 22,000 acres, cultivated land, gullies and stream channels, comprising less than 25% of the land area, contributed about 95% of the computed sediment yield. Pasture-idle land, 38-50% of the total area, contributed about 5% of the sediment. Forest land, 25 to 43% of the area, contributed only about 0.2% of the total sediment.

Gullies and channels, constituting less than 2% of the land area, contributed from 50 to 60% of the computed sediment yield. Obviously, effective erosion control on these two major sediment sources could conceivably reduce watershed sediment yields by one-half. On the other hand, complete erosion control on all pasture and forest land, nearly 75% of the total area, would achieve only insignificant reductions.

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