Sediment Movement in an Area of Suburban Highway Construction, Scott Run Basin, Fairfax County, Virginia, 1961–64

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1591–E

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By R. B. VICE, H. P. GUY, *and* G. E. FERGUSON

HYDROLOGIC EFFECTS OF URBAN GROWTH

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By R. B. Vice, H. P. Guy, and G. E. Ferguson

ABSTRACT

Movement of sediment during a period of intensive highway construction was studied in the Scott Run basin, Fairfax County, Va., from 1961 to 1964. The 4.54-square-mile drainage basin, which empties into the Potomac River about 6 miles above the head of the Potomac Estuary, was the scene of highway construction covering 11 percent of the basin; other types of urban construction in the basin during this time were minor.

Sediment that moved with the flow was measured at the gaging station by a system of representative samples. These samples made it possible to document the sediment yield for 88 storm events representing the overland runoff. Analysis of streamflow and sediment transport during the period showed that (1) the 88 events accounted for 37 percent of the runoff and 99 percent of the sediment movement in 3 percent of the time; (2) the highway construction areas, varying from less than 1 to more than 10 percent of the basin at a given time, contributed 85 percent of the sediment; (3) 38 percent of the sediment movement occurred during April, May, and June, and only 11 percent occurred during July, August, and September; and (4) on the basis of residual soil and stream-sediment particle sizes, the amount of sediment eroded from areas of construction was about twice that transported from the basin.

Precipitation during the study was about 12 percent less than the long-term average. If normal precipitation had prevailed, the estimated gross erosion in the construction area would have been about 20 percent more than actually occurred, giving an average of 151 tons per acre per year, about 76 tons of which would be transported from the basin. This amount is about 10 times that normally expected from cultivated land, 200 times that expected from grassland, and 2,000 times that expected from forest land.

INTRODUCTION

This report shows the extent to which earth materials may be eroded by rainfall and carried by stream systems during a period of disturbance of surface materials common to highway construction. The study was made in a drainage basin of 4.54 square miles in the northwestern part of Fairfax County near McLean, Va., during 1961 to 1964. The basin is drained by Scott Run which empties into the Potomac River 5.9 miles above the head of the Potomac Estuary at Washington, D.C.

The project was inspired by earlier studies (Guy and Ferguson, 1962; Guy, 1964, 1965) of the effects of urbanization on sedimentation in the suburban area of Washington, D.C. These investigations measured the large quantities of earth materials eroded at commercial and residential construction sites and carried by the stream systems during storm events. These studies also described the manner in which sediments of larger sizes were deposited in or below drainage facilities and in reservoirs, as well as the tendency of the finer materials to remain longer in suspension and cause turbidity in downstream water bodies, such as the Potomac Estuary. These studies, and others begun more recently (Wolman, 1964; Dawdy, 1967), provide some insight that may assist public officials and construction organizations in devising practices to minimize the movement of soil materials from construction sites.

The significant and impressive findings about fluvial sediments associated with building sites induced the authors to seek comparable information about sedimentation from highway construction where large areas of land are denuded and great quantities of soil and rock are excavated, transported, and placed. Moreover, new highways and streets occupy a sizable segment of the land under development in suburban areas.

Scott Run basin was chosen for the study site for several reasons.

1. The area under highway construction, constituting about 11 percent of the 4.54-square-mile drainage area, assured a source of streamborne sediments that could be measured effectively and that could be reasonably well identified with the sources. The construction area as it relates to the Scott Run stream system is shown in figure 1.
2. Nonhighway types of construction were expected to be minor during the study period so that most of the expected sediment would come from highway construction. Figure 2 is from an aerial photograph taken in March 1963 showing the extent of the highways and the nature of the land use at that time.
3. The study site was but a few miles from the residences of the authors, permitting them to reach the primary measuring site in time to make vital observations and measurements within the 2 hours or less between the period of concentrated rainfall and the passage of the sediment-laden flood waters past the measurement sites.

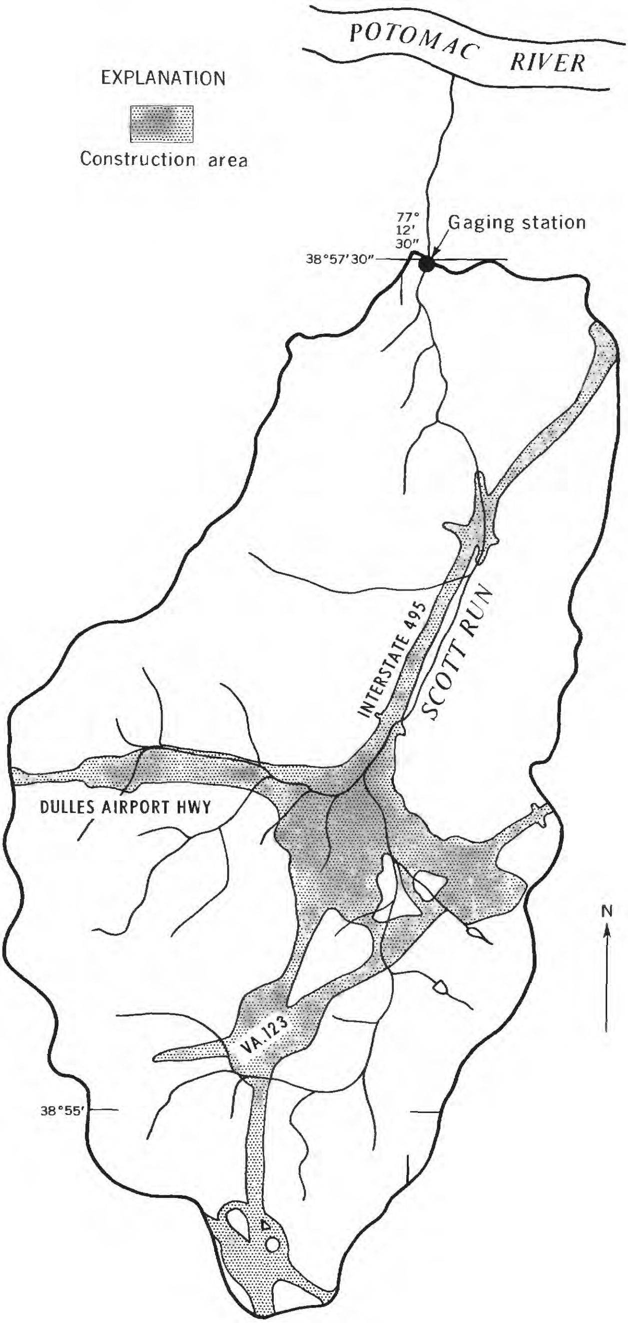

FIGURE 1.—Sketch of Scott Run basin showing the highway construction area and its relation to the stream system.

FIGURE 2.—Aerial photograph of Scott Run basin in March 1963 showing highways and land use.

The report, hopefully, will serve several needs. It should give a measure of the gross sediment erosion and deposition in the basin as well as the amount transported from the basin by the stream system during a period of rapid land-use change. The design and scheduling for construction of drainage features and other improvements along natural and other channels downstream from the highway locations may be influenced by the findings. The report should aid those responsible for highway design and for construction specifications. In illustration, the findings may help determine the promptness with which slopes of fresh cuts and fills should be stabilized by methods already developed.

It should be noted that the amount and deposition patterns of sediment resulting from the highway construction in Scott Run basin during the study period may vary greatly from those to be expected under similar highway programs in other basins or areas. Soil types, topography, basin shapes, proximity of the construction to the drainage system, channel slopes, and other factors that influence sediment movement vary greatly from basin to basin.

Acknowledgments of assistance—The authors are particularly grateful to the following persons and organizations for their valuable assistance and advice, as indicated, in the prosecution of the study and in the preparation of the report.

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BASIN CHARACTERISTICS

Scott Run drainage basin lies in Fairfax County, Va., in the Piedmont physiographic province, about 6 miles northwest of the line separating the Piedmont and Coastal Plain provinces, and about 10 miles west of downtown Washington, D.C. The basin extends from the mouth of Scott Run at the Potomac River, 60 feet above sea level southward about 4.5 miles to its source at Tysons Corner, 530 feet above sea level.

The basin is formed mostly in friable soils derived from deep weathering of schist in the Wissahickon Formation. A small area in the southern part of the basin at Tysons Corner is formed on a remnant of the Bryn Mawr gravel which overlies the Wissahickon Formation.

Drainage to the stream system moves over gentle to moderate slopes associated with broad ridges in the headwaters. The terrain becomes progressively steeper in the downstream direction. The slopes of the stream channels themselves, however, range from more than 0.10 near the headwaters to about 0.015 through midbasin, and to about 0.040 in the lower part of the basin. Figure 3 is a photograph of the channel taken about 50 feet upstream from the gaging stations showing the turbulent nature of the flow during storm runoff in this relatively steep part of the channel. Figure 4 shows two views of the channel in midbasin downstream of Interstate 495.

Summers are warm and humid, and most winters are mild in the study region. Pleasant weather prevails in spring and autumn. Climatological records at the Washington National Airport show that in January and February average low temperatures range from 20°–50° F, whereas in July average daily high temperatures fall in the upper 80's. The average frost-free season occurs between April 10 and October 28.

FIGURE 3.—Upstream view of Scott Run channel about 50 feet upstream of gaging station during storm runoff. Flow is considered sufficiently turbulent to suspend all but gravel-sized particles.

The long-term average precipitation at the Washington National Airport is 40.8 inches and is fairly well distributed through the year, as shown in table 1 and figure 5. In the absence of a complete precipitation record in the basin, the precipitation data for three nearby Weather Bureau stations were assembled in table 1. The Vienna-Dunn Loring station is about 1½ miles southwest of the basin, and the Falls Church station is about 3 miles southeast of the basin. The close agreement between the two stations lends support to the assumption of equivalent precipitation over the Scott Run basin, or an average of 40.4 inches per year for the period of study. The records of these stations are too brief to describe how the period of record differs from the long-term mean.

The Washington National Airport station, 11 miles southeast of the basin, shows consistently less rainfall which here averages 35.7 inches per year for the period. The airport record also shows a deficiency of 5.1 inches per year (about 12 percent) during the period of study when compared with the long-term average. We may assume that the deficiency on Scott Run basin for the period of study is also about 12 percent. An increase of 14 percent of the actual precipitation would have been required to yield normal precipitation for the period.

FIGURE 4.—Two views of Scott Run channel in relatively flat midchannel area taken downstream of Interstate 495. View nearest the bridge shows considerable deposition from the construction area.

TABLE 1.—*Precipitation in vicinity of Scott Run basin, Virginia, May 1961 to September 1964*

Location	Precipitation						
	1961 (8 months) (inches)	1962 (inches)	1963 (inches)	1964 (9 months) (inches)	Period Total (inches)	Period Average (inches per year)	Normal (inches per year)
Falls Church, Va	31. 02	36. 70	42. 32	27. 72	137. 76	40. 2	
Vienna-Dunn Loring, Va	31. 37	37. 06	41. 27	29. 31	139. 01	40. 7	
Washington National Airport	25. 69	33. 07	39. 34	23. 85	121. 95	35. 7	40. 8

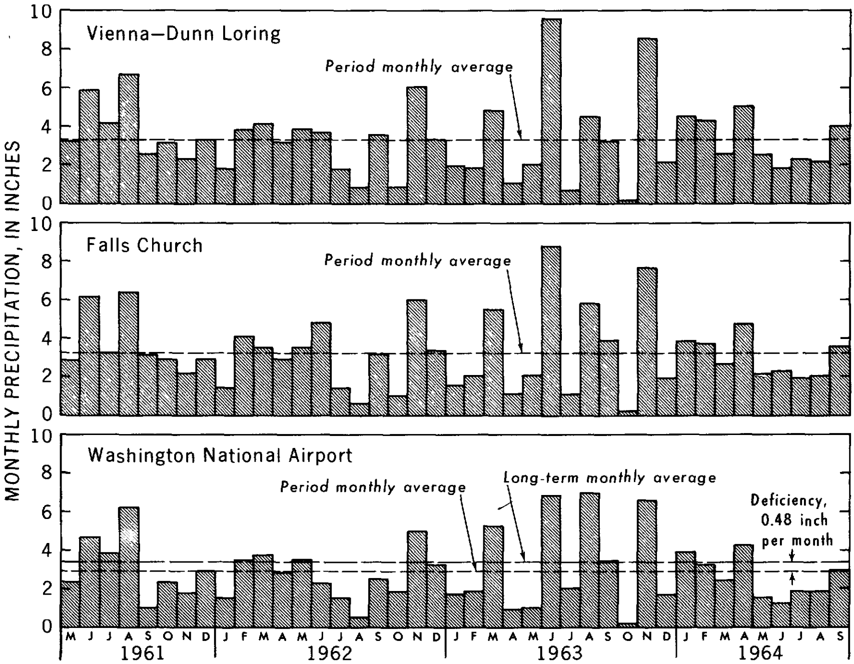

FIGURE 5.—Monthly precipitation in vicinity of Scott Run basin.

LAND USE

For the purpose of evaluating sediment-movement characteristics in the different areas of the basin, land use is classified into three categories:

1. Areas of *low* yield consisting of forest, grass, and established urban areas ranging from 2,390 acres in midsummer 1961 to 2,820 acres in early spring 1964.

2. Areas of *intermediate* yield consisting of cultivated land and a gravel pit, ranging from 210 acres in midsummer 1961 to 40 acres early in 1964.
3. Areas of *high* yield consisting of the exposed and disturbed soils in the construction areas ranging from 310 acres in midsummer 1961 to 40 acres in 1964.

A dominantly rural environment prevailed in Scott Run basin prior to the highway construction. Typical farming operations occurred in two areas in the central and western parts of the basin, on about 25–30 percent of the basin area. These farming operations were such that only a small part of the farmland was used for cultivated crops at any one time. Thus, most of the farming area was in the low-yield category.

The construction of three highways beginning in the fall of 1960 initiated a period of rapid change in land-use patterns in the basin. The observations upon which this report is based were thus started primarily to determine the effect of the land-use changes on erosion and movement of sediment through the stream system.

The nature of changes in land use and the rates of change have been determined by information from several sources. Seven sets of aerial photographs between August 1960 and September 1964 provided much quantitative information. Personnel of the Virginia Department of Highways and of the Federal Aviation Agency supplied dates and other pertinent information about the schedules for highway construction. Periodic basin reconnaissance by the authors together with statements by residents in the basin yielded supporting information. The data on land-use patterns given in table 2 were drawn from this information and from reasonable assumptions and interpolations. The more important changes in land use are discussed briefly in the following paragraphs.

FOREST AND GRASS

Forests and trees covered about 50 percent of the basin in 1960 and 43 percent by December 1964. Unlike the area occupied by grass which may fluctuate in size, the forest is doomed to persistent reduction as development proceeds. Most of the forest is approximately in its natural state. However, some low-density residential land with many trees is grouped with the forest land.

The major part of the farmland is under grass cover and is used for hay and grazing. These areas plus the grassy areas associated with low-density residential areas and areas of highway right-of-way on which sod cover is developed are included under grasslands. Paved areas of the highways and interchanges were included under grass-

TABLE 2.—*Land use in Scott Run basin, 1961–64*

Time	Low-yield area					Intermediate-yield area		High-yield area			
	Forest (acres)	Grass (acres)	Established urban (acres)	Total		Cultivated and quarry		Highway construction		Other construction	
				(acres)	(percent)	(acres)	(percent)	(acres)	(percent)	(acres)	(percent)
1961											
April	1, 320	920	290	2, 530	87. 0	130	4. 4	250	8. 6		
July	1, 280	820	290	2, 390	82. 2	210	7. 2	310	10. 6		
October	1, 270	910	290	2, 470	84. 9	140	4. 8	300	10. 3		
1962											
January	1, 270	970	290	2, 530	87. 0	70	2. 4	310	10. 6		
April	1, 270	935	290	2, 495	85. 8	110	3. 7	300	10. 3	5	0. 2
July	1, 270	915	290	2, 475	85. 1	150	5. 1	270	9. 3	15	. 5
October	1, 270	995	290	2, 555	87. 9	110	3. 8	230	7. 8	15	. 5
1963											
January	1, 270	1, 140	290	2, 700	92. 8	50	1. 7	140	4. 8	20	. 7
April	1, 270	1, 170	290	2, 730	93. 9	70	2. 4	85	2. 9	25	. 8
July	1, 270	1, 175	290	2, 735	94. 0	70	2. 4	70	2. 4	35	1. 2
October	1, 270	1, 190	310	2, 770	95. 2	70	2. 4	35	1. 2	35	1. 2
1964											
January	1, 270	1, 230	310	2, 810	96. 6	40	1. 4	35	1. 2	25	. 8
April	1, 260	1, 230	330	2, 820	96. 9	50	1. 7	10	. 3	30	1. 0
July	1, 260	1, 205	340	2, 805	96. 5	50	1. 7	10	. 3	45	1. 5
Average	1, 272	1, 057	299	2, 630		94		168		18	

lands as most runoff from these surfaces flow over adjacent grass covered surfaces.

Established residential and industrial areas occupied 10 percent of the basin along the eastern and southern boundaries in January 1961 and increased to 12 percent by October 1964 through the addition of finished units of residential and industrial construction. They are considered as low yield because most of the drainage surface is protected by pavement, roof, or sod.

CULTIVATION

Normal farming operations were pursued on about 800 acres of the basin in 1960 and prior years. The initiation of highway construction and ensuing potential for residential and industrial development caused a steady decline in cropland from 1961 to 1965.

The seasonal fluctuations from summer cultivated land to winter fallow and cover crops are not clearly evident from the photographs. However, reasonable approximations of the varying area of cultivated or unprotected land were developed from the photographs as shown in table 2.

An area of 30 acres in the southwestern part of the basin was used intermittently as a source of gravel. The area was constant in size and unprotected by vegetation for the entire period of the study. Because its sediment contribution is likely similar to other cultivated land, it has been so grouped in table 2 and subsequent analyses.

CONSTRUCTION

Three dual highways, including five interchanges, were constructed across the basin during the period 1960–62 (see figs. 1, 2). Active construction was underway on 32 acres in January 1961, reached a peak in the winter period 1961–62, and terminated for the most part in the fall of 1962. An additional small length of highway was built in 1964. Residual erosion effects of highway construction diminished rapidly in the fall of 1962 and spring of 1963, but they persisted with some effect until the end of the record in September 1964.

INTERSTATE HIGHWAY 495

The Virginia Department of Highways supervised the construction of 3.5 miles of Interstate 495 which runs north-south approximately along the major axis of the basin. Interchanges occur with State Highway 193, the Dulles Airport Highway, State Highway 123, and State Highway 7. Construction, underway on 32 acres in January 1961, expanded rapidly in the spring of 1961 and was practically completed by the fall of 1962. Final grading and seeding began in August 1962 and was completed in a few weeks.

The transition from freshly graded surfaces to protective sod cover is not well defined. It was assumed that average erodibilitiy diminished by 50 percent on the application of seed, mulch, and binder and continued to diminish to 80 percent as the grass germinated and grew to form sod cover over most of the area by May 1963. Repair of gullies and thin grass areas, together with natural seeding, continued to reduce erodibility to the level of complete grass cover by May 1964. These assumptions were supported by visual observations and the pattern of sediment transport from the basin.

DULLES AIRPORT HIGHWAY

The Federal Aviation Agency supervised the construction of 1.8 miles of a four-lane divided highway approximately along the east-west minor axis of the basin. The reach included interchanges with Interstate 495 and State Highway 123. Large-scale grading was started about March 1, 1961, and was completed by early October 1961. Final grading and seeding of about one-half of the contract area, not affected by continuing work about the two interchanges, was completed in October 1961. The transition of the seeded areas to sod cover was assumed to occur in the manner described for Interstate 495.

STATE HIGHWAY 123

The Virginia Department of Highways supervised the construction of 1.5 miles of a four-lane divided highway that trends northeast-southwest across the southern part of the basin. The reach includes the above-described interchanges with Interstate 495 and the Airport Highway. Construction and seeding occurred concurrently with the work on Interstate 495.

An additional 0.36 mile of this highway, reaching to the southwest boundary of the basin, was started and completed in the period from March to October 1964.

OTHER CONSTRUCTION

The conversion of 175 acres of farmland and woodland into McLean Hamlet residential subdivision began in late spring of 1964 and had affected about 40 acres by December 1964. The conversion of 33 acres of forest and meadow into the Dolly Madison-West Apartments likewise began in the spring of 1964 and included 19 acres by December 1964.

Three industrial areas, eventually affecting some 110 acres, and located near, or adjacent to, the intersection of State Highway 123 and

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Interstate 495, began construction in April 1962. The area of active construction grew to about 32 acres in 1963 and diminished to about 12 acres in December 1964. During the interval, 45 acres passed through the construction cycle to a completed state of buildings, pavement, and grass areas.

RUNOFF

Storm runoff from Scott Run basin was measured at the gaging station at State Highway 193 about 0.6 mile upstream from the Potomac River. Water discharge was defined by a continuous recording of stage when flow was greater than 20 cfs (cubic feet per second). It is convenient, then, to approximate direct storm runoff as the summation of flows occurring during intervals when the flow exceeded 20 cfs. Periodic streamflow measurements defined a stage-discharge relationship from which the direct runoff for the 88 storm events during the period of study was computed. The duration, mean rate, and volume of each runoff event are given in table 3. The aggregate storm runoff from May 1961 through September 1964 amounted to 1,735 cfs-days, or 14.2 inches, and averaged 4.16 inches per year.

The lack of a stage record for periods when flow was less than 20 cfs prevented the direct computation of total runoff from the basin. However, flow records for Difficult Run (an adjacent basin to the west), and Little Falls Branch (a near basin to the north) show total runoff for the period May 1961 through September 1964 of 37.7 and 39.1 inches, respectively. The average of these amounts (38.4 in.) is taken as a close approximation of the runoff of Scott Run basin. Thus, flow greater than 20 cfs prevailed for 3 percent of the time (39.1 days) and accounted for 37 percent of the runoff. Low flow, less than 20 cfs, prevailed for 97 percent of the time and accounted for 63 percent of the runoff.

The mean rate of storm runoff for the 88 storms ranged from 13 to 195 cfs and averaged 44 cfs. The rates of runoff for only 36 percent of the storm events (30 storms) exceeded the average rate. Table 4 shows the distribution of storms, in terms of average rate of storm runoff, by both size and season. It should be noted that very small storms in which the peak flow was less than 20 cfs were not counted. Table 4 shows that 67 percent of the storms occurred in the January–June period, whereas the large storms (greater than 80 cfs) were evenly distributed throughout the year.

TABLE 3.—*Summary of water discharge, sediment yield, and related variables by storm events for Scott Run near McLean, Va.*

Date	Storm measurement No.	Storm runoff: Duration (days)	Storm runoff: Mean rate (cfs)	Storm runoff: Volume (cfs-days)	Construction area (acres)	Seasonal adjustment factor	Sediment-transport: Rate (tons per day per acre of construction) 1	Sediment-transport: Rate (tons per day per acre of construction) 2	Sediment-transport: Amount (tons)	Accumulated: Water (cfs-days)	Accumulated: Sediment (tons)
1961											
5–12	1	0. 58	57. 8	33. 6	250	0. 82	8. 4	6. 9	995	33. 6	995
6–8		. 17	28. 2	4. 8		1. 23	2. 9	3. 6	150	38. 4	1, 145
6–9		. 21	34. 8	7. 3		1. 22	3. 9	4. 8	250	45. 7	1, 395
6–10	2	. 21	195	41. 0		1. 23	52. 0	64. 6	3, 390	86. 7	4, 785
6–25		. 125	19. 2	2. 4		1. 16	1. 6	1. 9	59	89. 1	4, 844
Total		1. 30		89. 1					4, 844		
7–13		. 29	105	30. 6	310	1. 07	21. 0	22. 4	2, 040	119. 7	6, 884
8–26	3	. 31	183	56. 7		. 65	47. 5	30. 7	2, 950	176. 4	9, 834
9–4		. 31	53. 8	16. 7		. 84	7. 6	6. 4	610	193. 1	10, 444
Total		. 91		104. 0					5, 600		
10–21	4	. 42	64. 8	27. 2	300	. 96	10. 0	9. 6	1, 210	220. 3	11, 654
11–23		. 50	25. 0	12. 5		. 60	2. 3	1. 4	210	232. 8	11, 864
12–12	5	. 42	40. 0	16. 8		. 67	4. 8	3. 2	402	249. 6	12, 266
12–17		. 29	16. 2	4. 7		. 60	1. 2	. 7	61	254. 3	12, 327
12–18		. 65	35. 4	23. 0		. 60	4. 0	2. 4	470	277. 3	12, 797
Total		2. 28		84. 2					2, 353		

TABLE 3.—*Summary of water discharge, sediment yield, and related variables by storm events for Scott Run near McLean, Va.*—Continued

Date	Storm measurement No.	Storm runoff: Duration (days)	Storm runoff: Mean rate (cfs)	Storm runoff: Volume (cfs-days)	Construction area (acres)	Seasonal adjustment factor	Sediment-transport: Rate (tons per day per acre of construction) 1	Sediment-transport: Rate (tons per day per acre of construction) 2	Sediment-transport: Amount (tons)	Accumulated: Water (cfs-days)	Accumulated: Sediment (tons)
1962											
1-6		0.90	27.6	24.8		0.60	2.7	1.6	450	302.1	13,247
1-15		.21	58.6	12.3		.60	8.7	5.2	340	314.4	13,587
2-19		.29	45.9	13.3		.60	5.9	3.4	310	327.7	13,897
2-19		.15	18.6	2.8	310	.60	1.5	.9	42	330.5	13,939
2-26	6	.48	60.7	29.1		.64	9.0	5.8	865	359.6	14,804
2-27		.52	27.3	14.2		.60	2.7	1.6	260	373.8	15,064
3-12	7	.79	56.1	44.4		.44	8.0	3.5	858	418.2	15,922
3-21		.56	26.3	14.7		.64	2.6	1.7	300	432.9	16,222
Total		3.90		155.6					3,425		
4-1		.71	26.2	18.6		.72	2.6	1.9	410	451.5	16,632
4-12		.44	18.4	8.1		1.21	1.5	1.8	240	459.6	16,872
4-13		.19	17.8	3.4		1.23	1.4	1.7	98	463.0	16,970
5-1		.42	122	51.1		1.39	26.0	36.1	4,630	514.1	21,600
5-24		.35	13.4	4.7	305	1.30	.9	1.2	130	518.8	21,730
5-24		.19	18.4	3.5		1.30	1.5	2.0	120	522.3	21,850
5-26		.35	79.0	27.6		1.29	13.2	17.0	1,810	549.9	23,660
5-31	8	.19	21.1	4.0		2.28	1.8	4.1	236	553.9	23,896
6-19		.125	15.2	1.9		1.18	1.1	1.3	50	555.8	23,946
6-20	9	.52	30.0	15.6		1.10	3.1	3.4	536	571.4	24,482
Total		3.49		138.5					8,260		
9-27	10	.23	13.5	3.1	285	.67	.9	.6	39	574.5	24,521

Total		.23		3.1					39	
11-2		.33	23.3	7.7	245	.62	2.1	1.3	100	582.2	24,621
11-10	11	.54	126	68.1		.58	23.0	13.3	1,770	650.3	26,391
11-18		.31	24.5	7.6		.60	2.3	1.4	110	657.9	26,501
11-21	12	.79	47.7	37.7		.32	6.2	2.0	390	695.6	26,891
12-6		.58	26.9	15.6		.60	2.6	1.8	260	711.2	27,151
Total		2.55		136.7					2,630		
1963											
1-11		.33	25.1	8.3	160	.60	2.4	1.4	74	719.5	27,225
1-12		.71	33.8	24.0		.60	3.7	2.2	250	743.5	27,475
1-13		.42	26.0	10.9		.60	2.5	1.5	100	754.4	27,575
1-19		.25	14.4	3.6		.60	1.0	.6	24	758.0	27,599
2-5		.21	19.5	4.1		.60	1.6	1.0	34	762.1	27,633
2-6		.17	16.5	2.8		.60	1.3	.8	22	764.9	27,655
2-22		.42	52.2	21.9		.60	7.3	4.4	300	786.8	27,955
3-6		.29	89.0	25.8		.97	16.0	9.6	450	812.6	28,405
3-6	13	.46	50.0	22.9		.60	6.6	6.4	469	835.5	28,874
3-12	14	1.00	78.9	78.9	160	.60	13.3	8.0	1,280	912.2	30,154
3-16		.79	19.8	15.6		.62	1.7	1.1	140	930.0	30,294
3-19	15	.83	42.2	35.3		.40	5.3	2.1	283	965.3	30,577
Total		5.88		254.1					3,426		
4-30		.21	27.6	5.8	110	1.40	2.7	3.8	88	971.1	30,665
6-3	16	.79	62.9	49.8		.84	9.3	7.8	683	1,020.9	31,348
6-7		.25	40.4	10.1		1.23	4.9	6.0	160	1,031.0	31,508
6-20	17	.21	50.5	10.6		1.09	6.8	7.4	171	1,041.6	31,689
6-30	18	.38	101	38.1		1.70	19.1	32.5	1,360	1,079.7	33,039
Total		1.84		114.4					2,462		

TABLE 3.—*Summary of water discharge, sediment yield, and related variables by storm events for Scott Run near McLean, Va.*—Continued

Date	Storm measurement No.	Storm runoff: Duration (days)	Storm runoff: Mean rate (cfs)	Storm runoff: Volume (cfs-days)	Construction area (acres)	Seasonal adjustment factor	Sediment-transport: Rate (tons per day per acre of construction) 1	Sediment-transport: Rate (tons per day per acre of construction) 2	Sediment-transport: Amount (tons)	Accumulated: Water (cfs-days)	Accumulated: Sediment (tons)
1961											
8-19		0. 29	18. 3	5. 3	105	0. 90	1. 5	1. 4	43	1, 085. 0	33, 082
8-20	19	. 25	64. 0	16. 0		1. 08	9. 8	10. 6	279	1, 101. 0	33, 361
9-29		. 38	46. 9	17. 8		. 72	6. 1	4. 4	180	1, 118. 8	33, 541
Total		. 92		39. 1					502		
11-1		. 42	13. 8	5. 8	70	. 63	1. 0	. 6	18	1, 124. 6	33, 559
11-6	20	. 96	89. 6	86. 0		. 70	16. 1	11. 2	751	1, 210. 6	34, 310
11-23		. 29	32. 2	9. 0		. 60	3. 5	2. 1	43	1, 219. 6	34, 353
11-29	21	. 25	78. 8	19. 7		. 28	13. 2	3. 7	65	1, 239. 3	34, 418
11-29		. 79	71. 1	56. 2		. 60	11. 3	6. 8	380	1, 295. 5	34, 798
12-8		. 38	29. 2	11. 1		. 60	3. 0	1. 8	48	1, 306. 6	34, 846
Total		3. 09		187. 8					1, 305		
1964											
1-1		. 71	31. 0	22. 0	60	. 60	3. 2	1. 9	81	1, 328. 6	34, 927
1-3	22	. 50	55. 8	27. 9		. 84	8. 0	6. 7	202	1, 356. 5	35, 129
1-7		1. 00	20. 9	20. 9		. 60	1. 8	1. 1	66	1, 377. 4	35, 195
1-9		. 92	63. 7	63. 7		. 60	11. 0	6. 6	360	1, 441. 1	35, 555
1-20		. 92	35. 6	35. 6		. 60	4. 6	2. 8	150	1, 476. 7	35, 705
1-21		. 50	11. 8	11. 8		. 60	2. 1	1. 3	39	1, 488. 5	35, 744

1-25		.88	27.5	24.2		.60	2.7	1.6	85	1,512.7	35,829
2-6	23	.75	47.2	35.4	60	.56	6.1	3.4	154	1,548.1	35,983
3-14		.38	15.5	5.9		.61	1.2	.7	16	1,554.0	35,999
3-22		.58	28.8	16.7		.64	2.9	1.9	66	1,570.7	36,065
Total		7.14		264.1					1,219		
4-2		.62	24.2	15.0		.80	2.2	1.8	45	1,585.7	36,110
4-7		.67	22.1	14.8		1.02	2.0	2.0	54	1,600.5	36,164
4-8		.83	36.3	30.1		1.04	4.2	4.4	150	1,630.6	36,314
4-19	24	.40	25.5	10.1		1.21	2.4	2.9	47	1,640.7	36,361
4-20		.31	29.1	9.0	40	1.38	3.0	4.1	51	1,649.7	36,412
4-30	25	.77	44.0	33.9		1.54	5.6	8.6	265	1,683.6	36,677
5-13	26	.38	39.7	15.1		1.96	4.8	9.4	143	1,698.7	36,820
5-17		.17	21.2	3.6		1.32	1.9	2.5	17	1,702.3	36,837
6-20		.17	20.6	3.5		1.17	1.8	2.1	14	1,705.8	36,851
Total		4.32		135.1					786		
7-8		.125	16.8	2.1		1.09	1.3	1.4	10	1,707.9	36,861
8-3	27	.17	22.4	3.8		1.10	2.0	2.2	20	1,711.7	36,881
8-30	28	.17	30.0	5.1	55	.90	3.1	2.8	26	1,716.8	36,907
9-19		.25	20.4	5.1		.76	1.8	1.4	19	1,721.9	36,926
9-29		.21	29.5	6.2		.72	3.0	2.2	25	1,728.1	36,951
9-30	29	.23	28.4	6.5		.66	2.9	1.9	24	1,734.6	36,975
Total		1.16		28.8					124		
Grand total		39.1		1,734.6					36,975		

1. Transport rate from regression curve of figure 7 in tons per day per acre of construction.

2. Transport rate as measured or adjusted for seasonal effect in tons per day per acre of construction.

TABLE 4.—*Distribution of storm-runoff events by rate of runoff and season, Scott Run basin, 1961–64*

Quarter	Average rate of storm runoff (cubic feet per second)					Total
	10–20	21–40	41–80	81–140	141–200	
January–March	7	11	11	1	------	30
April–June	6	15	5	2	1	29
July–September	4	4	3	1	1	13
October–December	2	8	4	2	------	16
Total	19	38	23	6	2	88

SEDIMENT TRANSPORT

Sediment transport past the gaging station at Highway 193 was computed in the customary manner for 29 of the storm events on the basis of sediment concentrations derived from suspended-sediment samples. Methods for the indirect computation of sediment discharge for the remaining 59 storm events and of accounting for other small amounts of sediment transport were devised. An allocation of the total amount of sediment to the several areas of origin then allowed a determination of the amount derived from highway construction.

SEDIMENT MEASUREMENTS

The concentration of suspended sediment during 29 storm events was determined by collecting representative samples of the flow. These samples were obtained from the highway bridge at the gage using the U.S. DH–59 sampler equipped with a three-sixteenth-inch nozzle. (U.S. Inter-Agency Comm. on Water Resources, 1963). An assembly of single-stage sample containers mounted with a vertical spacing of 6 inches was installed in 1962 to obtain samples on the rising phase of moderate to large runoff events. As with water flow, it was not feasible to measure the sediment content for every storm event. However, the measurements obtained are considered adequate to define sediment concentration in the stream section and the variations of concentration with time.

A graph showing the variation of concentration with time during each measured storm event was obtained by plotting the measured concentrations on a print of the gage-height chart and sketching the probable concentration trace through these points. Figure 6 is an example of such a concentration graph for a storm event on November 10, 1962. Table 5 shows a breakdown of this storm hydrograph and sediment concentration graph into 1- and 2-hour increments of mean gage height, mean water discharge, mean concentration, and sediment transported for each time interval. The mean rate and amount of sediment discharged by the 29 measured storm events were determined in this way and are given in table 3.

A relationship between suspended-sediment transport and the principal controlling factors, as defined by the 29 measured storm events, offered a method of computing the suspended-sediment discharge of the 59 unmeasured storm sevents. Simple graphic multiple-regression techniques were judged suitable for defining the relationships.

Experience and preliminary evaluation of the data showed that the quantity and mean rate of storm runoff, the area of disturbed soil and seasonal variations in erodibility, are the more important factors that influence the amount of sediment transported by storm runoff. Accordingly, a correlation of the mean flow and the mean sediment discharge for the 29 measured storm events (table 3) was developed as shown by figure 7.

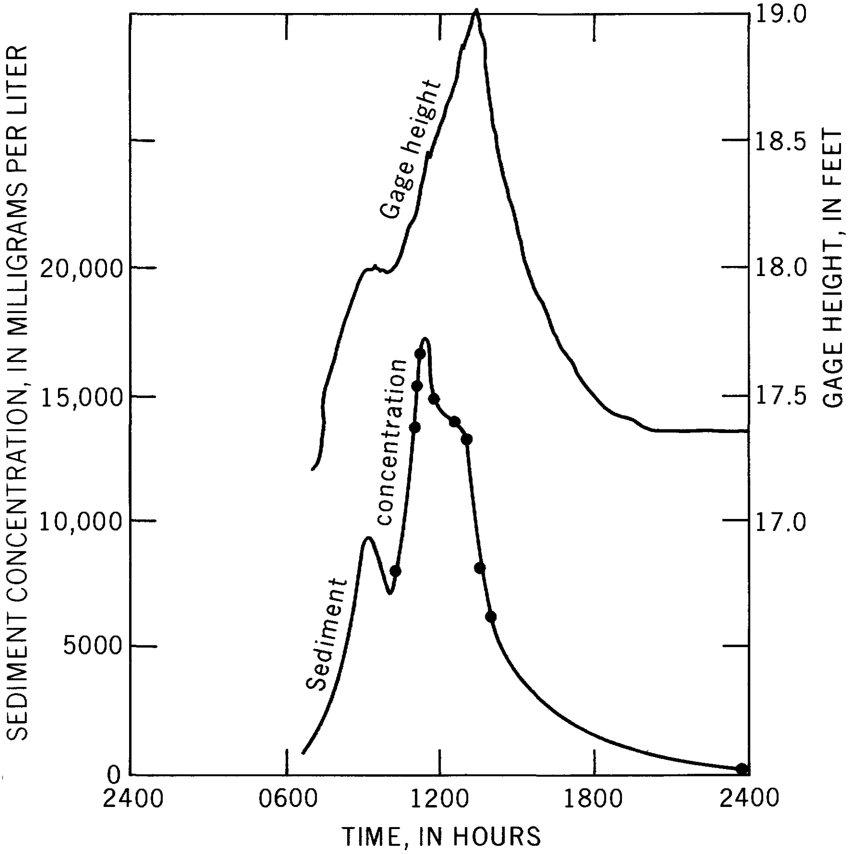

FIGURE 6.—Variation in sediment concentration and stream stage for a typical storm-runoff period.

TABLE 5.—*Increments of water and sediment concentration for storm runoff on November 10, 1962*

Time at beginning of increment	Increment duration (t) (hours)	Gage height (feet)	Mean stream discharge (q_w) (cfs)	Mean sediment concentration (C) (mg/l)	Sediment transported (q_s)[1] (tons)
0700	1	17.44	17.7	2,200	4
0800	1	17.84	61.4	6,000	41
0900	2	18.03	101	9,200	207
1100	1	18.39	209	15,700	369
1200	1	18.73	329	14,100	522
1300	1	18.90	398	10,200	456
1400	1	18.39	209	4,900	115
1500	1	18.01	95.9	2,900	31
1600	1	17.76	48.8	2,100	12
1700	1	17.59	29.0	1,700	6
1800	2	17.44	17.7	1,000	4
Total or mean	13	----------	[2] 68.1	[3] 6,170 [4] 9,630	1,767

[1] $q_s = q_w Ckt$ (k, a conversion factor, $=0.0001125$).
[2] Volume of storm runoff, cubic feet per second-days.
[3] Mean sediment concentration, time weighted.
[4] Mean sediment concentration, flow weighted.

The mean flow rates for water and sediment for each storm event, rather than the total quantities, were related because this relationship takes into account the different erosion capabilities of high- and low-intensity storms. Further, the relationship is dimensionally similar to, and compatible with, conventional water-sediment transport curves.

Preliminary analyses showed that nearly all the sediment was derived from construction areas. Accordingly, the correlation of figure 7 was simplified by expressing the mean storm-event sediment discharge in units of tons per day per acre of construction area. It would have been prefereable to relate water runoff per acre of construction area with sediment discharge per acre of construction area, but inability to determine the distribution of runoff between the several parts of the basin barred the approach. Thus, the entire basin runoff is taken as an approximate index of the runoff per acre of construction area. The regression defined by the curve of figure 7 has a standard error of 43 percent and can be expressed as:

$$Y = 0.019X^{1.5},$$

where

Y = the mean storm-event sediment-transport rate in tons per day per acre of construction, and

X = mean storm-event flow in cubic feet per second.

The pattern of deviations from the regression line of figure 7 suggests a consistent and significant seasonal variation in sediment transport. The sediment discharge rate for a storm in the spring was about double that of a like storm in the fall and winter. The deviations of the 29 measured storm events from the regression line of figure 7, expressed as a ratio of the measured yields and the average yield at the regression line, were plotted against the time of the year in figure 8.

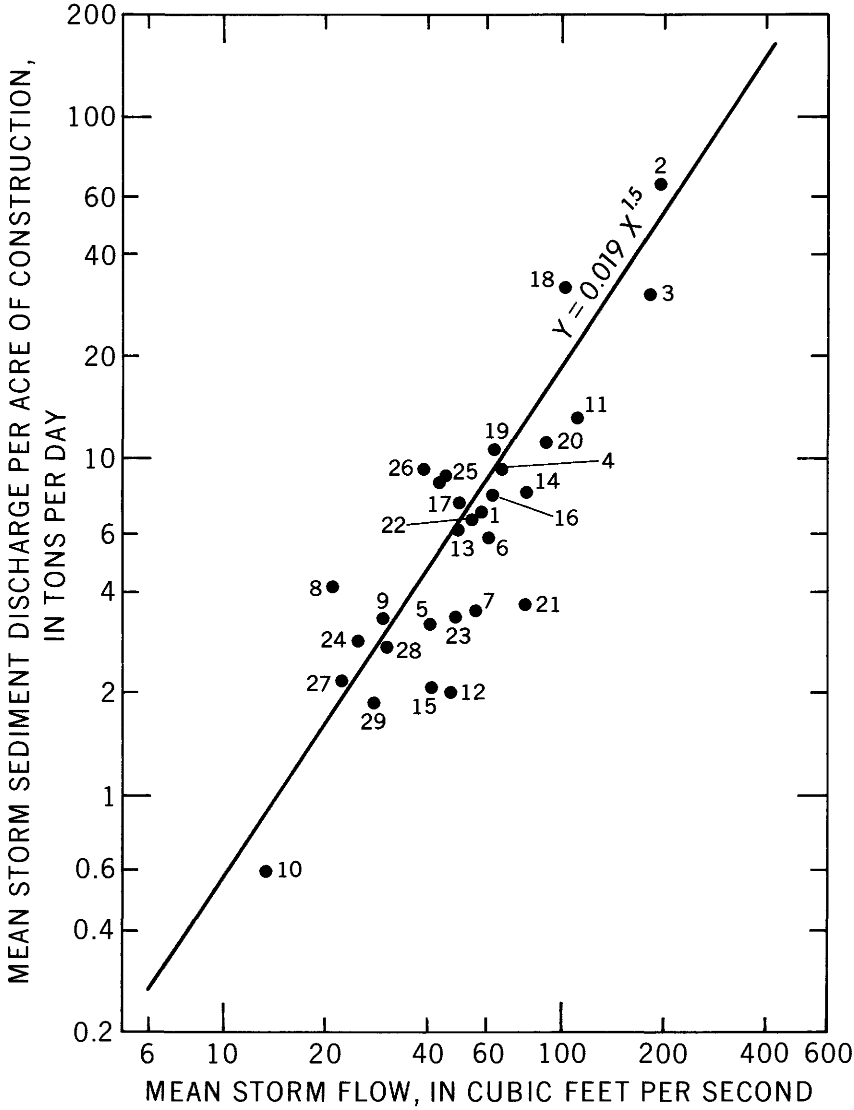

FIGURE 7.—Relation between runoff and sediment discharge for storm events in Scott Run basin.

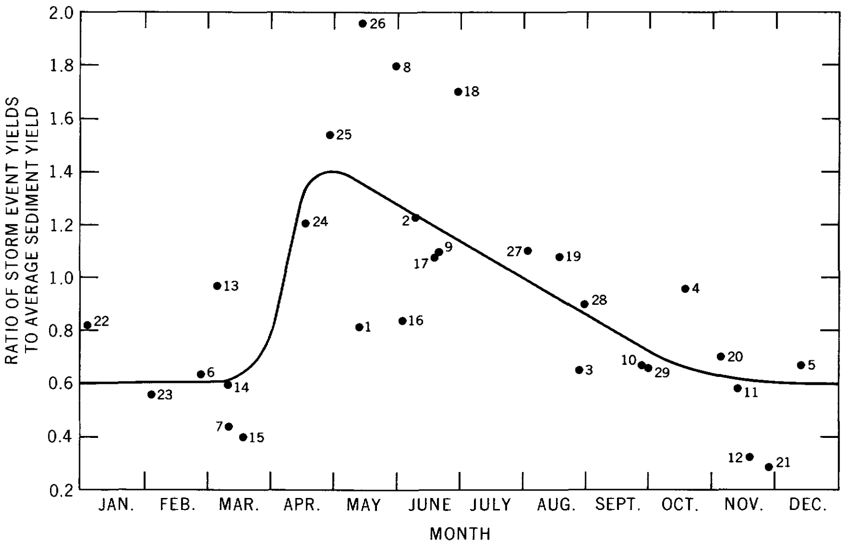

FIGURE 8.—Adjustment factor for seasonal variations in erodibility.

Figure 8 shows a definite, abrupt change from minimum to maximum erodibility during early April. Guy (1964) and others have found a similar and typical rise in erodibility in many basins of Eastern United States. Perhaps the freeze and thaw cycles of winter and early spring lowers the resistance to erosion of the soil mantle and accounts for much of the trend. The physical disturbance of the soil by cultivation in rural areas and by acceleration of construction activity also contributes to the trend.

Adjustment for seasonal variations in erodibility lowers the standard error of the regression of figure 7 to about 26 percent. The part of the exposed construction area over which earth moving and other construction activity was in progress fluctuated widely from time to time. This variety and other undefined factors account for the remaining scatter in figure 8.

Sediment discharge, in tons, for the 59 unmeasured storm events was computed in table 3 from the equation:

$$Q_s = Y\ T\ A\ E;$$

where

Y=mean storm-event sediment-transport rate in tons per day per acre of construction, from figure 7, corresponding to the measured mean storm flow (cfs) from table 3;

T=duration of storm runoff in days;

A=area of construction in acres; and

E=mean seasonal erodibility factor from figure 8.

The accumulated 36,975 tons (table 3) of suspended sediment thus computed to have been transported from the basin by the 88 storm events accounts for most, but not all, of the basin yield.

UNACCOUNTED SEDIMENT

The suspended-sediment discharge computed in table 3 does not account for some sediment moving mostly on and near the bed during storm runoff or for sediment moving with low flows (less than 20 cfs) between storm events.

The typically turbulent flow in Scott Run at the measuring station is evident in figure 3. The turbulent flow assures that most of the transported sediment will move in suspension with the concentration fairly even throughout the cross section of flow; thus, the sediment discharge computed with the sample data will closely approximate the total sediment discharge. Application of the method of Colby (1964) shows that the unmeasured sediment load is unlikely to be more than 5 percent of the computed suspended load. The unmeasured loads are estimated in table 6 as 5 percent of the measured loads, and total 1,850 tons during the period of study. The turbulent flow patterns kept fine material in suspension and thus assured that sand grains and coarser particles made up most of the unmeasured load.

It has been noted in Scott Run that flows of less than 20 cfs prevailed 97 percent of the time and accounted for 63 percent of the runoff (24.2 in.) during the period of study. Numerous observations showed that the sediment concentration during such low flows was less than 100 ppm (parts per million) most of the time; a mean concentration of 50 ppm for low flows is assumed and gives a sediment discharge of about 315 tons for the 1961–64 period. This quantity of sediment has been distributed to the 3-month periods in table 6 in proportion to the storm flow of the periods. The tranquil nature of low flows suggests that clay particles made up most of this load.

The total computed sediment yield of the basin during the 42-month period (39,140 tons) is shown in table 6 by 3-month periods. It is the sum of the computed suspended load during storm discharges (col. 3), the probable additional bedload during storm flow (col. 4), and the probable sediment discharge during low-flow periods (col. 5).

VARIATIONS AND TRENDS

The local impact of highway construction on the runoff of Scott Run was displayed most vividly in the color and sediment concentration of the flood flows. The reddish color of the flows deepened as construction increased, through 1961 to the summer of 1962, and then diminished through 1964. This trend is displayed in figure 9 by the

TABLE 6.—*Sediment yield, in tons, by quarters from different land-use areas in Scott Run basin*

Year and quarter	Storm runoff (cfs-days)	Amount of sediment discharge (tons): Storm runoff 1	Storm runoff 2	Low flow	Total	Low-yield area: Forest	Low-yield area: Grass and urban	Intermediate-yield area	High-yield area: Highway construction	High-yield area: Other construction
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1961										
2	89. 1	4, 844	240	15	5, 100	5	60	180	4, 850	----------
3	104. 0	5, 600	280	20	5, 900	10	70	265	5, 550	----------
4	84. 2	2, 353	120	15	2, 490	5	55	95	2, 340	----------
1962										
1	155. 6	3, 425	170	30	3, 620	10	110	85	3, 420	----------
2	138. 5	8, 260	410	25	8, 700	10	95	265	8, 190	140
3	3. 1	39	0	0	40	0	0	5	40	----------
4	136. 7	2, 630	130	25	2, 780	10	85	115	2, 410	160
1963										
1	254. 1	3, 426	170	45	3, 640	20	170	100	2, 930	420
2	114. 4	2, 462	120	20	2, 600	10	75	140	1, 840	540
3	39. 1	502	30	5	540	5	25	30	320	160
4	187. 8	1, 305	70	35	1, 410	15	125	105	580	580
1964										
1	264. 1	1, 219	60	50	1, 330	20	180	85	670	370
2	135. 1	786	40	25	850	10	90	115	160	480
3	28. 8	124	10	5	140	0	20	15	20	80
Total	1, 734. 6	36, 975	1, 850	315	39, 140	130	1, 160	1, 600	33, 320	2, 930

[1] Computed suspended-sediment discharge from table 3.
[2] Estimated additional sediment discharge moving on and near the bed.

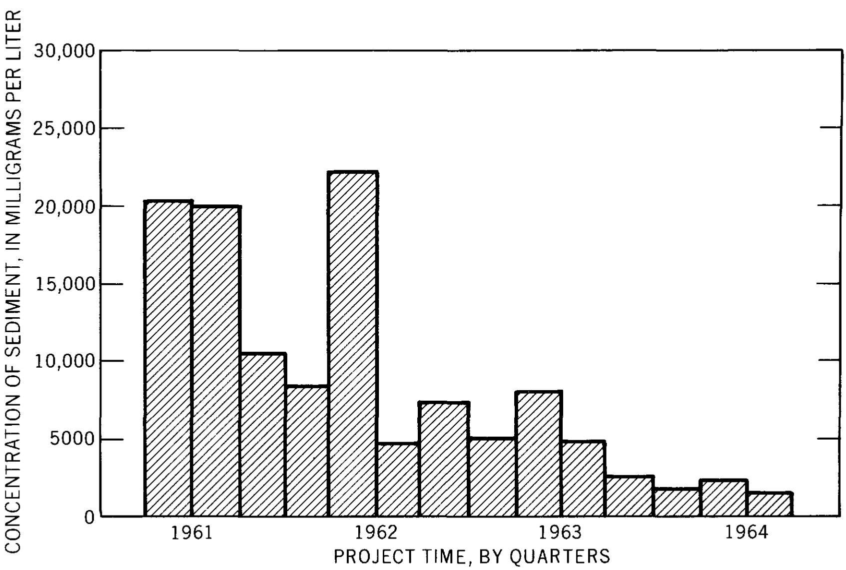

FIGURE 9.—Variations in mean concentrations of sediment for storm runoff, 1961–64.

90-day mean concentration during flood runoff events, 1961–64. Figure 10 displays the same trend toward diminishing concentration with time in the accumulative plot of water and sediment runoff. The slope of such a water-sediment accumulation curve is indicative of the mean concentration of sediment flow. The concentration ranged from more than 20,000 mg/l (milligrams per liter) in the early months of construction to about 2,000 mg/l in 1964.

SEDIMENT SOURCES

There is need to determine how much of the total sediment yield given in table 6 (col. 6) was derived from the low-yield forest and grass areas and the intermediate-yield cultivated and quarry areas; the remainder is a measure of the yield from construction areas. Estimates of the unit sediment yield from these kinds of areas are drawn from the literature and local conservationists and applied to land use as given in table 2.

LOW-YIELD AREA

Wark and Keller (1963) developed a general relation between average annual sediment yield and percent of forest land based on some 32 subbasins of the Potomac River. The relation has considerable scatter, but the regression shows that an area of 100-percent forest

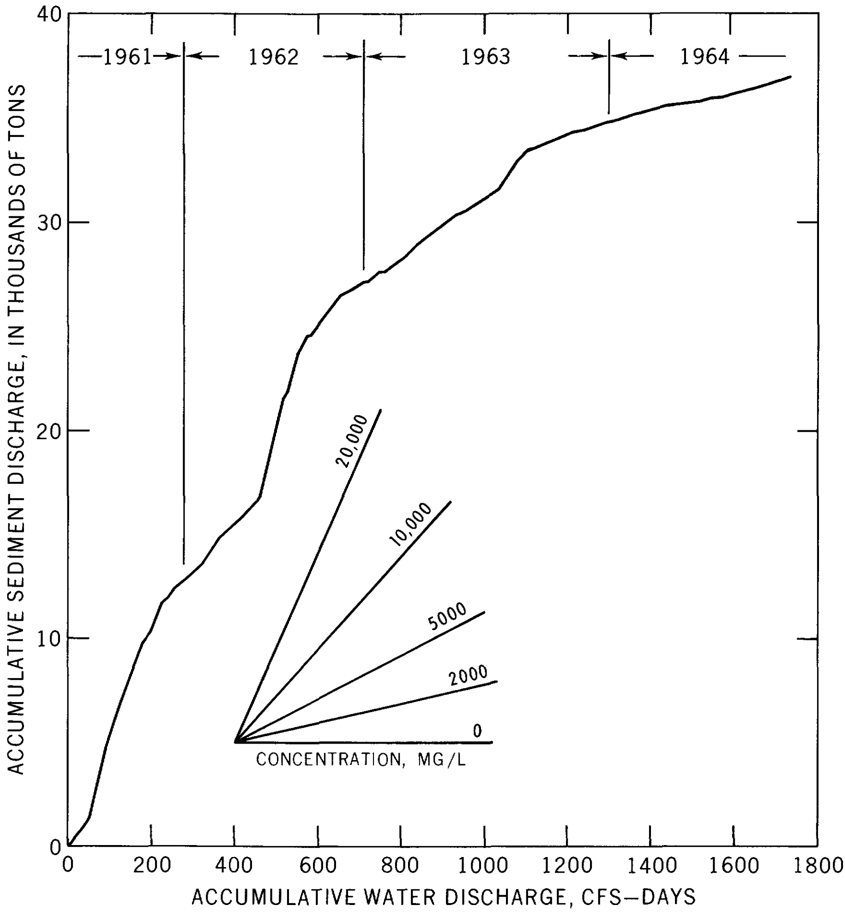

FIGURE 10.—Trend of accumulative sediment and water discharge of storm events, 1961–64. The slope varies with the concentration of sediment in the flow.

would yield about 0.03 ton per acre per year. This is similar to a relation developed by George (1963) which can be extended to about 0.02 ton per acre per year for 100 percent forest in the Stony Brook basin, New Jersey. An assumed 0.03 ton per acre per year for forest areas will be used. This yield rate when applied to the average forest area of 1,272 acres, in the study basin, for the project period of 3.4 years gives a total yield of 130 tons. This minor contribution is distributed over the 3-month periods of table 6 (col. 7) in proportion to the flood runoff of the periods.

Wark and Keller also developed a relation between percent of contributing area in cropland and sediment yield. Extension of this regression to 0 percent cropland shows a yield of about 0.10 ton per acre per year which, by definition, would include combinations of forest and pasture. If the average combination is ⅓ pasture and ⅔ forest, and the forest yield is 0.03, then the pasture portion should yield about 0.25 ton per acre per year. An average yield of 0.25 ton will be applied to the grass and established urban areas. This annual rate when applied to an average area of 1,360 acres for lawns, pasture, and urban areas gives a yield of 1,160 tons for the project period. This amount is distributed over the 3-month periods of table 6 (col. 8) in proportion to storm runoff. No greater precision is needed since the total for the low-yield area is such a small part of the total from Scott Run that a 100-percent change in the estimated yield would not appreciably change the results remaining for the high-yield area.

INTERMEDIATE-YIELD AREA

Glenn Anderson,[1] U.S. Soil Conservation Service, Fairfax, Va., from reconnaissance observations of soil, slope, cropping practice, and precipitation estimated the average annual sediment yield from cultivated fields in the basin to be about 13 tons per acre. Only a part of this sediment, however, will remain in transport and pass the measuring station near the mouth of Scott Run. From the method of Roehl (1962) it is estimated that about one-third of the sediment eroded from cultivated fields will pass the measuring station. Thus, about 4.3 tons per acre per year of sediment from cultivated land should be included in the Scott Run sediment measurements. Measurements by Wark and Keller (1963) in the Difficult Run basin, adjacent to Scott Run basin on the west, show an average annual yield of 0.44 ton per acre. It can be deduced that the probable annual yield from the approximate 5 percent of cropland in Difficult Run basin is about 6.5 tons per acre. An average of the two annual yields (6.5 and 4.3) suggests an average annual yield of about 5 tons per acre per year for cultivated and quarry land in Scott Run basin. At this annual-yield rate, an average area of 94 acres for 3.4 years would yield about 1,600 tons of sediment during the project study. This amount is distributed (table 6, col. 9) to the 3-month intervals of the project study in proportion to the product of storm runoff, acres of intermediate-yield area (table 2) and the seasonal erodibility factor (fig. 8).

[1] Oral commun., 1966.

CONSTRUCTION AREAS

The yield from construction areas is computed in table 6 (col. 10) by 3-month periods as the total-period discharge less the estimated yields of nonconstruction areas. The residual amount is divided between highway and other construction in proportion to their areas. It is probable that unit yields from the several types of urban construction do not greatly differ.

The relatively small contribution of the low- and intermediate-yield areas in comparison with the construction areas lends confidence to the contribution of the construction areas shown in table 6. More sophisticated techniques using approximate water-sediment transport curves could have been used in determining the contributions of the low- and intermediate-yield areas. The improvement, if any, would cause insignificant changes in the contributions of the construction areas. Also, use of the rating curve technique would require questionable assumptions about relative quantities of storm runoff from the varying areas and land uses in the basin.

Table 6 shows that 33,320 tons, or 85 percent of the total sediment transported past the gage, was derived from the highway construction areas. The remainder was derived from areas of various land uses as follows: forest 0.3 percent, grass and established urban 3.0 percent, intermediate-yield areas 4.1 percent, and other kinds of construction 7.5 percent. The average annual yield from the construction area was about 63 tons per acre.

SEASONAL FLOW AND TRANSPORT PATTERNS

The average characteristics of water and sediment runoff in Scott Run basin can now be summarized for assistance to public officials and contractors in planning policies and operations. The foregoing data have been arranged in table 7 and figure 11 to explain seasonal variations in duration, volume, and rate of storm runoff and in the amounts and rates of sediment yield with respect to construction area. Data for May and June 1961 were not included in table 7, because water and sediment runoff in the first half of the 3-month period were not observed.

The duration of storm runoff (fig. 11*A*) is greatest (5.6 days) in the first (Jan.–March) quarter and least (0.8 day) in the third (July–Sept.) quarter. The volume of storm runoff (fig. 11*B*) varies from season to season in about the same manner as duration, being greatest (225 cfs-days) in the first quarter and least (44 cfs-days) in the third quarter. Volume of runoff is a strong indicator of sediment transport.

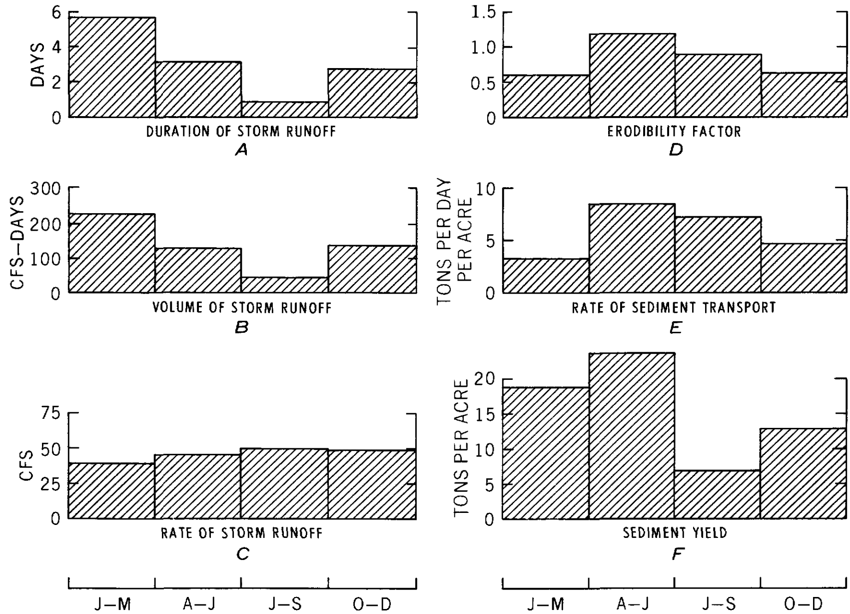

FIGURE 11.—Average seasonal variations in characteristics of storm runoff and sediment transport from construction areas in Scott Run basin.

The intensity or mean rate of storm runoff (fig. 11*C*) has important influence on erosion, but somewhat less than volume of runoff. The average rate of flow of storm runoff varies greatly from storm to storm, but less than might be expected between seasons, being somewhat less in the first quarter (40 cfs) than in the other three (45–50 cfs).

The relative erodibility of construction areas (fig. 11*D*) is taken from figure 8, and emphasizes the abrupt change from the least value, 0.60 in the first quarter, to the greatest, 1.20 in the second quarter.

The mean rate of sediment transport in tons per day per acre of construction (fig. 11*E*) illustrates the combined effects of erodibility and intensity of runoff on sediment yield. The first quarter shows the lowest value (3.3 tons) in contrast with the highest value (8.7 tons) for the second quarter.

The combined effect of the several parameters is illustrated by the mean quarterly yield of sediment in tons per acre (fig. 11*F*). The second quarter shows the highest sediment yield (24 tons per acre), mostly because of high erodibility. The first quarter has the next greatest yield (19 tons per acre) because of the large volume and duration of storm runoff, despite the lower erodibility. The third quarter shows least sediment (7 tons per acre), mostly because the volume of flow is small.

TABLE 7.—*Average seasonal variations in characteristics of storm runoff and sediment transport from construction areas in Scott Run basin*

Year and quarter	Storm runoff: Duration (days)	Storm runoff: Volume (cfs-days)	Storm runoff: Rate (cfs)	Construction area (acres)	Sediment yield: Amount (tons)	Sediment yield: Area rate (tons per acre [1])	Sediment yield: Time rate (tons per day [2])	Sediment yield: Time-area (tons per day per acre [1 2])
1961								
3	0.9	104.0	116	310	5,900	19.0	6,550	21.1
4	2.3	84.2	37	300	2,490	8.3	1,080	3.6
1962								
1	3.9	155.6	40	310	3,620	11.7	928	3.0
2	3.5	138.5	40	305	8,700	28.5	2,480	8.2
3	.2	3.1	16	285	40	.1	200	.7
4	2.6	136.7	52	245	2,780	11.3	1,080	4.4
1963								
1	5.9	254.1	43	160	3,640	22.8	620	3.8
2	1.8	114.1	64	110	2,600	23.6	1,440	13.1
3	.9	39.1	43	105	540	5.1	600	5.7
4	3.1	187.8	61	70	1,410	20.1	455	6.5
1964								
1	7.1	264.1	37	60	1,330	22.2	188	3.1
2	4.3	135.1	31	40	850	21.2	197	4.9
3	1.2	28.8	24	55	140	2.5	117	2.1
Total	38.0	1,645.5			34,040			
1961–64								
1	5.6	225	40			19		3.3
2	3.2	129	45			24		8.7
3	.8	44	50			7		7.4
4	2.7	136	50			13		4.8
Mean	3.1	133	46			16		6.0

[1] Based on construction area.
[2] Based on storm runoff duration.

It is apparent that erosion can be significantly reduced by scheduling construction during the third quarter when yields are lowest and avoiding or minimizing construction during the second quarter when yields are highest. About 68 percent of the average annual erosion occurs during the period January to June.

EROSION IN CONSTRUCTION AREAS

The foregoing discussion and table 6 show that about 33,320 tons, or 85 percent of the outgoing sediment, originated in areas undergoing highway construction. Roehl (1962) and many other investigators have shown that a large part of the sediment eroded from cultivated fields is commonly deposited again on gentler slopes, on flood plains, and in the channel system. It is reasonable to assume that this process of deposition must also apply to all sediments from Scott Run, including those eroded from construction areas, and that the gross erosion is greater than the computed transport amount. A typical example of erosion and deposition in the construction areas is shown in figure 12. Comparison of the size characteristics of the parent material and of the transported sediments should yield some information about those amounts.

SIZE COMPOSITION OF TRANSPORTED SEDIMENTS

The particle-size distribution of sediments passing the measuring station was determined on 19 occasions from 1961 to 1964; the results are given in table 8. Approximate regression lines were drawn (fig. 13) relating the average percentage content of sand, silt, and clay to the rate of flow at the time the observations were made. There appeared to be no significant shift in particle-size distribution with time; if present, such a shift was obscured by the scatter in the plotted points. The low-flow segments of the lines representing the percentage content of silt and clay have been adjusted to correspond to typical curves derived from data at many other locations. As flow decreases, velocity slows, and the silt particles, being heavier, drop to the streambed leaving the finer clay particles to become a greater portion of the load.

The probable quantities of suspended sand, silt, and clay transported by the stream during storm runoff are computed in table 9 for each of the 3-month periods on the basis of the mean flow rate and the computed sediment discharge for each period. The table shows that the computed suspended sediment transported by Scott Run during storm runoff periods from 1961 to 1964 was composed of 10 percent sand, 63 percent silt, and 27 percent clay. Table 10 combines the major quantities of sand, silt, and clay of table 9 with the minor estimated amounts for the unmeasured sediment discharge of storm runoff and for low-flow periods between flood events to arrive at the probable quantity and size composition for all the sediment transported from Scott Run basin. If it is assumed that the sediment transported from the nonconstruction areas would not appreciably alter the average gradation from the construction areas, then the 33,320 tons computed for the highway area (table 6) would have a distribution of 4,650 tons of sand, 20,000 tons of silt, and 8,650 tons of clay.

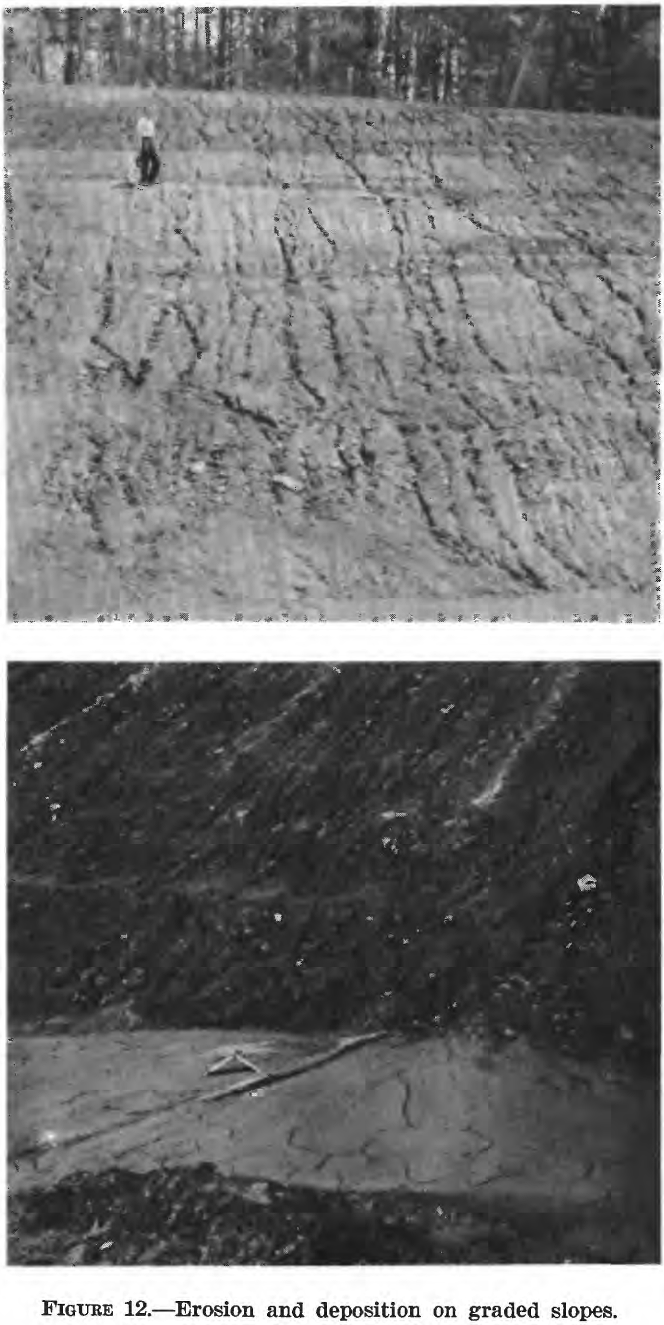

FIGURE 12.—Erosion and deposition on graded slopes.

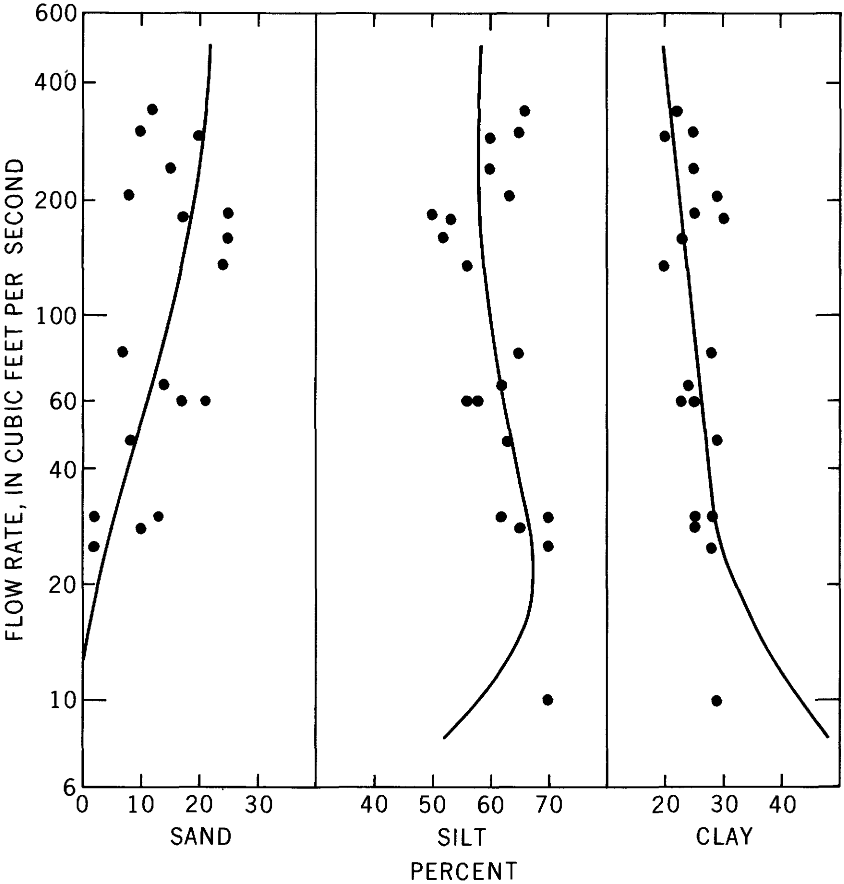

FIGURE 13.—Relation of sand, silt, and clay content of sediment discharge to flow rate for Scott Run basin, 1961–64.

SIZE COMPOSITION OF PARENT MATERIAL

The Virginia Highway Department obtained about 15 soil cores ranging in depth from 10 to 40 feet along the right-of-way of Interstate 495 and State Highway 123. Mr. A. W. Furgiuele, District Materials Engineer, reports [2] that the particle-size composition of the soils was found to be surprisingly consistent with respect to both location in the basin and depth and to average about 44 percent sand and gravel, 43 percent silt, and 13 percent clay.

[1] Oral commun., 1966.

TABLE 8.—*Measurements of particle-size distribution of suspended sediment transported from Scott Run basin, 1961–64*

Date	Flow rate (cfs)	Concentration (ppm)	Sediment discharge (tons per day)	Size distribution (percent)		
				Sand	Silt	Clay
1961						
5–12	205	12, 900	7, 100	8	63	29
	80	3, 720	800	7		
	30	2, 780	200	2		
8–26	290	28, 600	22, 400	20	60	20
	300	40, 700	33, 000	10		
	340	36, 700	33, 800	12	66	22
	240	6, 850	4, 450	15		
	180	4, 480	2, 180	17	53	30
10–21	60	11, 000	1, 700	17	58	25
1962						
2–26	30	5, 500	450	13	62	25
	135	18, 100	6, 620	24	56	20
	60	6, 860	1, 110	21	56	23
5–31	47	22, 300	2, 840	8		
	66	22, 800	4, 060	14		
	25	33, 200	2, 240	2		
	10	9, 010	240	1		
6–20	28	4, 500	340	10	65	25
1963						
3–6	185	18, 300	9, 150	25	50	25
6–20	160	13, 400	5, 800	25	52	23

It is reasonable to assume that almost all the clay-size particles entrained by flowing water remained in suspension and were transported down the channel system. If this is true, and if the size distribution from the soil cores held for all soil materials disturbed by highway construction whereas the distributions shown in table 10 represented all material leaving the basin, some interesting deductions as to initial erosion, deposition, and export of sediment are possible. Table 11 shows such estimates and indicates that the total amount of material removed from areas of highway construction was on the order of 66,500 tons. About 33,200 tons of this material was deposited within the basin, probably to a large extent at the base of cut and fill slopes, while about 33,300 tons was carried from the basin to downstream destinations.

The eroding forces of flood runoff are least effective in transporting the coarser particles of the soil materials. Although some of the sand detached by the eroding forces may be deposited within the immediate erosion areas, much is deposited at the foot of slopes, on flood plains, and in the channel system. Thus, only about 16 percent is transported past the measuring station. Efficiency in transporting the smaller silt-sized particles is shown to be much higher (70 percent). The assumption of 100 percent efficiency in transporting the clay materials is no doubt too high, as a small portion of the clay is also deposited on the

TABLE 9.—*Size composition of suspended sediment transported by storm runoff from Scott Run basin, 1961–64*

Year and quarter	Mean flow of storm runoff (cfs)	Sediment discharge (tons) [1]	Size composition (percent)			Period discharge (tons)		
			Sand	Silt	Clay	Sand	Silt	Clay
1961								
2 [2]	69	4, 844	12	62	26	580	3, 000	1, 260
3	116	5, 600	16	60	24	900	3, 360	1, 340
4	37	2, 353	7	65	28	165	1, 530	660
1962								
1	40	3, 425	8	64	28	275	2, 190	960
2	40	8, 260	8	64	28	660	5, 280	2, 320
3	16	39	1	63	36	0	25	15
4		2, 630	10	63	27	260	1, 660	710
1963								
1	43	3, 426	9	64	27	310	2, 190	920
2	64	2, 462	12	62	26	290	1, 530	640
3	43	502	9	64	27	45	320	135
4	61	1, 305	11	62	27	145	810	350
1964								
1	37	1, 219	7	65	28	85	790	340
2	31	786	6	66	28	45	520	220
3	24	124	4	66	30	5	80	35
Total		36, 975				3, 765	23, 285	9, 905
Percent		100				10	63	27

[1] Computed suspended-sediment discharge from table 3.
[2] Data available only for part of quarter.

TABLE 10.—*Size composition of sediment transported by Scott Run, 1961–64*

	Flow (cfs-days)	Size composition (percent)			Sediment loads (tons)			
		Sand and gravel	Silt	Clay	Sand	Silt	Clay	Total
Suspended sediment loads for storm runoff	1, 735	10	63	27	3, 765	23, 285	9, 905	36, 975
Additional sediment loads for storm runoff [1]		85	15		1, 570	280		1, 850
Estimated sediment loads for intervals between storm events	2, 952		25	75		80	235	315
Total	4, 680	14	60	26	5, 335	23, 645	10, 140	39, 140

[1] Estimated part of total sediment loads during storm runoff that moved below the sampling zone and was not included in computed suspended loads.

TABLE 11.—*Comparison of eroded and transported sediments in the highway construction area*

	Size distribution (percent)			Sediment amounts (tons)			
	Sand	Silt	Clay	Sand	Silt	Clay	Total
Eroded sediments	44	43	13	29, 250	28, 600	8, 650	66, 500
Transported sediments	14	60	26	4, 650	20, 000	8, 650	33, 300
Deposited sediments	75	25	0	24, 600	8, 600	0	33, 200
Percent of eroded sediments transported				16	70	100	48
Percent of eroded sediments deposited				84	30	0	52

flood plains by overbank flow. Nevertheless, it seems reasonable to conclude that about one-half of the material eroded from construction areas has been transported out of the basin and that gross erosion from construction areas would be on the order of two times the average annual yield of 63 tons per acre, or 126 tons per year per acre.

EROSION AND TRANSPORT WITH NORMAL PRECIPITATION

As noted before, the long-term average precipitation for the area exceeds the recorded precipitation during the period by about 14 percent (p. E7). The additional runoff that would have occurred with normal precipitation would have eroded additional sediment. The difference in the precipitation pattern for the basin during the period of study and the long-term average pattern probably consists of some increase in the number of storms and some increase in the size of storms. The change in sediment yield would depend on the related change in precipitation pattern and its season of occurrence (fig. 8).

If the precipitation deficiency was due to the nonoccurrence of storms of the same average size as those that did occur (fewer storms), the increase in storm runoff and sediment yield for normal precipitation would be in proportion to the increase in precipitation, or about 14 percent.

If the precipitation deficiency was due to a reduction in the average size of the actual storm events (smaller storms), the increase in storm runoff and sediment yield for normal precipitation would be somewhat greater than 15 percent. An approximate correlation between precipitation and storm runoff shows that the latter varies with about the 1.2 power of precipitation. Figure 7 shows that sediment discharge from the dominant source areas varies with the 1.5 power of storm runoff, and thus with about the 1.8 power of precipitation. Therefore, the normal sediment yield for the period of study with normal precipitation might have been 127 percent ($1.14^{1.8}$) of the observed yield.

It is assumed that normal precipitation during the period of study would have brought some increase in both the number of storms and the average size of storms. The increase in sediment yield corresponding to normal precipitation would then fall between 14 and 27 percent, or be on the order of 20 percent.

The average gross erosion per year for highway construction areas in Scott Run basin during 1961–64 has been computed as about 126 tons per acre, or 80,600 tons per square mile. Using the assumptions of preceding paragraphs, with normal precipitation, these yearly amounts would have been about 151 tons per acre, or 96,500 tons per square mile. The average yearly transport from the basin would have been increased from 63 to 76 tons per acre, or from 40,300 to 48,600 tons per square mile.

CONCLUSIONS

The conversion of rural lands to urban use includes an interval during construction when exceptionally high rates of erosion and sediment transport by streams occur. The accelerating growth of our urban areas and the concentration of capital and human resources in these areas assure that the relative importance of urban problems will increase.

The intensive construction activity in Scott Run basin, due primarily to the large amount of concurrent highway construction, involved 11 percent of the basin area. The portion of other suburban areas of this size undergoing construction at any one time will usually be less than in Scott Run basin.

The measured storm runoff for all 88 events exceeding a peak discharge of 20 cfs accounted for 37 percent of the total runoff and 3 percent of the time for the period of study from 1961 to 1964. The remainder, or 63 percent of the period runoff prevailing for 97 percent of the time, occurred in low-flow periods between measured events.

Suspended-sediment discharge, measured or computed for the 88 storm events, accounted for 94 percent of the total sediment discharge for the period. Sediment moving on or near the bed during the storm-flow periods and not reflected in the suspended-sediment computations accounts for an additional 5 percent of the total sediment discharge. Thus, 63 percent of the period runoff prevailing 97 percent of the time transported only about 1 percent of the total sediment discharge.

The allocation of sediment to source areas shows that highway construction areas, varying from less than 1 to more than 10 percent of the basin area at any particular time, contributed 85 percent of the sediment, whereas low-yield areas and intermediate-yield areas contributed 3 and 4 percent, respectively. The remaining 8 percent was derived from residential and industrial construction. The sediment yield per acre for an average storm event in construction areas was about 10 times greater than for cultivated land, 200 times greater than for grass areas, and 2,000 times greater than for forest areas. Although these ratios are based mostly on estimates from other studies in the Potomac Basin and may not apply to other areas, they serve to emphasize the magnitude of the problem.

The average percentage of the sediment discharge occurring in the quarterly periods of each year were 30, 38, 11, and 21, which suggest that remedial measures to reduce erosion from construction areas have the most importance during the January to June period when about 68 percent of the annual erosion occurs. This timing of erosion is mostly because storm runoff and duration were greater during the first and second quarters than during the remainder of the year.

Comparison of particle-size distribution of source materials and of transported sediments suggested that gross weight of material eroded from construction areas was about two times greater than the weight transported past the gage. It appeared that as much as 84 percent of the eroded sand and 30 percent of the eroded silt were deposited again before reaching the measuring station.

Precipitation during the study period was about 14 precent less than the long-term average. If normal precipitation had prevailed, the estimated amount of sediment eroded within, and transported from, the basin would have been increased about 20 percent over that measured to about 151 and 76 tons per year per acre, respectively.

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