Effects of Urbanization on Streamflow and Sediment Transport in the Rock Creek and Anacostia River Basins, Montgomery County, Maryland, 1962–74

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1003

Work done in cooperation with the Maryland-National Capital Park and Planning Commission (Montgomery County and Prince Georges County Planning Boards), the Washington Suburban Sanitary Commission, the District of Columbia Department of Environmental Services, the Montgomery County Department of Environmental Protection, and the Maryland Department of Natural Resources

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By THOMAS H. YORKE *and* WILLIAM J. HERB

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CONVERSION FACTORS

The following factors may be used to convert the English units published in this report to metric units.

Multiply English unit	*By*	*To obtain metric unit*
acres	0.4047	square hectometers (hm^2)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
cubic feet per second-day (ft^3/s-d)	2447	cubic meters (m^3)
	0.002447	cubic hectometers (hm^3)
cubic feet per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meters per second per square kilometer [(m^3/s)/km^2]
feet (ft)	0.3048	meters (m)
inches (in)	25.4	millimeters (mm)
miles (mi)	1.609	kilometers (km)
pounds per cubic foot (lbs/ft^3)	16.05	kilograms per cubic meter (kg/m^3)
square miles (mi^2)	2.590	square kilometers (km^2)
short ton	0.9072	metric tons or tonnes (t)
tons per acre	2.242	tonnes per square hectometer (t/hm^2)
tons per square mile ($tons/mi^2$)	0.3503	tonnes per square kilometer (t/km^2)

EFFECTS OF URBANIZATION ON STREAMFLOW AND SEDIMENT TRANPORT IN THE ROCK CREEK AND ANACOSTIA RIVER BASINS, MONTGOMERY COUNTY, MARYLAND, 1962-74

By THOMAS H. YORKE and WILLIAM J. HERB

ABSTRACT

Land use/land cover, precipitation, streamflow, and sediment data were collected from nine drainage subbasins in a 32-square-mile (83-square-kilometer) area north of Washington, D.C., in Montgomery County, Md. This study was begun in 1962 to define urban runoff and sediment problems and was expanded in 1966 to evaluate response to sediment-control practices in areas undergoing urban development. Land use/land cover varied considerably in the study subbasins, which ranged in size from 0.35 to 21.1 square miles (0.91 to 54.6 square kilometers). Three subbasins remained virtually rural, while the others underwent urban development. In 1974, urban land represented from 0 to 60 percent of the land use in the nine subbasins. Urbanization did not affect median and low flows, but did increase storm runoff and peak discharges.

Suspended sediment transported from one of the basins that underwent urban development, the 21.1 square mile (54.6 square kilometer) Anacostia River basin, averaged 14,800 tons (13,400 tonnes) per year between 1962 and 1974, while urban construction averaged about 3 percent of the drainage area during this period of time. Bedload was estimated to be 6 to 13 percent of the total sediment load. Most of the suspended load was transported during storms, and varied from storm to storm and seasonally. High loads were generally associated with high runoff in the spring and intense thunderstorms in the summer. Cropland, urban land, and construction sites were the major sources of sediment. Annual suspended-sediment yields from land under cultivation ranged from 0.65 to 4.3 tons per acre (1.5 to 9.6 tonnes per square hectometer), compared to estimated yields from forest and grasslands ranging from 0.03 to 0.2 ton per acre (0.07 to 0.45 tonne per square hectometer). Yields from urban land were about 3.7 tons per acre (8.3 tonnes per square hectometer), most of which came from stream-channel erosion.

Average annual suspended-sediment yields computed for urban construction sites ranged from 7 to 100 tons per acre (16 to 224 tonnes per square hectometer). The magnitude of the yield from construction sites was significantly affected by (1) the average slope of the sites, (2) the proximity to stream channels, (3) the existence of buffer zones of natural vegetation, and (4) the use of sediment-control measures. Sediment controls, particularly those enforced under a 1971 sediment-control ordinance, decreased construction-site suspended-sediment yields by 60 to 80 percent. It was estimated that the suspended-sediment load in the Anacostia River basin between 1962 and 1974 would have been reduced by 50 percent if strictly enforced sediment controls had been used throughout the period. Based on a reported cost of $1,030 per acre (0.4 square hectometer), the cost of sediment controls on the 1,900 acres (769 square hectometers) developed during the period would have been $19 per ton ($21 per tonne).

INTRODUCTION

Each year thousands of acres of pastures, cultivated fields, and woodlots are replaced by housing subdivisions, apartment complexes, and shopping centers. Urbanization is particularly evident in the Washington, D.C., metropolitan area. Guy and others (1963) estimated that 500 mi^2 (1,300 km^2) of rural land would be urbanized between the mid-1960's and 1980 to accommodate a population increase of 2 million. Urban construction activities and the resulting increase in impervious area place a tremendous stress on the local streams. Erosion and sediment transport increase manyfold during construction, and increased runoff from impervious surfaces causes stream-channel erosion and flooding after construction. Studies by Guy and Ferguson (1962), Wolman (1964), Guy (1965), and Vice, Guy, and Ferguson (1969) indicate that annual sediment yields for urban construction sites range from 25,000 to 120,000 tons/mi^2 (8,800 to 42,000 t/km^2) as compared with rural sediment yields of 150 to 500 tons/mi^2 (53 to 175 t/km^2) (Wark and Keller, 1963). Anderson (1970) reported that urbanization increased flood peaks in northern Virginia by a factor of 2 to 8, depending on relative impervious area and the density of the storm-sewer system.

This report presents the results of a study begun in 1962 to define urban sediment problems and which was expanded in 1966 to evaluate response to a program designed to control runoff and sedimentation from urbanizing areas. Facts about land use/land cover, streamflow, and sedimentation representative of urbanizing areas in the Washington, D.C., area are presented. The effects of different land uses, construction practices, and sediment-control methods on runoff and sediment are evaluated and summarized. This information should provide the basis for land-use planning that would minimize the damaging effects of urban development on streams in the Maryland Piedmont and other areas of the country with similar climatic and physiographic characteristics.

The study was made in a 32 mi^2 (83 km^2) area drained by the North Branch Rock Creek and the Northwest Branch Anacostia River. Both streams enter the Potomac River in the District of Columbia (fig. 1). Data from 9 streamflow-sediment monitoring stations, 9 recording rain gages, a varying number of nonrecording rain gages, and 14 sets of aerial photographs taken between 1963 and 1974 were used in the study. The locations of the gages are shown in figure 1. The type of recording and sampling equipment and the type and length of record available for each site are summarized in table 1.

Streamflow and suspended-sediment discharge were measured using the standard procedures described by Carter and Davidian (1968) and Guy and Norman (1970). Stage was recorded with digital water-stage recorders at a frequency of 48 to 288 readings per day, depending on the size of the drainage area and land use of the basin. Direct measurements of water discharge and indirect determinations of one or two peak discharges were used to establish the stage-discharge rating for each site. Suspended-sediment concentration was sampled with a combination of manual and automatic samplers. Each site was equipped with a single-stage sampler, which automatically collected samples at preselected levels during storms. Some sites were also equipped with pumping samplers. Hand samples were collected during most storms to provide a check on the automatic samplers and to monitor suspended-sediment concentration during recession flows.

Precipitation was measured with a network of recording and nonrecording rain gages. Recording gages were located to provide rainfall duration and intensity data for each subbasin within the study area. Eight sites were equipped with digital recorders having 5- or 15-minute recording intervals. One site was equipped with a weighing-type gage with a 24-hour continuous chart. Nonrecording gages were located throughout the basins to measure the areal distribution of precipitation.

Land use/land cover data were obtained from aerial photographs using grids with a dot density of 64 or 100 dots/in^2. The scale of photographs available prior to 1966 ranged from 1:23,000 to 1:37,000, and each dot represented 0.87 to 3.4 acres (0.35 to 1.4 hm^2), depending on the scale of the photographs and the dot-grid used. After 1966, 1:12,000-scale photographs were obtained at least annually. Each dot represented 0.36 acre (0.15 hm^2) on these photographs. Land use/land cover was summarized in five major categories: farmland and parks, rural residential, urban residential, commercial, and construction. The amount of cropland, grass, forest land, water, and impervious area was summarized for farmland and parks. The amount of grass, forest land, and impervious area was summarized for the residential or commercial categories.

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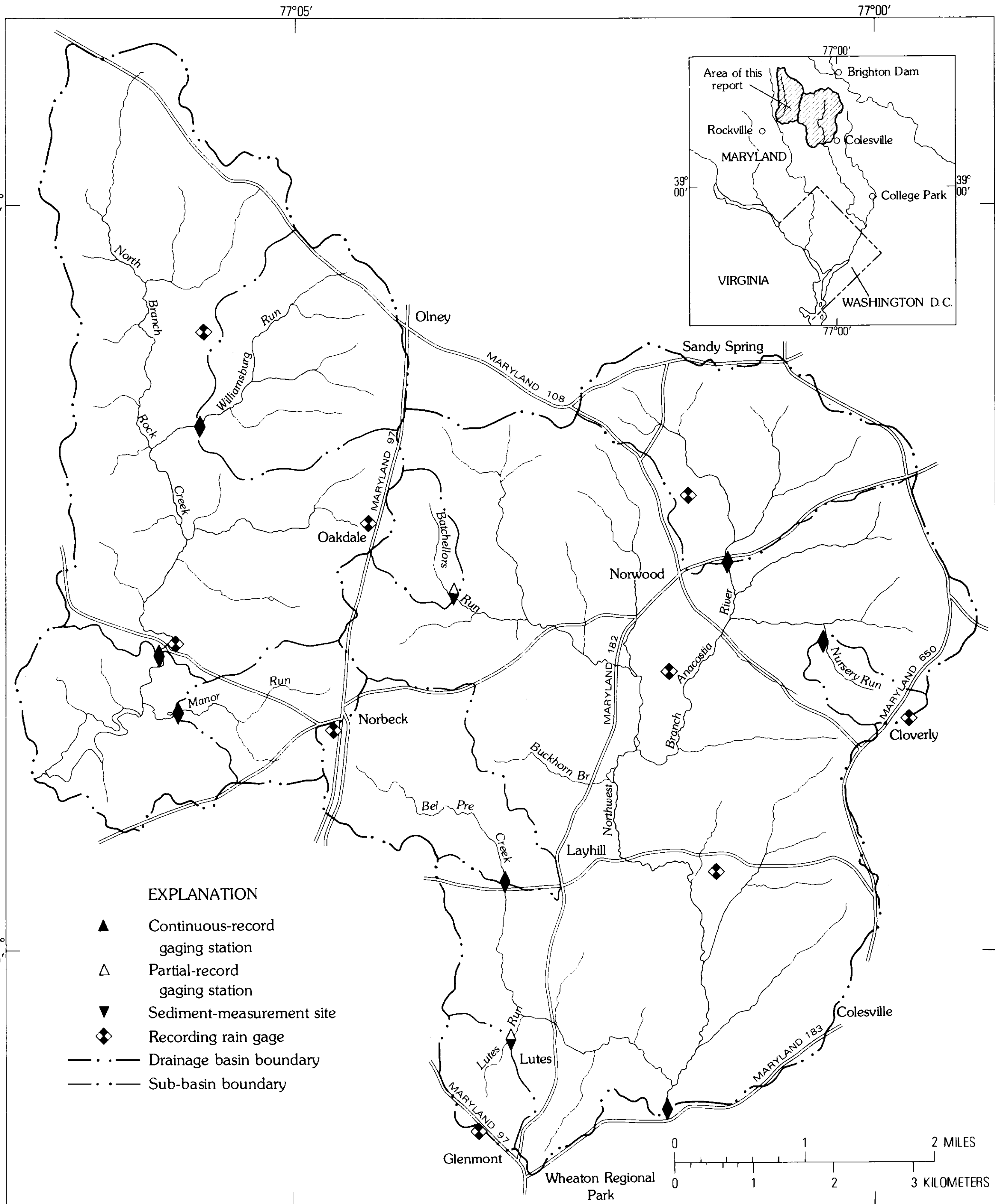
FACTORS AFFECTING STREAMFLOW AND SEDIMENT TRANSPORT

The streamflow and sediment characteristics of streams in the study area are affected by numerous factors including physiography, soils, climate, and



Base from U.S. Geological Survey
Beltsville, Clarksville, Kensington and Sandy Spring 1:24,000, 1971

FIGURE 1.—Location map of Northwest Branch Anacostia River and North Branch Rock Creek basins.

TABLE 1.—*Summary of streamflow, suspended-sediment, and recording precipitation stations in the Rock Creek and Anacostia River basins*

STREAMFLOW AND SUSPENDED-SEDIMENT STATIONS

Station	Station No.	Drainage area (mi^2)	Streamflow		Suspended sediment		Automatic sampling equipment
			Period of record	Type of record	Period of record	Type of record	
Williamsburg Run near Olney.	01647685	2.25	Oct. 1966–Sept. 1974	Daily	Oct. 1966–Sept. 1968 Oct. 1968–Sept. 1974	Daily Storm only	Pumping and single stage.
North Branch Rock Creek near Norbeck.	01647720	9.73	Oct. 1966–Sept. 1974	Daily	Nov. 1966–Sept. 1974	Storm only	Pumping and single stage.
Manor Run near Norbeck.	01647725	1.01	Oct. 1966–Sept. 1974	Daily	Nov. 1966–Aug. 1974	Storm only	Single stage.
Northwest Branch Anacostia River at Norwood.	01650050	2.45	Oct. 1966–Sept. 1974	Daily	Mar. 1967–Aug. 1974	Storm only	Single stage.
Nursery Run at Cloverly.	01650085	.35	Oct. 1966–Sept. 1974	Daily	Oct. 1966–Sept. 1968 Oct. 1968–Aug. 1974	Daily Storm only	Single stage.
Batchellors Run at Oakdale.	01650190	.47	Nov. 1966–Sept. 1974	Flood hydrograph	Aug. 1967–Aug. 1974	Storm only	Single stage.
Bel Pre Creek at Layhill.	01650450	1.69	Mar. 1963–Sept. 1966 Oct. 1966–Sept. 1974	Flood hydrograph Daily	Mar. 1963–Aug. 1974	Storm only	Single stage.
Lutes Run at Lutes	01650470	.47	Feb. 1963–Apr. 1970; July 1971–Sept. 1974	Flood hydrograph	Feb. 1963–Apr. 1970; June 1973–Sept. 1974	Storm only	Single stage. Pumping.
Northwest Branch Anacostia River near Colesville.	01650500	21.1	Oct. 1923–Sept. 1974	Daily	Sept. 1960–Sept. 1962 Oct. 1962–Sept. 1974	Storm only Daily	Pumping and single stage.

RECORDING PRECIPITATION STATIONS

Station	Station No.	Period of record	Recording frequency
Olney West	01647679	Nov. 1966–Sept. 1974	5-min. punch interval prior to Oct. 1968, 15-min. thereafter.
Oakdale	01647689	Mar. 1967–Sept. 1974	5-min. punch interval prior to Oct. 1968, 15-min. thereafter.
Norbeck Northwest	01647719	Dec. 1966–Sept. 1974	15-min. punch interval.
Sandy Spring South	01650029	Nov. 1966–Sept. 1974	5-min. punch interval prior to Oct. 1968, 15-min. thereafter.
Cloverly	01650079	Mar. 1967–Sept. 1974	5-min. punch interval prior to Oct. 1968, 15-min. thereafter.
Norwood South	01650119	May 1963–Sept. 1974	Continuous chart.
Layhill East	01650319	Mar. 1967–Sept. 1974	15-min. punch interval.
Norbeck	01650419	Nov. 1966–Sept. 1974	5-min. punch interval.
Glenmont	01650469	Mar. 1967–Sept. 1974	5-min. punch interval, Mar. 1967–Sept. 1968; Aug. 1972–Sept. 1974; 15-min. punch interval, Oct. 1968–July 1972.

land use/land cover. A summary of each of these factors as it relates to the study area and the relative influence of each on streamflow and sediment transport are discussed in the following sections.

PHYSIOGRAPHY

The nine study basins lie in the eastern division of the Piedmont physiographic province. A rolling topography, with low knobs and ridges rising above the general level, is typical of the area. Altitudes in the Anacostia River basin range from 270 ft (82 m) at the Colesville gaging station to 570 ft (174 m) near Olney. Altitudes in the North Branch Rock Creek basin range from about 280 ft to 570 ft (85 to 174 m). The stream valleys are deep and narrow. Slopes on the valley floors are generally 0–3 percent. Areas adjacent to the stream valleys have slopes that are typically greater than 8 percent, and commonly the range is between 15 and 25 percent. Farther from the stream valleys, the slopes tend to flatten and generally range between 0 and 8 percent along the drainage divides (pl. 1).

Slopes of construction sites for residential and commercial development may significantly affect sediment transport and runoff. Steep sites generally will require more earthmoving, resulting in more cut and fill areas and an increase in the erosion potential. Also, runoff from steep sites can cause extensive rill and gully erosion. After stabilization, water will run off rapidly from steep sites creating the potential for flooding immediately downstream or adding to flooding problems farther downstream. The same volume of water will probably run off impervious areas with mild slopes as from those with steep slopes, but not as rapidly, resulting in lower peak discharges.

GEOLOGY AND SOILS

Upland soils of the eastern division of the Piedmont plateau are common to the study area. These soils are developed in material weathered from igneous and metamorphic rocks. A large percentage of the bedrock is a soft micaceous schist, the principal parent material for the predominant Manor-Chester-Glenelg soil association. Most of the upland soils are silt loams in the Manor, Glenelg, Chester, Glenville, and Elioak series. There are a few channery silt loams and silty clay loams mixed with the silt loams. The surface soils of the silt loams and silty clay loams are composed of about 30 percent sand or larger particles and 70 percent silt and clay. Channery silt loams are composed of about 40 percent sand or larger particles and 60 percent silt and clay. Most of the soils in the stream valleys are Worsham and Wehadkee silt loams. The surface horizons of these soils are generally composed of the fine materials weathered from upland soils. (U.S. Department of Agriculture, 1961).

The soils generally are uniform with one major exception; the subsoils of the Manor and Glenville series are poorly developed, whereas the subsoils of the other series are well developed with moderate to strong blocky structures. The weak structure of the Manor and Glenville subsoils make them highly erodible. They are particularly susceptible during construction when surface soils are removed during rough grading for rights-of-way, parking lots, and foundations. The erodibility factor (k), which is used in the universal soil loss equation for predicting erosion (Wischmeir and Smith, 1965), ranges from 0.28 to 0.43 for the Glenelg and Elioak subsoils and from 0.43 to 0.64 for the Manor and Glenville subsoils (U.S. Department of Agriculture, 1970). The higher erodibility factors represent a greater susceptibility to erosion.

CLIMATE

The study area has a temperate and rather humid climate. The mean annual temperature is about 13° C. The length of the growing season is approximately 175 days; the last killing frost usually occurs in late April, and the first killing frost usually occurs in mid-October. Calculations based on the Environmental Data Service record of precipitation, 1926–74, at College Park, Md., show the annual precipitation averaged 42.27 in (1,074 mm). The average monthly precipitation ranged from 2.79 in (71 mm) in February, to 4.89 in (124 mm) in August. Summer precipitation is generally characterized by brief, high-intensity rains of convective storms. Winter precipitation, which is mostly rainfall, usually results from frontal storms and is characterized by low-intensity, long-duration rainfall.

The climate and the distribution of precipitation during the year significantly affect the streamflow and sediment-discharge characteristics in the study area. Because of higher evaporation and transpiration losses by vegetation during the growing season, the amount of rainfall that enters the streams as surface runoff and baseflow is less than in the dormant season. However, the high-intensity summer storms generally produce higher peak discharges than winter storms, particularly on the smaller streams. The erosion potential also is greater in the summer than in the winter. Intense rains have a high amount of energy to cause sheet erosion. Also, the rapid concentration of runoff caused by intense rains has high peak energy to erode the soil and transport it in the stream channels.

Figure 2 illustrates the monthly variation of precipitation in and near the study area between October 1962 and September 1974. The consistency between the four precipitation stations indicates a uniform distribution of precipitation throughout the study area. The illustration also indicates that the mean monthly precipitation between 1963 and 1974 is comparable with the mean monthly precipitation between 1926 and 1974 at College Park, Md. Mean annual precipitation for the 12-year period (1963–74) ranged from 38.50 in (978 mm) at the Rockville 3NE station to 42.59 in (1,082 mm) at College Park.

LAND USE/LAND COVER

While each of the factors discussed above influences the runoff and erosional processes, land use/land cover probably has the most dramatic effect. Increased storm runoff and sediment discharge resulting from forest clearing, cultivation, overgrazing, mining, and urbanization have been reported by many investigators. Annual sediment yields in Maryland range from about 20 tons/mi² (7 t/km²) for forest land and 300 to 500 tons/mi² (105 to 175 t/km²) for agricultural areas (Wark and Keller, 1963), to greater than 100,000 tons/mi² (35,000 t/km²) for urban construction sites (Guy, 1965; Wolman, 1964). Degradation of the stream environment related to increased sedimentation from urban developments is magnified because the streams affected are in or near population centers, where the use of water resources for water supply, waste assimilation, flood conveyance, and recreation is most intense.

Land use/land cover in the study area has changed considerably between 1963 and 1974. Suburban land, which includes all land in the rural and urban residential and the public-commercial categories in table 2, increased from 6 percent to 23 percent of the total drainage area of the Northwest Branch Anacostia River basin near Colesville between 1963 and 1974. In 1974, suburban land ranged from 13 percent in the Northwest Branch Anacostia River basin at Norwood to 73 percent in the Lutes Run basin. Urban land, which includes land in only the public-commercial and the urban residential categories of table 2, is probably more indicative of changes that have occurred in the study basins. Urban residential represents residential housing with lots one-half acre (0.2 hm²) or less,

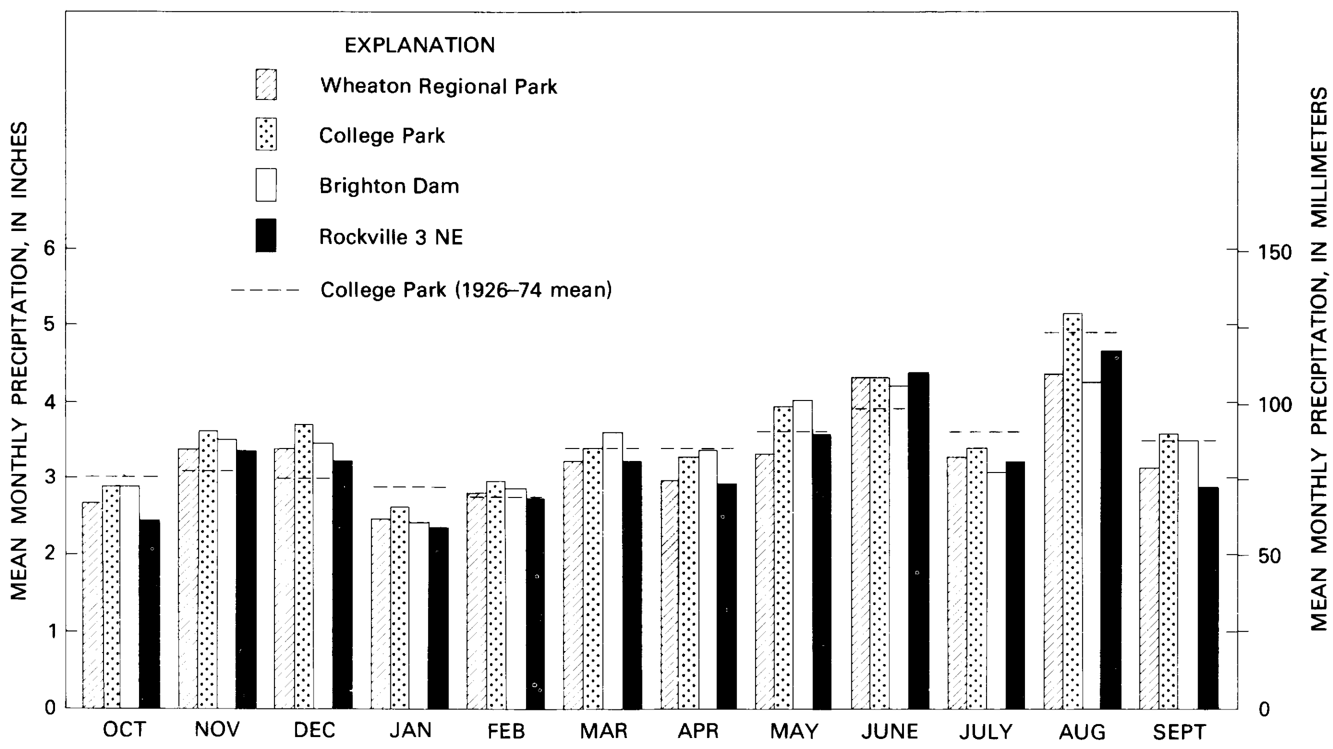


FIGURE 2.—Mean monthly rainfall at locations in and near the study area, October 1962–September 1974.

TABLE 2.—*Land use/land cover, in acres, in the Rock Creek and Anacostia River basins, 1963–74*

Date	Farmland and parks					Rural residential			Urban residential		Public and commercial		Construction
	Crops	Grass	Forest	Water	Impervious	Grass	Forest	Impervious	Grass	Impervious	Grass	Impervious	
Williamsburg Run near Olney (1,440 acres)													
1966	615	426	214	2	32	65	13	16	0	1	8	4	44
1967	603	371	211	2	27	74	12	18	0	1	8	4	109
1968	597	355	202	2	27	67	14	17	58	19	8	6	68
1969	597	330	202	2	27	67	14	17	76	30	21	14	43
1970	562	334	212	3	26	62	11	16	89	36	26	16	47
1971	409	414	211	4	22	65	8	18	121	52	26	16	74
1972	409	362	206	4	21	65	8	18	139	60	26	16	106
1973	408	331	198	4	21	66	8	19	183	80	27	22	73
1974	400	333	192	4	18	68	9	19	230	105	27	21	14
North Branch Rock Creek near Norbeck (6,228 acres)													
1966	1809	2137	1574	10	106	264	116	51	7	4	9	6	135
1967	1795	2074	1569	10	101	273	116	53	15	5	9	12	196
1968	1789	2063	1560	10	101	281	118	56	72	23	14	15	126
1969	1789	2037	1556	10	102	281	118	56	98	37	27	23	94
1970	1698	2065	1582	11	101	256	113	50	128	49	33	26	116
1971	1543	2105	1588	12	97	264	114	52	184	73	33	26	137
1972	1543	2035	1572	12	98	264	114	52	227	95	33	26	157
1973	1542	1998	1552	12	98	265	114	53	281	120	34	32	127
1974	1534	1992	1545	12	95	275	115	55	352	159	34	31	29
Manor Run near Norbeck (646 acres)													
1966	12	267	206	0	14	58	30	15	0	2	0	5	37
1967	12	231	203	0	13	58	30	15	6	3	0	5	70
1968	12	205	200	0	13	58	30	15	19	5	6	7	76
1969	22	152	182	0	9	50	55	23	39	22	18	12	62
1970	22	134	171	0	9	57	53	25	67	29	19	12	48
1971	22	122	171	0	9	58	53	25	89	31	19	12	35
1972	22	115	171	0	9	58	53	25	102	35	19	12	25
1973	22	119	171	0	9	58	53	25	113	40	19	12	5
1974	22	115	171	0	9	58	53	25	115	41	19	12	6
Northwest Branch Anacostia near Norwood (1569 acres)													
1966	321	483	575	3	23	48	49	16	0	0	33	15	3
1967	367	422	575	3	23	48	49	16	0	1	33	15	17
1968	367	407	575	3	23	59	50	18	0	1	43	20	3
1969	367	403	574	4	23	60	50	18	0	1	43	21	5
1970	367	397	574	4	23	61	50	18	0	1	44	23	7
1971	367	397	574	4	23	61	50	18	0	1	48	23	3
1972	367	397	574	4	23	61	50	18	0	1	49	23	2
1973	367	391	570	4	23	61	50	18	0	1	47	23	14
1974	367	389	539	4	23	61	50	18	0	2	51	26	39
Nursery Run at Cloverly (224 acres)													
1966	19	110	55	0	4	21	1	8	0	0	2	3	1
1967	19	110	55	0	4	21	1	8	0	0	3	3	0
1968	19	110	55	0	4	21	1	8	0	0	3	3	0
1969	19	109	55	0	4	21	1	8	0	0	3	4	0
1970	19	109	55	0	4	21	1	8	0	0	3	4	0
1971	19	109	55	0	4	21	1	8	0	0	3	4	0
1972	19	109	55	0	4	21	1	8	0	0	3	4	0
1973	19	108	55	0	4	21	1	8	0	0	3	4	1
1974	19	108	55	0	4	21	1	8	0	0	4	4	0
Batchellors Run at Oakdale (301 acres)													
1966	57	153	41	0	5	36	3	6	0	0	0	0	0
1967	52	153	41	0	5	36	3	6	0	0	0	0	5
1968	55	153	41	0	5	36	3	6	0	0	0	0	2
1969	55	153	41	0	5	36	3	6	0	0	0	0	2
1970	55	153	41	0	5	36	3	6	0	0	0	0	2
1971	56	152	41	0	6	36	3	6	0	0	0	0	1
1972	56	152	41	0	6	36	3	6	0	0	0	0	1
1973	56	152	41	0	6	36	3	6	0	0	0	0	1
1974	56	140	39	3	6	36	3	6	0	0	0	0	12
Bel Pre Creek at Layhill (1,082 acres)													
1963	55	334	595	0	37	22	14	6	11	6	1	1	0
1964	----	----	----	--	---	---	---	---	---	---	---	--	0

TABLE 2.—*Land use/land cover, in acres, in the Rock Creek and Anacostia River basins, 1963–74*—Continued

Date	Farmland and parks					Rural residential			Urban residential		Public and commercial		Construction
	Crops	Grass	Forest	Water	Impervious	Grass	Forest	Impervious	Grass	Impervious	Grass	Impervious	
Bel Pre Creek at Layhill (1,082 acres)—Continued													
1965	----	----	----	--	---	---	---	---	---	---	---	--	195
1966	10	360	371	4	14	70	46	20	13	19	1	3	151
1967	9	349	348	4	14	70	46	20	25	43	0	4	150
1968	9	377	345	6	15	71	46	20	34	49	0	4	106
1969	9	351	341	6	15	71	46	20	41	58	0	4	120
1970	9	349	341	6	15	71	46	20	44	62	0	14	105
1971	0	342	340	6	15	71	46	20	64	68	0	14	96
1972	0	313	306	6	15	71	46	20	63	80	0	14	148
1973	0	267	275	6	18	77	48	21	87	104	0	14	165
1974	0	278	257	9	18	77	37	14	101	158	0	14	119
Lutes Run at Lutes (301 acres)													
1963	0	88	95	0	0	12	16	3	16	10	0	0	61
1964	----	----	----	--	---	---	---	---	---	---	---	--	38
1965	----	----	----	--	---	---	---	---	---	---	---	--	20
1966	1	29	62	0	0	15	21	4	79	48	1	1	40
1967	0	25	48	0	0	18	19	3	90	64	3	3	28
1968	0	24	53	0	0	18	19	3	93	69	4	5	13
1969	0	20	53	0	0	18	19	3	93	69	4	9	13
1970	0	20	52	0	0	18	19	3	91	72	4	9	13
1971	0	21	56	0	0	18	19	3	91	72	5	11	5
1972	0	21	56	0	0	18	19	3	91	72	5	11	5
1973	0	21	56	0	0	18	19	3	91	72	5	11	5
1974	0	22	57	0	1	18	19	3	91	72	5	11	2
Northwest Branch Anacostia River near Colesville (13,504 acres)													
1963	3194	4987	3709	15	281	377	183	107	130	87	31	12	391
1964	----	----	----	--	---	---	---	---	---	---	---	--	297
1965	----	----	----	--	---	---	---	---	---	---	---	--	365
1966	1968	4900	4056	19	248	870	389	251	147	102	74	28	452
1967	1970	4774	3957	19	245	921	399	270	176	149	73	33	518
1968	1932	4744	3932	21	246	953	412	278	253	189	84	40	420
1969	1841	4635	3921	23	245	958	403	288	311	235	99	52	493
1970	1760	4655	3943	24	246	960	402	279	363	269	93	70	440
1971	1784	4516	3916	25	247	955	419	285	477	348	116	70	346
1972	1792	4450	3841	25	248	955	419	285	511	372	122	74	410
1973	1806	4349	3779	25	249	959	421	285	615	438	121	80	377
1974	1827	4301	3725	31	258	961	410	278	697	526	127	84	279

and it is generally characteristic of the construction in the study area, particularly between 1966 and 1974. Urban land increased from 3 to 11 percent of the Northwest Branch Anacostia River basin near Colesville between 1966 and 1974. Increases in urban land in the other study basins ranged from 0 percent of the Batchellors Run basin to 28 percent of the Manor Run basin.

The distribution of land use/land cover within the study basins is illustrated in plates 2 and 3. In 1966, construction for residential housing was concentrated near the business centers at Glenmont and Colesville. As the suburban area continued to expand, construction radiated from these points and became scattered throughout the basins except for the northern half of the Anacostia River basin, which remained essetially rural. The heaviest concentration of housing, other than in the two sites above, was at Norbeck, Olney, and Layhill. Construction in the North Branch Rock Creek basin was also concentrated near Norbeck and Olney. The runoff and sediment transport characteristics of Williamsburg Run, Manor Run, Lutes Run, and Bel Pre Creek reflect these land-use/land-cover changes.

STREAMFLOW

ANNUAL AND MONTHLY RUNOFF

Annual runoff in the Northwest Branch Anacostia River basin averaged 14.03 in (356 mm) between 1963 and 1974. Runoff was fairly consistent from year to year except for the exceptionally wet years in 1971 and 1972. It ranged from 8.51 in (216 mm) in 1969 to 29.50 in (749 mm) in 1972. Mean monthly runoff ranged from 0.56 in (14 mm) or 17 percent of mean monthly precipitation in September, to 1.72 in (44 mm) or 52 percent of mean monthly precipitation in March (fig. 3). Higher runoff rates in the late fall and winter and lower rates in the summer and early fall are generally

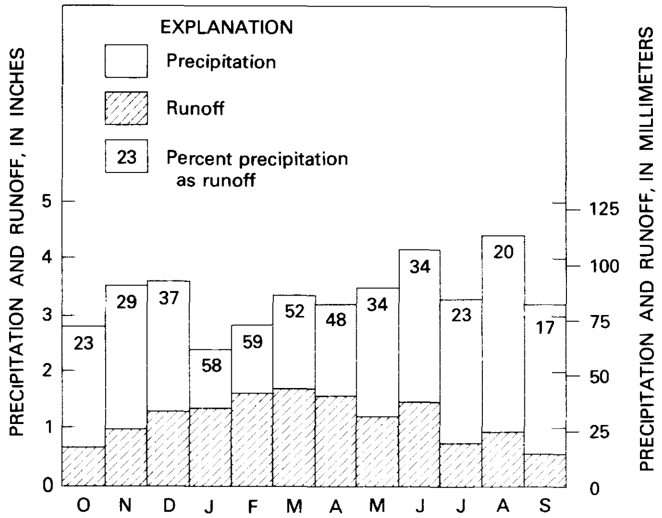


FIGURE 3.—Variation in mean monthly precipitation and runoff, Northwest Branch Anacostia River near Colesville, Md., October 1962–September 1974.

representative of the runoff regime of all the study basins and all streams in the Middle Atlantic States.

Runoff is directly related to the amount of rainfall, soil moisture, and ground-water levels. Snowmelt has no appreciable effect on the runoff regime in this area. The decline of streamflow in late spring and summer reflects the increase in evaporation and transpiration by plants. During the growing season, vegetation is constantly depleting soil moisture, which in turn reduces the amount of soil water available to percolate down to the water table. As ground-water levels decline, base flows in the streams decline. Direct runoff from thunderstorms in the summer is not an appreciable percentage of the total yearly runoff because most of the rain is absorbed by dry surface soils and only a small percentage of the precipitation becomes streamflow. Base flow and total streamflow begin to increase in the fall when the vegetation is dormant and evaporation is low. Base flow generally reaches maximum levels between January and March depending on the amount of fall and winter precipitation.

DURATION AND LOW FLOW

Another method of showing the distribution of runoff is the flow-duration curve. It is a cumulative frequency curve that shows the percentage of time that specific discharges were exceeded during a given period and shows the integrated effect of climatic, topographic, and geologic factors influencing the runoff characteristics of a stream (Searcy, 1959).

The three curves in figure 4 graphically illustrate flow duration of the Northwest Branch Anacostia River near Colesville for three periods: (*A*) 1923–39, 1961–74; (*B*) 1963–74; and (*C*) 1967–74. Curve *A* is for the period of record, except the years 1940 to 1960 when the flow in the Northwest Branch Anacostia River was augmented by pumpage for water supply from the Patuxent River basin. Curve *B* covers the period of daily sediment records in the Anacostia River basin, and curve *C* covers the period of intensive sampling at all sites in the study area.

The curves are similar for the range of discharge during the three periods. The 50-percent duration discharge, or the discharge that was exceeded 50 percent of the time, ranged from 11 ft^3/s (0.31 m^3/s) for 1963–74, to 13 ft^3/s (0.37 m^3/s) during 1967–74. The discharge that was exceeded 80 percent of the time for the three periods ranged from 6 to 7 ft^3/s (0.17 to 0.20 m^3/s). Similarly, the curves are virtually equal at the 1-percent duration. The only significant differences between the discharges for the three periods occur below 0.5 percent and above 80 percent. The departure below 0.5 percent reflects the magnitude of runoff during

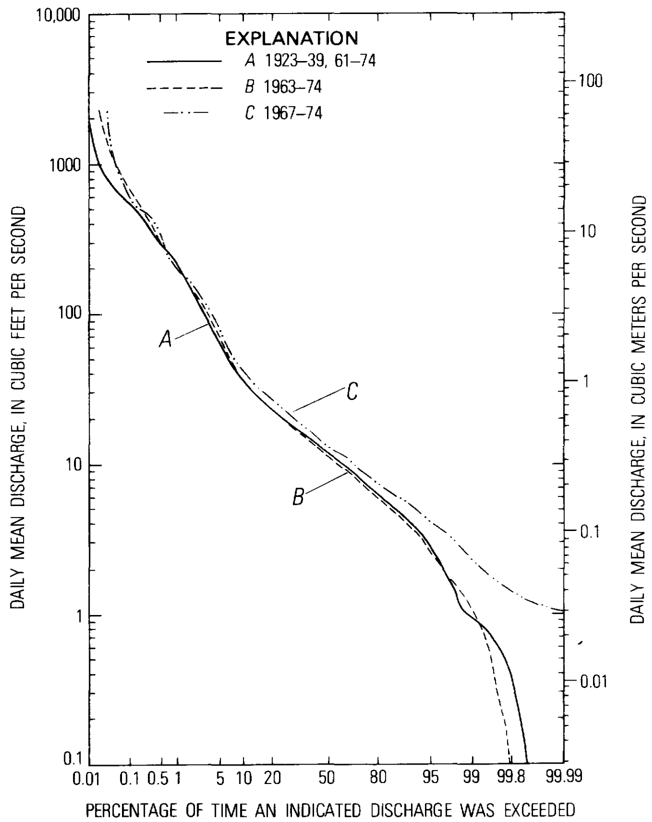


FIGURE 4.—Flow-duration curves for the Northwest Branch Anacostia River.

Hurricane Agnes (June 21–22, 1972) and differences in the length of record used for each curve. The departure of the curves above 80 percent illustrates the effect of severe droughts in the early 1930's and mid-1960's, which are reflected in curves *A* and *B*, but not curve *C*. The similarity of the curves in the medium and high discharge range, the discharges at which most of the sediment is transported, suggests there has been no change in the flow regime that would affect the sediment-transport characteristics of the stream.

Flow duration curves for the five small study basins with continuous streamflow records are shown in figure 5. Discharge was plotted as a unit value of $(ft^3/s)/mi^2$ $[(m^3/s)/km^2]$ to facilitate a comparison of the runoff characteristics of these basins. The wide variation of the curves illustrates the complex distribution of runoff from different drainage basins, even those in proximity. For example, the discharge that was exceeded 50 percent of the time varied from 0.3 $(ft^3/s)/mi^2$ $[(0.003\ m^3/s)/km^2]$ for Bel Pre Creek, to 1 $(ft^3/s)/mi^2$ $[(0.011\ m^3/s)/km^2]$ for Nursery Run. The variation at medium and high discharges probably reflects individual differences

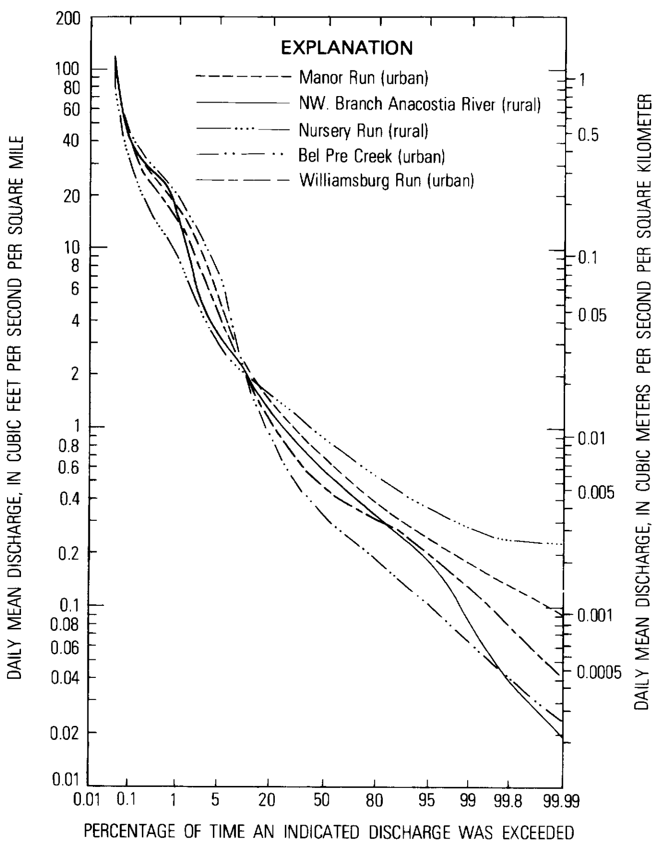


Figure 5.—Flow-duration curves for five small streams draining areas of different land use/land cover, 1967–74.

in basin response to precipitation that result from different soil, slope, and land-cover conditions. At low discharges, the divergence exhibited by the curves probably reflects the variability of the bedrock material and differences between the surface-water and ground-water basin divides in the individual drainage basins.

There is no consistent trend between land use and runoff characteristics evident from the curves except that the high discharges for the partly urban basins (Manor Run, Bel Pre Creek, and Williamsburg Run) tend to be slightly greater than for the rural basins (Nursery Run, North Branch Rock Creek, and Northwest Branch Anacostia River at Norwood). This difference would be expected since surface runoff from storms in urban areas will be higher because of the increase in impervious surfaces. Conversely, the median and low flow of streams draining urban areas would be expected to be lower because of reduced infiltration of precipitation to recharge soil moisture and ground-water levels. This assumption is not supported by the base-flow or low-flow part of the curves in figure 5. The curves scatter at the low discharge rates with no apparent relation to land use. Apparently, the type of bedrock and the distribution of ground water in the basins exhibit a stronger influence than land use on the low flow of the streams.

STORM RUNOFF AND FLOOD-PEAK DISCHARGES

Urbanization probably has the greatest impact on storm runoff and flood peaks. An increase in the amount of impervious area results in a greater percentage of the precipitation becoming surface runoff. Peak discharges are often increased because improvements in the drainage systems cause the surface runoff to concentrate faster. Differences between the storm runoff regimes of the rural and urban basins were evident in the study area.

The relations between storm runoff and precipitation for individual basins are shown in figure 6. Suspended-sediment samples from storms that occurred between 1971 and 1974 were used for determining the relations. This period was chosen in order to have sufficient storms representative of urban conditions. Storm runoff was determined as the total measured runoff minus the estimated base flow, which was defined as the discharge represented by the area below a straight line drawn from the point of initial rise to the point where the stage hydrograph approached a straight line. There are several more refined methods for hydrograph separation, but this simple procedure is probably suf-

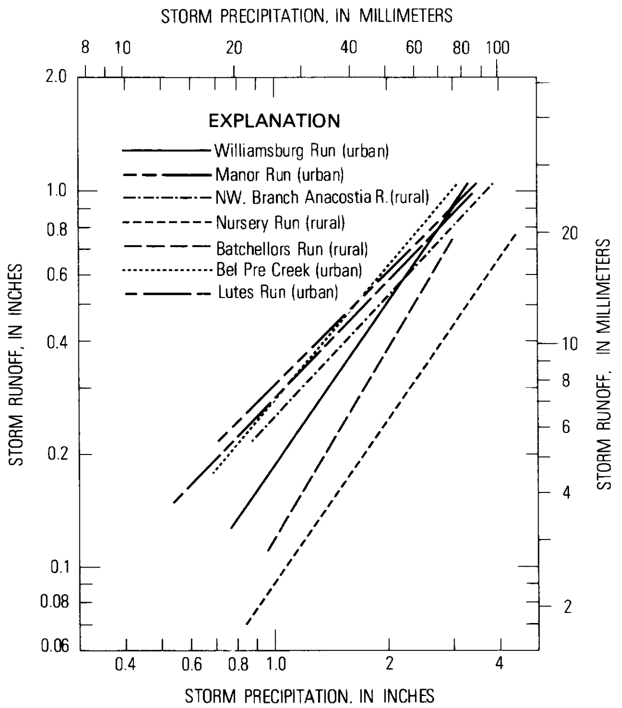


FIGURE 6.—Relation between storm runoff and precipitation for selected subbasins, 1971–74.

ficient for comparing differences in storm runoff between the basins.

The curves indicate that storm runoff was greater in the urban basins than in the rural basins. Runoff was highest in the Manor Run, Bel Pre Creek, and Lutes Run basins, which have the highest percentage of urban land. Runoff from the other urban basin, Williamsburg Run, was less than the runoff from the Northwest Branch Anacostia River, but considerably greater than the runoff from Nursery Run and Batchellors Run. The relatively high runoff from the Anacostia River basin may reflect the greater amount of cropland in the basin as compared with the other two rural basins. The general trend of greater storm runoff from urban basins is substantiated by an earlier study that compared storm runoff from the Bel Pre Creek basin before and after urban development (Yorke and Davis, 1972). In that study, it was found that storm runoff increased 30 percent as a result of urban construction in 15 percent of the basin.

Figure 6 also shows a tendency for the runoff of rural and urban basins to converge as storm size increases, reflecting a change in surface conditions during large storms. Much of the rain falling on pervious surfaces during small storms infiltrates into the soil or fills small depressions in the land surface; but as the storm size increases, the soils become saturated, and more and more of the rainfall becomes surface runoff. Virtually all the rain falling on impervious surfaces becomes runoff during both small and large storms; however, the relative contribution from impervious surfaces is greatest during the small storms when there is little runoff from pervious surfaces within the basins.

The impact of runoff from impervious surfaces is illustrated by the flood-frequency curves for five of the study basins (fig. 7). These curves are based on eight annual peak discharges, 1967–74, and should not be considered representative of constant land use or long-term climatic conditions; however, they do illustrate the effect of urban development in the basins. Normally, it would be expected that these curves would be parallel to each other, with the curves for the smaller streams plotting higher than those for the larger streams. The curves appear to be approaching a parallel condition for the higher recurrence interval peaks, but they diverge markedly for the more frequent floods. Each of the curves for the urban basins, Manor Run, Williamsburg Run, and Bel Pre Creek, has a flatter slope, indicating larger flood peaks than the rural basins for the more frequently occurring floods.

Although there are insufficient data, with respect to time and spatial variation, to permit a detailed quantitative analysis, trends detected are comparable with those determined during other studies of urbanization in the Piedmont. Anderson (1970) found significant increases in peak water discharges as a result of urbanization. He indicated that an increase in imperviousness alone could result in a doubling of the mean annual flood. If a small, steep basin were 100 percent impervious and completely sewered or channelized, the mean annual flood could be increased by a factor of 8 over that expected from a similar basin in its natural state. He further explained that the effect of these factors decreased as the recurrence interval of the peaks increased. For example, in the same basin the 50-year flood would be increased by a factor of 3.5 and the 100-year flood would be increased by a factor of 3. Putnam (1972) obtained similar results in the Piedmont streams in North Carolina. He found that flood-peak discharges increased by a factor up to 5, depending on the drainage-basin characteristics and the recurrence interval of the flood.

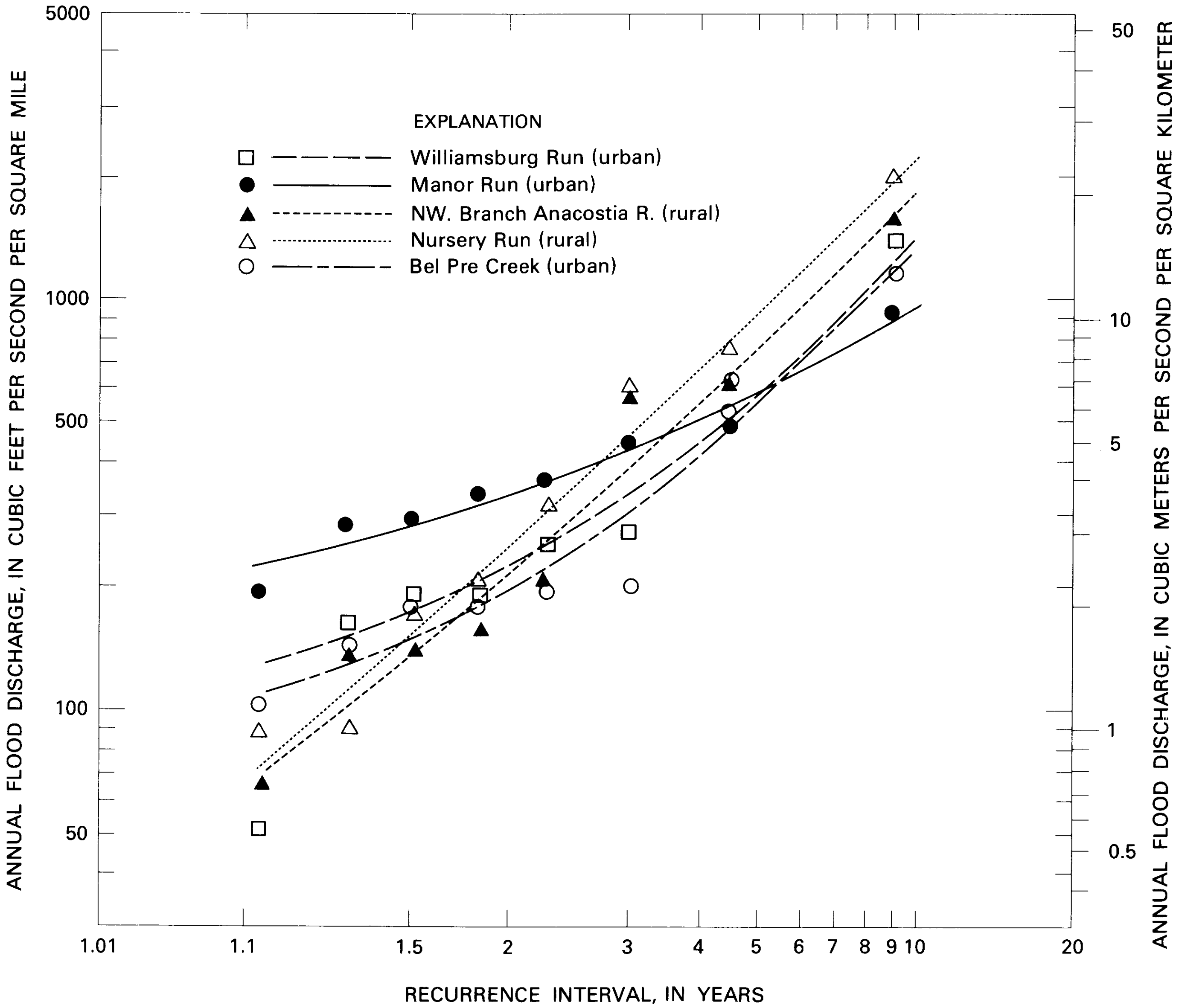


FIGURE 7.—Annual flood-frequency curves for selected subbasins, 1967–74.

SEDIMENT DISCHARGE

The total sediment discharge of a stream can be divided into two principal components: (1) the discharge transported through the stream system suspended in the runoff waters, called the wash or suspended load, and (2) the discharge transported by rolling, sliding, or skipping along the bottom of the stream, called the bedload. The suspended load consists of fine sediment particles and the discharge is dependent on the amount of material available for transport from sediment-source areas. The bedload generally consists of coarse sediment particles in the streambed that are moved at transport rates dependent on the competence of the stream.

ANNUAL AND MONTHLY SUSPENDED-SEDIMENT DISCHARGE

Suspended sediment transported from the Anacostia River basin averaged 14,800 tons (13,400 t) per year between 1963 and 1974. The annual discharge ranged from 5,500 tons (5,000 t) in 1974, to 31,000 tons (28,100 t) in 1972 (table 3). The exceptionally high sediment discharge in 1972 resulted from the high runoff and flooding during Hurricane Agnes in June. The suspended-sediment discharge transported during June 21–22 was 12,800 tons (11,600 t), which was greater than several previous annual discharges. Generally, wet years had high annual discharges and dry years had low annual

TABLE 3.—*Monthly and annual water and suspended-sediment discharge, Northwest Branch Anacostia River near Colesville, Md., 1963–74*

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
						Water discharge, in cubic feet per second-days							
1963	149.8	521.7	304.5	565.8	553.9	1,276.8	361.3	267.2	771.5	121.7	317.4	176.2	5,387.8
1964	117.0	807.3	448	1,531	871	998	976	485.3	263.1	151.9	116.6	79.4	6,844.6
1965	134.8	193.9	513.4	609.6	619.7	1,297	527	328.4	204.7	148.3	349.0	143.0	5,068.8
1966	526.9	160.4	158.4	226.2	1,153.7	505.4	650.9	530.3	548.3	401.8	1,724.9	627.1	10,757.3
1967	576.0	305.0	451.6	595	514.5	1,266	467	669	302.1	309.4	1,122	161.1	6,738.7
1968	227.1	267.5	1,114.7	947	370.6	989.6	440	633.1	680.0	298.5	105.1	123.9	6,188.1
1969	177.8	445.2	403.8	362.2	453.9	457.7	337.8	283.4	338.3	280.2	919.8	365.3	4,825.4
1970	215.9	309.9	1,024	665.8	784	673	1,559	759	693.9	882.0	321.5	167.8	8,055.8
1971	225.6	877.3	718.5	717	2,149.8	867	716	1,184	548.3	401.8	1,724.9	627.1	10,757.3
1972	1,132.0	1,149.0	789.0	884	2,027	1,340	1,556	1,382	4,244	1,403	530.6	296.3	16,732.9
1973	421.1	1,434.0	1,768	1,064	1,189	1,049	2,091	1,076	862	799.2	401.1	325.9	12,480.3
1974	314.7	261.1	1,260.8	1,016	509	1,088	867	557.8	475.1	172.2	284.1	425.7	7,231.5
Mean	351.55	561.02	746.22	765.3	933.01	983.96	879.08	679.62	797.32	419.37	518.61	319.0	7,954.1
						Suspended-sediment discharge, in tons							
1963	38.1	655.6	14.2	317.8	1,038.9	2,967.2	6.5	24.3	6,331.6	24.5	4,573.1	818.8	16,811.4
1964	3.0	2,994.9	326.6	5,141.5	835.6	700.7	885.0	68.3	62.2	153.7	309.9	114.9	11,596.3
1965	23.0	511.4	1,702.3	665.9	2,444.7	5,446.9	21.7	47.3	68.9	669.1	4,113.0	175.1	15,889.1
1966	3,042.2	0.6	2.3	45.1	4,354.2	192.6	1,091.2	978.4	51.0	105.2	68.0	4,471.2	14,402.0
1967	2,102.6	173.0	60.2	609.8	207.4	3,148.1	26.0	1,152.5	706.7	1,268.0	5,543.1	11.9	15,009.3
1968	344.33	135.29	2,255.50	812.82	62.62	1,561.52	45.62	1,550.84	2,758.80	600.97	5.44	364.71	10,498.46
1969	123.64	330.37	193.01	200.18	233.95	34.79	8.68	797.29	2,593.77	570.88	3,668.42	703.60	9,458.58
1970	84.80	100.49	1,925.36	88.37	684.68	121.61	3,823.02	2,753.00	3,652.57	3,253.04	560.71	222.58	17,270.23
1971	124.62	1,248.46	512.86	133.38	6,405.08	243.81	146.90	1,963.48	224.27	966.43	3,847.01	737.62	16,553.92
1972	2,209.38	1,179.91	191.90	95.72	4,325.41	1,380.66	1,936.92	1,538.62	14,529.45	2,955.40	635.75	10.15	30,989.27
1973	320.92	1,752.89	904.69	487.74	852.71	482.22	4,109.69	379.65	1,549.86	1,894.77	216.83	188.71	13,140.68
1974	66.80	7.29	1,614.01	406.37	36.79	1,744.16	278.05	458.55	158.49	60.48	445.64	225.42	5,502.05
Mean	706.95	757.52	808.58	750.39	1,790.17	1,502.02	1,031.61	976.02	2,723.97	1,043.54	1,998.91	670.39	14,760.11

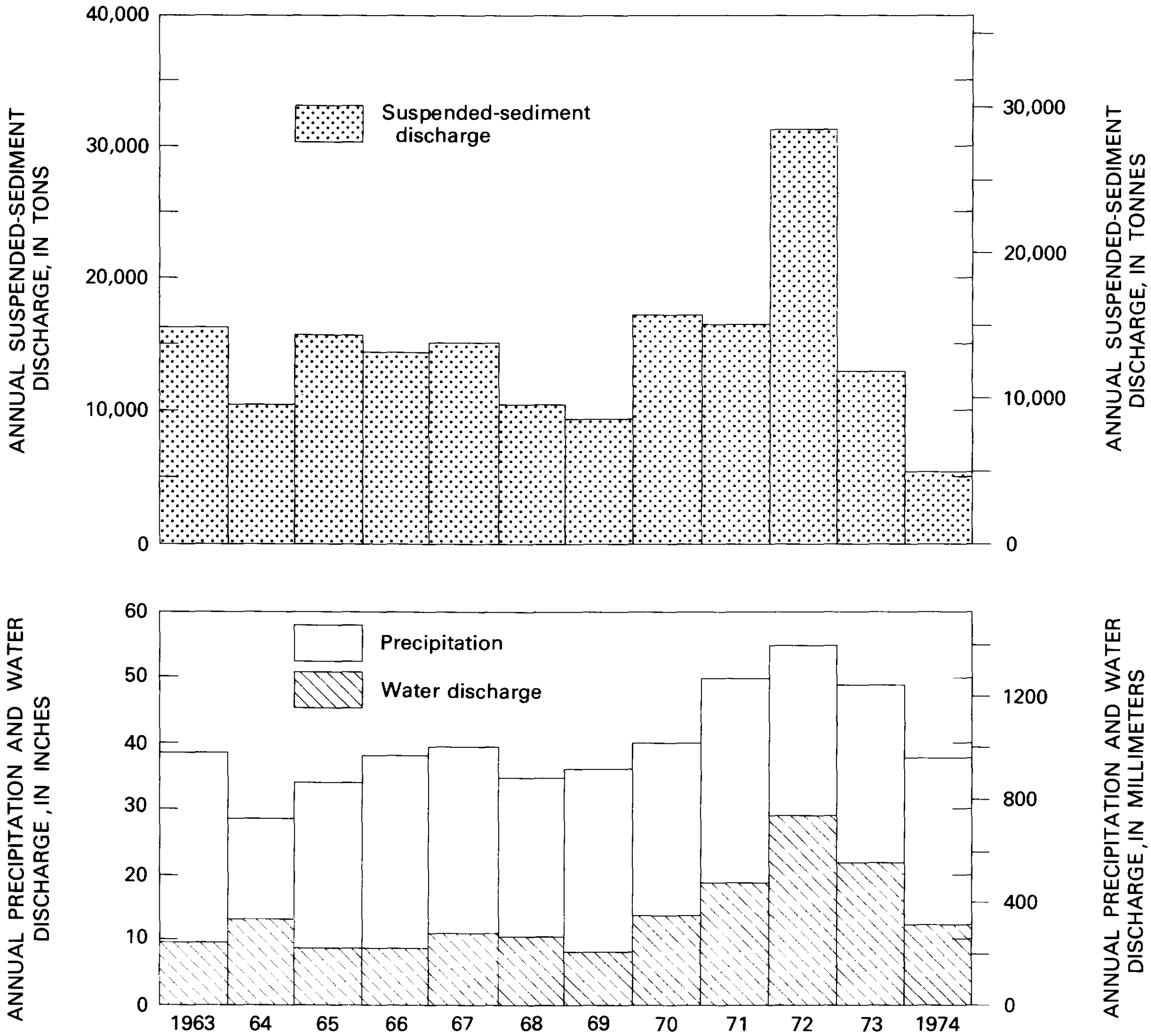


FIGURE 8.—Annual variation of precipitation, water discharge, and suspended-sediment discharge, Northwest Branch Anacostia River near Colesville, 1963–74.

discharges (fig. 8); however, a decreasing trend in suspended-sediment discharge with time was also apparent. This decrease in sediment discharge, as it relates to land use and sediment control, will be discussed in detail in later sections of this report.

Most suspended sediment was transported during large storms, as indicated by the duration curve of suspended-sediment discharge (fig. 9). Daily sediment discharge was greater than 100 tons/d (91 t/d) 5.7 percent of the time or 252 days for the 12 years of record shown on figure 9. The sediment discharge for those 252 days represents 94 percent of the sediment discharged during the 12-year period. Sediment discharges of 500 and 1,000 tons/d (454 and 907 t/d) were exceeded 2.2 and 1.0 percent of the time and represented 73 and 54 percent of the total. The quantity of sediment carried during storms, particularly large storms, is a significant factor that must be considered in any program designed to control erosion and sediment transport. If controls such as diversion berms and sediment basins are underdesigned, a large part of the total sediment eroded from construction sites will still reach the streams.

The seasonal variation of suspended-sediment discharge is another factor affecting sediment control. Sediment discharge is generally higher between February and August than it is between September and January. The average monthly load for the period 1963–74 ranged from 670 tons (609 t) in September, to 2,700 tons (2,400 t) in June (fig. 10). A comparison of the 1963–74 and the long-term precipitation in figure 2, indicates that lower monthly loads would be expected in November, December,

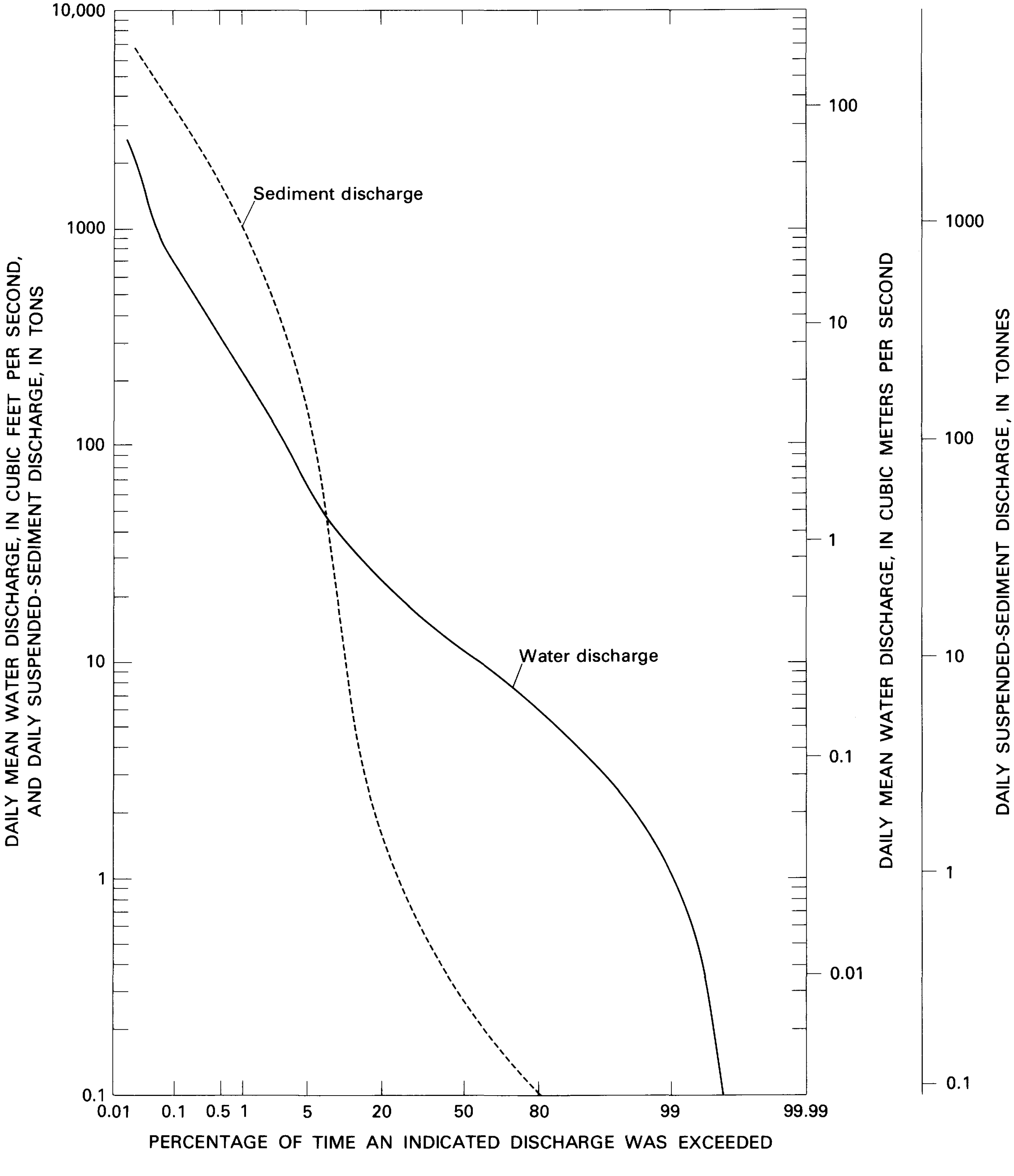


FIGURE 9.—Duration of water discharge and suspended-sediment discharge, Northwest Branch Anacostia River near Colesville, 1963–74.

and June, and higher loads would be expected in January, July, and August. With the slight adjustments to figure 10 considered, the distribution of sediment discharge compares favorably to the distribution of erosion index values for the Atlantic coast area (Guy, 1964). The erosion index is highest in

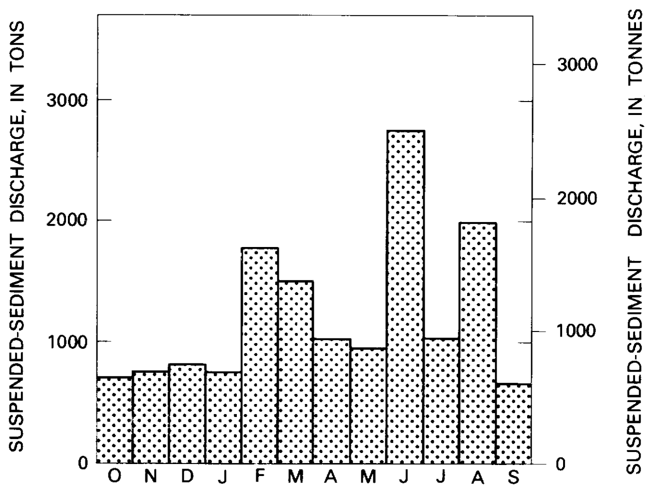


FIGURE 10.—Mean monthly suspended-sediment discharge, Northwest Branch Anacostia River near Colesville, 1963–74.

June, July, and August and decreases to lowest in December and January.

The variation of erosion potential and sediment discharge during the year creates an opportunity for an effective method of sediment control. Scheduling construction activities to coincide with the period of low erosion potential should result in a significantly lower sediment discharge. It is not possible or practical to restrict all grading and heavy earthmoving to the period between September through January, but it may be possible to schedule a major part of the grading on critical areas of construction sites during this period of low erosion potential. If major grading work were completed in the fall and protective measures were installed by midwinter, there would be protection during the high runoff in early spring and during the intense storms in the summer. Also, if construction activities were completed and critical sites were stabilized before the high-erosion periods, less intensive control measures would be required on the remainder of the construction area, resulting in an overall reduction in costs.

SIZE DISTRIBUTION OF SUSPENDED SEDIMENT

The size distribution of suspended sediment transported by a stream is an indicator of the sediment-source material and the competence of the stream. In the Northwest Branch Anacostia River near Colesville, suspended sediment transported during medium and high flows averaged 20 percent sand, 45 percent silt, and 35 percent clay (table 4). This approximates the distribution of particles in the predominant silt-loam and silty clay-loam soils found in the basin. The general relationship between water discharge and its capability to transport particles of various sizes in suspension is illustrated by the curves in figure 11. At low discharges, the suspended sediment is composed mostly of silt and clay. As the discharge increases, the percentage of the total suspended-sediment load consisting of silt and clay generally decreases, while the percentage consisting of sand increases.

The large scatter of points about the generalized relationships in figure 11 probably represents differences in the type and amount of sediment eroded from various sediment-source areas and the distance between the source areas and the sampling sites. The

TABLE 4.—*Particle-size distribution of suspended sediment, Northwest Branch Anacostia River near Colesville, Md. 1960–73*

Date	Water discharge (ft^3/s)	Suspended-sediment concentration (mg/l)	Suspended-sediment discharge (tons/day)	Percent suspended-sediment in size class		
				Sand	Silt	Clay
Sept. 12, 1960	628	895	1,520	27	62	11
Feb. 26, 1962	247	1,480	987	38	41	21
Mar. 12, 1962	788	1,080	2,300	30	51	19
June 3, 1963	141	4,700	1,790	17	52	31
Aug. 13, 1963	73	15,100	2,980	7	53	40
Oct. 7, 1965	662	8,590	15,400	20	44	36
Feb. 13, 1966	662	5,070	9,060	36	38	26
May 19, 1966	50	9,830	1,330	3	44	53
June 22, 1967	213	9,460	5,440	6	46	48
July 22, 1969	895	3,520	8,510	8	43	49
Apr. 2, 1970	71	198	38	6	21	73
Apr. 14, 1970	338	2,000	1,820	35	34	31
Oct. 21, 1970	169	2,070	945	17	55	28
July 29, 1971	197	3,700	1,970	14	45	41
Aug. 27, 1971	790	2,610	5,570	27	47	26
Nov. 29, 1971	213	836	423	24	44	32
Feb. 3, 1972	626	2,360	4,000	21	50	29
Feb. 2, 1973	376	1,660	1,690	24	45	31
Dec. 26, 1973	405	1,140	1,250	36	33	31
Sediment discharge-weighted average	---	----	----	20	45	35

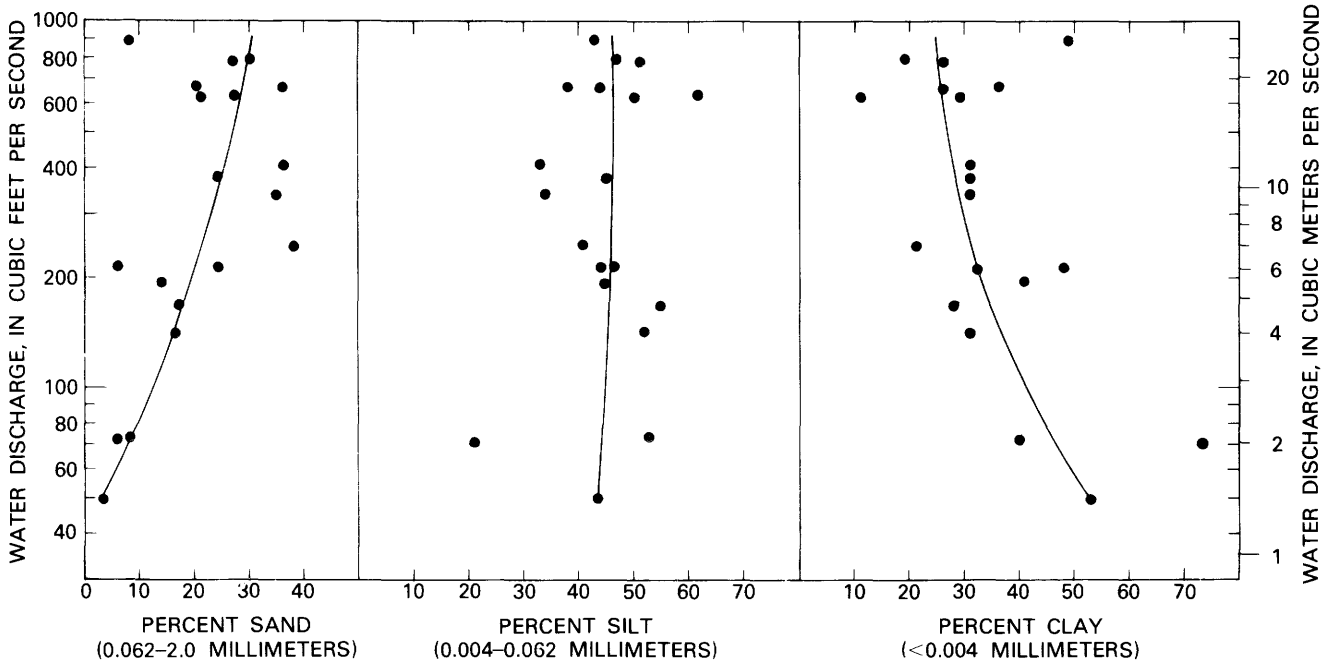


FIGURE 11.—Relation of sand, silt, and clay content of suspended sediment to water discharge, Northwest Branch Anacostia River near Colesville, 1960–73.

first storms after cropland or construction sites have been opened will generally erode and transport large quantities of fine (silt and clay) particles completely through the stream system. During these first few storms, the larger sand particles, eroded by the impact of rain on the bared soils or by runoff from the land surface, are generally deposited at some place on the site or in the stream channel near the point of erosion. Subsequent storms will continue to erode fine soil particles and also lift the heavier sand particles and redeposit them at some point farther downstream. If the surface soils are not reworked to expose new sources of fine sediments, the surface soils will gradually become armored with the remaining large particles. Thus, fewer fine particles will be available for transport, and sand particles will represent a greater percentage of the suspended load.

An increase in the sand percentage of suspended sediment can also be expected after construction areas have been stabilized with vegetation. A dramatic reduction in the total load occurs when active source areas are stabilized; however, large quantities of sand previously eroded from construction sites and deposited in stream channels are still available for transport. This is illustrated by the distribution of sand, silt, and clay transported during medium and high flows in the small study basins (fig. 12). Generally, the urban streams transported a higher percentage of sand than the rural basins. The suspended load ranged from 7 percent sand for Batchellors Run to 28 percent sand for Lutes Run. The higher levels of sand in the suspended load of urban streams can be expected to continue until a new equilibrium is established between the runoff regime, channel size, and bed material.

BEDLOAD CONTRIBUTION

Bedload was not measured directly during this study; however, the approximate range of its magnitude was computed for the Northwest Branch Anacostia River near Colesville, using the Schoklitsch and Meyer-Peter and Muller bedload formulas. Composite bed-material samples from several cross sections and discharge measurements ranging from 20 to 800 ft^3/s (0.57 to 22.7 m^3/s) were used for the computations.

The Meyer-Peter and Muller formula converted to English units by the U.S. Bureau of Reclamation (Sheppard, 1960) is

$$G_s = 1.606\ B\ \left[3.306\left(\frac{Q_s}{Q}\right)\left(\frac{D_{90}{}^{1/6}}{n_s}\right)^{3/2} dS - 0.627 D_m\right]^{3/2}$$

where

G_s = total bedload discharge, in tons per day;
B = bottom width of stream channel, in feet;

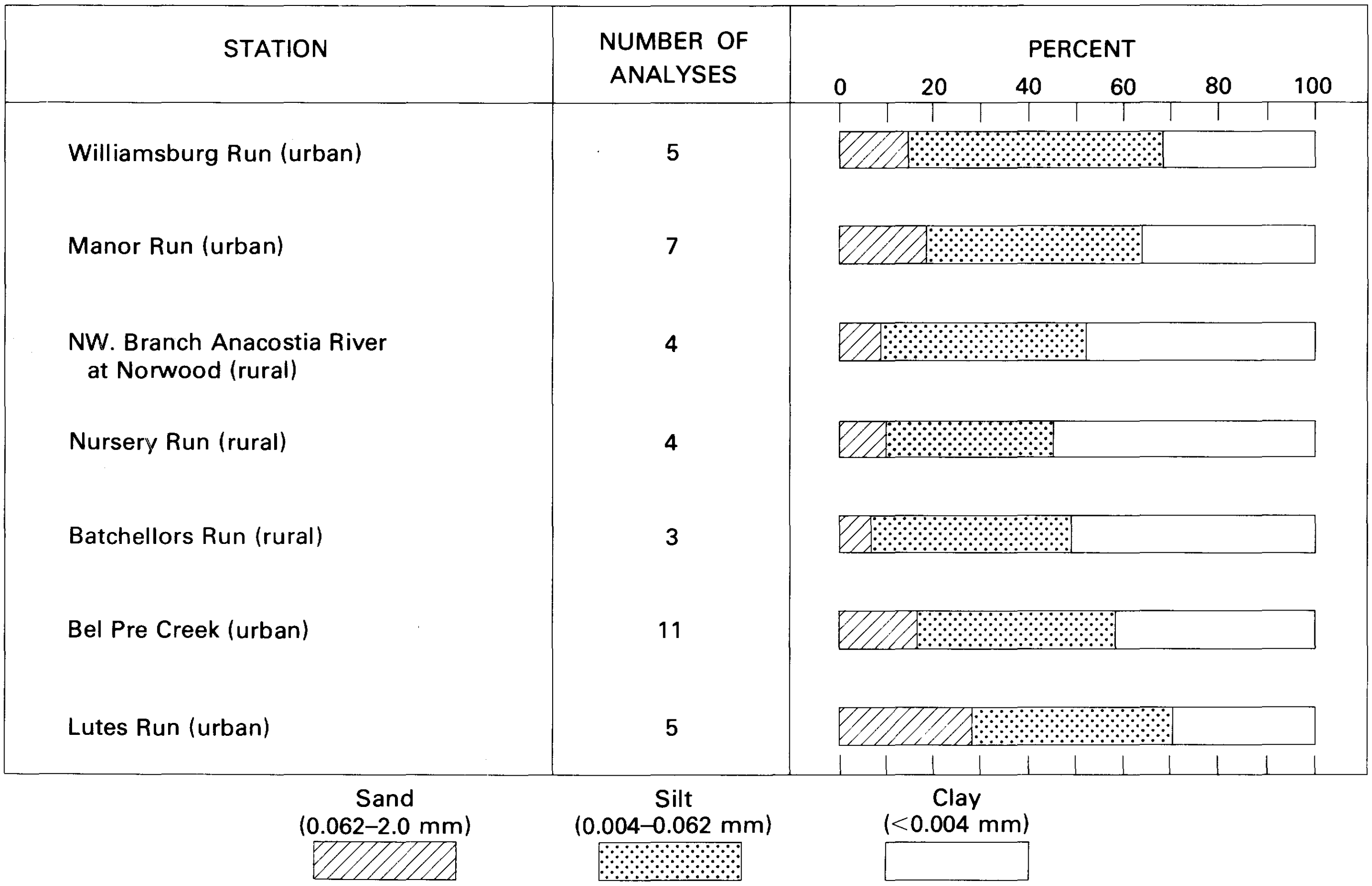


FIGURE 12.—Particle-size distribution of suspended sediment transported during medium and high flows in the small study basins, 1967–74. Values are sediment-discharge weighted averages.

Q_s = the water discharge determining the bedload, in cubic feet per second;
Q = total water discharge, in cubic feet per second;
D_{90} = particle size at which 90 percent of the bed material is finer, in millimeters;
n_s = Manning's roughness coefficient for the streambed;
d = depth of flow, in feet;
S = slope, in feet per foot, and
D_m = effective size of bed material, in millimeters.

$$D_m = \frac{\Sigma D \Delta p}{100}$$

where D is the geometric mean diameter of particles in a given size fraction and p is the percent by weight in that size fraction.

The nomographs and standard computation forms prepared by the U.S. Bureau of Reclamation were used for the computations.

The Schoklitsch bedload formula for bed material of uniform grain size, adapted from the English conversion by Shulits (1935), is

$$g_n = \frac{3745}{D_{50}^{1/2}} S^{3/2} \left(Q - \frac{0.00532 w D_{50}}{S^{4/3}} \right)$$

where

g_n = bedload discharge of particles in given size fraction, in tons per day;
D_{50} = median diameter of bed material particles, in inches;
S = slope of the energy gradeline, in feet per foot;
w = width of the stream, in feet, and
Q = total water discharge, in cubic feet per second.

The bed material was divided into uniform size fractions and the bedload was computed for each fraction. The total bedload discharge was computed by the formula

$$G=\frac{a_1g_1+a_2g_2+***a_ng_n}{100}$$

where

G=total bedload discharge, in tons per day, and

a_n=percent of bed material in size fraction.

Bedload transport curves computed by the two formulas and the average suspended-sediment transport curve for the period of record are shown in figure 13. The average annual bedload discharges computed for the 1963–74 period were 990 and 2,290 tons/yr (900 and 2,080 t/yr) for the Meyer-Peter and Muller and the Schoklitsch methods, repectively. Computed bedloads were 6 and 13 percent of the total sediment discharge for the same period. Bedload discharges for other streams in the study area were not computed; however, since the bed material and channel characteristics of the other streams in the study area were similar to those of the Northwest Branch Anacostia River, the bedloads probably represent about the same percentage of the total load. With other conditions affecting bedload being equal, the bedload probably would be slightly less in streams draining rural areas and slightly higher in urban streams because of the greater availability of sand-size particles in the urban streams.

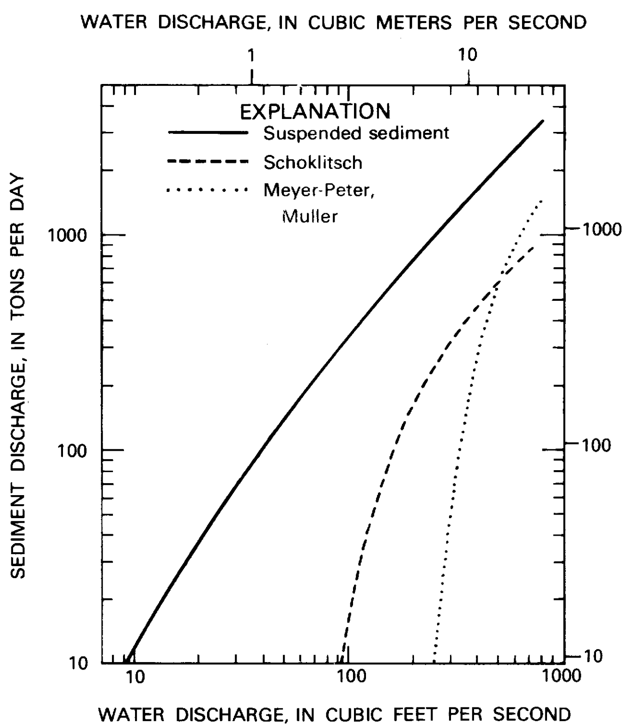


Figure 13.—Daily suspended-sediment and instantaneous bedload transport curves for the Northwest Branch Anacostia River near Colesville, 1963–74.

STORM VARIABILITY

The sediment discharge of a stream is highly variable from year to year, season to season, and storm to storm. Many factors affect the erosion of soil particles and transport of sediment to the stream system. Guy (1964) analyzed variables affecting storm-sediment loads for seven Atlantic coast streams with drainage areas ranging from 98.4 to 4,571 mi^2 (255 to 11,840 km^2). The variables that significantly affected sediment discharge included storm runoff, long-term mean air temperature as a measure of season, rainfall intensity, and a peakedness index.

The number of small drainage basins and the varying land use/land cover within the basins in this project provided an opportunity to expand on Guy's study to determine if the sediment-water discharge characteristics of urbanizing basins respond differently to various storm variables than the characteristics of rural basins. A total of 16 hydrologic variables or related factors was determined for each subbasin studied in the Rock Creek and Anacostia River basins. These variables are:

Storm suspended-sediment discharge (Q_s) — total suspended-sediment discharge transported during the runoff period, in tons.

Total runoff (Q_t) — total runoff during days of surface runoff, in cubic feet per second-day.

Storm runoff (Q_r) — total runoff minus estimated base flow, in cubic feet per second-day. (Base flow was estimated as the runoff below a straight line drawn from the point of initial rise to the point where the recession limb of the hydrograph approached a straight line.)

Peak discharge (Q_p) — instantaneous peak discharge, in cubic feet per second.

Antecedent discharge (Q_a) — mean daily discharge the day before the initial rise, in cubic feet per second.

Antecedent days (A_d) — the number of days between storms.

Total precipitation (R_t) — Average precipitation on the drainage basin, in inches, as

	determined by isohyetal maps for each storm, except as noted.
Rainfall intensity	maximum rainfall during a given interval, as determined from the closest available recording-rain gage:

R_{05}—maximum 5-min rainfall, in inches per hour.
R_{15}—maximum 15-min rainfall, in inches per hour.
R_{30}—maximum 30-min rainfall, in inches per hour.
R_{1h}—maximum 1-hr rainfall, in inches per hour.
R_{3h}—maximum 3-hr rainfall, in inches per hour.

NOTE.—The 5-min, 15-min, 30-min, and 1-hr rainfall intensities were determined for the Lutes Run basin. The 3-hr rainfall was substituted for the 5-min rainfall for the other seven basins.

Number of peaks (N_p)	number of peaks during storm.
Time (T_m)	number of months between the beginning of the record and the storm.
Construction (C_p)	percentage of basin area under active construction at the time of the storm.
Sediment concentration (C)	discharge-weighted mean sediment concentration.

$$C=\frac{370.37\ (Q_s)}{Q_r}$$

Peak ratio (P_r)	approximated as:

$$P_r=\frac{Q_p-Q_a}{Q_r}$$

The basic data compiled for each station are listed in table 5. The storms, which range in number from 26 for Batchellors Run to 93 for Williamsburg Run, represent all storms for which sediment sampling was adequate to define the sediment concentration for the period of storm runoff.

A stepwise multiple-regression model was selected to evaluate the effects of the different storm variables on sediment discharges. The output consists of a simple correlation matrix of all selected variables and a series of multiple-regression equations. In the first step of the regression program, all the variables are included in the computations. In subsequent steps, the variable with the least significant partial-regression coefficient in the preceding equation is eliminated from further computations. The elimination and recomputation continues until one independent variable remains.

In order to meet the assumptions of a linear regression model, hydrologic data generally have to be transformed to logarithms. A review of the study by Guy (1964) and a partial graphical analysis of data used in this study indicated that the following transformations were required: log Q_s, log Q_r, log Q_p, log $(10\times Q_a)$, log $(10\times R_t)$, log $(10\times R_{05})$, log $(10\times R_{15})$, log $(10\times R_{30})$, log $(10\times R_{1h})$, log $(10\times R_{3h})$, log C, and log P_r. Antecedent runoff and the rainfall factors were multiplied by 10 before conversion to simplify the logarithmic expression of the original values.

CORRELATION MATRIX

Simple correlation matrices of all selected variables for each station are summarized in table 6. These matrices were examined with three objectives: to investigate any bias caused by changes in sampling procedures or climatic conditions, to determine the degree of relation between the dependent variables (sediment discharge and sediment concentration) and the independent variables, and to determine the intercorrelation of the independent variables. The relation between time in months (hereafter referred to as the chronology factor) and the other independent variables was used as an indicator of a climatic or sampling bias during the study period.

An examination of the correlation between chronology and total storm rainfall indicated that there had been no significant change in the magnitude or intensity of the sampled rainfall events during the study period. Lutes Run was the only exception, exhibiting a highly significant (99 percent confidence level) negative correlation between chronology and total precipitation. Apparently, more smaller storms were sampled toward the end of the study period as a result of an improvement in equipment and techniques at the Lutes Run automatic pumping sampler.

In spite of the nonsignificant correlation between chronology and total storm precipitation for individual storms, there was a generally positive correlation between chronology and net storm discharge. Correlations were significant at the 95-percent confidence level for Williamsburg Run, Manor Run, and Northwest Branch Anacostia River. The positive correlations were probably related to the significant positive correlations between chronology and antecedent discharge, which reflected a trend toward wetter years at the end of the study. This interpretation was supported by the precipitation records for stations near the project area, which indicated an increase in average annual precipitation of about 10 inches (250 mm) during the second half of the sample period. Apparently, there were more storms and a shorter time between storms near the end of the project, resulting in higher soil moisture levels and higher base flows at the beginning of each storm.

Lutes Run and Bel Pre Creek, draining the two most extensively urbanized basins in the study area, were the only streams exhibiting significant positive correlation between chronology and peak ratio. This relationship indicated that the ratio of peak discharge to storm discharge had been increasing, probably as a result of the effects of increased impervious area and storm sewers in these basins. In the Lutes Run basin, the smaller storm size and disproportionate number of summer storms in 1973 and 1974 also contributed to the significant positive correlation between chronology and peak ratio. Summer storms with low runoff volumes generally have a single peak of relatively short duration, resulting in a high peak ratio.

The effect of each independent variable on suspended-sediment discharge and sediment concentration was evaluated in subsets to facilitate comparison between basins. Basins were considered as urban or rural and small or large. Basins with less than 10 percent of the area in urban residential or public-commercial were considered rural and the others were considered urban. The urban basins generally had active construction sites throughout the study period. Basins were classified as small or large depending on whether their drainage areas were less than or greater than 1.5 mi^2 (3.9 km^2).

The relation between each independent variable and both suspended-sediment discharge and sediment concentration was generally consistent. If the variable had a significant positive correlation with sediment discharge, it also had the same relation with sediment concentration. The only exception was storm runoff. There was no consistent trend between sediment concentration and storm runoff for the basins; however, there was a highly significant positive relation between suspended-sediment discharge and storm runoff. This was expected as runoff transports suspended sediment.

Other variables with a significant positive relation with suspended-sediment discharge were peak water discharge, total precipitation, and intensity parameters. These were significant for both small or large and rural or urban basins. The chronolgy factor and percentage construction were only significant for the urban basins. That there was no significant correlation between chronolgy and sediment discharge in the rural basins was further evidence that the sediment data were not biased by changes in sampling or climatic conditions.

Antecedent discharge, antecedent days, and peak ratio affected suspended-sediment discharges differently in the large and small basins. Sediment discharge had a significant positive correlation with antecedent water discharge and a significant negative correlation with antecedent days on the large basins. The relations were insignificant at the 95 percent confidence level on the small basins. This difference between the large and small basins was probably the result of a higher correlation between runoff volume and sediment discharges for the large basins. The sediment discharge from small basins was less affected by runoff volume and more dependent on the intensity or concentration of runoff. This was illustrated by the significant correlation between peak ratio and suspended-sediment discharge for the small basins.

A number of independent variables were found to be significantly correlated with each other. In particular, the correlations between the rainfall intensity parameters were highly significant. Correlations between rainfall parameters, peak discharge, and peak ratio were also high. A generally negative correlation existed between antecedent discharge and rainfall intensity. This correlation was apparently a reflection of the seasonal variation of storms, that is, of the occurrence of intense convective storms during the growing season when the base flow is generally lower than during the dormant season. Because of the intercorrelation of these variables, the regression model was set up so that these variables would not be considered simultaneously. As many as 10 runs of the model were made for each basin so that the effect of each of these variables could be evaluated without the influence of the other highly correlated independent variables.

REGRESSION EQUATIONS

The computer analyses of various combinations of independent variables produced regression models of the form

$$\log\ Q_s = b_0 + b_1 x_1 + b_2 x_2 + {*}{*}{*} + b_n x_n$$

where

Q_s = suspended-sediment discharge;

b_0 = regression constant;

b_1 = regression coefficient for the corresponding variables (x_n).

TABLE 5.—*Hydrologic characteristics and related factors for*

Period of storm runoff	Total runoff (Q_t) (ft³/s-d)	Storm runoff (Q_r) (ft³/s-d)	Mean sediment concentration (C) (mg/l)	Suspended-sediment discharge (Q_s) (tons)	Peak discharge (Q_p) (ft³/s)	Antecedent discharge (Q_a) (ft³/s)
						Williamsburg Run near
1966						
Nov. 28–29	7.40	5.00	644.44	8.70	20.0	1.00
1967						
Jan. 7– 9	14.00	6.20	436.08	7.30	17.0	1.70
Jan. 27–28	15.00	11.00	6,632.98	197.00	71.0	1.40
Mar. 6– 8	70.00	62.00	2,514.93	421.00	242.0	2.40
May 7– 8	19.00	15.00	1,604.94	65.00	51.0	1.30
Aug. 3– 5	22.00	20.00	7,296.28	394.00	127.0	.59
Aug. 24–25	60.00	58.00	1,749.68	274.00	424.0	.68
Oct. 10–11	2.10	.83	267.74	.60	6.7	.57
Oct. 25–26	4.50	2.70	1,248.28	9.10	26.0	.65
Nov. 2– 3	5.80	4.20	1,146.38	13.00	19.0	.69
Dec. 10–12	30.00	23.00	1,127.21	70.00	48.0	1.40
Dec. 28–29	25.00	20.00	425.93	23.00	64.0	1.70
1968						
Jan. 14–15	51.00	46.00	418.68	52.00	118.0	.98
Mar. 17–18	25.00	18.00	2,386.83	116.00	46.0	3.20
Apr. 24–25	5.30	2.10	617.28	3.50	11.0	1.10
May 27–29	38.00	33.00	1,010.10	90.00	84.0	.90
June 19–20	12.00	8.50	3,485.83	80.00	69.0	1.40
June 26–28	20.00	16.00	2,824.07	122.00	70.0	.98
Aug. 19–20	2.20	1.40	3,174.60	12.00	15.0	.34
Sept. 6	1.40	1.20	864.20	2.80	9.6	.17
Sept. 10–11	6.80	6.20	3,166.06	53.00	46.0	.18
Nov. 18–19	12.00	9.10	651.20	16.00	34.0	1.10
1969						
Jan. 21	6.20	5.00	585.18	7.90	15.0	.98
Feb. 24	8.20	4.20	520.28	5.90	20.0	6.20
May 20–21	3.30	1.30	1,054.13	3.70	9.1	.77
June 2– 3	13.00	12.00	1,141.97	37.00	96.0	.47
June 18–19	11.00	9.80	1,700.68	45.00	90.0	.40
July 20–21	8.20	7.60	1,023.39	21.00	75.0	.17
July 22–23	23.00	21.00	1,005.29	57.00	246.0	.66
Aug. 1– 4	49.00	45.00	1,045.27	127.00	606.0	.47
Aug. 9–10	33.00	31.00	800.48	67.00	259.0	.69
Aug. 18	22.00	21.00	1,022.93	58.00	118.0	.69
Sept. 3– 4	44.00	42.00	740.74	84.00	331.0	.78
Oct. 2	4.30	3.60	1,337.45	13.00	36.0	.60
Nov. 19–20	7.30	5.50	875.42	13.00	62.0	.61
Dec. 7– 8	5.50	3.60	627.57	6.10	45.0	.61
Dec. 10–11	24.00	21.00	776.01	44.00	105.0	1.00
Dec. 22–23	14.00	11.00	606.06	18.00	43.0	.90
1970						
Apr. 14–15	63.00	57.00	1,098.11	169.00	210.0	1.40
May 13–14	18.00	14.00	1,693.12	64.00	103.0	1.90
May 24–25	23.00	19.00	1,423.00	73.00	134.0	1.20
June 16–17	7.10	4.80	2,083.33	27.00	61.0	.85
June 21–22	17.00	15.00	3,012.34	122.00	112.0	.93
July 9–10	31.00	29.00	1,123.88	88.00	194.0	.68
July 20–21	44.00	41.00	1,056.91	117.00	427.0	.70
Sept. 10–11	6.00	4.60	3,462.15	43.00	67.0	.59
Nov. 3	4.20	3.40	871.46	8.00	26.0	.67
Nov. 4– 5	40.00	37.00	950.95	95.00	155.0	4.20
Nov. 14–15	22.00	18.00	1,008.23	49.00	90.0	1.50
Dec. 16–17	14.00	11.00	1,144.78	34.00	57.0	1.00
Dec. 22	18.00	15.00	691.36	28.00	69.0	1.20
1971						
Feb. 7– 9	80.00	72.00	1,347.73	262.00	271.0	3.80
Feb. 22–23	43.00	35.00	1,576.72	149.00	98.0	2.40
May 13–14	34.00	30.00	2,432.09	197.00	218.0	1.10
May 30–31	39.00	34.00	577.34	53.00	109.0	1.40
June 2– 4	38.00	28.00	3,558.19	269.00	345.0	2.30
July 29–30	8.80	7.30	3,754.43	74.00	63.0	.55
Aug. 1– 2	24.00	22.00	2,171.71	129.00	122.0	1.90
Aug. 3– 4	80.00	76.00	2,573.10	528.00	1,140.0	17.00

See footnotes at end of table.

storms in the Rock Creek and Anacostia River basins, 1962–74

Antecedent days (A_d)	Total precipitation (R_t) (inches)	Maximum 15-minute rainfall (R_{15}) (in/hr)	Maximum 30-minute rainfall (R_{30}) (in/hr)	Maximum 1-hour rainfall (R_{1h}) (in/hr)	Maximum 3-hour rainfall [1] (R_{3h}) (in/hr)	Peak ratio (P_r)	Number of peaks (N_p)	Time (T_m) (months)	Construction area (C_p) (percent of basin area)
Olney, Md.									
39	1.16	0.32	0.30	0.24	0.14	3.80	1	1	6.4
1	.26	.08	.08	.07	.03	2.47	1	3	6.4
2	1.02	2.20	1.40	.94	.37	6.33	1	3	6.4
10	2.68	.72	.68	.55	.41	3.86	1	5	7.0
9	1.92	.76	.70	.50	.40	3.31	1	7	7.6
13	2.61	4.24	2.52	1.38	.47	6.32	2	10	7.6
3	3.20	2.00	1.56	1.03	.59	7.30	1	10	7.6
43	[2] .84	.40	.30	.22	.18	7.39	1	12	6.6
14	.90	2.16	1.30	.75	.33	9.39	1	12	6.2
7	1.00	.52	.42	.34	.24	4.36	1	13	6.2
2	[2] 1.65	.44	.40	.38	.27	2.03	1	14	6.2
1	[2] 1.50	.88	.68	.45	.30	3.11	1	14	6.2
9	1.50	.52	.48	.46	.37	2.54	1	15	6.2
3	1.25	.40	.38	.33	.19	2.38	1	17	5.7
18	[2] .97	.76	.60	.40	.15	4.71	2	18	5.2
2	3.00	.80	.62	.50	.33	2.52	1	19	4.7
1	.96	2.84	2.28	1.16	.37	7.95	1	20	4.7
5	1.84	2.76	1.98	1.09	.62	4.31	2	20	4.7
1	[2] .70	3.00	1.66	.86	.29	10.47	1	22	4.3
17	[2] .83	1.12	.98	.79	.42	7.86	1	23	3.8
3	1.57	3.56	2.62	1.58	.65	7.39	1	23	3.8
3	[2] 1.35	.32	.30	.27	.19	3.62	2	25	3.8
1	.70	.20	.20	.16	.10	2.80	1	27	3.8
0	[2] 1.09	.16	.16	.15	.13	3.29	2	28	3.8
10	1.46	1.44	.76	.43	.18	6.41	2	31	3.0
11	2.42	2.12	1.84	1.53	.74	7.96	1	32	3.0
14	1.96	4.40	3.12	2.13	.76	9.14	1	32	3.0
30	[2] 1.81	5.36	3.16	1.78	.60	9.85	1	33	3.0
1	[2] 1.49	5.88	2.96	1.48	.49	11.68	1	33	3.0
2	3.20	5.60	4.04	2.54	.88	13.46	3	34	3.0
3	2.43	2.72	1.46	.80	.63	8.33	1	34	3.1
6	[2] 2.08	3.52	2.06	1.07	.36	5.59	2	34	3.1
11	3.51	2.28	2.06	1.22	.60	7.86	2	35	3.1
23	1.20	1.68	1.12	.61	.25	9.83	1	36	3.1
10	1.22	1.16	.72	.47	.22	11.16	1	37	3.1
16	[2] .90	.40	.36	.26	.19	12.33	1	38	3.2
1	1.46	.52	.44	.40	.28	4.95	1	38	3.2
10	1.10	.24	.24	.20	.15	3.83	1	38	3.2
11	3.06	.40	.38	.37	.27	3.66	1	42	3.2
18	1.41	2.48	1.26	.63	.38	7.22	1	43	3.3
6	1.57	2.56	1.48	.80	.32	6.99	2	43	3.3
21	1.81	2.40	1.54	.77	.26	12.53	1	44	3.3
2	1.51	1.96	1.86	.93	.39	7.40	1	44	3.3
16	2.71	2.00	1.52	1.04	.50	6.67	2	45	3.9
9	2.60	3.28	2.32	1.36	.50	10.40	1	45	3.9
17	1.26	2.44	1.68	.90	.30	14.44	1	47	3.9
2	[2] .57	.68	.48	.33	.15	7.45	1	49	3.9
0	2.04	.60	.52	.45	.36	4.08	1	49	3.9
2	1.05	.44	.44	.37	.21	4.92	1	49	3.9
3	1.04	.24	.24	.20	.16	5.09	1	50	3.9
4	1.01	.36	.34	.28	.18	4.52	1	50	3.9
0	1.86	.60	.42	.30	.25	3.71	2	52	4.5
7	1.69	.52	.30	.29	.17	2.73	2	52	4.5
4	2.09	1.32	1.06	.78	.48	7.23	1	55	5.1
3	1.62	.52	.36	.26	.20	3.16	2	55	5.1
1	1.70	.28	.28	.25	.20	12.24	2	56	5.1
27	1.84	2.16	1.58	1.10	.42	8.55	2	57	5.1
2	[2] 1.99	1.96	1.80	.96	.35	5.46	1	58	5.1
0	[2] 2.25	4.80	3.66	1.99	.77	14.78	1	58	5.1

TABLE 5.—*Hydrologic characteristics and related factors for storms*

Period of storm runoff	Total runoff (Q_t) (ft³/s-d)	Storm runoff (Q_r) (ft³/s-d)	Mean sediment concentration (C) (mg/l)	Suspended-sediment discharge (Q_s) (tons)	Peak discharge (Q_p) (ft³/s)	Antecedent discharge (Q_a) (ft³/s)
						Williamsburg Run near
1971—Continued						
Aug. 27–28	61.00	56.00	800.26	121.00	305.0	0.89
Oct. 10	33.00	30.00	1,333.33	108.00	160.0	1.30
Nov. 24–25	67.00	61.00	340.01	56.00	258.0	1.60
Nov. 29–30	21.00	15.00	345.68	14.00	84.0	2.40
Dec. 7	16.00	12.00	586.42	19.00	55.0	2.60
1972						
Feb. 3– 4	31.00	25.00	1,200.00	81.00	132.0	1.90
Feb. 13–14	42.00	34.00	1,546.84	142.00	139.0	1.80
Feb. 18–19	37.00	30.00	1,160,49	94.00	147.0	2.50
Mar. 16–17	39.00	33.00	751.96	67.00	121.0	2.90
Apr. 13	22.00	18.00	1,748.97	85.00	59.0	2.10
Apr. 16–17	54.00	46.00	2,922.70	363.00	368.0	5.60
May 3– 4	41.00	29.00	1,468.71	115.00	198.0	2.60
May 19–20	16.00	9.90	635.99	17.00	44.0	2.50
May 22–23	10.00	3.20	729.17	6.30	36.0	3.40
June 4– 5	13.00	7.30	3,044.14	60.00	85.0	2.20
June 29–30	60.00	50.00	1,066.67	144.00	411.0	2.60
July 2– 3	87.00	73.00	1,557.58	307.00	982.0	4.60
Oct. 28	14.00	13.00	911.68	32.00	51.0	.69
Nov. 8	21.00	19.00	604.29	31.00	82.0	.88
Nov. 14	39.00	34.00	675.38	62.00	184.0	1.00
Dec. 8– 9	52.00	42.00	793.65	90.00	266.0	2.70
1973						
Feb. 2	31.00	24.00	1,157.41	75.00	86.0	2.40
Apr. 4	20.00	15.00	888.89	36.00	112.0	4.10
Apr. 27	27.00	20.00	740.74	40.00	138.0	16.00
May 28	22.00	17.00	1,089.32	50.00	134.0	3.60
July 3– 4	35.00	32.00	2,754.63	238.00	567.0	2.70
July 20–21	41.00	37.00	2,072.07	207.00	320.0	.90
Sept. 14	16.00	15.00	839.50	34.00	57.0	.45
Oct. 2	6.30	5.40	1,028.80	15.00	30.0	.63
1974						
Mar. 30	67.00	60.00	802.47	130.00	365.0	2.00
Aug. 19	11.00	11.00	673.40	20.00	82.0	.49
Sept. 3– 4	10.00	8.30	397.14	8.90	38.0	.43
Sept. 6 –7	14.00	12.00	148.15	4.80	48.0	.68
Sept. 28	13.00	12.00	305.55	9.90	98.0	.49
						North Branch Rock Creek
1966						
Nov. 28–29	33.00	20.00	500.00	27.00	63.0	5.20
1967						
Jan. 27–28	55.00	38.00	3,118.90	320.00	164.0	6.70
Mar. 6– 8	308.00	266.00	2,826.51	2,030.00	800.0	10.00
Mar. 15–16	65.00	38.00	506.82	52.00	98.0	11.00
May 7– 8	90.00	66.00	1,352.41	241.00	187.0	7.10
June 22–23	14.00	7.50	938.27	19.00	33.0	2.10
Aug. 3– 5	92.00	78.00	5,935.41	1,250.00	317.0	1.70
Aug. 24–25	218.00	203.00	3,995.62	2,190.00	823.0	2.50
Aug. 27–28	54.00	36.00	6,224.27	605.00	132.0	9.10
Nov. 2– 3	22.00	14.00	396.82	15.00	50.0	3.20
Dec. 3– 4	68.00	50.00	496.30	67.00	104.0	4.70
Dec. 10–11	82.00	62.00	388.29	65.00	163.0	7.20
1968						
Jan. 14–15	204.00	182.00	830.28	408.00	413.0	5.50
Mar. 12–13	82.00	53.00	663.87	95.00	99.0	6.60
Mar. 17–18	113.00	66.00	1,032.55	184.00	139.0	16.00
May 27–29	138.00	118.00	1,117.39	356.00	233.0	4.20
June 16	17.00	12.00	4,228.39	137.00	123.0	4.00
June 19–20	48.00	37.00	3.533.53	353.00	196.0	7.60
June 26–28	88.00	74.00	2,007.00	401.00	255.0	4.10
Sept. 10–11	30.00	27.00	4,581.61	334.00	126.0	.71
Oct. 19–20	12.00	6.20	77.66	1.30	16.0	1.90

See footnotes at end of table.

in the Rock Creek and Anacostia River basins, 1962–74—Continued

Antecedent days (A_d)	Total precipitation (R_t) (inches)	Maximum 15-minute rainfall (R_{15}) (in/hr)	Maximum 30-minute rainfall (R_{30}) (in/hr)	Maximum 1-hour rainfall (R_{1h}) (in/hr)	Maximum 3-hour rainfall [1] (R_{3h}) (in/hr)	Peak ratio (P_r)	Number of peaks (N_p)	Time (T_m) (months)	Construction area (C_p) (percent of basin area)
Olney, Md.—Continued									
7	3.16	1.04	1.04	0.79	0.52	5.43	1	58	5.8
7	1.88	.68	.68	.55	.35	5.29	1	60	5.8
20	2.72	.52	.46	.39	.35	4.20	1	61	5.8
3	[2] .78	.44	.34	.25	.20	5.44	1	61	5.8
6	[2] .91	.40	.28	.22	.12	4.37	1	62	5.8
9	1.23	.40	.34	.29	.17	5.20	1	64	5.8
8	1.57	.28	.28	.26	.19	4.04	1	64	5.8
3	1.80	.28	.26	.24	.20	4.82	1	64	5.8
12	1.52	.84	.48	.27	.20	3.58	1	65	5.8
4	1.19	.44	.30	.23	.21	3.16	3	66	6.5
0	1.48	2.60	1.54	.91	.44	7.88	1	66	6.5
8	1.88	.84	.76	.55	.34	6.74	1	67	7.0
9	[2] 1.06	.32	.28	.23	.19	4.19	1	67	7.4
1	[2] .42	.84	.64	.39	.13	10.19	1	67	7.4
2	.76	2.68	2.52	1.31	.44	11.34	1	68	7.4
2	2.25	1.96	1.40	.73	.27	8.17	2	68	7.4
0	2.06	2.60	2.26	1.54	.66	13.39	2	69	7.4
8	1.54	1.84	1.20	.73	.31	3.87	2	72	6.5
10	1.52	.60	.52	.45	.30	4.27	1	73	6.5
5	2.00	.72	.52	.39	.34	5.38	1	73	6.5
1	1.94	.40	.38	.33	.30	6.27	1	74	6.5
3	1.21	.40	.32	.26	.18	3.48	2	76	6.5
1	.87	.44	.42	.38	.23	7.19	1	78	6.0
0	[2] 1.22	.48	.40	.35	.24	6.10	1	78	5.5
2	1.39	.68	.66	.49	.23	7.67	1	79	5.1
0	1.73	3.32	2.86	1.66	.57	17.63	1	81	5.1
15	2.49	2.60	2.48	1.43	.67	8.62	1	81	5.1
10	2.08	.80	.56	.50	.36	3.77	1	83	4.8
17	1.18	.28	.28	.23	.19	5.44	1	84	3.0
8	2.80	.72	.58	.47	.37	6.05	1	89	2.0
1	1.46	1.80	1.34	1.09	.45	7.41	1	94	1.0
4	1.57	.36	.24	.17	.11	4.53	2	95	1.0
1	1.46	.20	.18	.18	.17	3.94	1	95	1.0
20	1.85	1.08	.62	.48	.30	8.13	1	95	1.0
near Norbeck, Md.									
23	1.14	0.32	0.30	0.24	0.14	2.89	1	1	2.8
16	.97	2.20	1.40	.94	.37	4.14	1	3	2.8
10	2.67	.72	.68	.55	.41	2.97	1	5	2.8
5	1.02	1.04	.78	.49	.30	2.29	1	5	2.8
9	1.94	.76	.70	.50	.41	2.73	1	7	3.1
43	1.17	1.48	1.28	.93	.35	4.12	1	8	3.1
12	2.42	4.24	2.30	1.15	.47	4.04	2	10	3.1
2	3.06	2.00	1.56	1.03	.59	4.04	1	10	3.1
1	[2] .76	.52	.46	.27	.09	3.41	2	10	3.1
7	.97	.52	.42	.34	.24	3.34	1	13	2.5
29	[2] 1.34	.64	.56	.49	.32	1.99	1	14	2.5
5	[2] 1.48	.44	.40	.38	.27	2.51	1	14	2.5
9	1.49	.52	.48	.46	.37	2.24	1	15	2.5
37	1.95	.52	.34	.32	.19	1.74	1	17	2.5
3	1.20	.40	.38	.33	.19	1.86	2	17	2.5
2	2.96	.80	.62	.50	.33	1.94	1	19	2.0
2	[2] 1.39	1.96	1.18	.63	.14	9.92	1	20	2.0
1	.93	2.84	2.28	1.16	.39	5.09	1	20	2.0
5	1.82	2.76	1.98	1.09	.62	3.39	2	20	2.0
3	1.80	3.56	2.62	1.58	.65	4.64	1	23	2.0
11	[2] 1.44	.72	.42	.35	.25	2.27	1	24	1.7

TABLE 5.—*Hydrologic characteristics and related factors for storms*

Period of storm runoff	Total runoff (Q_t) (ft³/s-d)	Storm runoff (Q_r) (ft³/s-d)	Mean sediment concentration (C) (mg/l)	Suspended-sediment discharge (Q_s) (tons)	Peak discharge (Q_p) (ft³/s)	Antecedent discharge (Q_a) (ft³/s)
				North Branch Rock Creek near		
1969						
Jan. 21–22	32.00	17.00	261.44	12.00	42.0	5.20
June 2– 3	39.00	35.00	2,677.24	253.00	158.0	1.50
June 18–19	37.00	33.00	3,209.87	286.00	167.0	1.40
July 20–21	17.00	16.00	1,921.29	83.00	117.0	.42
July 22–23	67.00	64.00	2,777.77	480.00	332.0	3.10
Aug. 2– 3	142.00	132.00	1,083.05	386.00	676.0	3.80
Aug. 9–10	123.00	117.00	2,602.09	822.00	498.0	2.50
Aug. 18–20	102.00	88.00	1,094.27	260.00	207.0	2.50
Sept. 3– 5	193.00	176.00	2,735.69	1,300.00	706.0	2.40
Nov. 19–20	27.00	16.00	671.30	29.00	64.0	3.50
Dec. 10–11	86.00	68.00	1,612.20	296.00	255.0	8.20
Dec. 22	37.00	31.00	657.11	55.00	106.0	5.60
1970						
Apr. 1– 3	82.00	46.00	1,167.47	145.00	144.0	12.00
Apr. 14–15	237.00	208.00	1,572.29	883.00	455.0	9.00
May 13–14	69.00	52.00	3,262.10	458.00	255.0	8.10
May 24–25	99.00	82.00	4,042.45	895.00	455.0	6.50
June 16–18	47.00	31.00	812.42	68.00	98.0	3.50
June 21–22	63.00	51.00	2,316.63	319.00	287.0	4.70
July 9–10	156.00	145.00	2,998.72	1,174.00	438.0	2.50
Sept. 10	16.00	13.00	797.72	28.00	79.0	2.10
Nov. 4– 5	111.00	95.00	1,255.36	322.00	327.0	11.00
Dec. 16–17	50.00	31.00	585.42	49.00	130.0	4.70
Dec. 22–23	78.00	54.00	576.13	84.00	165.0	6.50
1971						
Feb. 7–10	317.00	285.00	1,806.36	1,390.00	606.0	19.00
Feb. 13–14	341.00	314.00	1,415.43	1,200.00	1,030.0	8.90
Feb 22–23	175.00	147.00	1,345.43	534.00	335.0	14.00
Apr. 6– 7	69.00	50.00	377.78	51.00	85.0	7.50
May 13–14	148.00	130.00	1,735.04	609.00	498.0	5.40
May 16–17	118.00	93.00	637.20	160.00	333.0	9.70
May 30-June 1	176.00	138.00	791.73	295.00	415.0	8.00
June 2– 4	109.00	70.00	3,910.05	739.00	382.0	15.00
July 1– 2	40.00	29.00	2,094.51	164.00	186.0	4.30
July 29–30	27.00	19.00	1,754.38	90.00	122.0	2.00
Aug. 1– 4	323.00	293.00	1,222.35	967.00	998.0	7.00
Aug. 19	22.00	17.00	849.67	39.00	112.0	3.40
Aug. 27–28	184.00	171.00	1,407.84	650.00	642.0	3.00
Sept. 17–18	25.00	11.00	841.75	25.00	59.0	5.60
Nov. 24–26	286.00	239.00	692.70	447.00	657.0	7.10
Nov. 29–30	85.00	57.00	487.33	75.00	237.0	14.00
Dec. 7– 8	75.00	44.00	404.04	48.00	159.0	10.00
1972						
Feb. 3– 4	110.00	81.00	2,016.46	441.00	308.0	10.00
Mar. 16–17	138.00	108.00	1,080.25	315.00	347.0	14.00
Mar. 22	30.00	15.00	740.74	30.00	85.0	13.00
Apr. 13	71.00	58.00	1,245.21	195.00	163.0	9.70
Apr. 16–17	175.00	136.00	3,867.10	1,420.00	642.0	24.00
May 3– 4	161.00	120.00	1,691.36	548.00	460.0	11.00
May 19–20	58.00	33.00	549.94	49.00	112.0	9.90
May 30–31	213.00	187.00	4,436.52	2,240.00	986.0	8.10
June 4– 5	38.00	18.00	2,818.93	137.00	123.0	9.70
Oct. 28	46.00	39.00	1,291.55	136.00	128.0	4.30
Nov. 8	75.00	65.00	695.16	122.00	268.0	5.50
Nov. 14–15	151.00	128.00	801.50	277.00	398.0	5.10
1973						
Feb. 2– 3	168.00	126.00	1,055.26	359.00	335.0	13.00
Apr. 1– 2	281.00	228.00	2,404.16	1,480.00	612.0	15.00
Apr. 4	97.00	78.00	1,158.59	244.00	362.0	23.00
Apr. 27	158.00	138.00	939.34	350.00	490.0	97.00
May 28–29	144.00	110.00	1,040.40	309.00	415.0	15.00
July 3– 4	146.00	127.00	1,971.42	676.00	660.0	31.00
July 20–21	223.00	207.00	2,343.89	1,310.00	978.0	4.50
Sept. 14–15	77.00	65.00	1,111.11	195.00	242.0	2.70

See footnotes at end of table.

in the Rock Creek and Anacostia River basins, 1962–74—Continued

Antecedent days (A_d)	Total precipitation (R_t) (inches)	Maximum 15-minute rainfall (R_{15}) (in/hr)	Maximum 30-minute rainfall (R_{30}) (in/hr)	Maximum 1-hour rainfall (R_{1h}) (in/hr)	Maximum 3-hour rainfall [1] (R_{3h}) (in/hr)	Peak ratio (P_r)	Number of peaks (N_p)	Time (T_m) (months)	Construction area (C_p) (percent of basin area)
Norbeck, Md.—Continued									
1	0.70	0.20	0.20	0.16	0.10	2.16	1	27	1.7
11	2.57	2.12	1.84	1.53	.74	4.47	1	32	1.5
14	2.14	4.40	3.12	2.13	.76	5.02	1	32	1.5
6	[2]1.44	5.36	3.16	1.78	.60	7.29	1	33	1.5
1	[2]1.24	5.88	2.96	1.48	.49	5.14	1	33	1.5
3	[2]3.12	5.60	4.04	2.54	.88	5.09	1	34	1.5
3	2.36	2.72	1.46	.80	.63	4.24	1	34	1.5
6	2.79	3.52	2.06	1.07	.36	2.32	4	34	1.5
13	3.39	2.28	2.06	1.22	.60	4.00	1	35	1.5
9	1.10	1.16	.72	.47	.22	3.78	1	37	1.5
1	1.49	.52	.44	.40	.28	3.63	1	38	1.5
10	1.09	.24	.24	.20	.15	3.24	1	38	1.5
2	.87	.24	.22	.21	.13	2.87	2	42	1.5
8	2.98	.40	.38	.37	.27	2.14	1	42	1.9
18	1.10	2.48	1.26	.63	.38	4.75	1	43	1.9
5	1.49	2.56	1.48	.80	.32	5.47	1	43	1.9
20	1.74	2.40	1.54	.77	.26	3.05	2	44	1.9
2	1.50	1.96	1.86	.93	.39	5.54	1	44	1.9
16	2.84	2.00	1.52	1.04	.50	3.00	1	45	1.9
17	1.41	2.44	1.68	.90	.30	5.92	1	47	1.9
0	1.92	.60	.52	.45	.36	3.33	1	49	1.9
24	1.00	.24	.24	.20	.16	4.04	1	50	1.9
3	1.06	.36	.34	.28	.18	2.94	1	50	1.9
0	1.70	.60	.42	.30	.25	2.06	2	52	1.9
2	1.97	1.24	.80	.62	.36	3.25	1	52	1.9
7	1.65	.52	.30	.29	.20	2.18	1	52	1.9
16	[2]1.53	.20	.16	.13	.10	1.55	1	54	2.2
3	2.14	1.32	1.06	.78	.48	3.79	1	55	2.2
1	1.32	.32	.30	.25	.22	3.48	1	55	2.2
3	1.41	.52	.36	.26	.20	2.95	2	55	2.2
0	1.21	.28	.28	.25	.20	5.24	2	56	2.2
22	1.09	1.12	.94	.84	.40	6.27	1	57	2.2
26	1.85	2.16	1.58	1.10	.42	6.32	1	57	2.2
1	4.70	4.80	3.66	1.99	.77	3.38	4	58	2.2
13	[2]1.06	1.24	.98	.71	.31	6.39	1	58	2.2
7	3.06	1.04	1.04	.79	.52	3.74	1	58	2.2
3	[2].58	1.28	.92	.61	.21	4.85	1	59	2.2
20	2.78	.52	.46	.39	.35	2.72	1	61	2.2
2	[2].78	.44	.34	.25	.20	3.91	1	61	2.2
6	[2].88	.40	.28	.22	.12	3.39	1	62	2.2
9	1.13	.40	.34	.29	.17	3.68	1	64	2.5
12	1.47	.84	.48	.27	.20	3.08	1	65	2.5
4	[2].49	.36	.28	.24	.09	4.80	1	65	2.5
4	1.10	.44	.30	.23	.21	2.64	1	66	2.5
2	1.42	2.60	1.54	.91	.44	4.54	1	66	2.5
8	1.90	.84	.76	.55	.34	3.74	2	67	2.5
8	[2]1.02	.32	.28	.23	.19	3.09	1	67	2.5
6	[2]2.40	3.44	3.38	2.24	.84	5.23	1	67	2.5
2	.65	2.68	2.52	1.31	.44	6.29	1	68	2.5
8	1.60	1.84	1.20	.73	.31	3.17	1	72	2.5
10	1.48	.60	.52	.45	.30	4.04	1	73	2.5
5	2.07	.72	.52	.39	.34	3.07	1	73	2.5
3	1.25	.40	.32	.26	.18	2.56	1	76	2.0
5	1.89	1.48	1.16	.62	.28	2.62	1	78	2.0
1	.83	.44	.42	.38	.23	4.35	1	78	2.0
0	[2]1.30	.48	.40	.35	.24	2.85	1	78	2.0
2	1.35	.68	.66	.49	.23	3.64	1	79	2.0
0	2.04	3.32	2.86	1.66	.57	4.95	1	81	2.0
15	2.72	2.60	2.48	1.43	.67	4.70	2	81	2.0
9	2.20	.80	.56	.50	.36	3.68	1	83	2.0

TABLE 5.—*Hydrologic characteristics and related factors for storms*

Period of storm runoff	Total runoff (Q_t) (ft³/s-d)	Storm runoff (Q_r) (ft³/s-d)	Mean sediment concentration (C) (mg/l)	Suspended-sediment discharge (Q_s) (tons)	Peak discharge (Q_p) (ft³/s)	Antecedent discharge (Q_a) (ft³/s)
				North Branch Rock Creek near		
1973—Continued						
Dec. 9	58.00	47.00	606.78	77.00	180.0	4.30
Dec. 20–22	259.00	230.00	790.66	491.00	460.0	5.50
1974						
Jan. 21	84.00	76.00	1,769.00	363.00	322.0	9.30
Mar. 21	35.00	27.00	1,536.35	112.00	204.0	7.10
Mar. 30–31	363.00	327.00	1,449.77	1,280.00	850.0	8.30
May 12–13	76.00	55.00	1,245.79	185.00	240.0	6.90
June 2	51.00	40.00	509.26	55.00	172.0	8.30
Aug. 19–20	64.00	59.00	1,494.03	238.00	465.0	2.20
Sept. 3– 4	27.00	20.00	259.26	14.00	55.0	1.40
Sept. 6– 7	41.00	33.00	258.14	23.00	114.0	2.10
Sept. 28	46.00	43.00	938.84	109.00	235.0	1.70
					Manor Run near	
1966						
Nov. 28	4.40	4.00	1,203.70	13.00	23.0	0.40
1967						
Jan. 27–28	8.60	5.90	13,370.97	213.00	57.0	.65
Mar. 6– 8	47.00	44.00	3,779.46	449.00	182.0	1.00
Mar. 15–16	8.40	6.10	1,578.63	26.00	26.0	1.10
Apr. 17–18	2.60	1.30	997.15	3.50	5.0	.63
May 7– 8	16.00	14.00	7,037.02	266.00	66.0	.78
June 22–23	4.60	4.10	11,020.76	122.00	110.0	.21
Aug. 3– 5	8.70	7.80	20,750.21	437.00	77.0	.19
Aug. 24–25	37.00	36.00	14,197.51	1,380.00	364.0	.27
Oct. 25	2.50	2.20	20,033.64	119.00	42.0	.26
Nov. 2	2.60	2.20	4,208.75	25.00	13.0	.31
1968						
Jan. 14–15	29.00	26.00	1,695.15	119.00	97.0	.50
Mar. 12–13	8.40	5.90	2,385.43	38.00	21.0	.74
Mar. 17–18	13.00	9.50	7,914.21	203.00	56.0	1.80
May 27–29	19.00	17.00	7,647.05	351.00	81.0	.43
June 12–13	3.20	2.20	9,764.29	58.00	19.0	.48
June 16	10.00	9.30	20,430.07	513.00	161.0	.43
June 19–20	11.00	9.30	19,633.58	493.00	194.0	1.10
June 26–28	10.00	8.00	12,962.95	280.00	114.0	.67
July 2– 3	6.50	5.20	16,452.97	231.00	95.0	.67
Sept. 10–11	9.50	8.90	24,219.69	582.00	196.0	.25
1969						
Jan. 21–22	5.60	2.60	3,133.90	22.00	10.0	.60
May 20–21	9.50	8.40	14,814.79	336.00	210.0	.48
June 2– 3	19.00	17.00	13,137.23	603.00	252.0	.28
June 8	2.30	1.90	4,288.49	22.00	64.0	.34
June 18–19	5.00	3.90	10,826.20	114.00	136.0	.34
July 22–23	2.40	1.70	13,943.34	64.00	76.0	.34
July 28	3.40	3.00	11,111.09	90.00	105.0	.28
Aug. 9–10	26.00	25.00	11,703.69	790.00	335.0	.31
Aug. 18	11.00	10.00	8,222.20	222.00	203.0	.31
Sept. 3– 4	11.00	10.00	8,999.98	243.00	151.0	.60
Oct. 2	3.40	3.10	8,960.56	75.00	89.0	.25
Dec. 10–11	16.00	14.00	6,296.29	238.00	100.0	.40
1970						
Apr. 1– 2	8.00	5.30	10,062.88	144.00	54.0	1.30
Apr. 14–15	32.00	29.00	4,699.86	368.00	126.0	.79
May 24–25	14.00	12.00	11,141.96	361.00	277.0	.52
June 16	8.90	8.50	8,932.45	205.00	262.0	.36
June 21–22	11.00	9.60	8,449.06	219.00	198.0	.39
July 20	18.00	18.00	3,703.70	180.00	448.0	.26
Aug. 14	11.00	11.00	4,814.80	143.00	214.0	.27
Sept. 10	8.40	8.10	7,956.09	174.00	246.0	.65
Nov. 3	2.40	2.00	1,851.85	10.00	30.0	.29
Nov. 4– 5	24.00	23.00	1,465.38	91.00	116.0	2.40
Nov. 14–15	12.00	11.00	2,491.58	74.00	102.0	1.00
Dec. 22	11.00	8.80	2,020.20	48.00	81.0	.74

See footnotes at end of table.

in the Rock Creek and Anacostia River basins, 1962–74—Continued

Antecedent days (A_d)	Total precipitation (R_t) (inches)	Maximum 15-minute rainfall (R_{15}) (in/hr)	Maximum 30-minute rainfall (R_{30}) (in/hr)	Maximum 1-hour rainfall (R_{1h}) (in/hr)	Maximum 3-hour rainfall [1] (R_{3h}) (in/hr)	Peak ratio (P_r)	Number of peaks (N_p)	Time (T_m) (months)	Construction area (C_p) (percent of basin area)
Norbeck, Md.—Continued									
3	1.29	0.40	0.36	0.28	0.19	3.74	1	86	1.2
10	[2]1.90	.40	.40	.26	.17	1.98	1	86	1.2
7	1.02	.56	.40	.36	.28	4.11	1	87	1.2
33	.85	.56	.44	.30	.22	7.29	1	89	1.2
7	2.78	.72	.58	.47	.37	2.57	1	89	1.2
28	1.38	1.16	.72	.51	.30	4.24	1	91	.5
19	1.64	.44	.32	.28	.22	4.09	1	92	.5
19	1.63	1.80	1.34	1.09	.45	7.84	1	94	.5
4	1.53	1.44	1.14	.74	.31	2.68	2	95	.5
1	1.45	.20	.18	.18	.17	3.39	1	95	.5
19	1.78	1.08	.62	.48	.30	5.43	1	95	.5
Norbeck, Md.									
38	1.29	0.92	0.76	0.50	0.25	5.65	1	1	5.2
11	.82	1.20	.68	.37	.18	9.55	1	3	5.2
9	2.61	.96	.86	.67	.47	4.11	1	5	5.2
7	.95	1.32	.90	.74	.35	4.08	2	5	5.2
3	[2].66	1.24	1.00	.59	.26	3.36	1	6	10.8
3	1.98	.68	.52	.46	.37	4.66	1	7	10.8
37	1.50	3.76	2.42	1.33	.50	26.78	1	8	10.8
13	2.18	2.88	1.76	.91	.32	9.85	1	10	10.8
4	3.28	1.64	1.22	.88	.59	10.10	1	10	10.8
14	.97	2.12	1.32	.77	.34	18.97	1	12	11.8
7	.98	.48	.40	.33	.24	5.77	1	13	11.8
8	1.49	.32	.30	.29	.24	3.71	1	15	11.8
10	1.73	.60	.42	.39	.20	3.43	1	17	11.8
3	1.29	.60	.50	.41	.24	5.71	2	17	11.8
2	2.83	.52	.44	.37	.23	4.74	2	19	11.8
13	[2].94	.64	.48	.38	.19	8.42	2	20	11.8
2	1.49	3.48	2.14	1.21	.40	17.27	1	20	11.8
1	.88	3.40	1.78	.89	.30	20.74	1	20	11.8
5	1.61	1.76	1.48	.81	.32	14.17	2	20	11.8
3	1.31	1.88	1.34	.91	.32	18.14	2	21	11.8
3	1.99	2.16	1.86	1.28	.53	21.99	1	23	11.8
1	.55	.12	.10	.08	.07	3.62	1	27	9.6
10	1.58	2.72	1.92	.99	.33	24.94	1	31	9.6
11	2.10	3.00	2.02	1.54	.74	14.81	1	32	9.6
4	.53	1.84	1.18	.60	.20	33.51	1	32	9.6
9	1.50	2.64	1.58	.84	.29	34.78	1	32	9.6
1	[2]1.11	4.00	2.20	1.15	.42	44.51	1	33	9.6
5	[2]1.12	2.28	1.24	.64	.24	34.91	1	33	9.6
5	2.83	2.84	1.50	.77	.75	13.39	2	34	9.6
7	2.50	3.60	2.18	1.15	.39	20.27	2	34	9.6
13	2.59	1.12	1.20	.66	.23	15.04	2	35	9.6
23	1.05	1.64	.98	.51	.22	28.63	1	36	9.6
1	1.45	.56	.46	.39	.27	7.11	1	38	9.6
2	.86	.88	.58	.33	.14	9.94	1	42	7.4
6	2.85	.52	.40	.36	.28	4.32	1	42	7.4
6	1.43	1.96	1.48	.75	.26	23.04	2	43	7.4
9	2.01	4.00	2.52	1.39	.46	30.78	2	44	7.4
3	1.45	2.48	1.28	.67	.37	20.58	3	44	7.4
9	2.38	3.08	2.34	1.39	.49	24.87	2	45	7.4
14	1.57	1.24	1.18	1.00	.45	19.43	1	46	7.4
17	1.76	3.08	2.40	1.35	.45	30.29	1	47	7.4
12	[2].53	.64	.38	.24	.12	14.85	1	49	7.4
1	1.90	.56	.54	.41	.34	4.94	1	49	7.4
2	1.02	.44	.38	.34	.21	9.18	1	49	7.4
4	1.15	.40	.34	.30	.18	9.12	1	50	7.4

TABLE 5.—*Hydrologic characteristics and related factors for storms*

Period of storm runoff	Total runoff (Q_t) (ft³/s-d)	Storm runoff (Q_r) (ft³/s-d)	Mean sediment concentration (C) (mg/l)	Suspended-sediment discharge (Q_s) (tons)	Peak discharge (Q_p) (ft³/s)	Antecedent discharge (Q_a) (ft³/s)
						Manor Run near
1971						
Feb. 7– 8	36.00	33.00	2,368.12	211.00	161.0	2.00
May 13	18.00	16.00	8,842.58	382.00	210.0	.52
July 29	8.40	8.00	6,851.84	148.00	182.0	.35
Aug. 1– 2	9.60	8.10	3,475.07	76.00	185.0	.81
Aug. 3– 5	37.00	34.00	2,766.88	254.00	510.0	1.00
Aug. 27	30.00	29.00	2,848.01	223.00	313.0	.39
Nov. 24–25	39.00	37.00	1,301.30	130.00	152.0	.53
1972						
Feb. 3– 4	17.00	15.00	1,925.92	78.00	105.0	.68
Feb. 13	17.00	16.00	1,342.59	58.00	74.0	.57
Mar. 16–17	18.00	15.00	1,283.95	52.00	69.0	1.10
Apr. 13	8.30	6.70	829.19	15.00	46.0	.93
May 4	12.00	9.80	2,380.95	63.00	134.0	1.00
June 29–30	36.00	32.00	1,828.70	158.00	370.0	.89
Aug. 27–28	11.00	9.80	1,625.09	43.00	169.0	.39
Oct. 28	9.30	8.70	1,830.56	43.00	73.0	.32
Nov. 14	17.00	15.00	567.90	23.00	106.0	.44
Dec. 8– 9	25.00	20.00	648.15	35.00	141.0	1.10
1973						
Apr. 1	19.00	14.00	3,518.51	133.00	196.0	2.20
Apr. 4	15.00	13.00	968.66	34.00	113.0	2.00
July 2	13.00	13.00	2,222.22	78.00	240.0	.85
Sept. 14	11.00	10.00	296.30	8.00	67.0	.37
Oct. 2	2.80	2.30	111.11	0.69	17.0	.37
1974						
Jan. 21	10.00	8.80	925.92	22.00	107.0	.76
May 12	12.00	11.00	942.76	28.00	124.0	.53
Aug. 9	7.90	7.40	750.75	15.00	124.0	.34
Aug. 19	16.00	16.00	1,412.03	61.00	295.0	.28
						Northwest Branch Anacostia
1967						
Mar. 15	14.00	11.00	437.71	13.00	44.0	2.00
May 7– 8	23.00	16.00	4,351.84	188.00	75.0	1.40
June 22–23	3.70	2.60	3,133.90	22.00	38.0	.52
Aug. 4– 5	14.00	12.00	5,925.91	192.00	205.0	1.90
Nov. 2– 3	3.80	2.30	338.16	2.10	13.0	.57
1968						
Jan. 14–15	46.00	42.00	379.19	43.00	139.0	2.20
Mar. 12–13	18.00	14.00	714.28	27.00	45.0	1.00
Mar. 17–18	30.00	21.00	1,040.56	59.00	89.0	2.60
May 27–29	39.00	33.00	819.30	73.00	121.0	.86
June 19–20	14.00	10.00	2,925.92	79.00	159.0	1.10
June 27–28	12.00	7.80	4,083.56	86.00	102.0	.79
1969						
June 2– 3	11.00	9.60	3,549.38	92.00	109.0	.45
June 18–19	6.30	4.90	3,023.43	40.00	107.0	.42
July 20–21	5.20	4.70	2,836.88	36.00	109.0	.05
Aug. 2– 3	30.00	28.00	2,407.40	182.00	496.0	.49
Aug. 9–10	43.00	41.00	2,511.29	278.00	441.0	.54
Aug. 18	14.00	13.00	968.66	34.00	155.0	.58
Dec. 10–11	32.00	28.00	1,124.34	85.00	162.0	1.50
1970						
Apr. 2– 3	26.00	20.00	1,962.96	106.00	110.0	2.90
Apr. 14–15	83.00	76.00	1,793.37	368.00	322.0	1.80
May 24–25	40.00	36.00	1,882.71	183.00	282.0	1.30
June 16–17	9.00	5.90	1,067.17	17.00	91.0	1.00
July 9–10	42.00	40.00	1,750.00	189.00	382.0	.86
July 20–21	34.00	32.00	1,493.05	129.00	362.0	.86
Nov. 4– 5	25.00	22.00	471.38	28.00	124.0	1.00
Dec. 22	16.00	13.00	284.90	10.00	69.0	1.50

See footnotes at end of table.

in the Rock Creek and Anacostia River basins, 1962–74—Continued

Antecedent days (A_d)	Total precipitation (R_t) (inches)	Maximum 15-minute rainfall (R_{15}) (in/hr)	Maximum 30-minute rainfall (R_{30}) (in/hr)	Maximum 1-hour rainfall (R_{1h}) (in/hr)	Maximum 3-hour rainfall [1] (R_{3h}) (in/hr)	Peak ratio (P_r)	Number of peaks (N_p)	Time (T_m) (months)	Construction area (C_p) (percent of basin area)
Norbeck, Md.—Continued									
1	1.99	0.88	0.62	0.41	0.32	4.82	2	52	5.4
4	2.15	1.92	1.30	.76	.49	13.09	1	55	5.4
51	2.19	2.16	1.74	1.48	.56	22.71	1	57	5.4
1	[2]1.63	1.72	1.48	.81	.36	22.74	2	58	5.4
1	[2]3.30	4.80	3.66	2.00	.77	14.97	2	58	5.4
7	3.18	1.24	1.00	.95	.56	10.78	1	58	5.4
16	2.70	.52	.46	.37	.34	4.09	1	61	5.4
5	1.14	.44	.38	.32	.19	6.95	1	64	3.9
8	1.62	.36	.30	.28	.21	4.59	1	64	3.9
1	1.53	.68	.42	.32	.21	4.53	1	65	3.9
2	1.05	.40	.34	.27	.22	6.73	1	66	3.9
1	[2].64	.60	.58	.37	.16	13.57	1	67	3.9
3	1.74	1.36	.92	.60	.24	11.53	2	68	3.9
19	[2]1.73	1.28	1.00	.85	.51	17.21	1	70	3.9
8	1.66	1.80	1.02	.60	.25	8.25	2	72	2.4
5	2.25	.60	.60	.45	.41	7.04	1	73	2.4
1	1.89	.56	.52	.41	.31	6.99	1	74	2.4
1	1.58	.36	.34	.32	.20	13.84	1	78	.8
1	.94	.20	.16	.15	.13	8.54	1	78	.8
1	[2]1.12	1.16	1.02	.64	.34	18.40	2	81	.8
7	2.02	.72	.52	.39	.27	6.66	2	83	.8
17	1.00	.36	.26	.24	.20	7.23	1	84	.8
8	.98	.80	.50	.47	.26	12.07	1	87	.9
2	1.40	1.72	1.24	.78	.38	11.22	1	91	.9
10	2.14	2.96	2.30	1.38	.59	16.71	2	94	.9
9	2.13	3.28	2.84	1.76	.60	18.42	1	94	.9
River at Norwood, Md.									
7	0.95	4.24	2.14	1.12	0.50	3.82	2	5	1.1
52	2.03	.76	.74	.57	.40	4.60	1	7	1.1
45	1.30	3.16	2.14	1.16	.44	14.42	1	8	1.1
14	2.54	2.92	1.94	1.09	.38	16.92	1	10	1.1
7	1.06	.44	.42	.32	.23	5.40	1	13	.2
16	1.54	.44	.40	.35	.25	3.26	1	15	.2
57	1.90	.68	.46	.43	.20	3.14	1	17	.2
3	1.56	.68	.56	.46	.25	4.11	2	17	.2
69	2.92	.56	.54	.41	.23	3.64	3	19	.2
20	1.04	4.12	2.44	1.23	.41	15.79	1	20	.2
6	1.75	1.92	1.10	.60	.25	12.98	1	20	.2
69	2.10	2.88	1.68	1.13	.61	11.31	1	32	.3
14	1.30	3.08	1.80	.97	.34	21.75	1	32	.3
30	[2]1.35	3.40	2.54	1.31	.44	23.18	1	33	.3
3	1.79	1.88	1.48	1.00	.36	17.70	1	34	.3
6	2.35	3.12	1.64	1.12	.74	10.74	1	34	.3
7	[2]1.66	4.16	2.24	1.17	.39	11.88	2	34	.3
2	1.46	.56	.42	.38	.27	5.73	1	38	.3
3	1.02	.58	.46	.29	.12	5.35	1	42	.4
11	3.16	.68	.60	.56	.39	4.21	1	42	.4
6	1.92	1.88	1.52	.94	.39	7.80	2	43	.4
21	1.64	1.68	1.62	.85	.29	15.25	1	44	.4
17	2.70	1.64	1.38	.97	.53	9.53	2	45	.4
9	2.37	3.20	2.26	1.49	.53	11.29	1	45	.4
12	2.02	.56	.48	.44	.34	5.59	1	49	.4
4	1.00	.36	.36	.30	.18	5.19	1	50	.4

TABLE 5.—*Hydrologic characteristics and related factors for storms*

Period of storm runoff	Total runoff (Q_t) (ft³/s-d)	Storm runoff (Q_r) (ft³/s-d)	Mean sediment concentration (C) (mg/l)	Suspended-sediment discharge (Q_s) (tons)	Peak discharge (Q_p) (ft³/s)	Antecedent discharge (Q_a) (ft³/s)
Northwest Branch Anacostia River						
1971						
Feb. 7– 9	94.00	84.00	1,009.70	229.00	280.0	5.40
May 13	38.00	33.00	2,065.09	184.00	240.0	1.50
July 1– 2	12.00	9.20	1,409.02	35.00	122.0	1.00
Aug. 1– 2	31.00	28.00	1,058.20	80.00	214.0	2.60
Aug. 3– 4	110.00	104.00	1,324.78	372.00	1,500.0	17.00
Aug. 27–28	67.00	64.00	729.17	126.00	374.0	.77
Nov. 24–25	74.00	65.00	837.61	147.00	253.0	1.60
Nov. 29–30	23.00	16.00	324.07	14.00	84.0	2.90
Dec. 7	18.00	15.00	271.60	11.00	70.0	2.10
1972						
Feb. 3– 4	39.00	31.00	1,851.85	155.00	200.0	2.10
Feb. 13	42.00	39.00	1,082.62	114.00	155.0	1.80
Feb. 18–19	57.00	42.00	1,772.48	201.00	218.0	6.00
Mar. 16–17	50.00	41.00	1,056.91	117.00	141.0	3.20
Apr. 16–17	40.00	30.00	1,024.69	83.00	143.0	7.40
May 3– 4	55.00	41.00	2,005.42	222.00	280.0	2.80
June 29–30	66.00	54.00	1,021.95	149.00	582.0	2.70
July 2– 3	57.00	46.00	998.39	124.00	338.0	4.70
July 16	70.00	67.00	989.50	179.00	980.0	2.30
Oct. 28	7.00	5.80	178.80	2.80	31.0	.86
Nov. 8	15.00	13.00	267.81	9.40	67.0	1.10
Nov. 14	35.00	30.00	555.55	45.00	209.0	1.30
Dec. 8– 9	58.00	48.00	632.72	82.00	308.0	3.10
1973						
Apr. 1– 2	58.00	39.00	2,174.74	229.00	313.0	4.30
Apr. 4	30.00	25.00	874.07	59.00	215.0	4.70
Apr. 27	33.00	24.00	586.42	38.00	191.0	9.50
July 3	16.00	14.00	1,931.21	73.00	210.0	2.10
July 20–21	29.00	25.00	1,244.44	84.00	225.0	1.20
Dec. 20–21	78.00	73.00	826.99	163.00	168.0	1.30
1974						
Jan. 21	16.00	13.00	826.21	29.00	96.0	2.10
Mar. 30	76.00	69.00	1,175.52	219.00	330.0	2.40
June 2	16.00	12.00	740.74	24.00	81.0	1.90
Aug. 19	7.70	6.90	2,039.72	38.00	116.0	.77
Nursery Run at						
1967						
May 7– 8	3.50	2.40	154.32	1.00	9.6	0.41
July 29–30	1.90	1.40	2,566.13	9.70	31.0	.14
Aug. 3– 5	5.10	3.90	1,519.47	16.00	42.0	.16
Aug. 24–25	13.00	12.00	1,450.62	47.00	120.0	.25
Oct. 25–26	1.10	.54	411.52	.60	8.7	.16
Nov. 2	.83	.60	61.73	.10	3.7	.17
1968						
Jan. 14–15	7.10	6.40	567.13	9.80	27.0	.18
Mar. 12–13	2.00	1.00	148.15	.40	4.6	.26
Mar. 17–18	3.60	2.40	92.59	.60	6.8	.49
May 27–28	3.30	2.30	209.34	1.30	8.7	.21
June 19	2.40	2.10	3,350.96	19.00	61.0	.36
June 26–28	1.40	.61	60.72	.10	2.9	.24
Sept. 10–11	.82	.54	137.17	.20	6.4	.10
1969						
Jan. 21	.94	.69	118.09	.22	1.8	.22
June 2– 3	.91	.64	144.68	.25	6.0	.12
June 18–19	1.90	1.50	5,185.18	21.00	35.0	.12
July 22–23	1.30	.95	779.73	2.00	14.0	.19
Aug. 2– 4	5.40	4.20	3,350.97	38.00	72.0	.19
Aug. 18	2.10	1.70	784.31	3.60	25.0	.17
Sept. 2– 3	1.40	.79	797.00	1.70	9.0	.15
Sept. 4	2.50	2.10	1,164.02	6.60	32.0	.64
Oct. 2– 3	1.00	.63	199.88	.34	4.6	.16
Dec. 10–11	3.90	2.90	447.00	3.50	18.0	.31
Dec. 22	2.00	1.50	246.91	1.00	8.0	.25

See footnotes at end of table.

in the Rock Creek and Anacostia River basins, 1962–74—Continued

Antecedent days (A_d)	Total precipitation (R_t) (inches)	Maximum 15-minute rainfall (R_{15}) (in/hr)	Maximum 30-minute rainfall (R_{30}) (in/hr)	Maximum 1-hour rainfall (R_{1h}) (in/hr)	Maximum 3-hour rainfall[1] (R_{3h}) (in/hr)	Peak ratio (P_r)	Number of peaks (N_p)	Time (T_m) (months)	Construction area (C_p) (percent of basin area)
at Norwood, Md.—Continued									
11	1.79	0.44	0.40	0.32	0.25	3.27	2	52	.2
4	2.26	1.52	1.12	.74	.50	7.23	1	55	.2
27	1.74	2.40	1.90	1.28	.49	13.15	1	57	.2
2	[2] 1.99	3.88	2.20	1.22	.49	7.55	2	58	.2
1	[2] 3.51	4.92	4.40	2.48	.90	14.26	1	58	.2
21	3.69	.96	.84	.76	.62	5.83	1	58	.2
20	3.09	.48	.46	.44	.37	3.87	1	61	.2
3	[2] .84	.44	.36	.27	.19	5.07	1	61	.2
7	[2] .91	.24	.18	.16	.12	4.53	1	62	.2
23	1.27	.48	.46	.39	.21	6.38	1	64	.1
9	1.69	.24	.22	.22	.20	3.93	1	64	.1
5	2.20	.48	.48	.47	.38	5.05	1	64	.1
12	1.60	.24	.24	.21	.09	3.36	1	65	.1
2	1.18	.64	.48	.36	.22	4.52	3	66	.1
10	2.22	1.40	.88	.63	.35	6.76	1	67	.1
5	1.74	3.24	2.06	1.13	.40	10.73	1	68	.1
1	1.73	2.20	1.98	1.37	.60	7.25	1	69	.1
7	1.87	3.16	2.16	1.27	.54	14.59	2	69	.1
8	1.55	.68	.68	.46	.26	5.20	2	72	.1
10	1.55	.64	.52	.46	.32	5.07	2	73	.1
5	1.90	.68	.50	.41	.31	6.92	1	73	.1
1	[2] 1.72	.68	.54	.44	.34	6.35	1	74	.1
5	1.65	1.36	.94	.52	.27	7.92	2	78	.9
1	.96	.60	.50	.47	.27	8.41	1	78	.9
15	[2] 1.03	.56	.46	.32	.20	7.56	1	78	.9
2	1.14	2.64	1.96	1.20	.40	14.85	1	81	.9
16	3.08	3.32	2.38	1.34	.77	8.95	2	81	.9
10	[2] 2.08	.48	.40	.31	.20	2.28	2	86	.9
9	.88	.48	.38	.36	.24	7.22	1	87	2.5
8	3.01	.84	.68	.56	.46	4.75	1	89	2.5
20	1.81	.48	.42	.32	.25	6.59	1	92	2.5
8	1.32	2.56	1.82	1.25	.46	16.70	1	94	2.5
Cloverly, Md.									
3	2.00	0.88	0.80	0.65	0.59	3.83	1	7	0.0
7	[2] 1.47	3.20	2.56	1.44	.49	22.04	1	9	.0
3	2.98	3.12	2.12	1.32	.47	10.73	2	10	.0
3	3.67	2.52	1.56	1.10	.61	9.98	1	10	.0
6	.95	1.88	1.28	.73	.31	15.81	1	12	.0
7	1.03	.40	.34	.28	.21	5.88	1	13	.0
15	1.61	.56	.46	.40	.17	4.19	1	15	.0
56	1.76	.72	.50	.42	.19	4.34	2	17	.0
3	1.68	.52	.44	.35	.23	2.63	2	17	.0
33	3.15	.48	.42	.38	.24	3.69	2	19	.0
1	1.24	3.80	2.30	1.15	.39	28.88	1	20	.0
5	1.26	1.48	.94	.51	.18	4.36	2	20	.0
3	1.41	.84	.64	.58	.33	11.67	1	23	.0
1	.70	.12	.12	.10	.07	2.29	1	27	.0
11	1.54	1.20	.76	.50	.33	9.19	1	32	.0
14	1.70	5.16	2.94	1.54	.52	23.25	1	32	.0
1	[2] 1.48	3.48	2.06	1.18	.44	14.54	1	33	.0
4	3.40	3.88	2.86	1.86	.88	17.10	2	34	.0
7	[2] 1.82	2.88	1.94	1.12	.38	14.61	2	34	.0
12	1.90	1.84	1.76	.91	.33	11.20	1	35	.0
1	1.05	1.52	1.32	.80	.29	14.93	1	35	.0
23	1.15	.68	.54	.31	.20	7.05	1	36	.0
1	1.93	.60	.52	.46	.34	6.10	1	38	.0
9	1.20	.52	.44	.39	.30	5.17	1	38	.0

TABLE 5.—*Hydrologic characteristics and related factors for storms*

Period of storm runoff	Total runoff (Q_t) (ft³/s-d)	Storm runoff (Q_r) (ft³/s-d)	Mean sediment concentration (C) (mg/l)	Suspended-sediment discharge (Q_s) (tons)	Peak discharge (Q_p) (ft³/s)	Antecedent discharge (Q_a) (ft³/s)
						Nursery Run at
1970						
Apr. 2	2.40	1.20	1,728.39	5.60	12.0	0.64
Apr. 14	6.00	5.20	619.66	8.70	28.0	.48
Apr. 24	1.00	.26	128.20	.09	1.8	.77
June 3	4.20	3.90	3,893.63	41.00	113.0	.28
June 16–17	2.30	1.30	1,111.11	3.90	26.0	.31
July 9–10	3.60	2.60	897.43	6.30	27.0	.22
July 20–21	3.90	3.00	2,716.05	22.00	74.0	.22
Nov. 4– 5	3.60	2.70	589.85	4.30	15.0	.35
Dec. 22	1.60	.96	246.91	.64	7.1	.35
1971						
Feb. 7– 9	9.30	7.50	938.27	19.00	28.0	.58
May 13	2.00	1.50	839.50	3.40	13.0	.31
July 1– 2	2.70	2.10	4,938.26	28.00	72.0	.22
July 29–30	1.20	.68	816.99	1.50	9.8	.15
Aug. 3– 4	7.30	6.20	4,599.75	77.00	260.0	1.90
Aug. 27	6.00	5.50	1,010.10	15.00	44.0	.19
Nov. 29	1.60	.91	227.92	.56	6.4	.57
Dec. 7	1.80	1.00	259.26	.70	5.4	.48
1972						
Feb. 3– 4	4.00	2.60	1,709.40	12.00	20.0	.45
Feb. 18–19	5.90	3.90	769.23	8.10	22.0	.61
June 21–22	69.00	66.00	1,402.92	250.00	695.0	.38
Nov. 14	3.20	2.60	470.08	3.30	16.0	.32
Dec. 8– 9	4.40	3.00	259.26	2.10	19.0	.50
1973						
Apr. 1– 2	5.10	3.10	1,911.59	16.00	25.0	.68
Apr. 4	2.60	1.80	493.83	2.40	17.0	.78
July 3	.80	.34	1,633.98	1.50	8.2	.46
July 20	2.20	1.90	2,729.04	14.00	25.0	.26
Sept. 14	1.40	1.10	175.08	.52	4.3	.18
1974						
Aug. 19	.69	.51	1,016.70	1.40	9.4	.16
						Batchellors Run
1967						
Aug. 4– 5	2.40	1.80	555.55	2.70	19.0	0.20
1968						
Jan. 14	12.00	10.00	185.18	5.00	41.0	.30
May 28	4.30	2.60	455.84	3.20	17.0	1.70
June 19–20	6.30	5.40	1,303.15	19.00	133.0	.30
June 27–28	1.90	.70	227.51	.43	7.0	.40
1969						
June 2– 3	2.50	1.90	1,364.52	7.00	20.0	.20
June 18–19	1.50	1.00	3,148.14	8.50	21.0	.10
Dec. 10–11	6.00	5.10	798.84	11.00	32.0	.20
1970						
Apr. 14	12.00	10.00	1,407.41	38.00	67.0	.40
July 20–21	5.40	4.90	400.60	5.30	102.0	.10
Nov. 4– 5	4.20	3.60	226.34	2.20	14.0	.20
Dec. 22	3.20	2.80	145.50	1.10	19.0	.20
1972						
Feb. 3– 4	7.10	5.70	1,039.63	16.00	39.0	.40
May 4	4.20	3.50	1,269.84	12.00	54.0	.60
Aug. 27–28	2.50	1.80	308.64	1.50	18.0	.20
Oct. 28	1.90	1.40	203.70	.77	5.7	.30
Nov. 8	2.50	2.20	144.78	.86	10.0	.20
Nov. 14	6.60	5.90	238.54	3.80	39.0	.30
Dec. 8– 9	11.00	8.30	446.23	10.00	76.0	.60
1973						
Feb. 2	4.80	3.30	426.49	3.80	14.0	.50
Apr. 1– 2	8.20	5.20	1,282.05	18.00	70.0	1.00

See footnotes at end of table.

in the Rock Creek and Anacostia River basins, 1962–74—Continued

Antecedent days (A_d)	Total precipitation (R_t) (inches)	Maximum 15-minute rainfall (R_{15}) (in/hr)	Maximum 30-minute rainfall (R_{30}) (in/hr)	Maximum 1-hour rainfall (R_{1h}) (in/hr)	Maximum 3-hour rainfall [1] (R_{3h}) (in/hr)	Peak ratio (P_r)	Number of peaks (N_p)	Time (T_m) (months)	Construction area (C_p) (percent) of basin area)
Cloverly, Md.—Continued									
3	1.11	1.04	0.64	0.37	0.18	9.47	1	42	0.0
10	4.32	.72	.68	.55	.43	5.29	1	42	.0
3	.38	.48	.36	.19	.06	3.96	1	42	.0
8	1.97	3.56	3.22	2.37	.80	28.90	1	44	.0
8	1.57	4.05	2.70	1.36	.45	19.76	1	44	.0
6	2.79	1.92	1.40	1.05	.45	10.30	2	45	.0
8	2.42	2.72	2.48	1.54	.54	24.59	2	45	.0
12	2.33	.68	.60	.51	.36	5.43	1	49	.0
4	1.15	.36	.36	.31	.19	7.03	1	50	.0
11	1.75	.56	.42	.33	.25	3.66	2	52	.0
4	2.02	1.20	.84	.66	.42	8.46	1	55	.0
15	2.30	4.60	3.70	1.90	.66	34.18	1	57	.0
26	1.88	2.48	1.58	1.16	.43	14.19	2	57	.0
1	[2]2.64	4.52	3.16	1.64	.63	41.63	1	58	.0
7	3.58	.84	.80	.62	.48	7.97	3	58	.0
3	[2].83	.36	.36	.32	.21	6.41	1	61	.0
6	[2]1.05	.24	.20	.16	.13	4.92	1	62	.0
9	1.39	.36	.34	.32	.22	7.52	1	64	.0
3	2.10	.20	.18	.18	.17	5.48	1	64	.0
2	[2]8.23	2.64	2.50	2.17	1.28	10.52	4	68	.0
5	1.77	.68	.60	.49	.41	6.03	1	73	.0
1	1.92	.56	.52	.40	.32	6.17	1	74	.0
1	1.86	2.48	1.40	.77	.38	7.85	2	78	.4
1	1.08	.76	.62	.62	.34	9.01	1	78	.4
2	.87	2.64	1.50	.87	.29	22.76	1	81	.4
8	[2]2.32	2.60	2.40	1.34	.72	13.02	2	81	.4
7	2.29	.56	.56	.44	.34	3.75	1	83	.4
2	1.23	1.76	1.58	.99	.38	18.12	1	94	.0
at Oakdale, Md.									
1	2.18	2.92	1.86	1.04	0.36	10.44	2	10	1.7
9	1.55	.44	.42	.37	.28	4.07	1	15	.7
3	2.94	.60	.48	.38	.24	5.88	1	19	.7
1	1.23	2.84	2.28	1.16	.39	24.57	1	20	.7
1	[2].58	1.92	1.28	.68	.19	9.43	1	20	.7
11	2.10	2.72	1.82	1.45	.61	10.42	1	32	.7
14	1.50	3.60	2.50	1.35	.46	20.90	1	32	.7
1	1.43	.44	.42	.35	.25	6.24	1	38	.7
6	3.05	.52	.42	.38	.34	6.66	1	42	.7
9	2.51	1.44	.96	.50	.23	20.80	1	45	.7
1	2.08	.60	.54	.44	.36	3.83	1	49	.7
4	1.06	.40	.36	.30	.18	6.71	1	50	.7
9	1.17	.48	.38	.33	.19	6.77	1	64	.3
1	[2]1.55	.60	.50	.35	.23	15.26	1	67	.3
17	[2]1.62	1.64	1.10	.88	.50	9.89	1	70	.3
8	1.64	1.56	1.04	.61	.26	3.86	1	72	.3
10	1.57	.72	.66	.57	.36	4.45	1	73	.3
5	1.91	.80	.54	.40	.33	6.56	2	73	.3
1	1.88	1.64	1.04	1.01	.57	9.08	1	74	.3
1	1.05	.40	.32	.26	.18	4.09	2	76	.3
5	1.70	2.20	2.04	1.30	.58	13.27	1	78	.3

TABLE 5.—*Hydrologic characteristics and related factors for storms*

Period of storm runoff	Total runoff (Q_t) (ft³/s-d)	Storm runoff (Q_r) (ft³/s-d)	Mean sediment concentration (C) (mg/l)	Suspended-sediment discharge (Q_s) (tons)	Peak discharge (Q_p) (ft³/s)	Antecedent discharge (Q_a) (ft³/s)
						Batchellors Run at
1973—Continued						
July 3– 4	6.70	5.40	672.15	9.80	122.0	0.80
July 20–21	7.60	7.10	573.81	11.00	130.0	.20
Sept. 14	1.20	.80	189.81	.41	3.6	.20
1974						
Jan. 21–22	3.80	1.90	467.84	2.40	25.0	.60
Aug. 19–20	4.00	2.70	1,508.91	11.00	39.0	.50
						Bel Pre Creek at
1963						
June 2– 3	23.00	22.00	286.19	17.00	61.0	0.20
Aug. 20–21	20.00	20.00	203.70	11.00	102.0	.30
Sept. 29	4.50	4.20	114.64	1.30	18.0	.10
Nov. 6– 7	40.00	38.00	136.45	14.00	80.0	2.00
1964						
Jan. 9–10	27.00	26.00	170.94	12.00	117.0	.40
Aug. 3– 4	1.30	1.20	277.78	.90	14.0	.10
Dec. 27–28	11.00	10.00	137.04	3.70	31.0	.20
1965						
Mar. 5– 6	75.00	71.00	944.18	181.00	260.0	.20
Aug. 26–27	71.00	70.00	4,851.84	917.00	410.0	.10
1966						
Jan. 6	6.30	4.50	1,646.09	20.00	22.0	1.20
Feb. 13	65.00	63.00	2,316.28	394.00	180.0	1.50
Apr. 12–13	23.00	19.00	2,358.67	121.00	62.0	.50
Sept. 14	59.00	55.00	2,249.15	334.00	370.0	.30
Oct. 18–19	35.00	34.00	1,361.65	125.00	84.0	.30
Nov. 28–29	13.00	12.00	1,666.66	54.00	63.0	.28
1967						
Jan. 27–28	9.50	8.30	4,283.79	96.00	56.0	.58
Mar. 6– 8	59.00	55.00	2,545.45	378.00	193.0	.98
Mar. 15–16	18.00	15.00	1,407.41	57.00	52.0	.98
Apr. 17–18	3.80	2.50	1,629.63	11.00	11.0	.58
May 7– 8	34.00	30.00	2,037.03	165.00	96.0	1.10
June 22–23	10.00	9.00	4,485.59	109.00	130.0	.39
July 20–21	7.30	6.60	3,198.65	57.00	85.0	.17
Aug. 3– 5	26.00	24.00	8,009.25	519.00	158.0	.24
Aug. 24–25	67.00	64.00	2,575.23	445.00	338.0	.57
Oct. 25–26	12.00	11.00	4,377.10	130.00	135.0	.25
Nov. 2– 3	9.30	8.30	1,383.31	31.00	58.0	.29
Dec. 3– 4	31.00	28.00	396.82	30.00	68.0	.41
Dec. 28–29	29.00	27.00	644.72	47.00	81.0	.49
1968						
Jan. 14–15	48.00	45.00	510.29	62.00	159.0	.30
Mar. 12–13	25.00	22.00	993.26	59.00	63.0	.46
Mar. 17–18	35.00	28.00	1,574.07	119.00	95.0	1.90
May 27–29	44.00	40.00	1,074.07	116.00	106.0	.32
June 16–17	17.00	15.00	1,567.90	104.00	137.0	.37
June 19–20	16.00	14.00	2,804.23	106.00	178.0	1.50
June 27–28	20.00	18.00	5,020.56	244.00	134.0	.40
July 2– 3	16.00	15.00	4,395.05	178.00	114.0	.27
Sept. 6– 7	2.70	2.50	962.96	6.50	29.0	.15
Sept. 10–11	9.70	9.20	2,173.91	54.00	104.0	.11
Oct. 6– 7	4.70	4.40	690.23	8.20	34.0	.17
1969						
Jan. 21–22	12.00	11.00	505.05	15.00	23.0	.47
May 20–21	15.00	14.00	3,412.69	129.00	192.0	.53
June 2– 3	29.00	29.00	1,915.71	150.00	206.0	.10
June 18–19	7.20	6.50	3,646.72	64.00	113.0	.21
July 20–21	14.00	14.00	10,952.36	414.00	214.0	.09
July 22–23	6.00	5.10	5,010.88	69.00	57.0	1.20
Aug. 9–10	58.00	57.00	1,858.35	286.00	307.0	.19
Sept. 2– 4	12.00	11.00	2,794.61	83.00	164.0	.23
Nov. 19–20	11.00	10.00	888.89	24.00	66.0	.21
Dec. 10–11	34.00	33.00	808.08	72.00	153.0	.67

See footnotes at end of table.

in the Rock Creek and Anacostia River basins, 1962–74—Continued

Antecedent days (A_d)	Total precipitation (R_t) (inches)	Maximum 15-minute rainfall (R_{15}) (in/hr)	Maximum 30-minute rainfall (R_{30}) (in/hr)	Maximum 1-hour rainfall (R_{1h}) (in/hr)	Maximum 3-hour rainfall [1] (R_{3h}) (in/hr)	Peak ratio (P_r)	Number of peaks (N_p)	Time (T_m) (months)	Construction area (C_p) (percent) of basin area)
Oakdale, Md.—Continued									
3	0.99	2.36	1.92	1.21	0.40	22.44	1	81	0.3
15	[2]2.21	2.60	2.48	1.43	.67	18.28	1	81	.3
11	1.87	.72	.54	.41	.31	4.25	1	83	.3
8	1.08	.60	.50	.45	.30	12.84	1	87	4.0
1	2.23	2.40	2.16	2.01	.82	14.26	1	94	4.0
Layhill, Md.									
2	[2]2 95	0.44	0.36	0.33	0.22	2.76	1	3	0.0
5	[2]2.75	1.94	1.72	1.00	.52	5.08	2	5	.0
12	[2]2.10	.56	.40	.39	.26	4.26	1	6	.0
3	[2]3.30	.40	.36	.35	.30	2.05	1	8	.0
1	[2]1.16	.36	.32	.25	.22	4.48	1	10	.0
20	[2]1.95	.84	.52	.40	.20	11.58	1	17	.0
13	[2].72	.60	.40	.25	.13	3.08	1	21	3.1
7	[2]2.95	2.64	1.34	.67	.22	3.66	1	24	18.0
3	[2]2.81	3.32	2.24	1.40	.49	5.86	2	29	18.0
88	[2].89	.16	.14	.12	.07	4.62	1	34	14.0
1	[2]1.73	1.48	.80	.43	.17	2.83	2	35	14.0
17	[2]2.20	.20	.18	.15	.13	3.24	1	37	14.0
19	[2]5.48	1.12	1.10	.95	.72	6.72	2	42	14.0
14	[2]2.45	.44	.30	.25	.22	2.46	1	43	13.8
35	1.29	.92	.76	.50	.25	5.23	1	44	13.8
18	.75	1.20	.68	.37	.18	6.68	1	46	13.8
12	2.55	.96	.86	.67	.47	3.49	1	48	13.8
7	.85	1.32	.90	.74	.35	3.40	2	48	13.8
9	[2].66	1.24	1.00	.59	.26	4.17	1	49	13.9
3	2.01	.68	.52	.46	.37	3.16	1	50	13.9
33	1.49	3.76	2.42	1.33	.50	14.40	1	51	13.9
16	.96	1.28	.80	.47	.23	12.85	1	52	13.9
3	2.28	2.88	1.76	.91	.32	6.57	2	53	13.9
3	3.69	1.64	1.22	.88	.59	5.27	3	53	13.9
6	1.14	2.12	1.32	.77	.34	12.25	1	55	10.0
7	1.02	.48	.40	.33	.24	6.95	1	56	10.0
30	[2]1.42	.40	.34	.30	.21	2.41	1	57	10.0
4	[2]1.48	.48	.36	.22	.17	2.98	1	57	10.0
15	1.36	.32	.30	.29	.24	3.53	1	58	10.0
37	1.79	.60	.42	.39	.20	2.84	1	60	10.0
3	1.49	.60	.50	.41	.24	3.32	2	60	10.0
2	2.76	.52	.44	.37	.23	2.64	1	62	9.8
2	[2]1.21	3.48	2.14	1.21	.40	9.11	1	63	9.8
1	1.04	3.40	1.78	.89	.30	12.61	1	63	9.8
6	1.70	1.76	1.48	.81	.32	7.42	2	63	9.8
3	[2]1.36	1.88	1.34	.91	.32	7.58	2	64	9.8
19	[2].76	.64	.48	.37	.19	11.54	1	66	9.8
3	1.50	2.16	1.86	1.28	.53	11.29	2	66	9.8
26	[2]1.18	.36	.34	.32	.27	7.69	2	67	9.8
28	.56	.12	.10	.08	.07	2.05	1	70	9.8
10	1.47	2.72	1.92	.99	.33	13.68	1	74	11.1
11	1.92	3.00	2.02	1.54	.74	7.10	1	75	11.1
9	1.34	2.64	1.58	.84	.29	17.35	2	75	11.1
30	[2]1.13	3.60	2.14	1.11	.38	15.28	1	76	11.1
1	[2]1.11	4.00	2.20	1.15	.42	10.94	1	76	11.1
4	3.16	2.84	1.50	.77	.75	5.38	2	77	11.1
12	1.48	1.12	1.20	.66	.23	14.89	6	78	11.1
10	1.15	1.04	.70	.48	.27	6.58	1	80	11.1
1	1.45	.56	.46	.39	.27	4.62	1	81	9.7

TABLE 5.—*Hydrologic characteristics and related factors for storms*

Period of storm runoff	Total runoff (Q_t) (ft³/s-d)	Storm runoff (Q_r) (ft³/s-d)	Mean sediment concentration (C) (mg/l)	Suspended-sediment discharge (Q_s) (tons)	Peak discharge (Q_p) (ft³/s)	Antecedent discharge (Q_a) (ft³/s)
						Bel Pre Creek at
1970						
Apr. 1– 2	23.00	21.00	1,975.31	112.00	117.0	2.00
Apr. 14–15	79.00	76.00	1,310.91	269.00	234.0	.78
July 9–10	44.00	43.00	956.07	111.00	265.0	.23
July 20–21	32.00	31.00	1,051.37	88.00	313.0	.22
Aug. 14–15	12.00	11.00	1,212.12	36.00	116.0	.15
Sept. 10	7.80	7.50	1,629.63	33.00	141.0	1.10
Oct. 21	7.20	6.70	939.74	17.00	61.0	.15
Nov. 3	2.90	2.40	324.07	2.10	19.0	.29
Nov. 4– 5	37.00	35.00	529.10	50.00	138.0	2.90
1971						
Feb. 22–23	39.00	34.00	1,209.15	111.00	105.0	1.50
July 29	13.00	13.00	5,527.05	194.00	180.0	.12
Aug. 1– 2	34.00	32.00	5,925.92	512.00	255.0	3.10
Aug. 3– 4	91.00	87.00	2,303.10	541.00	1,030.0	15.00
Aug. 27–28	63.00	60.00	2,641.97	428.00	262.0	.33
Sept. 11–12	27.00	24.00	5,679.00	368.00	173.0	.33
Nov. 24–25	68.00	63.00	1,475.60	251.00	198.0	.38
Nov. 29–30	17.00	13.00	1,111.11	39.00	59.0	1.10
Dec. 7	19.00	16.00	1,018.52	44.00	65.0	.86
1972						
Mar. 16–17	50.00	45.00	2,230.45	271.00	160.0	1.50
Apr. 16–17	33.00	27.00	2,414.26	176.00	134.0	6.80
June 21–22	381.00	368.00	3,713.76	3,690.00	1,930.0	1.80
July 2– 3	56.00	49.00	2,494.33	330.00	264.0	2.60
Oct. 28	20.00	19.00	6,354.77	326.00	106.0	.46
Nov. 8	22.00	21.00	1,181.66	67.00	90.0	.45
Nov. 14	36.00	35.00	761.90	72.00	142.0	.43
Dec. 8– 9	52.00	50.00	1,022.22	138.00	154.0	1.50
1973						
Feb. 2	34.00	29.00	1,583.65	124.00	90.0	1.00
Apr. 1– 2	50.00	40.00	2,527.77	273.00	198.0	3.40
Apr. 4	26.00	23.00	1,433.17	89.00	150.0	2.10
Apr. 25–26	31.00	26.00	740.74	52.00	105.0	1.10
Apr. 27	31.00	27.00	1,001.37	73.00	135.0	21.00
June 29	8.20	7.20	2,006.17	39.00	107.0	.65
July 3– 4	24.00	22.00	2,912.45	173.00	276.0	3.20
Sept. 14	19.00	18.00	1,481.48	72.00	79.0	.29
Oct. 2– 3	7.90	6.90	1,610.30	30.00	44.0	.31
Dec. 5	5.90	4.70	1,260.83	16.00	43.0	.24
1974						
Jan. 21	19.00	16.00	2,500.00	108.00	131.0	1.00
Mar. 30–31	71.00	63.00	1,064.08	181.00	244.0	1.30
May 12–13	27.00	22.00	1,060.60	63.00	198.0	.63
June 2	9.70	7.70	577.20	12.00	50.0	.81
July 29–30	6.30	5.00	2,444.44	33.00	120.0	.11
Aug. 9	11.00	9.60	4,089.50	106.00	109.0	1.00
Aug. 19–20	13.00	11.00	2,424.24	72.00	128.0	.40
						Lutes Run at
1963						
June 2– 3	9.10	8.10	9,785.07	214.00	50.0	0.30
Nov. 6– 7	9.70	8.80	9,301.32	221.00	37.0	.40
1964						
Jan. 9	7.70	7.10	11,632.73	223.00	42.0	.10
Aug. 3	3.40	2.80	10,846.54	82.00	48.0	.50
1965						
Feb. 7– 8	7.60	5.80	6,066.40	95.00	36.0	.80
Mar. 26	4.80	3.60	3,909.46	38.00	46.0	1.00
Oct. 7– 8	37.00	34.00	3,834.42	352.00	350.0	.70
1966						
Feb. 13	18.00	12.00	8,950.60	290.00	170.0	7.00
Nov. 28	3.40	3.20	1,851.85	16.00	23.0	.10

See footnotes at end of table.

in the Rock Creek and Anacostia River basins, 1962–74—Continued

Antecedent days (A_d)	Total precipitation (R_t) (inches)	Maximum 15-minute rainfall (R_{15}) (in/hr)	Maximum 30-minute rainfall (R_{30}) (in/hr)	Maximum 1-hour rainfall (R_{1h}) (in/hr)	Maximum 3-hour rainfall [1] (R_{3h}) (in/hr)	Peak ratio (P_r)	Number of peaks (N_p)	Time (T_m) (months)	Construction area (C_p) (percent of basin area)
Layhill, Md.—Continued									
2	1.06	0.88	0.58	0.33	0.14	5.48	2	85	9.7
6	2.92	.52	.40	.36	.28	3.07	1	85	9.7
16	3.18	2.24	1.80	1.23	.52	6.16	2	88	9.7
9	2.46	3.08	2.34	1.39	.49	10.09	2	88	9.7
6	1.40	1.24	1.18	1.00	.45	10.53	1	89	9.7
17	1.48	3.08	2.40	1.35	.45	18.65	1	90	9.7
4	[2]1.35	.72	.50	.39	.24	9.08	1	91	9.7
2	[2].53	.64	.38	.24	.12	7.80	1	92	9.7
0	1.94	.56	.54	.41	.34	3.86	1	92	9.7
8	1.65	.40	.34	.30	.18	3.04	2	95	8.9
3	2.21	2.16	1.74	1.48	.56	13.84	1	100	8.9
2	[2]1.63	1.72	1.48	.81	.36	7.87	2	101	8.9
0	[2]3.30	4.80	3.66	2.00	.77	11.67	1	101	8.9
7	3.37	1.24	1.00	.95	.56	4.36	1	101	8.9
11	3.20	1.72	1.20	.84	.47	7.19	5	102	8.9
16	2.50	.52	.46	.37	.34	3.14	1	104	8.9
3	[2].67	.40	.32	.24	.17	4.45	1	104	8.9
5	[2].97	.32	.24	.18	.12	4.01	1	105	8.9
1	1.55	.68	.42	.32	.21	3.52	1	108	13.7
2	1.03	.72	.50	.28	.16	4.71	3	109	13.7
6	[2]8.23	2.40	2.30	1.85	1.48	5.24	2	111	13.7
1	1.72	2.60	2.54	1.57	.65	5.33	2	112	13.7
8	1.65	1.80	1.02	.60	.25	5.55	2	115	13.7
10	1.50	.64	.52	.45	.29	4.26	2	116	13.7
5	2.00	.60	.60	.45	.41	4.04	1	116	13.7
1	1.85	.56	.52	.41	.31	3.05	1	117	13.7
3	1.09	.24	.20	.18	.13	3.07	2	119	15.2
5	1.55	.36	.34	.32	.20	4.86	2	121	15.2
1	.95	.20	.16	.15	.13	6.43	1	121	15.0
14	[2]1.94	.68	.56	.38	.22	4.00	2	121	15.2
0	[2]1.37	.60	.50	.42	.26	4.22	1	121	15.2
3	.78	1.00	.84	.57	.20	14.77	1	123	15.2
3	2.03	3.24	2.38	1.23	.41	12.40	1	124	15.2
7	1.87	.72	.52	.39	.27	4.37	3	126	15.2
17	1.05	.36	.26	.24	.20	6.33	1	127	15.2
36	.92	.52	.38	.25	.14	9.10	2	129	13.1
8	.93	.80	.50	.47	.26	8.13	1	130	13.1
8	2.63	.64	.52	.45	.36	3.85	1	132	13.1
27	1.50	1.72	1.24	.78	.38	8.97	2	134	11.0
19	1.45	.44	.34	.28	.23	6.39	1	135	11.0
35	1.03	2.68	1.61	.87	.34	23.98	1	136	11.0
9	2.23	2.96	2.30	1.38	.59	11.25	2	137	11.0
9	1.50	3.28	2.84	1.76	.60	11.60	1	137	11.0
Lutes, Md.									
2	[2]2.93	0.44	0.36	0.33	0.60	6.14	4	5	20.3
3	[2]2.80	.40	.36	.35	.72	4.16	2	10	14.3
1	[2]1.16	.36	.30	.25	.48	5.90	1	12	14.3
20	[2]1.95	.84	.52	.40	1.20	16.96	1	19	11.3
12	[2]1.38	.24	.22	.20	.48	6.07	1	25	8.3
6	[2]1.26	.40	.34	.30	.84	12.50	1	26	8.3
12	[2]3.45	1.44	1.30	1.02	2.52	10.27	3	33	6.7
1	[2]1.71	1.48	.82	.42	3.60	13.58	3	37	13.3
24	1.17	.92	.76	.50	.96	7.16	1	46	10.3

TABLE 5.—*Hydrologic characteristics and related factors for storms*

Period of storm runoff	Total runoff (Q_t) (ft³/s-d)	Storm runoff (Q_r) (ft³/s-d)	Mean sediment concentration (C) (mg/l)	Suspended-sediment discharge (Q_s) (tons)	Peak discharge (Q_p) (ft³/s)	Antecedent discharge (Q_a) (ft³/s)
					Lutes Run at Lutes,	
1967						
Jan. 27	2.90	2.70	11,659.79	85.00	44.0	0.10
May 7	9.10	8.30	2,989.73	67.00	43.0	1.30
June 22	5.00	4.80	4,629.62	60.00	189.0	.10
July 20	5.90	5.80	4,661.55	73.00	194.0	.10
July 29–30	3.70	3.50	2,539.68	24.00	153.0	.10
Aug. 3– 5	13.00	13.00	2,849.00	100.00	221.0	.10
Aug. 19	2.70	2.60	4,843.30	34.00	88.0	.10
Oct. 25–26	3.80	3.60	3,292.18	32.00	101.0	.10
Nov. 2	3.00	2.90	753.51	5.90	26.0	.10
1968						
Jan. 14–15	12.00	11.00	673.40	20.00	65.0	.20
Mar. 17–18	8.60	7.30	1,522.07	30.00	51.0	.50
May 27–29	10.00	9.10	1,221.00	30.00	75.0	.20
June 19–20	6.70	6.20	3,643.96	61.00	270.0	.20
July 2– 3	8.90	8.20	2,393.85	53.00	218.0	.20
Sept. 2	.88	.84	2,425.04	5.50	48.0	.02
1970						
Apr. 2	3.90	3.50	5,396.82	51.00	83.0	.20
1973						
June 29	4.10	3.90	2,943.97	31.00	137.0	.20
July 3	4.50	4.10	3,703.70	41.00	170.0	.40
Sept. 14	5.20	5.10	275.96	3.80	43.0	.10
Oct. 2	3.30	3.20	231.48	2.00	26.0	.10
1974						
May 12	.64	.45	987.65	1.20	176.0	.20
June 16	2.80	2.70	905.35	6.60	112.0	.10
June 26	.45	.30	197.53	.16	9.3	.20
July 5	.33	.22	538.72	.32	15.0	.10
July 29	2.70	2.60	2,136.75	15.00	176.0	.10
Aug. 4	.26	.21	194.00	.11	12.0	.05
Aug. 9	2.90	2.80	1,230.16	9.30	153.0	.10
Aug. 28	.31	.25	400.00	.27	12.0	.06
Aug. 30	1.40	1.30	769.23	2.70	90.0	.06
Sept. 3	3.30	3.20	578.70	5.00	95.0	.06
Sept. 6– 7	7.30	7.10	156.49	3.00	44.0	.10

[1] Maximum 5-minute rainfall for Lutes Run, maximum 3-hour rainfall for all other stations.
[2] From single rain gage in or near the basin.

Each model for each station was analyzed, and the best models with one, two, three, and four independent variables were selected on the basis of the multiple correlation coefficient and the standard error of estimate. The regression equations summarized in table 7 were generally consistent with the results of the correlation analyses. Storm runoff was the most significant parameter affecting suspended-sediment discharge. It explained 52 to 72 percent of the variation of sediment discharge for the five sites when it was the most significant independent variable. Peak discharge was the most significant independent variable at three sites: North Branch Rock Creek, Manor Run, and Nursery Run. It explained 40, 83, and 86 percent of the variation of suspended-sediment discharge, respectively. There was no apparent relation between the size of the basin or degree of urban development and the significance of peak discharge in the regression equations. The addition of a second independent variable to the regression model for each basin generally resulted in a marked improvement in the multiple correlation coefficient and standard error of estimate. This was particularly true in the basins where storm runoff was the most significant independent variable. The addition of the third and fourth independent variables improved the relations to a lesser extent. The standard error tended to increase with the addition of a fourth independent variable at stations having a small number of storms available for analysis.

The second and third most significant independent variables in the regression models were generally related to storm intensity. Peak ratio, 15-min rainfall, or 30-min rainfall was selected at all sites except Nursery Run. Percentage of construction or

in the Rock Creek and Anacostia River basins, 1962–74—Continued

Antecedent days (A_d)	Total precipitation (R_t) (inches)	Maximum 15-minute rainfall (R_{15}) (in/hr)	Maximum 30-minute rainfall (R_{30}) (in/hr)	Maximum 1-hour rainfall (R_{1h}) (in/hr)	Maximum 3-hour rainfall [1] (R_{3h}) (in/hr)	Peak ratio (P_r)	Number of peaks (N_p)	Time (T_m) (months)	Construction area (C_p) (percent) of basin area)
Md.—Continued									
17	0.74	1.24	0.68	0.39	3.60	16.26	1	48	10.3
9	2.06	.64	.54	.46	.96	5.02	2	52	9.3
5	1.39	3.32	2.22	1.23	4.20	39.35	1	53	9.3
4	1.42	2.84	2.10	1.22	3.12	33.43	1	54	9.3
7	.70	3.60	2.16	1.15	3.60	43.69	1	54	9.3
3	2.67	2.88	1.76	.91	4.20	16.99	3	55	9.3
13	[2] 1.29	2.52	1.30	.75	4.44	33.81	2	55	9.3
5	1.32	2.80	1.80	1.07	3.48	28.03	1	57	9.3
6	.97	.44	.38	.31	.48	8.93	2	58	9.3
14	1.45	.44	.38	.33	.44	5.89	2	60	9.3
3	1.84	.60	.50	.49	.84	6.92	2	62	4.3
2	3.13	.56	.48	.43	.72	8.22	1	64	4.3
1	.70	3.40	1.78	.89	4.44	43.52	1	65	4.3
3	1.98	2.88	1.98	1.20	3.96	26.56	3	66	4.3
11	[2] .56	1.68	1.10	.56	2.04	57.12	2	68	4.3
3	[2] .65	1.24	.74	.44	1.24	23.66	1	87	4.3
2	.98	1.96	1.32	.88	1.96	35.08	1	125	1.7
2	[2] .78	3.24	2.38	1.23	3.96	41.37	1	126	1.7
6	1.85	.64	.46	.36	.84	8.41	4	128	1.7
1	1.10	.32	.30	.25	.36	8.09	4	129	.7
8	[2] .17	1.20	.92	.61	1.20	390.67	1	136	.7
13	[2] 1.04	.56	.36	.25	.56	41.44	3	137	.7
2	[2] .20	.28	.24	.18	.36	30.33	1	137	.7
6	[2] .20	.44	.22	.13	.60	67.73	1	138	.7
23	.95	2.08	1.34	.74	3.00	67.65	1	138	.7
4	[2] .17	.52	.26	.15	.84	56.90	1	139	.7
4	[2] .68	1.76	1.26	.67	2.52	54.61	1	139	.7
1	[2] .25	.44	.40	.20	1.08	47.76	1	139	.7
1	.53	1.48	.82	.47	2.40	69.18	1	139	.7
3	1.40	1.00	.62	.46	1.92	29.67	2	140	.7
1	1.50	.28	.26	.25	.36	6.18	1	140	.7

the chronology factor was also selected as the second or third independent variable for most stations. In fact, these were the only factors that showed any difference between the urban and rural streams. Each basin with active construction showed a significant relation between suspended-sediment discharge and percentage of construction or the closely related chronology factor.

These analyses indicate the complex relation between sediment discharge and the factors affecting erosion and sediment transport. As in the study of large Atlantic coast streams (Guy, 1964), storm runoff, rainfall intensity, and storm peak ratio significantly affect the sediment discharge. However, even though a relatively dense network of rain gages was used to determine rainfall amount and intensity, the relationships developed for these small basins are no better, and in some cases worse, than the relationships developed for the large basins. The lowest standard error of estimate for the equations in table 7 is 0.221 log units, or about 52 percent. Part of the error is attributable to the inaccuracies inherent in suspended-sediment sampling; however, much of the error is probably attributable to factors not analyzed by the regression model. Factors such as the location of sediment source areas and differing soil and cover conditions, with respect to the areal distribution of rainfall, must be analyzed before individual storm sediment discharges can be defined by regression or other modeling techniques.

EFFECTS OF LAND USE/LAND COVER

AVERAGE ANNUAL SEDIMENT YIELDS

Average annual suspended-sediment yields were computed for periods of equal land use/land cover in the study basins using flow duration and sedi-

TABLE 6.—*Simple correlation coefficients*

	Suspended-sediment discharge (log Q_s)	Mean sediment concentration (log C)	Storm runoff (log Q_r)	Peak discharge (log Q_p)	Antecedent discharge (log 10 Q_a)	Antecedent days (A_d)
						Suspended-sediment
Williamsburg Run	1.00	---	[1]0.84	[1]0.84	[1]0.38	[1]—0.37
Manor Run	1.00	---	[1].50	[1].63	—.07	—.08
N. Br. Rock Creek	1.00	---	[1].84	[1].91	[2].26	[2]—.26
N.W. Br. Anacostia River	1.00	---	[1].74	[1].83	[2].29	—.05
Nursery Run	1.00	---	[1].81	[1].95	.20	—.16
Batchellors Run	1.00	---	[1].72	[1].84	---	---
Bel Pre Creek	1.00	---	[1].76	[1].84	[1].31	[2]—.26
Lutes Run	1.00	---	[1].85	[1].57	---	---
						Mean sediment
Williamsburg Run	---	1.00	0.11	[1]0.27	0.05	—0.12
Manor Run	---	1.00	—.21	.17	[1]—.33	.10
N. Br. Rock Creek	---	1.00	[1].32	[1].53	—.01	—.13
N.W. Br. Anacostia River	---	1.00	—.04	[2].33	—.21	.23
Nursery Run	---	1.00	[1].44	[1].79	.10	—.15
Bel Pre Creek	---	1.00	.12	[1].45	.08	—.03
						Storm runoff,
Williamsburg Run	[1]0.84	0.11	1.00	[1]0.89	[1]0.44	[1]—0.39
Manor Run	[1].50	—.21	1.00	[1].70	[1].32	—.23
N. Br. Rock Creek	[1].84	[1].32	1.00	[1].92	[1].40	[1]—.29
N.W. Br. Anacostia River	[1].74	—.04	1.00	[1].79	[1].56	[2]—.27
Nursery Run	[1].81	[1].44	1.00	[1].82	[1].26	—.11
Batchellors Run	[1].72	---	1.00	[1].80	---	---
Bel Pre Creek	[1].76	.12	1.00	[1].80	[1].38	[1]—.35
Lutes Run	[1].85	---	1.00	[1].56	---	---
						Peak discharge,
Williamsburg Run	[1]0.84	0.27	[1]0.89	1.00	[1]0.37	[1]—0.32
Manor Run	[1].63	.17	[1].70	1.00	—.03	—.08
N. Br. Rock Creek	[1].91	[1].53	[1].92	1.00	[1].33	[1]—.29
N.W. Br. Anacostia River	[1].83	[2].33	[1].79	1.00	[1].35	[2]—.30
Nursery Run	[1].95	[1].79	[1].82	1.00	.17	—.19
Batchellors Run	[1].84	---	[1].80	1.00	---	---
Bel Pre Creek	[1].84	[2].45	[1].80	1.00	[2].27	[1]—.34
Lutes Run	[1].57	---	[1].56	1.00	---	---
						Antecedent discharge,
Williamsburg Run	[1]0.38	0.05	[1]0.44	[1]0.37	1.00	[1]—0.43
Manor Run	—.07	[1]—.33	[1].32	—.03	1.00	[1]—.44
N. Br. Rock Creek	[2].26	—.01	[1].40	[1].33	1.00	[1]—.29
N.W. Br. Anacostia River	[2].29	—.21	[1].56	[1].35	1.00	[1]—.40
Nursery Run	.20	.10	.26	.17	1.00	[2]—.30
Bel Pre Creek	[1].31	.08	[1].38	[1].27	1.00	[2]—.25
						Antecedent
Williamsburg Run	[1]—0.37	—0.12	[1]—0.39	[1]—0.32	[1]—0.43	1.00
Manor Run	—.07	.10	—.23	—.08	[1]—.44	1.00
N. Br. Rock Creek	[2]—.26	—.13	[1]—.29	[1]—.29	[1]—.29	1.00
N.W. Br. Anacostia River	—.05	.23	[2]—.27	[2]—.30	[1]—.40	1.00
Nursery Run	—.16	—.15	—.11	—.19	[2]—.30	1.00
Bel Pre Creek	[2]—.26	—.03	[1]—.35	[1]—.34	[2]—.25	1.00
						Total precepitation,
Williamsburg Run	[1]0.64	0.18	[1]0.69	[1]0.69	0.06	0.05
Manor Run	[1].54	.04	[1].73	[1].63	—.14	.09
N. Br. Rock Creek	[1].56	[2].25	[1].63	[1].58	[1]—.28	.03
N.W. Br. Anacostia River	[1].59	[2].27	[1].54	[1].54	—.04	.21
Nursery Run	[1].67	[1].38	[1].79	[1].70	—.12	.12
Batchellors Run	.29	---	.29	.18	---	---
Bel Pre Creek	[1].51	.07	[1].69	[1].65	.02	—.20
Lutes Run	[1].78	---	[1].92	[2].38	---	---
						Maximum 5-minute
Lutes Run	[2]0.36	---	0.17	[1]0.72	---	---
						Maximum 15-minute
Williamsburg Run	[1]0.36	[1]0.54	0.08	[1]0.37	[1]—0.29	0.08
Manor Run	[1].39	[1].48	—.06	[1].49	[1]—.47	.20

See footnotes at end of table.

of storm-related variables

Total precipitation (log 10 R_t)	Maximum 5-minute rainfall (log 10 R_{05})	Maximum 15-minute rainfall (log 10 R_{15})	Maximum 30-minute rainfall (log 10 R_{30})	Maximum 1-hour rainfall (log 10 R_{1h})	Maximum 3-hour rainfall (log 10 R_{3h})	Number of peaks (N_p)	Chronology factor (T_m)	Percent construction (C_p)	Peak ratio (log P_r)
discharge, log Q_s									
0.64	---	[1]0.36	[1]0.41	[1]0.45	[1]0.55	0.13	0.12	[1]0.27	0.08
[1].54	---	[1].39	[1].39	[1].41	[1].43	.14	[1]—.33	[1].42	[2].25
[1].56	---	[1].35	[1].38	[1].38	[1].49	.16	.05	.14	.05
[1].59	---	.21	.22	[2].28	[1].34	—.01	.09	—.05	.07
[1].67	---	[1].55	[1].59	[1].65	[1].70	[2].33	.16	.01	[1].52
.29	---	.14	.20	---	---	---	—.02	---	[2].49
[1].51	---	[1].41	[1].43	[1].45	[1].49	[2].26	[2].26	[1].51	—.02
[1].78	[2]0.36	[2].33	[2].39	---	---	---	[1]—.80	[1].70	[1]—.47
concentration, log C									
0.18	---	[1]0.54	[1]0.57	[1]0.56	[1]0.44	0.09	—0.20	[2]0.23	[1]0.36
.04	---	[1].48	[1].43	[1].37	.18	.05	[1]—.59	[1].69	[1].48
[2].25	---	[1].57	[1].59	[1].57	[1].49	.08	—.14	.19	[1].47
[2].27	---	[1].53	[1].52	[1].51	[1].37	—.19	[2]—.28	.12	[1].56
[1].38	---	[1].71	[1].73	[1].73	[1].63	.10	.25	.10	[1].78
.07	---	[1].55	[1].53	[1].50	[1].34	[2].25	[1].31	[1].58	[1].46
log Q_r									
[1]0.69	---	0.08	0.13	0.19	[1]0.39	0.10	[1]0.29	0.18	—0.14
[1].73	---	—.06	.01	.11	[1].40	.14	[2].27	[2]—.28	[2]—.26
[1].63	---	.03	.06	.08	[1].32	.18	.19	.04	[1]—.33
[1].54	---	—.18	—.16	—.09	.12	.15	[1].36	—.18	[1]—.39
[1].79	---	.17	.22	[2].33	[1].54	[1].49	.01	—.11	.04
.29	---	—.24	—.18	---	---	---	.05	---	.08
[1].69	---	.06	.11	.18	[1].39	.15	.08	.20	[1]—.48
[1].92	0.17	.18	.27	---	---	---	[1]—.59	[1].51	[1]—.64
log Q_p									
[1]0.69	---	[1]0.37	[1]0.42	[1]0.46	[1]0.59	0.08	[1]0.35	0.10	[1]0.31
[1].63	---	[1].49	[1].55	[1].58	[1].62	[1].22	[1].31	—.18	[1].51
[1].58	---	[1].23	[2].26	[1].29	[1].46	.12	[1].28	—.02	.07
[1].54	---	[2].32	[1].35	[1].40	[1].47	—.01	[2].33	—.12	.25
[1].70	---	[1].61	[1].66	[1].73	[1].78	[1].37	.08	—.07	[1].59
.18	---	.24	---	---	---	---	---	---	[1].66
[1].65	---	[1].50	[1].56	[1].59	[1].67	[2].22	[1].27	[2].24	.14
[2].38	[1]0.72	[1].78	[1].81	---	---	---	—.13	.05	.27
log 10 Q_a									
—0.06	---	[1]—0.29	[2]—0.26	[1]—0.27	[2]—0.21	0.01	[1]0.27	[1]0.44	—0.16
—.14	---	[1]—.47	[1]—.44	[1]—.43	[1]—.34	.04	.17	[2]—.27	[1]—.43
[1]—.28	---	[1]—.44	[1]—.42	[1]—.43	[1]—.38	—.01	[2].23	[2].25	[1]—.28
—.04	---	[2]—.29	[2]—.28	[2]—.27	—.19	.09	[1].40	.40	[1]—.38
—.12	---	—.21	—.21	—.22	—.17	—.08	[2].30	.19	—.12
.02	---	—.13	—.10	—.11	—.06	0	[1].34	[2].21	[2]—.25
days, A_d									
0.05	---	0.08	0.05	0.04	0.02	—0.08	—0.19	—0.07	0.13
.09	---	.20	.21	[2].25	.19	—.17	—.14	.02	.18
.03	---	.01	—.01	.02	.01	—.15	—.06	—.02	.06
.21	---	.03	.05	.06	.06	.04	[1]—.41	.03	—.03
.12	---	—.06	—.08	—.06	—.11	.17	—.19	—.14	—.14
—.20	---	[2]—.21	[2]—.21	[2]—.23	[1]—.28	—.11	—.11	.05	.08
log 10 R_t									
1.00	---	[1]0.40	[1]0.43	[1]0.49	[1]0.69	0.20	0.12	—0.12	0.08
1.00	---	[2].30	[1].37	[1].47	[1].70	[2].24	.10	—.05	—.02
1.00	---	[1].41	[1].43	[1].48	[1].65	[2].25	—.03	—.09	—.16
1.00	---	.20	.26	[1].34	[1].54	.10	.01	—.09	—.03
1.00	---	[2].35	[1].40	[1].52	[1].74	[1].57	.06	—.06	.14
1.00	---	.06	.06	---	---	---	—.04	---	—.06
1.00	---	.28	[1].34	[1].44	[1].65	[2].21	—.10	—.05	—.18
1.00	---	.06	.15	---	---	---	---	---	—.71
rainfall, log 10 R_{05}									
---	1.00	---	---	---	---	---	—0.09	0.05	---
rainfall, log 10 R_{15}									
[1]0.40	---	1.00	[1]0.98	[1]0.95	[1]0.81	0.11	—0.11	—0.11	[1]0.66
[2].30	---	1.00	[1].98	[1].93	[1].71	[2].27	—.16	[2].22	[1].73

TABLE 6.—*Simple correlation coefficients*

	Suspended-sediment discharge (log Q_s)	Mean sediment concentration (log C)	Storm runoff (log Q_r)	Peak discharge (log Q_p)	Antecedent discharge (log 10 Q_a)	Antecedent days (A_d)
Maximum 5-minute rainfall,						
N. Br. Rock Creek	[1] 0.35	[1] 0.57	0.03	[2] 0.23	[1] —0.44	0.01
N.W. Br. Anacostia River	.21	[1] .53	—.18	[2] .32	[2] —.29	.03
Nursery Run	[1] .55	[1] .71	.17	[1] .61	—.21	—.06
Batchellors Run	.14	---	—.24	.24	---	---
Bel Pre Creek	[1] .41	[1] .55	.06	[1] .50	—.13	[2] —.21
Lutes Run	[2] .33	---	.18	[1] .78	---	---
Maximum 30-minute						
Williamsburg Run	[1] 0.41	[1] 0.57	0.13	[1] 0.42	[2] —0.26	0.05
Manor Run	[1] .39	[1] .43	.01	[1] .55	[1] —.44	.21
N. Br. Rock Creek	[1] .38	[1] .59	.06	[2] .26	[1] —.42	—.01
N.W. Br. Anacostia River	.22	[1] .52	—.16	[1] .35	[2] —.28	.05
Nursery Run	[1] .59	[1] .73	.22	[1] .66	—.21	—.08
Batchellors Run	.20	---	—.18	---	---	---
Bel Pre Creek	[1] .43	[1] .53	.11	[1] .56	—.10	[2] —.21
Maximum 1-hour						
Williamsburg Run	[1] 0.45	[1] 0.56	0.19	[1] 0.46	[1] —0.27	0.04
Manor Run	[1] .41	[1] .37	.11	[1] .58	[1] —.43	[2] 0.25
N. Br. Rock Creek	[1] .38	[1] .57	.08	[1] .29	[1] —.43	.02
N.W. Br. Anacostia River	[2] .28	[1] .51	—.09	.40	[2] —.27	.06
Nursery Run	[1] .65	[1] .73	[2] .33	[1] .73	—.22	—.06
Bel Pre Creek	[1] .45	[1] .50	.18	[1] .59	—.11	[2] —.23
Maximum 3-hour						
Williamsburg Run	[1] 0.55	[1] 0.44	[1] 0.39	[1] 0.59	[2] —0.21	0.02
Manor Run	[1] .43	.18	[1] .40	[1] .62	[1] —.34	.19
N. Br. Rock Creek	[1] .49	[1] .49	[1] .32	[1] .46	[1] —.38	.01
N.W. Br. Anacostia River	[1] .34	[1] .37	.12	[1] .47	—.19	.06
Nursery Run	[1] .70	[1] .63	[1] .54	[1] .78	—.17	—.11
Bel Pre Creek	[1] .49	[1] .34	[1] .39	[1] .67	—.06	[1] —.28
Number of						
Williamsburg Run	0.13	0.09	0.10	0.08	0.01	—0.08
Manor Run	.14	.05	.14	.22	.04	—.17
N. Br. Rock Creek	.16	.08	.18	.12	—.01	—.15
N.W. Br. Anacostia River	—.01	—.19	.15	—.01	.09	.04
Nursery Run	[2] .33	.10	[1] .49	[1] .37	—.08	.17
Bel Pre Creek	[2] .26	[2] .25	.15	[2] .22	0	—.11
Chronology						
Williamsburg Run	0.12	—0.20	[1] 0.29	[1] 0.35	[1] 0.27	—0.19
Manor Run	[1] —.33	[1] —.59	[2] .27	[1] .31	.17	—.14
N. Br. Rock Creek	.05	—.14	.19	[1] .28	[2] .23	—.06
N.W. Br. Anacostia River	.09	[2] —.28	[1] .36	[2] .33	[1] .40	[1] —.41
Nursery Run	.16	.25	.01	.08	[2] .30	—.19
Batchellors Run	—.02	---	.05	---	---	---
Bel Pre Creek	[2] .26	[1] .31	.08	[1] .27	[1] .34	—.11
Lutes Run	[1] .80	---	[1] —.59	—.13	---	---
Percent						
Williamsburg Run	[1] 0.27	[2] 0.23	0.18	0.10	[1] 0.44	—0.07
Manor Run	[1] .42	[1] .69	[2] —.28	—.18	[2] —.27	.02
N. Br. Rock Creek	.14	.19	—.04	—.02	[2] .25	—.02
N.W. Br. Anacostia River	—.05	.12	—.18	—.12	.02	.03
Nursery Run	.01	.10	—.11	—.07	.19	—.14
Bel Pre Creek	[1] .51	[1] .58	.20	[2] .24	[2] .21	.03
Lutes Run	[1] .72	---	[1] .51	.05	---	---
Peak ratio,						
Williamsburg Run	0.08	[1] 0.36	—0.14	0.31	—0.16	0.13
Manor Run	[2] .25	[1] .48	[2] —.26	[1] .51	[1] —.43	.18
N. Br. Rock Creek	.05	[1] .47	[1] —.33	.07	[1] —.28	.06
N.W. Br. Anacostia River	.07	.56	[1] —.39	.25	[1] —.38	—.03
Nursery Run	[1] .52	[1] .78	.04	[1] .59	—.12	—.15
Batchellors Run	[2] .49	---	.08	[1] .66	---	---
Bel Pre Creek	—.02	[1] .46	[1] —.48	.14	[2] —.25	.08
Lutes Run	[1] —.46	---	[1] —.64	.27	---	---

[1] Significant at 99 percent confidence level.
[2] Significant at 95 percent confidence level.

of storm-related variables—Continued

Total precipitation (log 10 R_t)	Maximum 5-minute rainfall (log 10 R_{05})	Maximum 15-minute rainfall (log 10 R_{15})	Maximum 30-minute rainfall (log 10 R_{30})	Maximum 1-hour rainfall (log 10 R_{1h})	Maximum 3-hour rainfall (log 10 R_{3h})	Number of peaks (N_p)	Chronology factor (T_m)	Percent construction (C_p)	Peak ratio (log P_r)
log 10 R_{15}—Continued									
[1]0.41	---	1.00	[1]0.98	[1]0.95	[1]0.81	0.19	—0.16	—0.07	[1]0.51
.20	---	1.00	[1].99	[1].96	[1].77	.05	—.23	.03	[1].77
[2].35	---	1.00	[1].99	[1].95	[1].75	.20	—.02	.09	[1].84
.06	---	1.00	---	---	---	---	—.06	---	[1].68
[1].28	---	1.00	[1].98	[1].94	[1].74	.14	.04	.07	[1].64
.06	---	1.00	---	---	---	---	---	---	[1].51
rainfall, log 10 R_{30}									
[1]0.43	---	[1]0.98	1.00	[1]0.98	[1]0.85	0.07	—0.11	—0.08	[1]0.67
[1].37	---	[1].98	1.00	[1].97	[1].77	[2].27	—.13	.20	[1].72
[1].43	---	[1].98	1.00	[1].98	[1].84	.19	—.16	.02	[1].51
[2].26	---	[1].99	1.00	[1].98	[1].80	.04	—.20	.02	[1].78
[1].40	---	[1].99	1.00	[1].98	[1].80	.22	.03	.08	[1].85
.06	---	---	1.00	---	---	---	—.02	---	[1].71
[1].34	---	[1].98	1.00	[1].98	[1].80	.18	.07	.06	[1].63
rainfall, log 10 R_{1h}									
[2]0.49	---	[1]0.95	[1]0.98	1.00	[1]0.90	0.05	—0.09	—0.08	[1]0.64
[1].47	---	[1].93	[1].97	1.00	[1].86	.22	—.09	.15	[1].65
[1].48	---	[1].95	[1].98	1.00	[1].89	.15	—.16	0	[1].51
[1].34	---	[1].96	[1].98	1.00	[1].87	0	—.17	.03	[1].74
[1].52	---	[1].95	[1].98	1.00	[1].89	[2].28	.04	.08	[1].82
[1].44	---	[1].94	[1].98	1.00	[1].89	.16	.08	.04	[1].58
rainfall, log 10 R_{3h}									
[1]0.69	---	[1]0.81	[1]0.85	[1]0.90	1.00	0.02	—0.02	—0.05	[2]0.49
[1].70	---	[1].71	[1].77	[1].86	1.00	.17	.02	.02	[1].36
[1].65	---	[1].81	[1].84	[1].89	1.00	.08	—.10	—.03	[1].34
[1].54	---	[1].77	[1].80	[1].87	1.00	—.01	—.05	.07	[1].51
[1].74	---	[1].75	[1].80	[1].89	1.00	[2].33	.12	.10	[1].62
[1].65	---	[1].74	[1].80	[1].89	1.00	.13	.11	.01	[1].34
peaks, N_p									
0.20	---	0.11	0.07	0.05	0.02	1.00	0.01	—0.03	—0.06
[2].24	---	[2].27	[2].27	.22	.17	1.00	.04	0	.13
[2].25	---	.19	.19	.15	.08	1.00	—.06	.02	—.16
.10	---	.05	.04	0	—.01	1.00	0	—.12	—.25
[1].57	---	.20	.22	[2].28	[2].33	1.00	.03	.03	—.06
[2].21	---	.14	.18	.16	.13	1.00	.13	.08	.08
factor, T_m									
0.12	---	—0.11	—0.11	—0.09	—0.02	0.01	1.00	—0.15	0.16
.10	---	—.16	—.13	—.09	.02	.04	1.00	[1]—.85	.09
—.03	---	—.16	—.16	—.16	—.10	—.06	1.00	[1]—.54	.19
.01	---	—.23	—.20	—.17	—.05	0	1.00	[2].31	—.07
.06	---	—.02	.03	.04	.12	.03	1.00	[1].49	.13
—.04	---	—.06	—.02	---	---	---	1.00	---	.01
—.10	---	.04	.07	.08	.11	.13	1.00	.37	[2].25
[1]—.61	—0.09	---	—.08	---	---	---	1.00	[1]—.91	[1].57
construction, C_p									
—0.12	---	—0.11	—0.08	—0.08	—0.05	—0.03	—0.15	1.00	—0.19
—.05	---	.22	.19	.15	.02	0	[1]—.85	1.00	.10
—.09	---	—.01	.02	0	—.03	.02	[1]—.54	1.00	—.17
—.09	---	.03	.02	.03	.07	—.12	[2].31	1.00	.09
—.06	---	.09	.08	.08	.10	.03	[1].49	1.00	.02
—.05	---	.07	.06	.04	—.01	.08	[1].37	1.00	.02
---	0.05	---	---	---	---	---	[1]—.91	1.00	---
log P_r									
0.08	---	[1]0.66	[1]0.67	[1]0.64	[1]0.49	—0.06	0.16	—0.19	1.00
—.12	---	[1].73	[1].72	[1].65	[1].36	.13	.09	.10	1.00
—.16	---	[1].51	[1].51	[1].51	[1].34	—.16	.19	—.17	1.00
—.03	---	[1].77	[1].78	[1].74	[1].51	—.25	—.07	.09	1.00
.14	---	[1].84	[1].85	[1].82	[1].62	—.06	.13	.02	1.00
—.06	---	[1].68	[1].71	---	---	---	.01	---	1.00
—.18	---	[1].64	[1].63	[1].58	[1].34	.08	[2].25	.02	1.00
[1]—.71	---	[1].51	---	---	---	---	---	---	1.00

TABLE 7.—*Regression coefficients, multiple correlation coefficient, and standard error of best equations explaining the variation of storm suspended-sediment discharge*

Number of independent variables	Storm runoff (log Q_r)	Peak discharge (log Q_p)	Total precipitation (log R_t)	Percent construction (C_p)	Maximum 30-minute rainfall (log 10 R_{30})	Maximum 15-minute rainfall (log 10 R_{15})	Chronology factor (T_m)	Peak ratio (log P_r)	Antecedent discharge (log 10 Q_a)	Multiple correlation coefficient	Standard error of estimate (log units)	Regression constant
Williamsburg Run near Olney												
1	[1] 1.08	---	---	---	---	---	---	---	---	0.84	0.304	0.387
2	[1] 1.03	---	---	---	[1] 0.45	---	---	---	---	.90	.253	.051
3	[1] .99	---	---	[1] 0.05	[1] .48	---	---	---	---	.91	.240	—.166
4	[1] .94	---	---	[2] .04	[1] .52	---	---	---	[1] 0.13	.91	.238	—.241
North Branch Rock Creek near Norbeck												
1	---	[1] 1.49	---	---	---	---	---	---	---	0.91	0.255	—1.22
2	[1] 1.50	---	---	[1] 0.15	---	---	---	---	---	.92	.239	—1.53
3	---	[1] 1.44	---	[1] .15	---	[1] 0.23	---	---	---	.93	.223	—1.63
4	0.30	[1] 1.13	---	[1] .14	---	[1] .29	---	---	---	.93	.221	—1.46
Manor Run near Norbeck												
1	---	[1] 0.83	---	---	---	---	---	---	---	0.63	0.410	0.334
2	---	[1] 1.07	---	---	---	---	[1] —0.01	---	---	.84	.288	.371
3	---	[1] 1.24	---	---	[2] —0.32	---	[1] —.01	---	---	.85	.278	.385
4	0.09	[1] 1.16	---	---	—.01	---	[1] .03	---	---	.86	.280	.411
Northwest Branch Anacostia at Norwood												
1	[1] 0.97	---	---	---	---	---	---	---	---	0.74	0.336	0.530
2	[1] 1.19	---	---	---	---	---	---	[1] 0.88	---	.84	.274	—.522
3	[1] 1.31	---	---	---	---	---	[1] —0.004	[1] .92	---	.87	.252	—.470
4	[1] 1.20	---	0.35	---	---	---	[2] —.004	[1] .86	---	.87	.250	—.743
Batchellors Run at Oakdale												
1	[1] 1.18	---	---	---	---	---	---	---	---	0.72	0.372	0.049
2	[1] 1.13	---	---	---	---	---	---	[1] 0.88	---	.84	.297	—.757
3	[1] 1.07	---	0.44	---	---	---	---	[1] .90	---	.85	.295	—1.283
4	[1] 1.07	---	.43	---	---	---	—0.001	[1] .90	---	.85	.300	—1.211
Nursery Run at Cloverly												
1	---	[1] 1.49	---	---	---	---	---	---	---	0.95	0.253	—1.33
2	---	[1] 1.47	---	---	---	---	[2] 0.003	---	---	.95	.245	—1.45
3	0.21	[1] 1.33	---	---	---	---	[2] .003	---	---	.96	.242	—1.34
4	.29	[1] 1.34	—0.22	---	---	---	[2] .003	---	---	.96	.243	—1.10
Bel Pre Creek at Layhill												
1	[1] 1.12	---	---	---	---	---	---	---	---	0.76	0.402	0.458
2	[1] 1.44	---	---	---	---	---	---	[1] 1.09	---	.85	.324	—.791
3	[1] 1.31	---	---	[1] 0.051	---	---	---	[1] .97	---	.91	.256	—1.088
4	[1] 1.18	---	---	[1] .052	---	[2] 0.28	---	[1] .60	---	.92	.248	—.934
Lutes Run at Lutes												
1	[1] 1.52	---	---	---	---	---	---	---	---	0.85	0.473	0.438
2	[1] 1.05	---	---	---	---	---	[1] —0.008	---	---	.93	.345	1.37
3	[1] 1.32	---	---	---	---	---	[1] —.010	[1] 0.66	---	.96	.274	.520
4	[1] 1.24	---	---	---	---	0.14	[1] —.010	.52	---	.96	.277	.582

[1] Signicant at 99 percent confidence level.
[2] Significant at 95 percent confidence level.

ment-transport curves as described by Miller (1951). The number of yields estimated for each basin varied depending on land-use/land-cover changes in the basins. For example, six average annual yields were estimated for the Williamsburg Run basin because of changes in the amount and location of construction within the basin. In the rural basins, only one average annual yield was estimated since the land use/land cover was essentially constant during the study period. A total of 27 yields was determined for the eight basins.

The initial selection of periods for which average annual sediment yields were to be estimated was based on the variation of land use/land cover between 1967 and 1974. Periods of equal land use/land cover were determined by examining aerial photographs, field notes, and grading and paving permits furnished by the Montgomery County Department of Public Works. Because of constantly changing conditions on construction sites, it was not possible to define exact periods of equal land use/land cover, but the beginning and ending of each period were selected so that the land use/land cover on aerial photographs would be representative of average conditions during the period. An effort was made to delineate periods by the amount of construction and the location of construction within the basins so that a range of physical conditions on construction sites (slope, proximity to stream, and so forth) could be evaluated.

Once the periods were selected, sediment-transport curves were prepared for the periods having adequate storm data. The curves were developed from logarithmic plots of daily suspended-sediment discharges and the corresponding daily water discharges. Particular attention was given to the medium and high ranges of water and sediment discharge since most of the annual sediment load was transported during large storms. Curves for several periods were not used because the high ends of the curves were poorly defined or because a disproportionate number of storms were sampled during either the growing or dormant season.

The sediment-transport curves were used in conjunction with duration curves of water discharge for the corresponding streams to compute the average annual sediment yields. Flow-duration curves for the period 1967–74 were available for all stations except Lutes Run and Batchellors Run. Since only data for days with storm runoff and selected base-flow days were available at these two stations, curves were estimated using graphical-regression methods and the duration curves of the other sites.

An example of the computation of the average annual sediment yield is illustrated by figure 14 and table 8. Average water discharges for selected time intervals were determined from the flow-duration curves (fig. 14*A*). Suspended-sediment discharges corresponding to the water discharges were determined from sediment-transport curves and multiplied by the duration intervals of water discharge to calculate the average annual sediment discharge. In the example, the average water discharge for 2.5 to 4.5 percent of the time is 14 ft^3/s or 0.40 m^3/s for Williamsburg Run (fig. 14*A*). The corresponding suspended-sediment discharge is 29 tons or 26 t (fig. 14*B*). Multiplying the suspended-sediment discharge by the time interval for each interval in table 8 and dividing the sum of column 5 (table 8) by 100 yields the mean daily sediment discharge. The mean daily discharge times 365 days equals the average annual suspended-sediment discharge.

TABLE 8.—*Example of computation of average annual suspended-sediment discharge*

[Data from 1967–74 duration curve and January 1972 to December 1973 sediment-transport curve of Williamsburg Run near Olney]

Cumulative time (percent) (1)	Time in interval (percent) (2)	Midordinate (percent) (3)	Water discharge (cubic feet per second) (4)	Suspended-sediment discharge (tons) (5)	Suspended-sediment discharge for interval (tons)[1] (6)
0.25	0.25	0.125	68	260	65
.75	.50	.50	42	163	81
1.5	.75	1.125	32	119	89
2.5	1.0	2.0	20	61	61
4.5	2	3.5	14	29	58
8.5	4	6.5	6.5	5.2	21
15	6.5	11.75	3.5	.9	5.8
25	10	20	2.5	.3	3.0
35	10	30	1.9	.1	1.0
45	10	40	1.6	0	0
55	10	50	1.4	----	----
75	20	65	1.0	----	----
95	20	85	.65	----	----
100	5	97.5	.32	----	----
Total --	---	----	----	----	384.8

Mean daily suspended-sediment discharge = 384.8 ÷ 100 = 3.85 tons.
Average annual suspended-sediment discharge = 3.85 × 365 = 1,400 tons.
[1] Column 6 = column 2 × column 5.

The average annual suspended-sediment yields calculated by this method represent the average annual yields that would have been expected between 1967 and 1974 if land-use/land-cover conditions at each site had remained the same as the average during the selected periods. The use of the 1967–74 flow-duration curves assures that the water discharge component of the computations was equal for each period at each site. The one questionable component of computations is whether the sediment data used for developing the individual sediment-transport curves were significantly affected by different climatic conditions during the selected periods. A change in the statistical distribution of total precipitation for the sample storms or a change in the intensity or time of concentration of storm runoff could result in a substantial bias in the computed sediment yields. However, the regression models discussed previously indicate no substantial change in storm magnitude or intensity during the period of record.

Another factor that could affect the computed yields is the total precipitation during the selected periods. Miller (1951) found that the flow-duration sediment-transport curve method generally overestimated the long-term load when sediment data were collected during dry years and underestimated it when data were collected during wet years. The estimate may be incorrect because the greater number of storms during wet years exhausts the supply of sediment readily available for transport. Although the total load for the year is higher, the average load per storm is less than during dry years. This explanation may not be valid for urban construction sites where the land surface is reworked frequently for right-of-way grading, installation of utilities, lot grading, and final grading prior to stabilization.

The calculated suspended-sediment yields and land-use/land-cover conditions corresponding to the sample periods are listed in table 9. The basin sediment yields range from 0.27 to 11.3 tons/acre (0.61 to 25.3 t/hm^2). Land under construction ranges from 0 to 13.9 percent of drainage area. Cropland ranges from 0 to 43.8 percent, and urban land ranges from 0 to 54.2 percent of drainage area.

Regression equations were computed to determine the effect of the land-use factors on suspended-sediment yield. Equation 1, which is the simple

TABLE 9.—*Average annual suspended-sediment yields and selected land-use/land-cover factors*

Period	Basin sediment yield (tons/acre)	Percentage of basin area		
		Cropland	Urban	Construction
Williamsburg Run near Olney, Md.				
Oct. 1966–Mar. 1968	1.98	43.8	0.1	7.6
Apr. 1968–Mar. 1969	1.61	43.3	5.3	4.7
Apr. 1969–Mar. 1971	1.18	42.1	8.1	3.1
Apr. 1971–Dec. 1971	1.16	29.9	12.0	5.1
Jan. 1972–Sept. 1973	.98	29.8	16.0	6.2
Jan. 1974–Sept. 1974	.57	29.0	24.7	1.0
North Branch Rock Creek near Norbeck, Md. [1]				
Oct. 1966–Mar. 1968	2.07	26.4	0.4	1.8
Apr. 1969–Mar. 1971	2.01	25.9	.8	1.3
Apr. 1971–Dec. 1971	1.39	25.3	1.8	1.3
Jan. 1972–Dec. 1973	1.43	25.3	2.7	1.1
Jan. 1974–Sept. 1974	1.33	25.3	3.7	.3
Manor Run near Norbeck, Md.				
Mar. 1967–Sept. 1968	11.26	3.9	2.5	11.3
Jan. 1969–Dec. 1969	10.34	4.8	9.4	9.6
Apr. 1970–Dec. 1970	4.92	4.8	14.9	7.4
Feb. 1971–Dec. 1972	2.05	4.8	19.8	4.6
Apr. 1973–Aug. 1974	1.32	4.8	23.8	.9
Northwest Branch Anacostia River at Norwood, Md.				
Jan. 1968–Mar. 1974	0.96	24.9	0	0.3
Nursery Run at Cloverly, Md.				
May 1967–Aug. 1974	0.62	10.3	0	0
Batchellors Run at Oakdale, Md.				
Aug. 1967–Sept. 1973	0.32	20.3	0	0.7
Bel Pre Creek at Layhill, Md.				
Mar. 1963–Dec. 1964	0.27	6.5	0	0
Jan. 1966–Dec. 1967	3.31	2.2	4.6	13.9
Jan. 1968–Dec. 1969	3.27	2.2	8.4	10.4
Jan. 1970–Dec. 1971	2.13	1.8	11.0	9.2
Jan. 1973–Sept. 1974	1.90	1.7	20.8	13.1
Lutes Run at Lutes, Md.				
Oct. 1966–Jan. 1968	5.08	0	51.2	9.8
Mar. 1968–Apr. 1970	2.79	0	54.2	4.3
June 1973–Sept. 1974	2.21	0	54.2	1.2

[1] Sediment yield and land-use/land-cover percentages equal total for North Branch Rock Creek near Norbeck minus the contribution of the Williamsburg Run tributary.

linear relation between the logarithm of the sediment yield and percentage of the basin under construction, was the best equation for explaining the variability of sediment yield.

$$\text{Log } Y_s = 0.059\ C - 0.047 \qquad (1)$$

where

Y_s = suspended-sediment yield, in tons per acre;

C = percentage of land under construction.

Forty-seven percent of the variation of the sediment yield is explained by this equation. The standard error of estimate is 0.28 log units, or about 62 percent. The use of percentage of urban and percentage of cropland as additional variables did not significantly improve the explained variation of sediment yield. The addition of the percentage of urban land increased the explained variation to 50 percent, and the addition of the percentage of cropland as a third independent variable increased the explained variation of sediment yield to 51 percent. The standard errors of estimate for both equations are 0.28 log units, the same as the simple relation between sediment yield and percentage of construction.

The relatively low percentage of variation explained by the regression equations is illustrated by the scatter of data points in figure 15. This large scatter indicates that factors other than the vari-

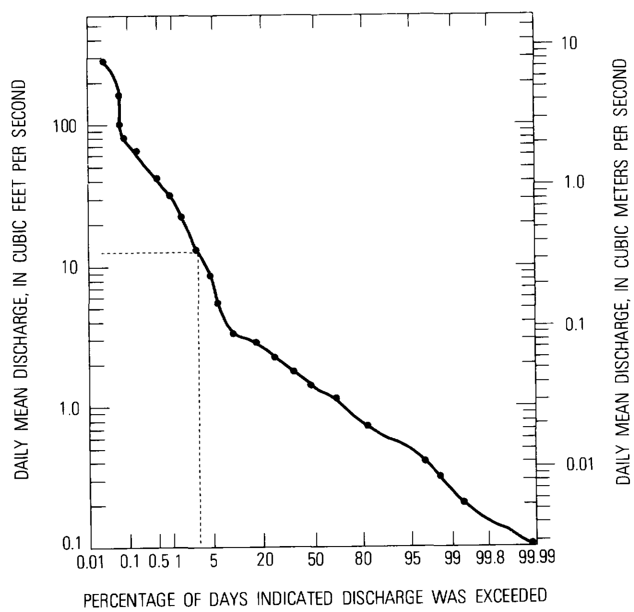


FIGURE 14.—Example of flow-duration (*A*) and suspended-sediment transport (*B*) curves used for computing average annual sediment loads. *A*, Williamsburg Run flow-duration curve, 1967–74. *B*, Williamsburg Run sediment-transport curve, January 1972 to December 1973.

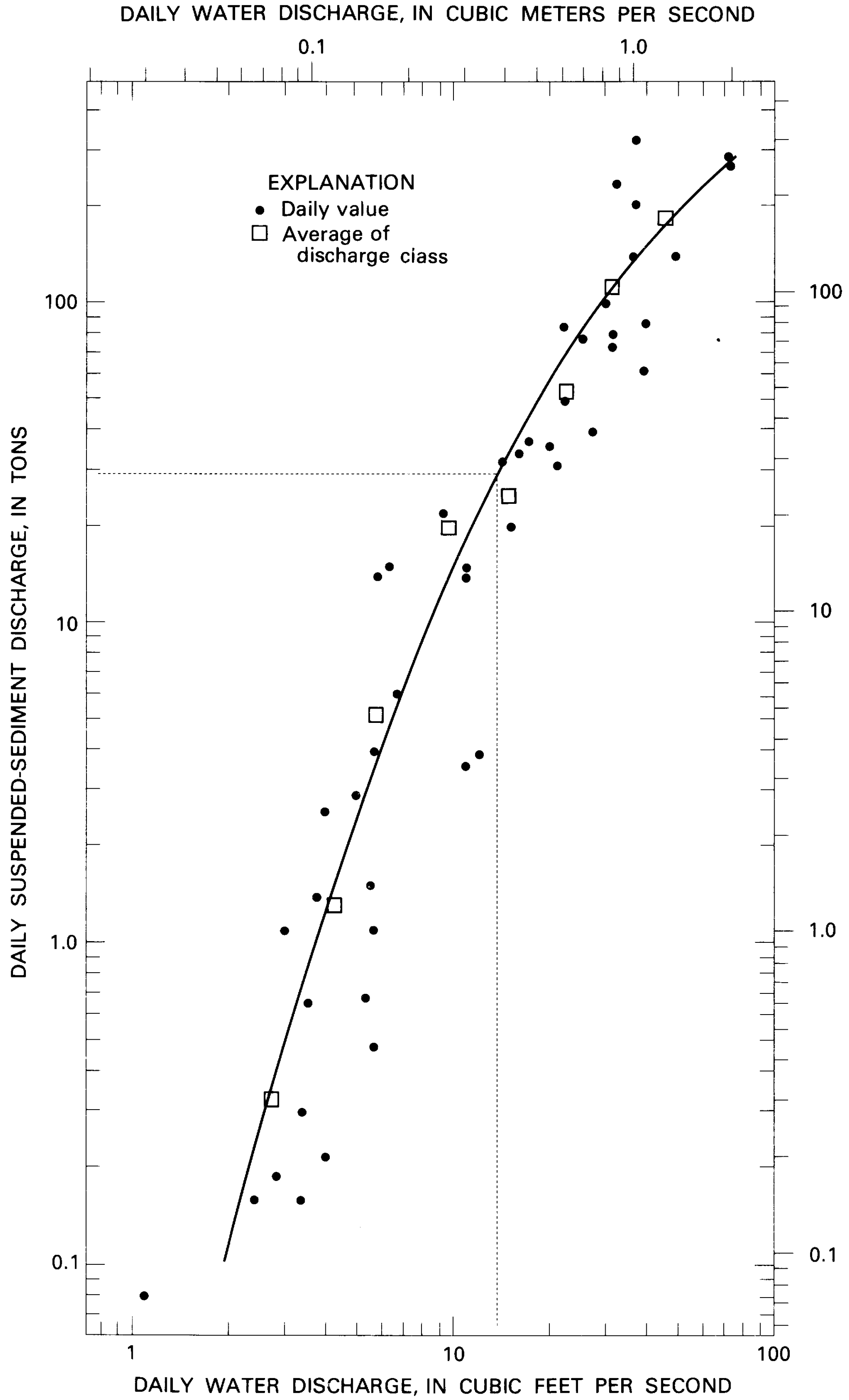


FIGURE 14.—Continued.

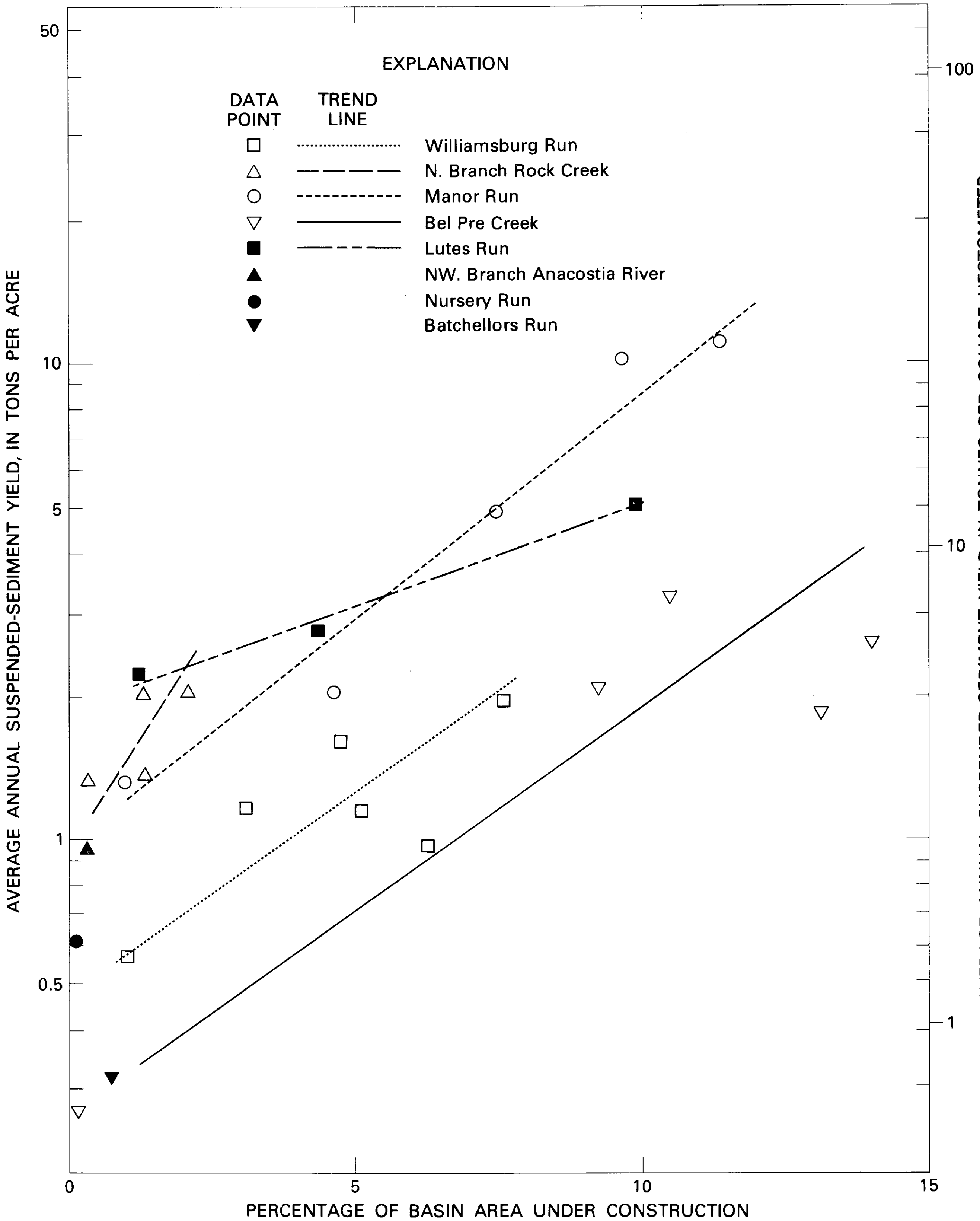


FIGURE 15.—Relation of suspended-sediment yield to percentage of drainage basin under construction.

ables used in the regression equations affect the suspended-sediment yields of the basins. The lines on figure 15, which represent the approximate relation between sediment yield and percentage of construction for different periods on individual basins, further illustrate the variation of sediment yields. Apparently, other basin factors such as slope or soil conditions caused substantially greater sediment yields in the Manor Run, North Branch Rock Creek, and Lutes Run basins than in the Bel Pre Creek and Williamsburg Run basins.

CONSTRUCTION-SITE SEDIMENT YIELDS

To evaluate the variation of suspended-sediment yields from construction sites, a simple arithmetic procedure was used to successively eliminate the part of each basin yield attributable to other land use/land cover, so that the remainder represented only the yield from construction sites. Land use/land cover in each period for each basin was first summarized in the following categories: Forest land, grass, crops, rural residential, urban residential, public and commercial, and construction. These categories represent the same general categories of table 2 except that the impervious category of farmland and parks was placed in the cropland category because most of this area consisted of dirt roads with unimproved roadside ditches.

The next step was to estimate suspended-sediment yields for the different land-use/land-cover categories with relatively low erosion potential. Williams and George (1968) determined that the sediment yield from basins in Pennsylvania with 100 percent forest cover averaged 0.03 (ton/acre)/yr [(0.07 t/hm^2)/yr]. Sediment yields from forested watersheds in Mississippi were reported as 0.02 (ton/acre)/yr [(0.04 t/hm^2)/yr] by Ursic and Dendy (1965). Wark and Keller (1963) found that forested areas in the Potomac River basin averaged about 0.03 (ton/acre)/yr [(0.07 t/hm^2)/yr]. On the basis of these previous investigations, the annual sediment yield from forested areas in the study basins was assumed to be 0.03 ton/acre (0.07 t/hm^2).

Ursic and Dendy (1965) found the annual sediment yield of grazed pastures and abandoned fields in Mississippi averaged 1.6 and 0.12 tons/acre (3.6 and 0.27 t/hm^2), respectively. The grass category in this study is generally well-managed turf on golf courses, abandoned fields, or lightly grazed pastures. These conditions are probably comparable to the abandoned fields in Mississippi; therefore, an annual sediment yield of 0.2 ton/acre (0.45 t/hm^2) was assumed for the grass category.

The yields for rural residential and commercial-public areas within the basins were assumed to be 0.5 and 0.3 (ton/acre)/yr [(1.1 and 0.7 t/hm^2)/yr], respectively. The rural residential yield was assumed to be considerably higher than the yield for grass because a fairly large part of the rural residential area was used for large gardens and for grazing horses. Also, some of the roads and roadside ditches in these areas were unimproved. The yield for commercial-public land was assumed to be somewhat lower than rural residential because most of this land was in either well-managed turf or impervious surfaces. It was assumed to be greater than grass, however, because of accelerated erosion in the stream channels immediately downstream caused by increased runoff from the impervious surfaces. This subject will be discussed in more detail in the section on stream-channel erosion.

Suspended-sediment yields for urban residential, cropland, and construction areas were determined by subtracting the assumed yields for forest land, pasture, rural residential, and public-commercial from the total sediment yields of each basin. For example, the sediment yield for cropland was determined for four basins during periods when there were no urban residential or construction areas. Example 1 for Bel Pre Creek during the March 1963 to December 1964 sample period illustrates this method.

EXAMPLE 1.—*Bel Pre Creek, March 1963 to December 1964*
Average annual sediment yield=295 tons; drainage area=1,082 acres.

(1) Land use/land cover	*(2)* Acres	*(3)* Sediment yield	Columns (2)×(3)
Forest	619	0.03	18.6
Pasture	375	.2	75
Rural residential	18	.5	9
Crops	70	--	--
Sum	1,082	--	102.6

Annual sediment yield from cropland=(295−102.6) tons÷70 acres=2.7 tons/acre.

The computed annual yields for cropland in the four basins were:

	Tons/Acre
Batchellors Run	0.65
Bel Pre Creek	2.7
Nursery Run	4.3
Northwest Branch Anacostia River	3.3

Similarly, the annual yield for urban residential was determined by subtracting other known or assumed yields from the total yields of the basins during periods with no construction or only minimal construction activities (Example 2).

EXAMPLE 2.—*Lutes Run, June 1973 to September 1974*
Average annual sediment yield=664 tons, drainage area=301 acres.

(1) Land use/land cover	(2) Acres	(3) Sediment yield	Columns (2)×(3)
Pasture	17	0.2	3.4
Forest land	54	.03	1.6
Rural residential	48	.5	24
Urban residential	163	--	--
Commercial-public	15.5	.3	4.7
Construction	3.5	Assumed 10	35
Sum	301	--	68.7

Annual sediment yield from urban land=
(664–68.7) tons ÷ 163 acres=
3.65 tons/acre.

The annual suspended-sediment yields computed for Lutes Run and Manor Run were 3.6 and 3.9 tons/acre (8.1 and 8.7 t/hm^2), respectively.

The computed values of cropland and urban residential were then used with the other assumed values to compute the construction-site sediment yield for basins with active construction. If cropland or urban yields were computed for individual basins, these values were used; otherwise, the average of the yields computed for all basins were used.

Construction-site sediment yields computed for the different time periods in the five basins with active construction ranged from 7.2 to 100.8 (tons/acre)/yr [(16.1 to 226 t/hm^2)/yr] and averaged 32.7 (tons/acre)/yr [(73.3 t/hm^2)/yr]. The yields are comparable to those found by previous investigators. Vice, Guy, and Ferguson (1969) reported that the yield from highway construction in northern Virginia was about 100 tons/acre (220 t/hm^2). Guy and Ferguson (1962) estimated the yield from residential construction sites near Lake Barcroft, Va., to be 39 tons/acre (87 t/hm^2).

Several factors could affect the variation of construction-site yields. Slope conditions on the sites, proximity to stream channels, buffer zones of natural vegetation, ratio of the largest construction site to total construction area in the basin, and the percentage of construction area with sediment controls were factors considered for analysis. Other factors are probably significant, but could not be evaluated properly. Soils, particularly their relative erodibility, could result in substantial variation of sediment yields; however, the soil conditions were generally uniform except for one or two sites. The density of housing could affect the construction methods, but, again, the conditions in the basins were too uniform to detect significant differences. Another important factor that could not be evaluated for use in the analysis was the length of time that sites were not stabilized, as the period of nonstabilized construction activity varied among sites within an individual basin.

Average slope on the construction sites was determined by using the average slope map shown in plate 1 as an overlay to the aerial photographs of the study basin. The construction area in each slope class was determined with a dot-grid, and a weighted average was calculated. This method averaged the slope conditions of different sites within the basins, which could obscure the influence of extreme conditions. However, it did provide a relative index of slope for evaluating the variation of yields among the basins. Average slopes ranged from 4.30 to 7.34 percent.

The amount of construction within 200 ft (61 m) of stream channels was selected as an arbitrary index of the proximity of construction to the drainage net. An overlay of streams shown on the U.S. Geological Survey quadrangles and U.S. Soil Conservation Service soil maps of the study basins was used with aerial photographs to measure the percentage of construction area within this category. Construction within 200 ft (61 m) of stream channels (hereafter referred to as the proximity factor) ranged from 17.4 to 64.8 percent of the total construction area in the basins.

The existence of buffer zones of natural vegetation between the construction sites and the stream channels was also evaluated. The percentage of construction area without a 200 ft (61 m) strip of natural vegetation between the site and the natural drainage to the stream channels was determined from aerial photographs. This parameter ranged from 52 to 100 percent.

The size of the construction sites was also considered as a possible source of variation of site yields. The area of the largest construction site as a percentage of the total construction area within each basin was used as an index of this parameter.

The last parameter considered for analysis was the percentage of the construction sites with adequate sediment-control measures. This parameter was based on county-wide field surveys, which will be discussed in more detail in the section on sediment control. Some adjustments to the average values determined by the field surveys were made in cases where observations by project personnel were available. These adjustments to the average values were particularly necessary during the initial periods of development when many sites did not have controls. Sites with control measures constituted 0 to 68 percent of the total construction area in the basins.

Construction-site suspended-sediment yields and the corresponding site factors are summarized in table 10. These data were analyzed graphically and with correlation and multiple regression techniques to determine the relative effect of each site factor on construction-site yields. Graphical and correlation analyses indicate that there is a poor relationship between site yields and the individual site factors. Correlation coefficients between the logarithm of site yield and the site factors are: 0.36 for average slope, 0.36 for the proximity factor, 0.28 for the percentage of construction area represented by one large site, 0.18 for construction sites without buffer zones, and −0.67 for the percentage of construction sites with sediment controls. The correlation coefficient for site yield and percentage of controls is the only one significant at the 95 percent confidence level.

The multiple effect of the site factors was evaluated with a multiple-regression model. The logarithm of construction-site sediment yield was the dependent variable and the site factors were the independent variables. Equations 2, 3, and 4 illustrate the results of the regression analysis.

$$\log S_y = 1.73 - 0.010\ C,\ \text{S.E.} = 0.24 \text{ log units} \quad (2)$$

$$\log S_y = 0.86 + 0.143\ S - 0.010\ C,\ \text{S.E.} = 0.22 \text{ log units} \quad (3)$$

$$\log S_y = 0.67 + 0.143\ S + 0.002\ B - 0.010\ C,\ \text{S.E.} = 0.22 \text{ log units} \quad (4)$$

where

S_y = construction site suspended-sediment yield, in tons per acre per yr;

C = percentage of construction area with sediment control;

S = average slope of construction sites, in percent;

B = percentage of construction area without a buffer of natural vegetation.

Equation 2 explains 45 percent of the variation of construction-site yield. Equations 3 and 4 explain 59 and 60 percent of the variation, respectively. The use of additional variables did not significantly increase the explained variation of site yield.

The analysis suggests that sediment controls used to limit erosion and sediment transport from the construction sites significantly reduced construc-

TABLE 10.—*Construction-site sediment yields and related factors*

Period		Construction area (acres)	Average annual sediment yield (tons/acres)	Average slope of construction area (percent)	Construction area within 200 ft of channel (percent)	Ratio of area of largest development to total (percent)	Construction area without 200 ft buffer zone (percent)	Construction area with adequate sediment control (percent)
Williamsburg Run near Olney, Md.								
Oct. 1966–Mar. 1968	(1)	109	20.6	5.45	25.3	99.3	96.6	10
Apr. 1968–Mar. 1969	(2)	68	24.4	5.75	20.4	83.3	85.2	36
Apr. 1969–Mar. 1971	(3)	45	22.8	5.97	26.1	39.8	52.0	42
Apr. 1971–Dec. 1971	(4)	74	14.4	4.30	20.0	24.0	88.0	49
Jan. 1972–Sept. 1973	(5)	90	8.6	5.15	17.4	39.0	75.6	60
North Branch Rock Creek near Norbeck, Md.[1]								
Oct. 1966–Mar. 1968	(1)	87	46.4	6.70	52.1	45.1	88.7	5
Apr. 1969–Mar. 1971	(2)	60	63.0	7.64	20.3	74.3	81.4	36
Apr. 1971–Dec. 1971	(3)	63	12.5	7.34	29.2	58.3	91.7	49
Jan. 1972–Dec. 1973	(4)	52	15.1	6.94	7.0	49.2	52.8	60
Manor Run near Norbeck, Md.								
Mar. 1967–Sept. 1968	(1)	73	96.4	6.38	36.6	87.2	81.7	10
Jan. 1969–Dec. 1969	(2)	62	100.8	6.72	41.7	88.9	100.0	15
Apr. 1970–Dec. 1970	(3)	48	54.4	5.90	37.5	80.0	87.5	27
Feb. 1971–Dec. 1972	(4)	30	21.2	7.28	22.2	46.1	88.6	52
Bel Pre Creek at Layhill, Md.								
Jan. 1966–Dec. 1967	(1)	150	21.1	5.72	19.3	88.1	65.1	0
Jan. 1968–Dec. 1969	(2)	113	26.4	5.92	32.4	92.4	93.8	35
Jan. 1970–Dec. 1971	(3)	100	16.5	5.56	34.8	83.0	67.8	45
Jan. 1973–Sept. 1974	(4)	142	7.2	5.58	25.0	91.7	97.0	68
Lutes								
Oct. 1966–Jan. 1968	(1)	29.5	31.8	5.42	55.0	35.0	75.0	0
Mar. 1968–Apr. 1970	(2)	13.0	17.0	6.58	64.8	66.7	78.5	38

[1] Represents North Branch Rock Creek near Norbeck excluding Williamsburg Run.

tion-site suspended-sediment yields. The slope of the construction sites was also a significant factor affecting the site yields. Construction on mild slopes resulted in lower sediment yields than construction on steep slopes. The relative size of the largest construction site in the basin and the amount of construction within 200 ft (61 m) of the stream channel did not significantly affect the suspended-sediment yields. This outcome could be due to the small number of observations available, or due to the effect of other factors not analyzed in the regression analysis.

Figure 16 illustrates the slope factor in two of the study basins. The average slope on construction sites in Bel Pre Creek basin was 5.72 percent during the January 1966 to December 1967 sampling period, and the average annual sediment yield was 21.1 (tons/acre)/yr [(47.3 t/hm²)/yr]. In contrast, the average slope on the Manor Run construction sites was 6.38 percent and the average annual sediment yield was 96.4 (tons/acre)/yr [(216 t/hm²)/yr] between March 1967 and September 1968. Virtually all the construction in Bel Pre Creek was on slopes ranging from 3 to 8 percent, whereas a large part of the construction area in Manor Run was on slopes between 8 and 15 percent. Some sites had slopes greater than 15 percent. The photograph in figure 17 shows the severity of erosion on the long, steep slopes in the Manor Run basin. The extensive rill and gully erosion on slopes greater than 10 percent apparently resulted in the high sediment yield from this basin.

The implementation of sediment controls is illustrated by aerial photographs of the Bel Pre Creek basin for June 1966 and June 1974 (fig. 18). The 1966 photograph shows 148 acres (60 hm²) of land

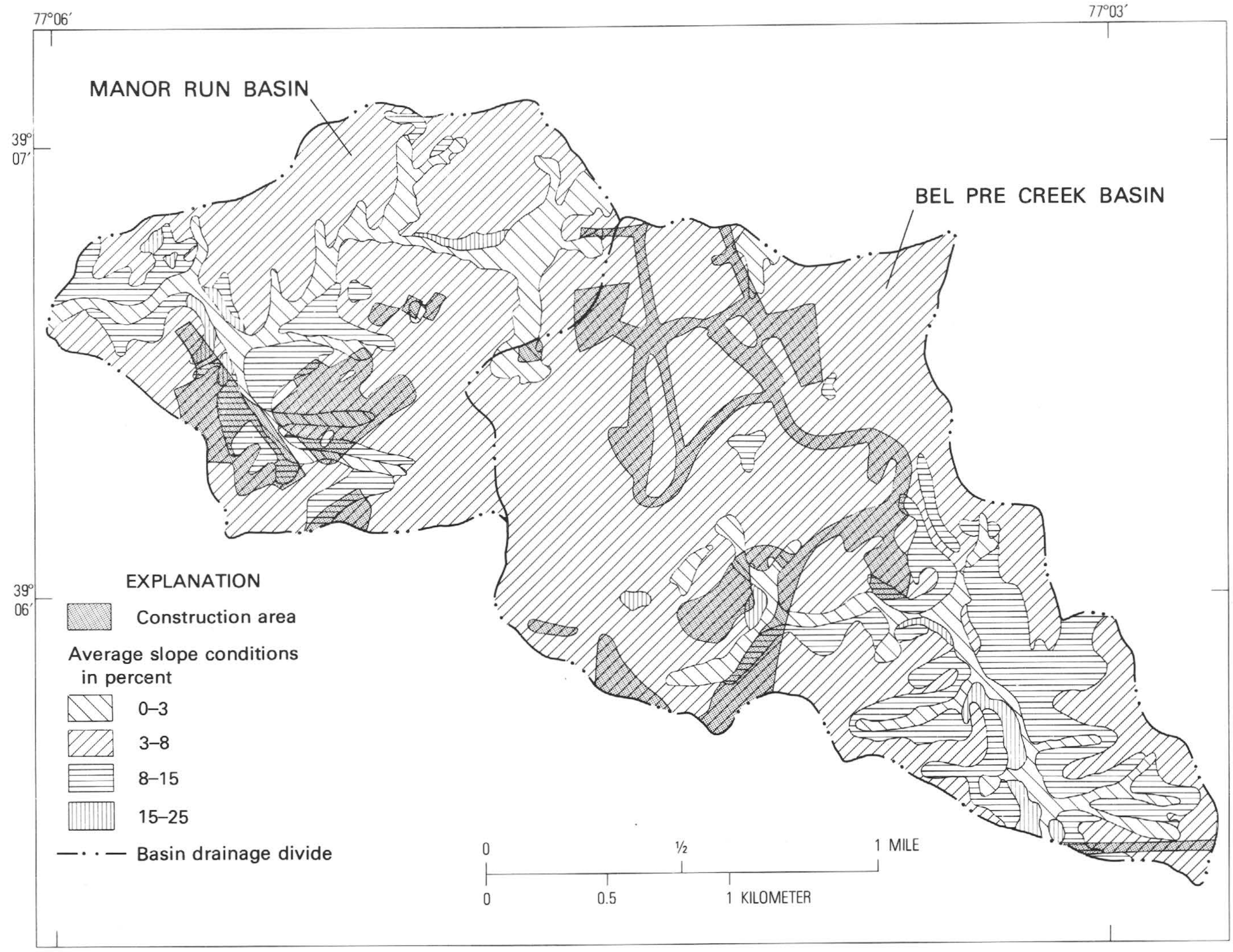
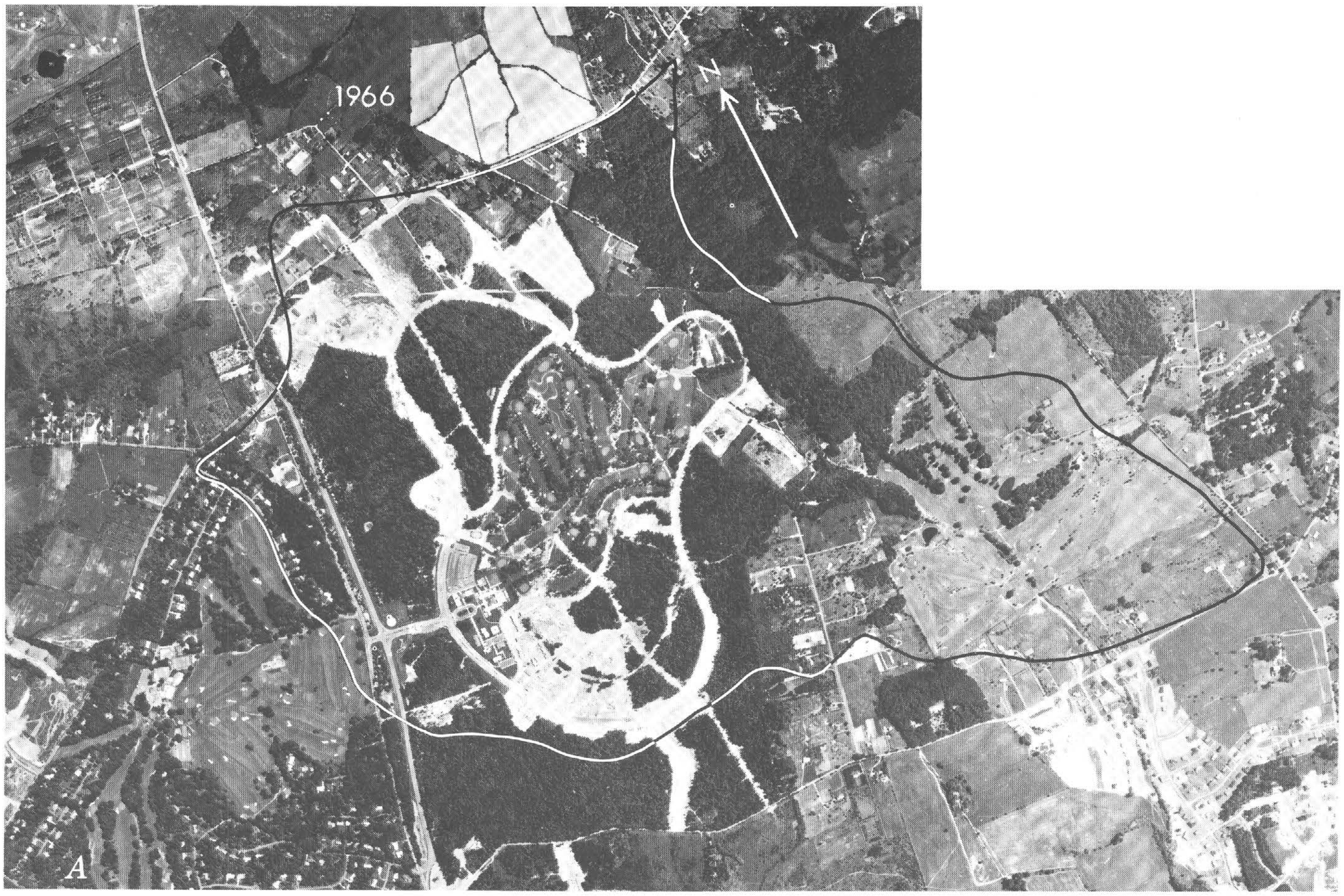


FIGURE 16.—Construction sites and average slope conditions, Bel Pre Creek and Manor Run basins, June 1967. Land slope adapted from Soil Survey of Montgomery County, Md. (U.S. Dept. Agriculture, 1961)

FIGURE 17.—Extensive erosion in the Manor Run basin, 1967.

under construction with no sediment controls. The 1974 photograph shows about the same amount of construction controlled by a network of five sediment basins. Some of the basins are temporary and others are designed as permanent stormwater management structures (fig. 19). The increased use of sediment basins and other control measures has substantially reduced the construction-site sediment yields of the study basins. For example, the average annual sediment yield delivered to the stream channels from construction sites shown in figure 18 was reduced from 26 to 7 tons/acre (58 to 16 t/hm^2) between 1968 and 1974.

To further examine the relation between construction-site sediment yields and various site factors, the relation between computed site yields and the yields estimated with equation 3 is shown in figure 20. The scatter about the line of equality is significant, reflecting the large standard error of estimate of the regression equation. The data points with the greatest departure from the line of equality were probably influenced by other site factors not used in the equation. For example, the high computed yields for Manor Run sample periods 1, 2, and 3 probably result from grading activities adjacent to and within the stream channels (fig. 21). The proximity factor averaged 39 percent in Manor Run during these periods. In contrast, the relatively low proximity factors for period 1 in the Williamsburg Run and Bel Pre Creek basins, 25.3 and 19.3 percent, are reflected by the low computed sediment yields. An earlier study in the same basins found that construction-site sediment yields from summer storms increased as the amount of construction within 100 and 300 ft (30 and 91 m) of stream channels increased (Yorke and Davis, 1972). The lower sediment yields from construction sites farther from stream channels represent the effects of filtering of sediment-laden runoff waters by vegetation. As runoff transporting sediment from a construction site passes through a heavily vegetated zone, velocity is reduced by an increase in friction.



APPROXIMATE SCALE 1:24 000

FIGURE 18.—Construction activities, *A*, without (1966) and, *B*, with (1974) sediment controls, Bel Pre Creek basin. Circles indicate locations of sediment basins.

This action reduces the competence of the water to transport sediment. A less important factor in the reduction in competence is a loss of water through infiltration into the soil of the vegetated zone. As a consequence, much of the sediment is deposited before it enters the stream.

The low computed yields in the Lutes Run basin, where the percentage of the construction area with sediment controls was lower than average and the slope of construction sites was higher than average, are indicative of another factor affecting site yields. One construction site in this basin was opened prior to 1963 and remained undeveloped through 1973 (fig. 22). The low yields from the Lutes Run basin, in general, and this site in particular, probably resulted from the site being open long enough for natural stabilization to develop. As fine soil particles are eroded and transported from a site, the remaining large particles armor the soil mass. The gradual increase in the size of remaining soil particles results in decreased sediment yields because the particles are too large to be transported except by the very large storms.

In summary, the degree of sediment control and the slope of construction sites are the most significant factors affecting construction-site sediment yields. Buffer zones of vegetation, proximity of construction to stream channels and the length of time the sites are not stabilized affect the annual yield to a lesser degree.

STREAM-CHANNEL EROSION

In anticipation of significant urbanization during the period covered by the project, three channel reaches were selected to study possible changes in channel geometry. The reaches are located immediately downstream from the gaging stations (fig. 1) on Manor Run, Northwest Branch Anacostia River at Norwood, and Batchellors Run. Drainage areas above the study reaches range from 0.47 to 2.45

APPROXIMATE SCALE 1:24 000

FIGURE 18.—Continued

FIGURE 19.—Large sediment-stormwater management basin used to trap sediment before it can leave construction sites, Bel Pre Creek basin, 1974.

mi² (1.22 to 6.35 km²). The basins were basically rural at the beginning of the study period with only small amounts of impervious area.

Stream channels selected for study are incised in Wehadkee silt loam, which is commonly found in stream valleys of the study area. The texture of Wehadkee silt loam varies from a silty clay loam to a light silt loam, and the soil is susceptible to frost action and very erodible (U.S. Dept. of Agriculture, 1961). The Manor Run and the Northwest Branch Anacostia River channels are typical U-shaped channels carved in flood-plain sediments. Low berms defining the low-water channel are generally absent except at the inside of meanders. In contrast, the Batchellors Run channel has distinct berms or terraces between the low-water channel and the flood plain (fig. 23).

Channel-geometry reaches were established and surveyed in 1967. Cross sections in these reaches

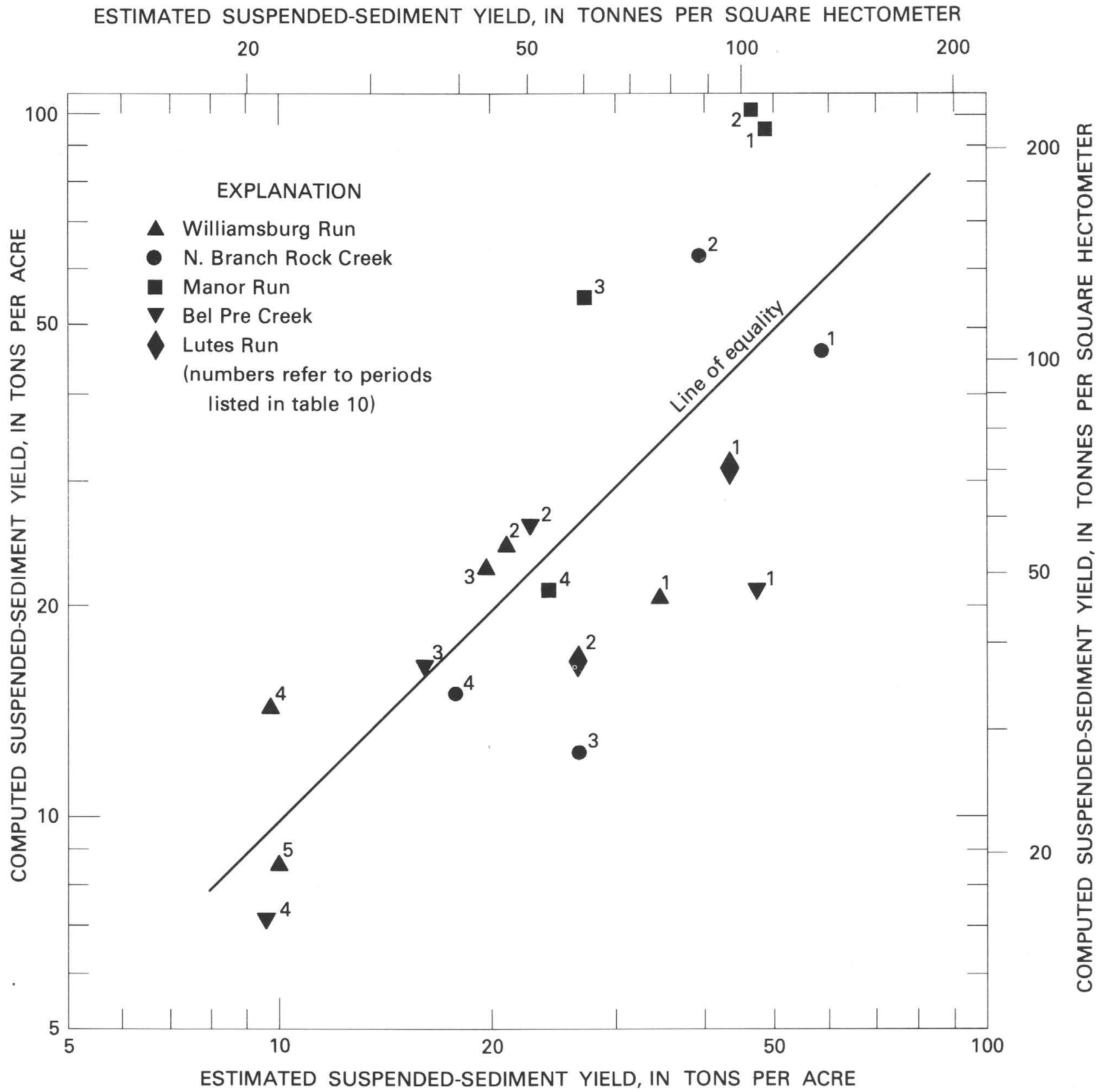


FIGURE 20.—Relation between construction-site sediment yields computed from observed data and those estimated by equation 3.

were selected to represent typical conditions and variations in stream-channel geometry. Cross sections were defined by determining the elevation of selected points along a line perpendicular to the stream banks to the nearest 0.1 ft (0.03 m) with transit and rod. Elevations were determined at 1- or 2-ft (0.3- or 0.6-m)-horizontal intervals across the streambed, at 5-ft (1.5 m) intervals in the flood plain, and at breaks in slope. The position of the thalweg was located by azimuth and stadia; thalweg elevations were determined to the nearest 0.01 ft (0.003 m).

The channel reaches were resurveyed in 1974 to determine changes in the cross sections and total volume of the active channels. Cross sections were located through the 1967 thalweg and perpendicular to the banks. Additional cross sections were measured in some reaches to facilitate computation of the channel volume. Changes in the cross sections typical of straight and curved reaches of the channels for each stream are shown in figure 24.

FIGURE 21.—Grading for street right-of-way within the Manor Run stream channel, 1967.

From the information obtained by the 1967 and 1974 channel surveys, four channel-geometry parameters were chosen for study. These parameters include channel length, cross-sectional area, channel volume, and channel width. Channel length was defined as the total distance between successive thalweg locations in the study reaches. Cross-sectional area was determined by plotting the channel cross-sections as determined from the survey field notes and planimetering the area below a line drawn between the top bank elevations. Total channel volume was calculated as the sum of the products of each cross-sectional area times one-half the distance between the thalweg of the section and the thalwegs of the preceding and succeeding sections. Channel width was determined as the horizontal distance, perpendicular to the channel, between the top of the low bank and the wall of the opposite bank.

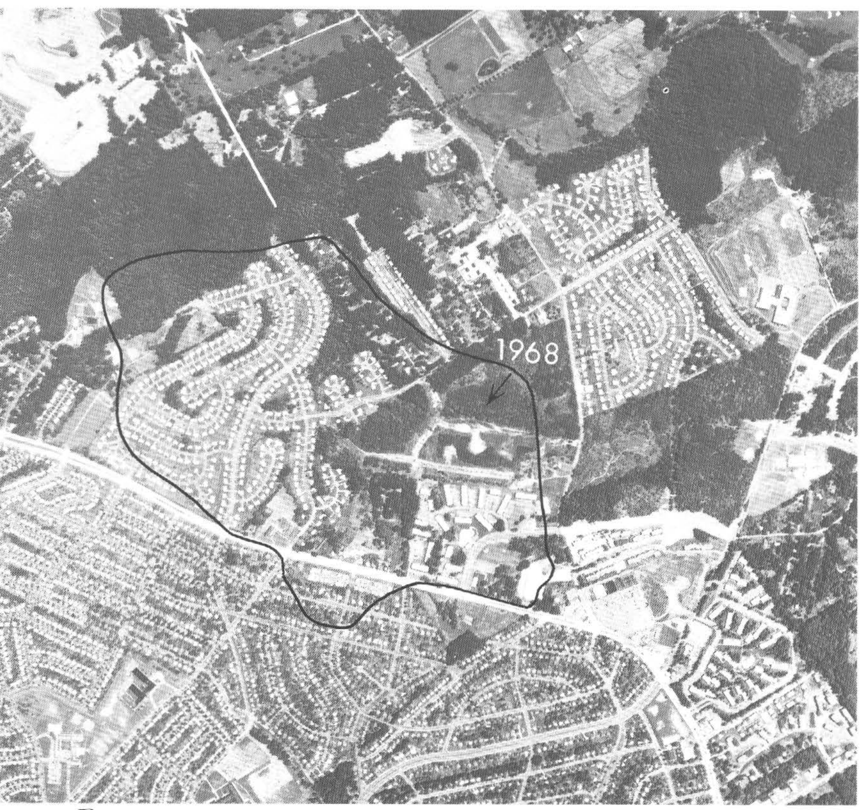
The effects of urbanization and the associated increase in flood peaks are illustrated by the differences in the channel-geometry parameters of Manor Run and the other two streams (table 11). Each of the parameters, except for channel length, increased in the Manor Run basin as the impervious area increased from 5.6 percent in 1966 to 13.5 percent in 1974. In the Northwest Branch Anacostia River, all the channel parameters increased slightly as the impervious area increased from 3.4 to 4.4 percent. In the Batchellors Run basin, channel parameters increased slightly, except for a slight decrease in channel cross-sectional area, as the impervious area increased from 11 to 12 acres (4.5 to 4.9 hm^2), 3.6 to 4.0 percent of the basin area.

The changes in the stream channel parameters are consistent with changes found in previous investigations. Leopold (1968) indicated that stream channels form in response to the regimen of the stream and will carry, without overflow, a discharge which is somewhat smaller than the average annual flood. Brown (1971) showed that the 5-year flood has a direct positive relationship with channel capacity. Because urbanization causes increased flood peaks, as discussed earlier, a substantial enlargement of the channels of urban streams should be expected. Apmann (1974) found that in any watershed in which the runoff volumes and flood peaks are increasing, the tendency will be for the stream channel to increase its cross-sectional area and length of meander. Hammer (1972) found that channel enlargement was related to the amount of impervious area, particularly impervious areas more than 4 years old.

The two parameters indicating a large difference between Manor Run and the other basins were the average cross-sectional area and channel volume. Channel cross-sectional area increased 28 percent in the Manor Run basin. It increased 5 percent and decreased 6 percent in the Northwest Branch Anacostia River and Batchellors Run basins, respectively. Statistical analysis indicated that the 1974 cross sections for Manor Run were significantly larger than the 1967 cross sections at the 95-percent confidence level. The difference between the 1967 and 1974 cross sections for the other two basins were not significant at the 95-percent confidence level. The volume of the Manor Run channel increased 34 percent between 1967 and 1974. Channel volume increased 12 percent in the Northwest Branch Anacostia River basin and increased 2 percent in the Batchellors Run basin during the same period.

An examination of the individual cross sections and the streambed profiles of each channel reach indicated substantial differences between Manor Run and the other two streams. The increase in channel cross-sectional area in Manor Run resulted from a combination of bank erosion and degradation of the streambed. Each cross section was deeper and all except one section had greater cross-sectional areas in 1974. In straight channel reaches, in particular, cross sections were scoured to a nearly rectangular shape instead of the V- or U-shaped sections common in 1967. In contrast, the cross sections of Batchellors Run and Northwest Branch Anacostia River did not exhibit any consistent pattern of bank erosion or bed degradation. The channels generally

A APPROXIMATE SCALE 1:22 800



B APPROXIMATE SCALE 1:24000

C APPROXIMATE SCALE 1:24 000

FIGURE 22.—Construction site in the Lutes Run basin, 1964 (*A*), 1968 (*B*), and 1974 (*C*).

FIGURE 23.—Stream channel-geometry reaches, 1974: Manor Run (*A*), Northwest Branch Anacostia River at Norwood (*B*), and Batchellors Run (*C*).

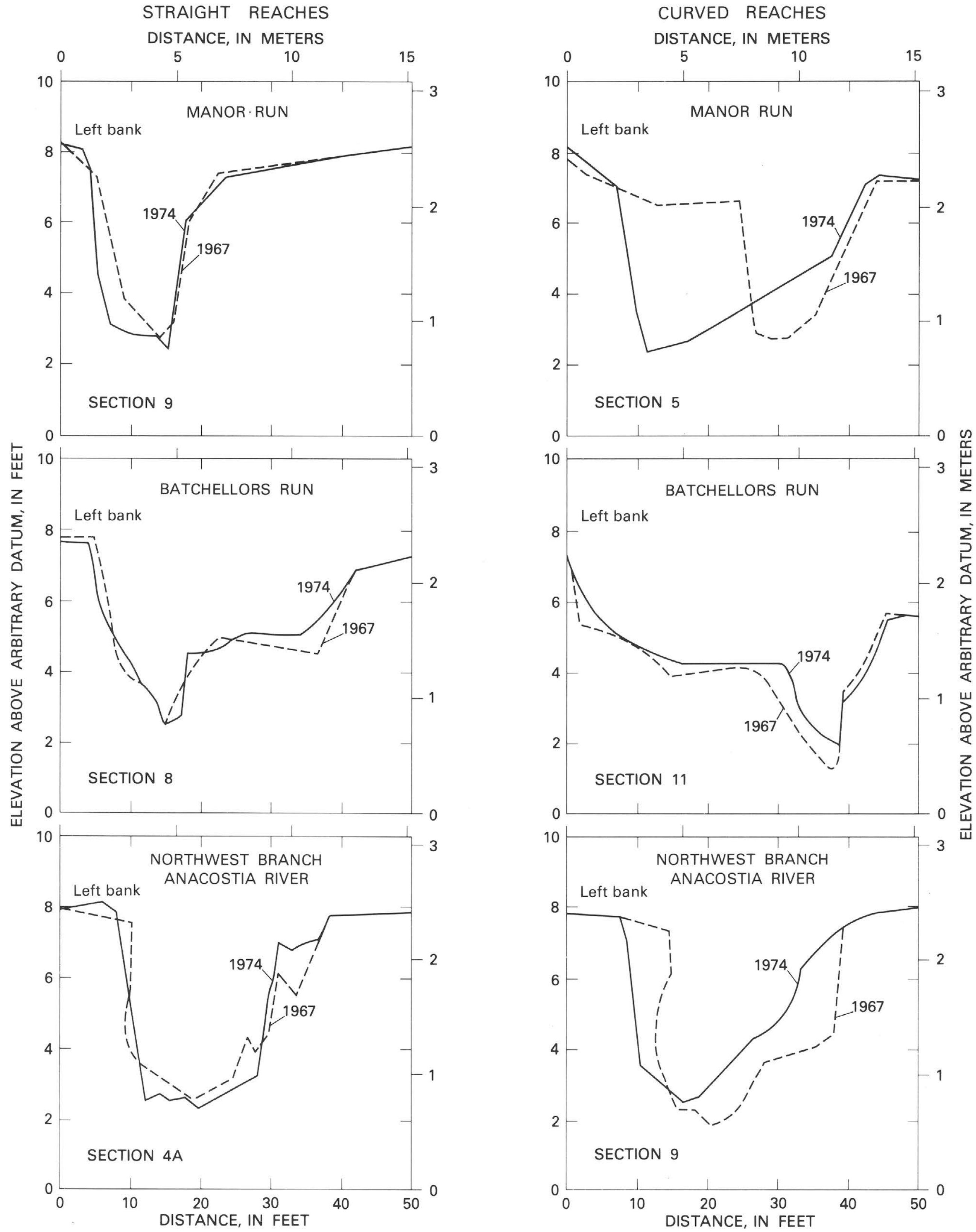


FIGURE 24.—Typical cross-section changes between 1967 and 1974 in straight (sections 9, 8, and 4A) and curved (sections 5, 11, and 9) reaches of three typical stream channels in the study area.

TABLE 11.—*Summary of stream-channel surveys*

	Drainage area (mi^2)	Number of cross sections	Impervious area (percent)		Channel length (ft)		Average channel width (ft)		Average cross-sectional area (ft^2)		Channel volume (ft^3)	
			1966	1974	1967	1974	1967	1974	1967	1974	1967	1974
Manor Run near Norbeck	1.01	12	5.6	13.5	271	269	22.6	24.9	59.8	76.8	15,600	20,900
N. W. Br. Anacostia River at Norwood	2.45	15	3.4	4.4	427	444	32.6	34.5	104	109	45,200	50,500
Batchellors Run at Oakdale	.45	8	3.6	4.0	235	243	34.7	35.9	74.8	70.4	16,800	17,200

retained their original shape within slight shifts of the meander pattern. Virtually all the increase in average cross-sectional area in the Northwest Branch Anacostia River channel was attributable to increases at three sections located on an active meander.

The increase in suburban land area and impervious surfaces is apparently the only factor that could have caused the channel enlargement in Manor Run. Each of the streams is carved through similar soils, and the rainfall characteristics for the three basins were similar during the period of comparison (1967–74).

The change in Manor Run channel volume over 7 years has resulted in a removal of approximately 5,300 ft^3 (150 m^3) of soil from the area of the stream channel. Based on an assumed density of 100 lbs/ft^3 (1,600 kg/m^3), 265 tons (240 t) of soil was eroded from a channel reach 270 ft (82 m) long. This erosion is equivalent to about 1 ton per foot (3 t/m) of channel over 7 years. In other words, every 7 ft (2.1 m) of channel length contributed approximately 1 ton (0.9 t) of sediment to the stream annually. Based on a total channel length of 5,000 ft (1,520 m) from the outlet of storm sewers in the upstream developments to the gaging station, the contribution of stream-channel erosion to the total sediment load measured at the gaging station would be about 700 tons/yr (640 t/yr). Suspended-sediment load would probably represent about 90 percent of the total load or about 630 tons/yr (570 t/yr). Suburban land averaged about 250 acres (101 hm^2) between 1967 and 1974. If all the stream-channel erosion was attributable to increased runoff from impervious surfaces in this area, the sediment yield from stream channels would be about 2.5 tons/yr (2.3 t/yr) for each acre (0.4 hm^2) of suburban land. This is a temporary source of sediment that would be expected to diminish to zero when the stream channel reached equilibrium with the post-development runoff regime.

SEDIMENT CONTROL

In the past 10 years, sediment control has become an integral part of urban construction. Control programs have been implemented by all local jurisdictions in the Baltimore-Washington area. The impetus for these programs was a study begun by the Interstate Commission on the Potomac River Basin in the early 1960's. The Commission's study group recommended that sediment control become the stated policy of local governments, that urban development be planned carefully, and that local ordinances be adopted to require developers to employ erosion-control measures on construction sites (Guy and others, 1963).

The Montgomery County sediment-control program evolved from a Sediment Control Task Force formed to study the possibility of reducing sediment from developing areas in the Rock Creek watershed, which was being considered for a Public Law 566 flood-control project. The Task Force drew up a program for voluntary sediment control, and it was adopted as county policy in 1965. This action was followed by a mandatory program in 1967 that required developers to submit sediment control plans along with preliminary subdivision plans. This regulation provided for review of plans by the Montgomery County Soil Conservation District; however, there was no provision for field inspections to assure that the approved control measures were installed and properly maintained. In 1971, however, the Montgomery County Council enacted a Grading and Sediment Control ordinance, which established an enforcement unit within the county's Department of Environmental Protection. This unit has the responsibility of inspecting construction sites to insure that approved sediment-control measures are properly installed and adequately maintained throughout the construction period.

The urban sediment-control program adopted by Montgomery County is similar to the program used for many years in agricultural areas. The basic principles, as outlined by the Maryland-National Capital Park and Planning Commission (1967), are:

1. The smallest practical area of land should be exposed at any one time during development.
2. When land is exposed during development, the exposure should be kept to the shortest practical period of time.
3. Temporary vegetation and (or) mulching should be used to protect critical areas exposed during development.
4. Sediment basins (debris basins, desilting basins, or silt traps) should be installed and maintained to remove sediment from runoff waters from land undergoing development.
5. Provisions should be made to effectively accommodate the increased runoff caused by changed soil and surface conditions during and after development.
6. The permanent final vegetation and structures should be installed as soon as practical in the development.
7. The development plan should be fitted to the topography and soils so as to create the least erosion potential.
8. Wherever feasible, natural vegetation should be retained and protected.

FIELD APPLICATIONS

The field application of the principles outlined above required a gradual training program for developers, engineers, and grading contractors. In the past, developers generally did all the rough grading on the site at one time to minimize expenses for heavy grading equipment. Engineers and grading contractors designed and built drainage systems to facilitate rapid runoff from the sites. Final road surfaces, drainage channels, and vegetative cover were installed after houses were sold and ready for occupancy. Major changes in these methods of operation were required to accomplish the principles of the sediment-control program.

The first attempt at sediment control was the installation of sediment basins. These basins could be built at minimal cost at the same time heavy equipment was rough-grading street rights-of-way. They were generally located in small drainage swales at the edge of the development so they would not interfere with the standard construction methods. In general, they were small and underdesigned, as illustrated by figure 25. Many of these basins were filled with sediment in one or two storms and were of no value thereafter. The net result was a generally ineffective program between 1965 and 1968.

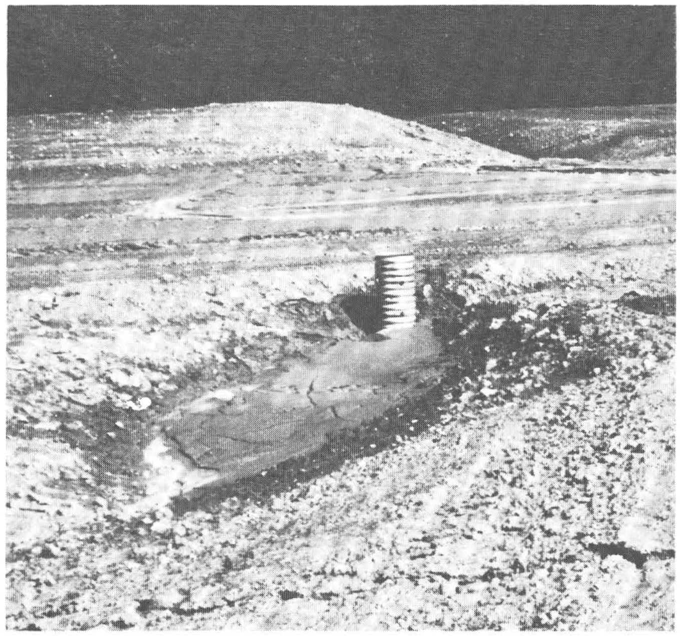


FIGURE 25.—Typical sediment basin used in 1966.

The lack of effective control during the early stages of the program occurred because it was a learning period for all concerned. Representatives of the Soil Conservation District and the county were trying to develop effective standards and specifications for measures that would control sediment transport from construction sites, but that would not place undue restrictions on construction activities. At the same time, developers and engineers were trying to control erosion without the benefit of adequate standards. As specifications became available, the program gradually improved: Better planning limited grading to the smallest practical area to reduce the amount of land exposed to erosion at any one time; straw mulch and temporary vegetation were used to protect exposed soils; diversion berms, level spreaders, and stabilized water-ways were used to reduce erosion on critical slopes; and properly designed sediment basins were used to trap the sediment before it could leave the construction site (U.S. Dept. of Agriculture, 1969).

Between 1968 and 1971, most of the sediment-control plans were implemented in the field; however, there were still problems with contractors unfamiliar with sediment control measures. Some control measures were installed improperly, and many others were not adequately maintained. There was also a lack of coordination between the different

FIGURE 26.—Sediment basin before (*A*) and after (*B* and *C*) it was breached for installation of a sewer line. Note the scour of previously accumulated sediments.

contractors involved in the housing developments. Rough-grading, utility installation, and paving were not coordinated so as to reduce the length of time that construction sites were subject to erosion. Sometimes utility contractors would remove or alter controls that were installed by the developer. For example, interceptor berms on rights-of-way were frequently removed during utility installation and not replaced after the utilities were in place. In other instances, the embankments of sediment basins were breached for installation of sewer lines and were not rebuilt, resulting in the subsequent discharge of sediments previously trapped by the basin (fig. 26). Photograph *A* in figure 26 shows a well-built basin at one of the construction sites in the study area. Photographs *B* and *C* show the same basin after the embankment was breached for a sewer line. This embankment was eventually rebuilt, but not until much of the trapped sediments had been scoured by a series of storms.

Another problem between 1968 and 1971 was a general lack of maintenance of control measures. Berms destroyed or altered by construction traffic were not replaced. Temporary vegetation and mulch were not maintained. Sediment basins, the prime means of control, were not maintained. When basins became filled, the accumulated sediments were not removed. As the trap efficiency is related to the ratio between the storage capacity of basins and the inflow, the accumulation of sediment greatly reduced the value of the basins. During some storms, sediment-filled basins probably had a negative trap efficiency, as runoff scoured more sediment from the basins than was deposited in them (fig. 27).

After the Sediment Control Section was established in the Montgomery County Department of Environmental Protection, control measures improved markedly. Inspectors were on hand to see that controls were installed properly. Inspections at regular intervals throughout the period of construction ensured that controls were adequately maintained and that additional controls were installed as needed. Improvements in the sediment control program are illustrated by the summary of field evaluations listed:

Year	*Percentage of total construction area with approved sediment-control measures*
1968	36
1970	41
1972	56
1974	74

These field evaluations were made by several groups. The 1968 and 1970 evaluations were made by members of the Montgomery County Sediment Control Task Force. The 1972 evaluation was made by the Montgomery County Sediment Control Section, and the 1974 evaluation was made by representatives of the Sediment Control Section and U.S. Geological Survey personnel assigned to this project. All except the 1974 evaluation were countywide. The 1974 evaluation considered only sites in the study area.

EFFECTS OF SEDIMENT-CONTROL MEASURES

The effectiveness of the sediment-control program was illustrated in the earlier discussion of construction-site sediment yields. The quantity of suspended sediment transported by the streams decreased markedly as the percentage of construction sites with approved controls increased. In the Bel Pre Creek basin, suspended-sediment yields from construction areas decreased from 26.4 tons/acre (59.2 t/hm^2), when there were minimal controls, to 7.2 tons/acre (16.1 t/hm^2), when about 70 percent of the construction area was adequately controlled. Similar decreases were observed in the other study basins. Sixty to eighty percent decreases were observed in the Williamsburg Run, North Branch Rock Creek, and Manor Run basins.

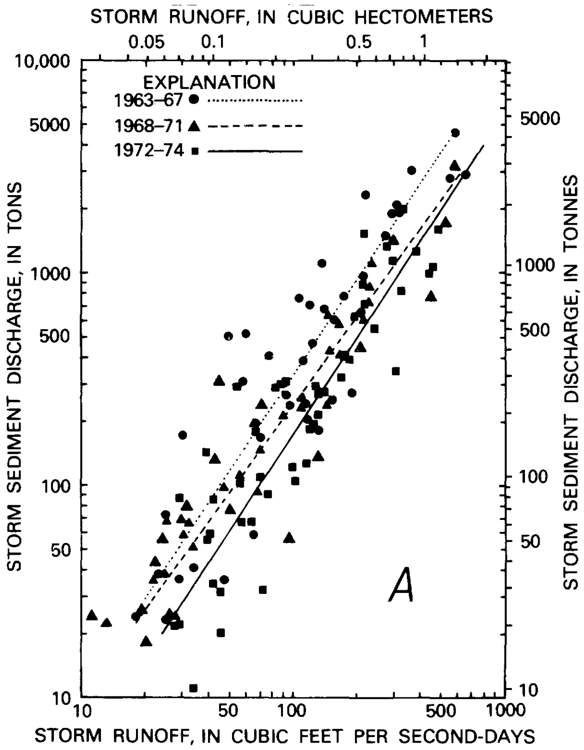
Another example of reduced sediment yields from construction sites is shown in figure 28. The curves

FIGURE 27.—Small sediment basin requiring maintenance.

in figure 28 represent the average relation between storm runoff and suspended-sediment discharge in the Northwest Branch Anacostia River near Colesville for three periods: 1963–67 water years, when no controls were used on construction sites; 1968–71 water years, when controls were mandatory; and 1972–74 water years, when controls were mandatory and subject to inspection by the Sediment Control Section. The curves indicate a substantial reduction in sediment discharge during each succeeding period. An analysis of covariance found that the regression curves for the dormant-season storms were significantly different for all periods. The differences of the adjusted means of the dormant-season loads for the periods 1963–67 versus 1968–71 and 1968–71 versus 1972–74 were significant at the 95-percent confidence level. The difference between the 1963–67 and 1972–74 adjusted means were significant at the 99-percent confidence level. Growing-season adjusted means were significantly different at the 99-percent confidence level, except for the periods 1963–67 and 1968–71, which were not significantly different at the 95- or 99-percent confidence level.

Several factors could account for the reduced suspended-sediment discharge from the basin. A decrease in the amount of sediment source area would be the most obvious. Land under construction averaged 2.87, 3.15, and 2.63 percent of the total basin area for 1963–67, 1968–71, and 1972–74, respectively. On the basis of construction area alone, a slight increase over the 1963–67 period would be expected in 1968–71 and a slight decrease expected between 1972 and 1974. However, a decrease was observed between 1968 and 1971. The large decrease in sediment discharge between 1972 and 1974 is not the likely result of the small decrease in construction area. Cropland decreased during the period, but the increase in new urban land was greater than the decrease in cropland. The sediment yield from these two sources probably did not change appreciably because the yield from urban land and stream channels downstream from urban land was greater than or equal to the cropland yields observed for the small study basins.

Changes in soil and slope conditions on construction sites and a decrease in the size or intensity of storms could also affect the sediment discharge, but these did not change significantly during the study period. Soil conditions were generally uniform except for the greater erodibility of the subsoil in the Manor series. A substantial decrease in construction on the Manor Soils was not observed. Slope varied between construction sites, but there was no



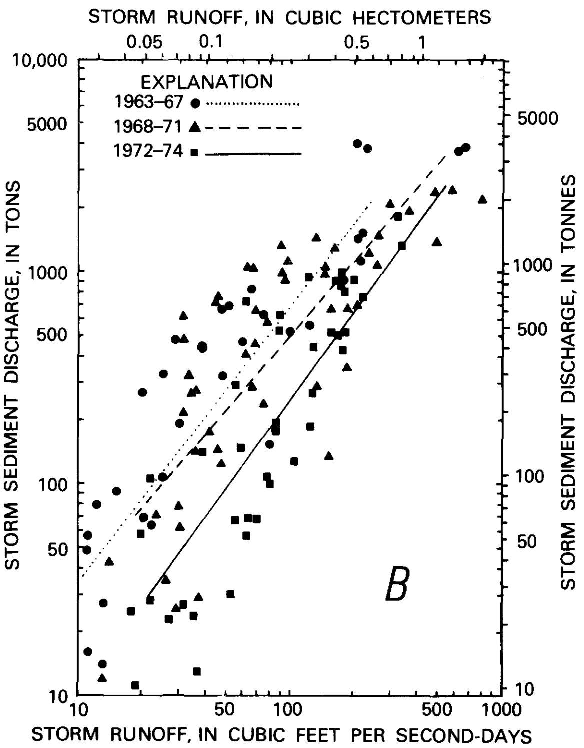


FIGURE 28.—Relation between suspended sediment and storm runoff for dormant season (*A*) and growing season (*B*) storms, Northwest Branch Anacostia River near Colesville, 1963–74.

trend of decreasing slope conditions during the 12-year period. Total precipitation varied during the periods, but the magnitude and intensity of storms did not decrease significantly.

The use of sediment controls is the one factor that has changed appreciably during the three periods represented by the curves in figure 28. Total suspended-sediment discharge that would have occurred if each condition had existed throughout the 12-year period was estimated as shown:

Degree of sediment control	*12-yr sediment load transported by storms*	
	Growing season (tons)	*Dormant season* (tons)
None	114,000	93,000
Mandatory, no enforcement	79,000	60,000
Mandatory, with enforcement	52,000	52,000

The seasonal regression curves and the storm runoff for all significant storms that occurred between October 1962 and September 1974, except for Hurricane Agnes, were used in the computations. The Agnes storm runoff was not used because it far exceeded the sample range of the 1963–67 and 1968–71 periods. Suspended-sediment discharge of the storms used in the computations is 92 percent of the 12-year total sediment discharge, excluding the load transported during Hurricane Agnes. The other 8 percent represents the load transported during base flow and small storms for which no samples were collected.

The estimated loads indicate that a substantial reduction in sediment discharge would have occurred if sediment controls had been used throughout the study period. Sediment yields under mandatory controls were estimated to be 33 percent lower than yields estimated for conditions of no control. A slightly larger reduction would have occurred during the dormant season. Enforcement of controls throughout the study period would have resulted in a total yield reduction of 103,000 tons (93,400 t), or 50 percent. The largest reduction under enforced controls occurred during the growing season. This is probably the result of an improvement in the designs of structures and better maintenance, which provided greater control of runoff during intense summer storms. Scheduled inspections of construction sites resulted in prompt replacement and maintenance of sediment controls damaged by normal construction traffic and a substantial reduction in sediment discharge.

COST OF SEDIMENT CONTROLS

Sediment-control measures implemented on urban construction sites apparently have reduced the sediment loads in the receiving streams. The installation of these controls, however, represents an additional expense to developers, builders, and ultimately, the property owner. The standard control measures used in the field, the cost of the control program, and the relative costs incurred due to sediment damage downstream from construction sites are discussed in this section.

After standards and specifications for soil erosion and sediment control (U.S. Department of Agriculture, 1969) were prepared, sediment-control measures in the field have become fairly uniform. The conventional method used on most construction sites includes a combination of:

1. Mulch and (or) temporary vegetation to protect exposed slopes.
2. Interceptor dikes to reduce erosion on rights-of-way by diverting storm runoff to temporary outlets where the water can be transported with minimal erosion.
3. Grassed waterways, level spreaders, and grade stabilization structures to convey storm runoff through the construction site without erosion.
4. Diversion berms to divert storm runoff from areas with critical slopes.
5. Sediment basins to trap and store sediment eroded from construction sites before it can enter the stream system.

Complete descriptions and illustrations of these and other commonly used control measures are available in reports by the U.S. Department of Agriculture (1969), Thronson (1971), and Becker and Mills (1972).

The cost of these conventional controls has been evaluated in several studies. Brandt and others (1972) interviewed developers in Montgomery County, Md., to determine the average cost of individual controls. Hotes and others (1973) obtained similar information for a cost comparison between sediment controls in northern Virginia and central California. The costs for the commonly used control measures in Maryland and northern Virginia were estimated as:

Surface stabilization	$209–$567/acre
Diversion and intercepter dikes	$1.25–$3.70/ln ft (linear foot)
Sodded ditches	$4.50/ln ft
Grade stabilization structures	$2.80–$28/ln ft
Level spreaders	$1.36–$3.16/ln ft
Sediment basins	$1,500–$2,560/basin

The range in costs reflects differences in the type of materials used for the controls, differences in sediment-control specifications in Maryland and Virginia, and different time periods during which the costs were determined.

An average unit cost of $1,026/acre for sediment control was estimated by Brandt and others (1972), based on sediment-control plans submitted by seven developers in Montgomery County. This represents an average cost of $55/acre for engineering, plus $421/acre for structures and sediment basins, plus $500/acre for surface stabilization, plus $150/acre for maintenance of structures and repair of erosion damage, minus $100/acre for the residual value of surface stabilization. The significance of these costs can be shown by the total cost of sediment control in the Anacostia River basin. Between 1962 and 1974, 1,900 acres of land was developed for houses, apartments, schools, and shopping centers. If an average cost of $1,026/acre is assumed, the total cost of sediment control would have been $1.9 million. This represents an approximate cost of $19 for each ton (0.9 t) of sediment that would have been prevented from entering the stream system if mandatory controls had been enforced between 1962 and 1974.

The cost of onsite sediment control falls somewhere within the range of costs incurred for sediment removal from ponds, reservoirs, streets, basements, and sewers. These costs range from $2.50/ton for removal of sediment from an urban pond (Becker and Mills, 1972) to $134/ton for removal from sewers (Hotes and others, 1973). Dredging cost can range from $0.11 to $9.00/ton depending on the amount of sediment to be dredged and the distance from the dredging operation to a suitable disposal site (Hotes and others, 1973). Many other costs are incurred as a result of increased sedimentation caused by urban construction; however, an analysis of these costs is beyond the scope of this study. These include: increased water treatment costs, increased flooding, decreased commercial fish and shellfish harvests, decreased sport fishing, decreased esthetic values in streams and estuaries, and decreased shipping due to harbor shoaling.

Most sediment damages and the related reduction in costs resulting from onsite sediment control can be calculated, but there are several damages that cannot be evaluated based on present knowledge. Several unanswered questions are: What are the toxic levels of turbidity, suspended sediment, and pollutants associated with suspended sediment for indigenous fish and other aquatic life in the local streams and ponds? What is the effect of estuarine sedimentation on marine life cycles? What is the acceptable level of turbidity and sedimentation for recreational use of streams and lakes? Will sediment controls reduce the impact of urban sediment on these conditions? When these questions are answered, local officials will be better able to determine whether the costs of sediment control are justified by the benefits.

SUMMARY

This report presents the results of a field investigation of the effects of urbanization and sediment-control measures on streamflow and sediment transport in Montgomery County, Md. The study was made between 1962 and 1974 in a 32-mi^2 (83-km^2) area in the headwaters of the Rock Creek and Anacostia River basins. Data from 9 streamflow-sediment stations, 9 recording rain gages, numerous nonrecording rain gages, 14 sets of aerial photographs, and channel surveys on 3 stream reaches were used for the study.

Land use/land cover varied considerably in the study basins. Three subbasins remained virtually rural, the others underwent urban development with as much as 20 percent of one subbasin undergoing active construction at one time. Urban area ranged from 0 to 60 percent in the subbasins in 1974. Suburban land in the Anacostia River basin increased from 6 to 23 percent of the drainage area between 1962 and 1974.

Precipitation and streamflow between October 1962 and September 1974 were essentially the same as the long-term conditions in the study basins. Streamflow was higher than normal between 1966 and 1974, and the increase in volume was mostly due to higher base flows. Urbanization did not affect median and low flows in the study basins; however, storm runoff and peak discharges were greater in the urban basins.

Suspended sediment transported from the Anacostia River basin averaged 14,800 tons (13,400 t) per year between 1962 and 1974. The annual suspended-sediment discharge ranged from 5,500 tons (4,990 t) in 1974, to 31,000 tons (28,100 t) in 1972, when the runoff from Hurricane Agnes transported 12,800 tons (11,600 t) in a 2-day period. Bedload was estimated to be 6 to 13 percent of the total load. Most of the load was transported during storms, 73 percent in 2.2 percent of the time and 94 percent in 5.7 percent of the time. The temporal distribution of suspended sediment closely approximated the seasonal variability of the erosion index; high loads generally occurred in the late winter, early spring and midsummer, and low loads occurred in the fall and early winter.

Sediment loads were highly variable from storm to storm. Loads were most closely related to the volume of storm runoff and peak discharge. Other factors affecting the load variation for individual streams include the relative basin area under construction, antecedent moisture levels, total precipitation, and an index of the storm intensity. Useful storm-intensity indices were maximum 15- or 30-minute rainfall or the ratio of peak discharge to runoff volume.

Cropland, urban land, and construction sites were the major sources of sediment. Suspended-sediment yields from land under cultivation ranged from 0.65 to 4.3 tons/acre (1.5 to 9.6 t/hm^2). Yields from forest lands and grasslands were estimated as 0.03 ton/acre (0.07 t/hm^2) and 0.2 ton/acre (0.45 t/hm^2), respectively. Urban land yielded about 3.7 tons/acre (8.3 t/hm^2), mostly from stream-channel erosion immediately downstream from newly completed residential and commercial areas. In one urban basin, channel surveys indicated that stream-channel erosion contributed 1 ton (0.9 t) of sediment per foot (0.3 m) of main channel length to the total sediment yield of the basin between 1967 and 1974.

Suspended-sediment yields from urban construction sites ranged from 7 to 100 tons/acre (16 to 224 t/hm^2) and averaged 33 tons/acre (74 t/hm^2). Most of the variation in yields was attributable to the increased use of effective sediment-control measures in construction areas between 1966 and 1974. The average slope of the construction sites also was determined to be a significant factor affecting sediment yields. Other factors affecting sediment yields to a lesser extent were the proximity of construction to stream channels and the existence of buffer zones of undisturbed vegetation between construction sites and stream channels.

Construction-site sediment yields decreased as use of sediment-control measures increased. Yields were reduced from 26 tons/acre (58 t/hm^2) to 7 tons/acre (16 t/hm^2) in the Bel Pre Creek basin. Sixty to eighty percent decreases were observed in the other subbasins. If controls had been used between 1963 and 1974 in the Anacostia River basin, suspended-sediment discharge would have decreased about 103,000 tons (93,400 t), or 50 percent between 1963 and 1974. Reportedly, the cost of controlling sediment on the 1,900 acres developed during this period would have been \$1,030/acre (0.4 hm^2) or \$19 for each ton (0.9 t) of sediment controlled. The data indicate that control could be achieved at less expense if construction were limited to areas with slopes less than 10 percent and if sites immediately adjacent to stream channels were avoided. If construction were required in these critical areas, substantial control could be achieved by limiting construction to the period of low erosion potential between September and January. These restrictions would reduce the direct cost of sediment control, but they may introduce additional costs whose evaluation is beyond the scope of this report.

Standard cost-benefit methods can only be used to partly assess the effect of enforcing sediment-control measures or alternative restrictions on construction activities. Although costs of controlling sediment on site can be compared with the costs of removing sediment at downstream locations, there are intangible damages associated with allowing sediment to leave the construction site. It is difficult to assign costs of increased flood potential, deterioration of the esthetic quality of streams, and damage to the flora and fauna of streams, lakes, and estuaries, but there can be little doubt that these costs are real.

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